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REDU-CE-D

REDU-CE-D Strategy

Deliverable 1.4.1

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1. Introduction

Partners in the REDU-CE-D project (short for "customized Environmental Management System (EMS) to increase energy efficiency and reduce energy consumption of different transport modes in Central Europe,") collaborate to enhance the energy efficiency of various transport modes by aligning their efforts with the transposition of the European Energy Directive. The consortium consists of a diverse group of project partners (PPs) representing multiple transport sectors, with each mode of transport supported by two key organisations from different Central European countries. These partners jointly implement innovative pilot actions focused on the deployment of Energy Management Systems (EMS). Throughout this process, stakeholders are actively engaged in testing and training activities, as well as in advocacy efforts aimed at supporting policy integration and adoption.

The purpose of this document is to outline a common strategy that builds upon existing solutions and best practices in energy transition. The strategy aims to align these practices with the specific needs of different transport modes, leveraging the insights and expertise of key stakeholders and subject-matter experts to ensure effective and sustainable implementation.

1.1. Overview of the activity

The primary objective of the REDU-CE-D project is to improve the energy efficiency of various transport modes in Central Europe (CE) by supporting the transposition of the European Energy Efficiency Directive (EED) into the air, urban, waterway, and rail transport sectors. This is to be achieved through the testing, development, and dissemination of customised Environmental Management Systems (EMS) that align with EU requirements and are guided by a jointly defined transnational strategy.

The project adopts a transnational and cooperative approach to the development of this strategy, building upon a comprehensive assessment, mapping, and evaluation of best practices for monitoring energy consumption in the transport sector.

As part of Activity A1.1, project partners assessed their current energy status and related processes using the Assessment Grid for Data Collection (Deliverable 1.1.1) and their respective Local Assessment Reports (Deliverable 1.1.2). These inputs informed the creation of a Transnational Assessment Report (Deliverable 1.1.3), which offers a comparative analysis of environmental and energy management practices across transport sectors in CE, integrating local insights into a broader transnational perspective.

In Activity A1.2, partners collected and evaluated best practices in energy transition and optimisation with the aim of identifying effective, scalable sustainability measures for adaptation across the sector. This process was supported by the Transnational Working Group, which assessed the adaptability of the selected practices and provided strategic recommendations for their implementation and capitalisation.

Key findings from this structured research will be presented at the REDU-CE-D Conference in April 2025.

To validate the effectiveness of the customised EMS support packages, the project will conduct one pilot action in each of four distinct transport contexts, involving:

- Air Transport (in Croatia);
- Urban Transport (in Poland);
- Waterway Transport (in Hungary);
- Rail Transport in Italy.

Each pilot will be implemented through a collaboration of two project partners per transport mode, ensuring sector-specific expertise and cross-national collaboration. The potential for transferability across other CE regions will be facilitated through the engagement of key stakeholders—including airports, ports, rail authorities, and urban mobility agencies—who are not formal project partners but will participate in the four pilot testing site visits.

The joint evaluation of each pilot action, with input from all project partners, will produce a consolidated report serving as the foundation for the final validation of the EMS packages. This validation will be completed during the Transnational Advisory Forum.

To ensure proper uptake and widespread application of the EMS support packages, the project will undertake the following actions:

- Training activities for internal staff and external stakeholders across CE (e.g., airports, railway companies, and urban mobility agencies);
- Awareness-raising campaigns to build public and institutional support for EMS implementation;
- Advocacy and lobbying efforts aimed at promoting the adoption of EMS support packages within national and regional regulatory frameworks;
- Targeted transfer roundtables with transportation authorities to foster institutional commitment and encourage EMS adoption.

To achieve the objectives of the REDU-CE-D project, transnational cooperation among transport authorities, policy makers, and sectoral experts is essential. The project not only aims to create tailored EMS support packages for the benefit of participating organisations but also seeks to contribute to the broader implementation of the Energy Efficiency Directive.

By providing a concrete and scalable framework for EMS implementation, the project aspires to catalyse energy transition investments by major transport operators and public service providers, ultimately supporting the long-term objective of a climate-neutral Central Europe.

1.2. Importance of Energy Transition in transportation

The European Union (EU) has set ambitious energy and climate goals to mitigate the adverse effects of climate change, enhance energy security, and foster sustainable economic growth. Transportation is among the key sectors targeted for transformation, which remains a significant contributor to greenhouse gas (GHG) emissions, air pollution, and fossil fuel dependency. Meeting the EU's energy objectives in the transport sector is of crucial due to its environmental, economic, and social impact.

First and foremost, the transport sector is responsible for approximately 25% of the EU’s total GHG emissions, with road transport being the predominant source. The transition to cleaner energy sources, such as electrification and sustainable biofuels, is essential for meeting the EU's goal of climate neutrality by 2050 as outlined in the European Green Deal. Reducing emissions from transport not only helps mitigate climate change but also improves air quality, reducing health risks linked to pollution-related diseases.

Furthermore, improving energy efficiency and diversification in transport enhances energy security by reducing dependence on imported fossil fuels. The EU remains vulnerable to geopolitical uncertainties that can disrupt energy supply chains, affecting economic stability. A shift toward domestically produced renewable energy sources enhances resilience to external shocks and promotes economic competitiveness through technological innovation and green job creation.

Lastly, sustainable transport systems offer social benefits, including enhanced mobility, reduced traffic congestion, and improved public health. Investing in clean energy infrastructure and sustainable urban transport planning fosters inclusive and accessible mobility solutions while reducing socioeconomic disparities.

In conclusion, aligning the transport sector with the EU's energy goals is a crucial step toward a sustainable and resilient future. By prioritising decarbonization, energy efficiency, and innovation in transportation, the EU can lead the global transition toward cleaner mobility, ensuring long-term economic and environmental sustainability.

2. Objectives

2.1. Main goals of the transnational Strategy

The REDU-CE-D Strategy is structured around three key objectives:

- Integrate findings from the Transnational Assessment Report with the key outcomes of the Transnational Technical Working Group meetings, ensuring that both practical experiences and expert insights are fully integrated.
- Address the four transport modes—air, urban, waterway, and rail—through a dual structure: a common, overarching section presenting shared themes and synergies, and four mode-specific chapters offering tailored guidance for sustainable energy improvements.
- Provide an overview of energy-related improvement projects, facilitating an integrated and holistic approach to energy transition in the transport sector.

During the local assessment phase, project partners identified multiple synergies, which were subsequently consolidated in the Transnational Assessment Report. This methodology and its findings provides a practical framework for identifying bottlenecks and opportunities within the energy management and policy structures of transport organisations.

The contributions of the Transnational Technical Working Group—comprising experts from six countries and all four transport sectors—underscored the importance of cross-sectoral collaboration in evaluating best practices. Their input focused particularly on the adaptability, implementation timeline, cost implications, and return on investment of selected measures, ensuring that recommendations are both strategic and actionable.

While energy efficiency and climate mitigation in transport cover a broad range of measures, the strategy strives to remain as specific as possible. This specificity is achieved by addressing each transport sector individually, ensuring that transport operators—regardless of size or specialisation—can easily locate relevant guidance for the energy challenges they face. Additionally, cross-cutting issues that are common to all transport types (e.g., energy management in office buildings) are treated in the common chapter, promoting consistency and synergy.

Finally, the strategy goes beyond the implementation of specific measures. It includes critical reflections on prioritisation, monitoring, stakeholder engagement, and alignment with European Union climate and energy objectives. By doing so, it offers a strategic framework that may serve as a reference for future funding schemes and grant programmes, both at the national and EU levels. The methodologies, tools, and measures presented herein aim not only to support immediate action but also to shape the long-term transition to energy-efficient and climate-resilient transport systems across Central Europe.

2.2. Alignment with EU Green Deal and Climate Plan

The European Green Deal, introduced by the European Commission, establishes ambitious energy-related goals to achieve climate neutrality by 2050. A key pillar of this initiative is the transition to a clean, renewable-based energy system, reducing reliance on fossil fuels while ensuring energy security and affordability. This involves increasing the share of renewable energy sources, improving energy efficiency, and modernizing the energy infrastructure to support the integration of decentralized and digitalized energy solutions. The EU aims to accelerate the deployment of wind, solar, and hydrogen technologies while phasing out coal and other high-emission energy sources.

In addition to enhancing the sustainability of energy production, the Green Deal emphasises efficiency measures to reduce overall energy consumption. The "Energy Efficiency First" principle guides policies aimed at improving building insulation, industrial processes, and transportation systems to minimise energy waste. The Renovation Wave strategy specifically targets the modernization of Europe’s building stock, which is one of the most energy-intensive sectors. Moreover, the EU seeks to establish a fully interconnected and smart energy grid, enhancing cross-border cooperation and optimising energy distribution across member states.

The implementation of these energy-related objectives is supported by regulatory frameworks and financial mechanisms designed to facilitate a just transition. The EU Emissions Trading System (ETS) is being reformed to increase carbon pricing incentives, discouraging emissions-intensive activities while promoting green investments. Additionally, funding instruments such as the Just Transition Fund and the InvestEU program provide financial assistance to regions and industries facing economic challenges due to the shift towards sustainability. Through these measures, the Green Deal aims to create a resilient, competitive, and sustainable European energy sector that aligns with global climate commitments.

The European Union’s climate plan, primarily articulated through the European Green Deal and the European Climate Law, aims to achieve climate neutrality by 2050. This long-term strategy is supported by legally binding commitments, including the intermediate target of reducing greenhouse gas (GHG) emissions by at least 55% by 2030 compared to 1990 levels. The EU’s approach integrates policy measures across various sectors, including energy, industry, transport, and agriculture, to ensure a comprehensive and coordinated transition toward sustainability. The Fit for 55 package, a legislative framework introduced to align EU policies with the 2030 target, strengthens carbon pricing mechanisms, promotes renewable energy, and enforces stricter emissions standards.

A key component of the EU’s climate strategy is the enhancement of carbon pricing and market-based mechanisms to drive emissions reductions. The revision of the ETS increases the cost of carbon-intensive activities, encouraging industries to invest in cleaner technologies. Additionally, the introduction of the Carbon Border Adjustment Mechanism (CBAM) seeks to prevent carbon leakage by levying tariffs on imported goods based on their carbon footprint. These measures are complemented by regulatory initiatives such as stricter vehicle emissions standards and the expansion of carbon sinks through afforestation and soil restoration efforts.

Furthermore, the EU promotes innovation and research in green technologies through programmes like Horizon Europe, fostering the development of low-carbon solutions. By integrating regulatory, financial, and social measures, the EU climate plan seeks to balance environmental ambition with economic resilience and social equity, positioning the Union as a global leader in climate action.

With its clearly defined goals and efforts, REDU-CE-D project contributes to a cleaner, less energy consuming, more energy-efficient and more climate-friendly transport sector in the European Union. The project aspires to ensure that its approaches and best practices reach not only European but also global transport companies and decision makers. In this strategy the REDU-CE-D partnership has gathered all the necessary inputs and aspects to be able to set up a long-term and sustainable energy policy at the level of transport companies.

3. Methodology

3.1. Data collection and analysis

Effective data collection and analysis are essential for transport companies aiming to improve energy efficiency and sustainability. To ensure a structured and comprehensive approach, organisations should focus on both quantitative and qualitative data gathering. This involves not only collecting numerical data related to energy consumption but also understanding operational practices, management strategies, and environmental impacts.

3.1.1. Establishing a Data Collection Framework

The first step in data collection is developing a standardised assessment framework. This should include a structured template that covers all critical aspects of energy usage and environmental impact. The framework should be designed to capture a wide range of energy-related questions, ensuring that no key factors are overlooked.

A well-structured data collection tool should typically include the following categories:

- Energy and Resource Consumption – Measuring the usage of different energy sources (electricity, fossil fuels, renewables) and identifying major energy-consuming activities (e.g., vehicle operations, facility maintenance).
- Environmental Impact – Assessing emissions, waste generation, and pollution control measures.
- Management Systems and Policies – Evaluating internal energy policies, sustainability strategies, and regulatory compliance.
- Innovative and Climate-Related Measures – Identifying implemented solutions for reducing energy demand and improving sustainability.

To support this process, structured assessment tools have already been developed and successfully implemented within the project:

D1.1.1: Assessment Grid for Data Collection – A standardised template developed by the University of Maribor, which structured both quantitative and qualitative data collection. It was reviewed by project partners, refined based on their feedback, and divided into four main subsections:

- Energy and Resources – Measuring energy consumption and sources, including electricity, fossil fuels, and renewables.
- Environment – Assessing emissions, pollution control, and waste management.
- Management Systems – Reviewing internal sustainability policies and regulatory compliance.
- Other Climate Change Measures – Identifying broader environmental initiatives taken by transport companies. Project partners were asked to provide energy consumption profiles, including the types of energy sources used and the main sources of energy consumption in their operations (e.g., cars, buses, trains). Additionally, they could elaborate on pre-identified energy efficiency measures or contribute custom solutions not initially included in the assessment grid.

D1.1.2: Local Assessment Reports – This document built upon the assessment grid (D1.1.1) but focused on more qualitative insights. While D1.1.1 captured structured, standardised data, D1.1.2 allowed partners to describe their specific energy management practices, challenges, and best practices.

- Partners elaborated on energy efficiency measures, explaining how effective they were, any challenges faced, and areas for improvement.
- They were also asked to reflect on gaps in their current practices, identifying where further development or adaptation was needed.
- Unlike D1.1.1, which was based on selecting predefined options, this deliverable encouraged detailed descriptions and real-world examples, offering deeper insights into energy management strategies.

In addition to these assessments, best existing practices in energy management and sustainability were systematically collected through two additional deliverables which will also be updated during the full duration of the project:

D1.2.1: Methodology for Selection of Best Practices – A structured template was developed to guide the selection and documentation of best practices. This methodology ensured that good practices were consistently documented, capturing key information such as:

- Type of practice (transport facility, transport mode, year of implementation),
- Description of the practice,
- Estimated costs and financial feasibility,
- Relevant standards and compliance requirements,
- Photos or visual documentation,
- Contact details of the implementing facility for direct knowledge exchange.

D1.2.2: Collection of Best Practices – Based on the methodology from D1.2.1, project partners provided real-world examples of best practices implemented in different transport sectors across Europe. These were systematically documented, highlighting:

- Practical implementation insights,
- Success stories and challenges faced,
- Scalability and transferability to other companies or sectors,
- Financial aspects and potential return on investment,
- Long-term sustainability benefits.

By combining quantitative energy data (D1.1.1, D1.1.2) with qualitative best practices (D1.2.1, D1.2.2), transport companies were provided with both analytical tools and practical guidance to improve their sustainability efforts.

3.1.2. Balancing Quantitative and Qualitative Data

An effective energy assessment requires a combination of numerical metrics and descriptive insights. While quantitative data helps in benchmarking and tracking energy consumption, qualitative inputs provide context, revealing the effectiveness of various sustainability measures.

Quantitative Data Collection:

- Fuel and electricity consumption records,
- CO_2 emissions data,

- Operational efficiency metrics (e.g., fuel consumption per km),
- Energy cost breakdowns.

Qualitative Data Collection:

- Existing best practices in energy efficiency,
- Challenges encountered in energy management,
- Innovations and improvements implemented,
- Employee and stakeholder perspectives on sustainability efforts.

Additionally, it is important to recognise that some energy efficiency measures may not always be the most cost-effective in the short term but can provide long-term benefits such as improved sustainability, reduced environmental impact, and healthier working conditions. Investing in cleaner energy sources, for instance, might not lead to immediate financial gains but can significantly enhance the overall ecological footprint of a transport company.

3.1.3. Ensuring Data Usability for Decision-Making

Once data is collected, the focus should shift to its interpretation and application. This involves:

- Data Validation and Refinement – Ensuring accuracy by reviewing and cross-checking entries.
- Comparative Analysis – Identifying trends and benchmarking against industry standards.
- Strategic Planning – Using data insights to set energy reduction goals and prioritise sustainability initiatives.

By following these principles, transport companies can establish a structured and effective energy data collection and analysis process. The previously completed deliverables have demonstrated how such an approach can be successfully implemented, offering valuable insights and methodologies that can be adapted across different organisations. Furthermore, while financial feasibility is a key consideration, companies should also weigh the long-term environmental and societal benefits of their energy strategies. Some sustainability measures may require higher upfront costs, but lead to cleaner air, healthier urban environments, and stronger compliance with future regulatory standards. This balance between economic efficiency and sustainability should be carefully assessed to create a resilient and future-proof energy strategy.

3.2. REDU-CE-D Transnational Assessment and key results

3.2.1. Assessment methodology

The assessment methodology provides a detailed explanation of the data analysis process carried out in Activity A1.1: Transnational Assessment. This section aims to present a more in-depth examination of the data analysis phase, which was conducted after collecting responses from project partners. Following the completion of data collection, the gathered information underwent a structured analytical process to ensure accuracy, relevance, and applicability. The analysis was carried out through a series of elementary steps, which are detailed below. These steps enabled a systematic evaluation of the collected data, the identification of trends, and the extraction of key insights relevant to the project's objectives.

1. Review & Standardise Data
   The first step in the data analysis process was a thorough review of all reports to ensure completeness, consistency, and accuracy. Reports submitted by project partners were examined for missing information or inconsistencies that could affect the assessment. Project partners who had not fully completed their reports were notified and asked to provide the missing data. This step was essential to ensure a comprehensive dataset for analysis. Once all reports were fully completed, the analysis was divided into quantitative and qualitative analysis.

2. Quantitative Analysis
   The results were classified, and the rate of implementation of specific measures across project partners was calculated and visually represented in a graphical format. Additionally, several solutions were identified that had not been widely adopted or had not been implemented at all by any project partners. Some of these measures were selected and highlighted as promising candidates for broader implementation, based on their potential benefits and applicability.

3. Qualitative Analysis
   Other results - such as noteworthy practices and solutions mentioned by project partners, which could not be analysed quantitatively—were examined in this section. These practices were evaluated and assessed for their potential broader implementation. Many were also documented with images, which was beneficial as it visually demonstrated that project partners had already taken steps toward reducing energy consumption and addressing ecological concerns. This visual documentation was particularly useful, as it provided other project partners with concrete ideas for implementation. The collected data was then compiled and recorded in document D1.1.3. However, it was noted that some project partners did not implement any measures or did not submit information on implemented solutions.

4. Identify Gaps & Areas for Improvement
   After all data provided by project partners was analysed, a detailed analysis identified the areas with the fewest implemented measures. These gaps were highlighted as key areas for improvement during project duration.

3.2.2. Assessment results

Results were primarily presented in the Transnational Assessment Report (D1.1.3), offering a comprehensive analysis of environmental and energy management practices across transport sectors in Central Europe. The findings indicate that while basic sustainability measures—such as energy efficiency improvements, waste separation, and simple monitoring—are widely implemented, the adoption of advanced technologies and structured environmental management systems (EMS) remains limited. This indicates a strong potential for transitioning from compliance-based actions to more strategic, data-driven sustainability practices. One key observation is the inconsistency in tracking and reporting environmental performance. While some sectors collect data on emissions, energy use, and resource efficiency, others still lack systematic monitoring and evaluation systems. Without comprehensive tracking, organisations face challenges in identifying areas for improvement, measuring progress, and optimising resource use. Expanding data collection and reporting mechanisms is essential for informed decision-making and long-term sustainability improvements. The assessment also reveals gaps in renewable energy integration, climate adaptation, and waste management. While photovoltaic (PV) systems are widely adopted, other renewable sources and energy storage solutions remain underutilized, limiting energy diversification. Similarly, climate adaptation measures are often insufficient, despite increasing risks from extreme weather events. Many organisations lack infrastructure investments such as flood barriers, green infrastructure, or emergency preparedness plans, leaving them vulnerable to climate-related disruptions. Another challenge identified is the limited collaboration and structured employee training in sustainability efforts. While some organisations engage employees in environmental initiatives, many lack regular training programmes and measurable sustainability goals. Strengthening these areas could foster a culture of sustainability and enhance the effectiveness of implemented measures. Additionally, external collaboration with suppliers, local communities, and industry partners remains low, despite the potential for joint sustainability initiatives to drive greater impact.

The most significant output of the transnational assessment is its suggestions for improvement, forming the backbone for Section 4. The 25 key recommendations described in Section 4 provide a structured approach to advancing sustainability across sectors, covering actions such as:

- Energy and infrastructure upgrades: Implementation of solar panels, investing in geothermal energy systems, predictive maintenance, automated lighting and HVAC controls, and integrating renewable energy.
- Sustainable building practices: Constant renovation and certification of buildings, relocation of wildlife during construction, and achieving zero pesticide policies.
- Sustainable mobility and fleet modernization: Constant modernization of electrical and conventional vehicle fleets, exploring hydrogen use for transport, promoting micro-mobility, and expanding central systems.
- Operational improvements and waste reduction: Reducing plastic use, introduction of oil/water separators, investing in newer equipment, noise pollution mitigation, and regular maintenance of infrastructure.
- Technology, monitoring, and strategic planning: Data analysis and reporting, implementation of warning systems, helpful maps and programmes, and advocating for new incentives.

3.2.3. Best practices to be considered

In this section, the practices mentioned in A1.1 will be described; however, not all of them will be included. For a more detailed and comprehensive overview, document D1.2.2 provides an extensive description of all best practices. Instead, this summary focuses on three selected practices that are considered to have the highest potential applicability across various transport sectors. These practices have been implemented by companies and reported by project partners. It is important to note that this selection does not imply that these practices are necessarily the most effective in terms of applicability, cost, or ease of implementation. Rather, they have been chosen to provide insight into potentially valuable approaches while acknowledging that other practices may also offer significant benefits depending on specific circumstances.

1. Installation of Photovoltaic (PV) Panels on Unused Surfaces (OLGA)

In France, a renewable energy project is being implemented at an airport in 2024, led by Groupe ADP, DGAC, and ITW GSE. The installation of photovoltaic (PV) systems aims to reduce grid electricity dependence, lower emissions, and cut operational energy costs. These PV panels will cover a significant portion of the airport's energy needs, charge Electric Ground Vehicles (EGVs) to replace fossil fuels, and act as solar shields, reducing thermal regulation demands. The project requires a moderate to high initial investment, partially financed by EU sustainability programmes, with a payback period of 10-15 years. PV panels have a lifespan of 20-25 years, ensuring low maintenance costs and long-term savings. Challenges include high upfront costs if incentives are unavailable, structural adjustments for panel installation, energy storage needs, and ensuring PV energy production aligns with airport consumption. This initiative marks a significant step toward sustainable aviation, reinforcing the commitment of Groupe ADP, DGAC, and ITW GSE to greener infrastructure.

Figure 1: Installation of Photovoltaic (PV) Panels on Unused Surfaces (OLGA)

2. Deploying E-Chargers (Partially Financed by EU) – Strategic Goal: Net Zero Airport by 2035

An ongoing 2024 e-mobility project at Budapest Airport is revolutionising airport ground operations by expanding electric charging infrastructure to support sustainable aviation. By integrating fast-charging stations, the initiative enables the transition to electric ground support equipment and passenger transport, significantly reducing fuel consumption and emissions. The project enhances charging efficiency with smart energy management, optimising charging times and peak demand regulation to prevent grid overload. Real-time monitoring and a mobile app ensure smooth operations by managing vehicle charging and availability. Challenges include ensuring sufficient power supply, vehicle compatibility, and effectively managing the simultaneous fast charging of multiple vehicles. By accelerating e-mobility adoption, this initiative strengthens the airport's commitment to decarbonization and energy-efficient transport.

Figure 2: Deploying E-Chargers (Partially Financed by EU) – Strategic Goal: Net Zero Airport by 2035

3. LEED Environmental Certification in Real Estate Development

A sustainability initiative at Csepel Freeport, implemented by Freeport of Budapest Logistics Ltd., focuses on LEED-certified real estate development to enhance energy efficiency and environmental responsibility in an inland waterways port. The C1 and E2 warehouses, certified LEED Silver, integrate sustainable design features that reduce energy consumption by up to 50%, improve insulation, and use efficient lighting and smart energy management. Key environmental measures include water-efficient appliances, waste-sorting facilities, and priority parking for low-emission vehicles. The project also emphasises reducing pollution, planting native vegetation, and minimising light pollution, contributing to healthier and more eco-friendly infrastructure. Despite moderate investment costs, long-term savings stem from lower energy, water, and maintenance expenses, contributing to an overall increase in property value. Challenges include retrofitting existing buildings, meeting certification standards, and adapting operations to green practices. By prioritising sustainability in logistics, this initiative sets a benchmark for eco-friendly port operations.

Figure 3: LEED Environmental Certification in Real Estate Development

3.3. Technical Working Group (TWG)

3.3.1. Role of TWG and procedures

The Transnational Technical Working Group (TWG) was established to foster structured collaboration among project partners, with the primary objective of generating actionable insights and recommendations to inform the development of the REDU-CE-D strategy. The TWG plays a key role in supporting the energy transition of Central Europe's transport systems by leveraging regional expertise and aligning local implementation practices with broader EU sustainability objectives.

The TWG's responsibilities are multifaceted, encompassing the evaluation of best practices, the identification of priority areas for intervention, and the formulation of recommendations that are both adaptable across different transport modes and impactful within diverse regulatory and operational contexts. By synthesising insights from both regional experiences and transnational discussions, the TWG contributes to the development of a comprehensive and scalable strategy tailored to the unique energy challenges of Central European transport sectors.

A significant milestone in the TWG's activities was the October 2024 workshop, which served as a critical platform for participants to collaboratively assess best practices and refine their strategic inputs. The workshop emphasised the importance of stakeholder engagement, regulatory harmonisation, and the adoption of innovative energy solutions as essential enablers of effective energy transition.

Following the workshop, the TWG was structured into three thematic subgroups, each reflecting the core focus areas identified through collective discussions. These subgroups reconvened in February 2025 for dedicated online sessions to further explore and address the most pressing aspects of energy transition in the transport sector. Their work culminated in the "TWG Follow-Up Report" (Deliverable 1.3.1), which documents the methodologies applied, findings gathered, and strategic recommendations developed through this collaborative process.

3.3.2. TWG input to Strategy

The TWG workshop brought together a diverse set of best practices representing innovations in energy efficiency and renewable energy integration across various transport modes. These practices were selected based on their relevance to the REDU-CE-D objectives and their demonstrated success in local or regional contexts. The evaluation framework for the TWG workshop focused on two primary criteria: transferability and impact.

The adaptability of best practices across different transport modes was a key focus of the workshop discussions. Insights gained during these sessions include:

- **Urban Transport:**
    - Practices like energy-efficient fleet management and smart energy systems were highlighted as highly adaptable to urban settings. Participants emphasised the importance of tailoring these practices to local transit patterns and user behaviours.
- **Rail Transport:**
    - Renewable energy solutions for rail systems were discussed extensively, with participants identifying opportunities for integrating solar panels along rail corridors and developing hybrid locomotives powered by a combination of renewable and traditional energy sources.
- **Waterways:**
    - Innovations in logistics, such as optimised route planning and energy-efficient cargo handling, were identified as particularly impactful for reducing emissions in inland and coastal waterways.
- **Air Transport:**
    - The application of sustainable aviation fuels (SAFs) was a primary focus, with participants discussing their potential to reduce lifecycle emissions significantly. Challenges such as the scalability of SAF production and cost implications were addressed, alongside strategies for incentivising adoption through policy and subsidies.
    - Energy-efficient ground handling operations at airports, including the use of electric ground support equipment (GSE), were identified as impactful practices to reduce energy consumption on the ground.
    - Innovations in flight path optimisation, enabled by advanced navigation technologies, were highlighted as a means to improve fuel efficiency and reduce emissions during flights.

Participants also highlighted the importance of fostering cross-sector collaboration to maximise the adaptability and impact of these practices. This includes engaging stakeholders from government, private sector, and community organisations to ensure a holistic approach to implementation.

During the workshop, the partnership established four thematic subgroups to address the critical aspects of energy transition within the transportation sector. These subgroups reflected the key focus areas identified through collaborative discussions and evaluations. Moving forward, the work continued along these thematic lines to ensure targeted and effective implementation. The subgroups and their corresponding objectives were as follows:

1. **Energy Management**:
   This subgroup concentrated on exploring and implementing alternative energy sources to reduce reliance on traditional liquid fuels. Key areas included battery technology, Sustainable Aviation Fuels (SAF), and renewable energy solutions such as PV solar panels. Additional focus is placed on

infrastructure improvements like dynamic apron lighting and compliance with energy management systems, including ISO50001. These measures aimed to enhance energy efficiency and sustainability across transportation modes.

2. **Digitalization**:
   Digitalization plays an important role in optimising energy consumption and environmental impact. This subgroup was tasked with modernizing data collection methods, such as meter upgrades, and establishing unified measurement systems for environmental indicators. Other priorities included the digitalization of parking systems and predictive modelling for usage patterns, which would improve operational efficiency.
3. **Mobility**:
   With an emphasis on sustainable transportation solutions, the mobility subgroup worked on projects like e-mobility for company fleets, regenerative braking systems, and advanced fuel management technologies, including TAXI BOT systems. These initiatives aim to enhance the energy efficiency of transport operations while reducing emissions.
4. **Motivation**:
   Recognising that technical solutions must be accompanied by behavioural and policy-driven changes, this subgroup focused on fostering motivation through policies and engagement strategies. Examples included implementing frameworks such as BREEAM and developing incentives to encourage participation in sustainability initiatives.

Within the four thematic subgroups, the Transnational Technical Working Group (TWG) was able to conduct a more in-depth evaluation of selected best practices, with the objective of showcasing a potential prioritisation methodology that could support the development of long-term, sustainable energy policies within transport companies. The methodology applied during the online subgroup meetings was based on two key project deliverables: D.1.2.1 – Methodology for Selection of Best Practices and D.1.2.2 – Collection of Best Practices.

As a first step, the partnership undertook a detailed analysis of the collected best practices, disaggregating complex projects into individual, actionable measures. Where appropriate, overlapping or similar practices were merged and reframed into sector-neutral measures, allowing for broader applicability across transport modes. This refined set of measures was then aligned with the TWG Workshop Board, previously developed during the in-person meeting in Budapest. The final, harmonised list of best practice measures was subsequently distributed among the four subgroups for detailed evaluation and discussion.

Each subgroup evaluated the given measures in 4+1 dimensions:

- Adaptability for the represented sector (if it was not applicable at the given measure the TWG member did not evaluate this measure),
- Impact (Nothing, Low impact, Middle impact, Great impact),
- Time to implement (Immediately, Less than half year, Half to two years, Two to five years, More than five years),
- Cost (Almost zero cost, Low budget – easily manageable, Middle budget – manageable, High budget – hardly manageable, Extremely high budget – not manageable),
- Return on investment (Financially profitable in less than 5 years, Financially profitable in 5-10 years, 10-20 years, 20-30 years, Not financially profitable).

The Mobility Subgroup concluded that the introduction of integrated train and bus ticketing systems would have the highest impact—particularly in contexts where such integration has not yet been implemented—as it significantly enhances the attractiveness and accessibility of public transport. While certain technological solutions, such as regenerative braking systems, fuel cell-powered hydrogen locomotives in rail freight, and TAXIBOTs (taxiing assistance vehicles for aircraft), were deemed highly effective, their applicability was limited to specific sectors. In addition, the development and adoption of a comprehensive e-mobility strategy received a consistently high impact rating across various transport modes.

In the Digitalization Subgroup, the restriction of night flights emerged as a high-impact measure for noise reduction; however, experts noted that such restrictions are already in place at many airports. In terms of waste management, the establishment of waste sorting facilities was considered highly impactful, particularly in larger operational areas. Within the energy usage domain, the digitalization of data collection and the use of predictive modeling were identified as transformative measures, with the potential to significantly optimise energy efficiency.

The Motivation Subgroup found that replacing disposable plastic cutlery had the most immediate and visible environmental impact. However, the second most impactful measure was the establishment of environmental partnerships. TWG experts emphasised that such initiatives can be implemented with relatively low or manageable costs and may yield a return on investment within six months to two years, particularly when designed to foster collaboration and long-term behavioral change.

Finally, the Energy Management Subgroup identified two measures as having the greatest potential impact: increasing the share of renewable energy sources and optimising heating and cooling systems. Experts agreed that the effective implementation of both measures requires the prior or concurrent introduction of an Energy Management System (EMS). The EMS provides the necessary framework for monitoring, controlling, and continuously improving energy performance across organisational operations.

The TWG discussions clearly highlighted four main priority areas to focus on:

1. Optimising energy consumption,
2. Increasing the share of renewable energy sources,
3. Leveraging EMS to enhance the effectiveness of measures through digitalization and monitoring ,
4. Enhancing environmental values related to energy management .

Optimising the energy usage essentially means to identify weak points where it is unnecessary to “burn” our energy. According to the TWG evaluation, heating and cooling systems represent the most impactful areas to focus on, while the lighting systems should also be considered. Regenerative braking systems are another key aspect, because dissipating converted energy as heat represents a significant inefficiency. Optimisation is in close relation with monitoring (and digitalization), as the optimal solutions can only be identified through reliable and high-quality data. The evaluation confirmed that optimisation measures have usually manageable or slightly challenging costs but these investments can become profitable in the mid-term (10-15 years). If service providers can plan long-term within a predictable, stable legal and economic environment, they are more likely to invest in these solutions. Additionally, specific loans can even further catalyse these processes.

The most diversified priority area is increasing the share of renewable energy sources. Besides using photovoltaic solar panels, geothermal energy or SAF (sustainable aviation fuel), the promotion of e-mobility is also a key element. In general, the investment costs of these measures fall into the higher-cost category, but similarly to the first priority area, these investments can achieve payback within 10-15 years. The high costs and the continuous technological development requires a long-term, strategic thinking from the service providers. However, the implementation of these measures can be accelerated through favorable loans and other kinds of subsidies.

Having an EMS in a transport company offers several benefits, including cost savings, environmental responsibility, and operational efficiency. An EMS helps monitor and optimise fuel consumption, reducing costs of fleets, and it can also identify the most energy-efficient routes, thereby lowering fuel usage. Additionally, EMS supports predictive maintenance by analysing energy consumption patterns to prevent costly repairs. Beyond ensuring regulatory compliance, EMS can help achieve sustainability standards, which can also enhance brand value. Through the digitalization and real-time monitoring, it allows tracking precise energy consumption, leading to improved driver behaviour, fleet optimisation and data-driven decision making. While investment costs are lower compared to the first two priority areas, the return on investment (ROI) period is significantly longer (20+ years). Moreover, it is difficult to estimate the direct financial impact of EMS.

Preserving related environmental values includes various measures, such as the reduction of noise pollution, waste management, reduction of plastic usage and establishing warning systems. Although the investment costs differ significantly across these measures, it is generally true that such projects rarely are financially profitable. However, the positive external effects of these measures - such as social and environmental benefits - can be quantified in monetary terms, but will not appear directly on the bank account of the company. Therefore regulations and subsidies are surely essential for further development in this field.

For aligning regional and sectoral efforts, partnership is a keyword in local, national and international levels. At the local level two best practices were identified in our long list: creating an energy community (within the facilities and the neighbourhoods) and setting up an (airport) environmental partnership. Both initiatives bring together the key stakeholders and create a shared platform for long-term goals.

Building a two-way communication with national authorities is also crucial in our case. As technologies evolve rapidly, regulatory frameworks must adapt accordingly. Without the active participation of the service providers, authorities can not develop realistic and incentivizing regulations. On the other hand, without a competent and transparent presence of the authorities, those service providers committed to European energy and environmental goals may face competitive disadvantages compared to those prioritising only profit maximisation.

International partnerships play a key role in accelerating the energy transition. On one hand, international partners are usually not closest competitors, which can allow sharing best practices, experiences and even failures. On the other hand, participating in international (pilot) programmes can introduce new solutions to the sector, which can also enhance a company’s brand reputation.

4. Triggering the transformation of the energy system in the transportation sector

In this chapter, the REDU-CE-D partnership systematically analysed the improvement suggestions outlined in the Transnational Assessment Report (D.1.1.3) across different transport sectors. As the foundation of the REDU-CE-D strategy, each sector-specific measure was evaluated based on potential implementation methods, time required to implement, cost considerations—assessed through the lens of manageability—and expected return on investment. The partners aimed to strike a balance between a broad, strategic perspective and sector-specific insights to ensure both adaptability and the effective transfer of experiences across different contexts.

4.1. Common comprehensive section

Among the 25 proposed improvements, the partnership identified seven measures that are independent of the specific transport sector in which they are implemented. To avoid redundancy and ensure a more comprehensive analysis, these seven measures are examined collectively in a dedicated section, rather than being repeated within each transport sector.

4.1.1. Energy and resources - electrical energy

4.1.1.1. Constant participation in pilot projects

Continuous engagement in pilot projects in the transport sector plays a vital role in advancing energy efficiency and sustainability. As e-mobility gains importance, these initiatives help reduce reliance on fossil fuels, lower carbon emissions, and promote the integration of renewable energy. By testing and refining electric vehicle (EV) solutions, charging infrastructure, and smart grid technologies, stakeholders contribute to cleaner transportation systems. Additionally, pilot projects encourage the development of energy-efficient innovations, such as solutions, which allow EVs to support power grids, ultimately aligning transport with broader energy goals.

The time required to implement transport pilot projects varies depending on their scale and complexity. Small initiatives, such as testing new charging technologies or optimising traffic management systems, can be deployed within months. However, larger projects, like city-wide EV adoption or hydrogen-powered public transport, may take years due to infrastructure demands and regulatory approvals. Regular participation in pilot projects helps stakeholders refine implementation strategies, address potential obstacles early, and accelerate the transition from testing to full-scale deployment.

Managing costs is a key consideration in transport pilot projects, as investments in infrastructure and new technologies can be substantial. However, these projects often benefit from government funding, incentives, and industry partnerships that help distribute financial risk. Pilot participation enables organisations to evaluate economic feasibility before committing to large-scale deployment, optimising spending while achieving technological advancements. Additionally, by identifying cost-effective solutions during testing phases, stakeholders can reduce future expenses and improve long-term financial sustainability.

Pilot projects provide valuable returns by enhancing innovation, improving operational efficiencies, and creating new market opportunities. Businesses gain insights that drive product development and competitive advantage, while cities and governments benefit from improved mobility and environmental sustainability. Beyond financial returns, these projects contribute to a smarter, greener transport infrastructure, ensuring long-term economic and social benefits. By continuously engaging in pilot initiatives, stakeholders position themselves at the forefront of transportation evolution, ready to capitalise on emerging trends and opportunities.

4.1.1.2. Constant renovation of buildings

Constant renovation of buildings plays a crucial role in improving energy efficiency and reducing environmental impact. Well-maintained buildings consume less energy, making them a key component of sustainability efforts. This is especially critical for buildings that rely on electricity or natural gas for heating, as proper insulation, upgraded windows, and modernized heating systems can drastically lower energy consumption. Renovation projects also enable the integration of renewable energy sources, such as PV systems and smart energy management systems, further aligning with long-term energy efficiency goals. By continuously upgrading buildings, stakeholders contribute to a greener, more sustainable built environment.

The timeline for building renovations depends on the scale and complexity of the upgrades. Simple improvements, such as sealing leaks, upgrading insulation, or replacing inefficient heating systems, can be completed within months. However, large-scale renovations, including structural upgrades, installing energy-efficient facades, or transitioning to smart building technology, may take years. Regular renovation ensures that buildings remain up to date with evolving efficiency standards, preventing the need for costly overhauls in the future. Continuous participation in renovation projects also helps streamline implementation by leveraging best practices and proven solutions.

While building renovations require financial investment, they are often more manageable when carried out incrementally rather than waiting for major overhauls. Many renovation projects receive government incentives, subsidies, or support from energy efficiency programmes, making them more financially viable. Additionally, modernizing buildings can lead to significant cost savings by reducing energy expenses and maintenance costs. By participating in ongoing renovation initiatives, stakeholders can spread out expenses over time, optimising costs while improving overall building performance and sustainability.

Renovating buildings delivers substantial returns in both financial and environmental terms. Energy-efficient upgrades lower operational costs, increase property value, and enhance occupant comfort. Businesses and homeowners benefit from reduced utility bills, while governments and municipalities achieve broader sustainability targets. Additionally, well-maintained buildings require fewer repairs over time, ensuring long-term savings. Beyond direct financial returns, continuous renovation contributes to climate goals, strengthens energy resilience, and future-proofs infrastructure, making it a highly beneficial investment for all stakeholders.

4.1.1.3. Certification of buildings

Certification of buildings plays a key role in advancing energy efficiency and sustainability goals. By adhering to voluntary certification standards during construction, buildings can significantly reduce pollution and lower energy consumption throughout their operational life. Certifications such as LEED, BREEAM , or other internationally recognised certification standards ensure that buildings meet strict environmental and energy efficiency criteria, promoting the use of sustainable materials, smart energy systems, and efficient insulation. This proactive approach supports global energy-saving initiatives, helping reduce the carbon footprint of the built environment while improving overall energy performance.

The time required to obtain building certification depends on the complexity of the project and the level of certification pursued. While some energy efficiency improvements can be implemented relatively quickly, achieving full certification often requires careful planning, documentation, and third-party verification.

Integrating certification standards from the design phase can significantly streamline the process, ensuring compliance without delays. For existing buildings, retrofitting to meet certification criteria may take months or even years, but the long-term benefits of reduced energy consumption and improved sustainability justify the effort.

Although obtaining building certification involves upfront costs for assessments, energy-efficient materials, and compliance measures, these expenses can be outweighed by long-term savings. Certified buildings benefit from lower energy and water bills, reduced maintenance costs, and potential tax incentives. Additionally, property values tend to increase for certified buildings, making them more attractive to investors and tenants. By factoring certification costs into the initial planning stage, stakeholders can effectively manage expenses while achieving significant sustainability and financial gains.

Building certification provides substantial returns, both financially and environmentally. Certified buildings not only reduce operational costs through energy efficiency but also enhance marketability and long-term asset value. Businesses and property owners can attract eco-conscious tenants and investors, while municipalities benefit from lower overall energy demand and improved air quality. Furthermore, certification helps future-proof buildings against tightening regulations and evolving energy standards. In the long run, the investment in certification leads to healthier, more sustainable buildings that offer financial, environmental, and social benefits for all stakeholders.

4.1.2. Energy and resources – use of renewable energy sources

4.1.2.1. Implementation of solar panels

The implementation of solar panels plays a crucial role in transitioning towards a greener and healthier environment by increasing the amount of energy produced from renewable sources. Solar energy reduces reliance on fossil fuels, significantly lowering carbon emissions and contributing to global sustainability efforts. By harnessing solar power, buildings can produce clean electricity, decreasing overall energy consumption from conventional sources. Additionally, integrating solar panels with energy storage systems allows for more efficient energy use, enhancing energy independence and grid stability while supporting long-term environmental goals.

The time required for solar panel implementation depends on the scale of the project. Residential installations can often be completed within a few days or weeks, while large-scale solar farms or commercial projects may take several months due to permitting, engineering, and grid integration requirements. Advances in solar technology and streamlined regulatory processes have accelerated installation timelines, making it easier for individuals and businesses to transition to solar energy. With proper planning, solar panel projects can be executed efficiently, ensuring quick returns on energy savings and sustainability benefits.

The initial cost of installing solar panels can be significant, covering equipment, installation, and potential infrastructure upgrades. However, various financial incentives, such as government subsidies, tax credits, and net metering programmes, help reduce upfront expenses and improve affordability. But that strongly depends on the national regulation. Additionally, solar technology costs have steadily decreased over the years, making it a more viable investment. Companies can also explore financing options like leasing or power purchase agreements to manage costs while still benefiting from renewable energy production.

Solar panel implementation offers substantial returns by lowering electricity bills, reducing dependence on external energy sources, and increasing property value. Over time, the savings from reduced energy costs typically offset the initial investment, leading to long-term financial gains. Furthermore, companies can produce additional revenue through surplus energy sales via net metering or feed-in tariffs. Beyond financial returns, solar energy contributes to a more sustainable environment, reducing carbon footprints and supporting energy resilience. As technology advances and adoption grows, the return on investment for solar power continues to improve, making it a smart choice for both economic and environmental reasons.

4.1.2.2. Investing in geothermal energy systems

Investing in geothermal energy systems is a crucial step toward achieving energy sustainability and reducing carbon emissions. Some project partners have favorable locations for utilizing geothermal energy, making it an efficient and reliable renewable energy source. When combined with electricity from other renewable sources, geothermal energy helps decrease reliance on fossil fuels, significantly lowering CO_2 emissions. Since geothermal systems provide a stable and continuous energy supply, they contribute to long-term energy security and resilience, supporting the transition to a cleaner and more sustainable energy mix.

The timeline for implementing geothermal energy systems depends on the scale and complexity of the project. Small-scale geothermal heat pump installations for buildings can be completed within a few months, while large-scale geothermal power plants require extensive feasibility studies, drilling, and infrastructure development, often taking several years. However, once installed, geothermal systems have long lifespans and require minimal maintenance, ensuring consistent energy production. Proper site selection and early investment in research and development can streamline implementation, accelerating the benefits of geothermal energy adoption.

The initial investment for geothermal energy systems can be high due to drilling and installation costs. However, these expenses are often offset by long-term savings on heating, cooling, and electricity costs. Many governments and energy agencies provide financial incentives, and tax benefits to support geothermal projects, making them more economically feasible. Additionally, geothermal systems have low operational costs and high efficiency, ensuring long-term financial sustainability. By carefully managing the investment through phased implementation and public-private partnerships, stakeholders can make geothermal energy a cost-effective solution.

Geothermal energy offers substantial returns by providing a stable, low-cost energy source that reduces dependence on fluctuating fossil fuel prices. The long-term savings on energy expenses and reduced carbon emissions make it a valuable investment for businesses and also municipalities. Additionally, properties with geothermal systems often have higher market value due to their energy efficiency and sustainability benefits. Beyond financial gains, investing in geothermal energy contributes to global climate goals, ensuring cleaner air, reduced greenhouse gas emissions, and a more resilient energy infrastructure for the future.

4.1.3. Environment

4.1.3.1. Relocation of wildlife when building

The relocation of wildlife during construction plays a vital role in balancing development with environmental responsibility. One project partner demonstrated this by collaborating with wildlife experts to safely relocate a significant ground squirrel population found in their construction area. Such efforts help preserve local ecosystems, prevent habitat destruction, and maintain biodiversity. By incorporating wildlife care into construction planning, companies can ensure that infrastructure projects align with broader sustainability goals, reducing the environmental footprint while supporting conservation efforts. This proactive approach also strengthens public trust and sets a standard for responsible development.

The time required to relocate wildlife depends on factors such as species type, habitat complexity, and regulatory approvals. In the case of the ground squirrel relocation, experts had to assess the population size, identify a suitable new habitat, and execute a careful transfer, which likely took several weeks or months. More complex relocations involving endangered species or large-scale ecosystems may take significantly longer due to the need for detailed studies and continuous monitoring. However, by integrating wildlife assessments early in the project timeline, companies can avoid construction delays while ensuring ethical and effective relocation practices.

Wildlife relocation adds costs to a construction project. Costs may include environmental assessments, expert consultations, habitat preparation, and ongoing monitoring. However, proactive relocation efforts can help avoid legal fines, regulatory issues, and reputational damage that could arise from harming wildlife. Additionally, partnerships with conservation organisations or government agencies may provide funding support or guidance, reducing the financial burden. In the long run, ethical wildlife relocation fosters goodwill and enhances a company's corporate social responsibility profile.

Companies that engage in ethical environmental practices enhance their reputation, making them more attractive to eco-conscious investors, clients, and stakeholders. Responsible development also minimises legal risks and ensures compliance with environmental regulations, reducing the likelihood of project delays or penalties. Moreover, preserving biodiversity contributes to the long-term health of ecosystems, supporting sustainable development initiatives. By demonstrating a commitment to wildlife protection, businesses not only fulfill their construction goals but also create a lasting positive impact on the environment and their public image.

4.1.3.2. Zero pesticide company

Transitioning to a zero-pesticide company is a significant step toward environmental sustainability. Excessive pesticide use can harm ecosystems, contaminate groundwater, and negatively affect biodiversity. By eliminating harmful chemicals and adopting safer alternatives, businesses contribute to a healthier environment, protect wildlife, and promote cleaner air and water sources. This shift aligns with global sustainability efforts, ensuring that agricultural and landscaping practices support long-term ecological balance rather than disrupting natural systems. A pesticide-free approach also sets an example for other companies, encouraging industry-wide improvements in environmental responsibility.

The transition to a zero-pesticide company depends on the scale of operations and the alternatives being implemented. Small-scale businesses can make changes relatively quickly by replacing synthetic pesticides with organic or biological alternatives. However, larger companies may require more time to research, test, and scale new methods effectively. The process often includes soil regeneration efforts, integrated pest management techniques, and employee training on sustainable practices. While the shift may take months or even years, incremental steps can ensure a smooth transition without disrupting productivity.

Eliminating pesticides may require initial investments in research, alternative pest control methods, and new technologies. However, many cost-effective solutions like organic treatments, can provide sustainable long-term benefits. Additionally, reduced pesticide use can lower expenses related to chemical purchases, environmental fines, and soil restoration efforts. Many governments and environmental organisations offer financial incentives and support programmes for businesses making the transition, helping offset costs and ensuring economic feasibility.

Becoming a pesticide-free company yields strong financial and environmental returns. Healthier ecosystems lead to improved soil fertility and better water quality, reducing long-term operational costs. Businesses that prioritise sustainability also benefit from enhanced brand reputation, stronger regulatory compliance, and reduced legal risks. In the long run, adopting a zero-pesticide approach fosters a more resilient business model while contributing to a cleaner, safer, and more sustainable world.

4.2. Air transport

Air transport is a vital component of the global transportation network, enabling rapid connectivity between regions, supporting international trade, and fostering economic development. It plays a key role in the mobility of people and goods over long distances, particularly in areas with limited alternative transport infrastructure. Moreover, addressing the environmental impacts of air transport, such as greenhouse gas emissions and noise pollution, is essential for achieving sustainable development goals and mitigating climate change. In the REDU-CE-D project Dubrovnik Airport and Budapest Airport represented the segment of air transport; the following chapter highlights the experiences of them.

4.2.1. Energy and resources - electrical energy

4.2.1.1. Constant modernization of the electrical vehicle fleet

Modernizing an airport's vehicle fleet with electric alternatives is a crucial step in reducing emissions, lowering fuel costs, and complying with sustainability regulations. Airports operate various types of ground vehicles, including passenger transport buses, tractors for aircraft towing, baggage transporters, and maintenance vehicles. Transitioning these vehicles to electric models enhances efficiency while reducing dependence on fossil fuels.

To support this transition, airports can advocate for government grants, tax incentives, and regulatory policies that promote electric vehicle (EV) adoption. Collaborating with vehicle manufacturers, energy providers, and policymakers can facilitate infrastructure improvements, such as charging station installations that enable seamless electrification of ground operations. Challenges of the transition to the EV vehicles are battery life cycles, possible higher operational limitation and slow upgrade of electric grids to support the modernization.

Transitioning to an electric vehicle fleet offers significant benefits:

- Lower Carbon Emissions: EVs produce no direct emissions, reducing an airport's environmental impact.
- Operational Efficiency: Electric vehicles have fewer moving parts, resulting in lower maintenance requirements and improved reliability.
- Cost Savings: Over time, reduced fuel and maintenance costs make EVs more cost-effective than traditional internal combustion engine vehicles.
- Regulatory Compliance: Many governments are implementing stricter emissions regulations, making early adoption of EVs a proactive compliance strategy.
- Enhanced Public Image: Airports investing in sustainability initiatives attract eco-conscious travelers and business partners, improving their reputation as environmentally responsible entities.

The transition to a fully electric airport vehicle fleet requires a phased approach:

- Short-term (6-12 months): Conduct feasibility studies, assess infrastructure needs, and secure initial funding.
- Mid-term (1-5 years): Begin phased replacement of existing vehicles, install charging stations, and train staff on EV operations.
- Long-term (5-15 years): Achieve full fleet electrification, integrate renewable energy sources for charging stations, and optimise vehicle deployment for maximum efficiency.

Modernizing an airport's vehicle fleet requires significant capital investment and operational challenges, but financial incentives and long-term savings improve affordability. Key cost factors include:

- Vehicle Procurement: EVs generally have a higher initial purchase cost compared to traditional vehicles and some EVs vehicles have higher operational limitations when compared to the vehicles with internal combustion engines, so additional number of units might be required.
- Charging Infrastructure: Installing fast-charging stations and upgrading electrical grids to support higher power demand.
- Training and Maintenance: Staff training for electric vehicle maintenance and investment in diagnostic tools.
- Battery Lifecycle Management: Proper disposal and recycling of EV batteries to ensure sustainability.

Government incentives, industry subsidies, and strategic partnerships can offset many of these costs, making EV fleet modernization more feasible. The ROI for fleet modernization is realised through reduced energy consumption, lower maintenance costs, and compliance with future regulatory standards:

- Short-term ROI (1-5 years): Initial savings on fuel costs and reduced routine maintenance expenses.
- Medium-term ROI (5-10 years): Increased efficiency from optimised EV fleet operations and energy management systems.
- Long-term ROI (10-20 years): Full cost recovery through significant reductions in operational expenses, improved infrastructure sustainability, and regulatory incentives.

By strategically modernizing their vehicle fleets, airports can reduce their environmental footprint, improve cost efficiency, and future-proof their ground transportation operations against evolving sustainability regulations.

4.2.1.2. Awareness raising campaigns

Awareness-raising campaigns are a critical component of airport sustainability strategies, aiming to foster a culture of energy efficiency among diverse stakeholder groups. These initiatives engage airlines, terminal service providers, ground handling companies, retail tenants, employees, and passengers, promoting responsible energy use and environmental stewardship across all operational levels. By encouraging behavioral change and sustainability awareness, airports can significantly reduce their environmental footprint and operational energy consumption.

Campaigns can take multiple formats, including digital displays in terminals, reminder signage on HVAC units, staff workshops, and incentive programmes that reward departments for achieving the highest energy savings. Interactive tools—such as real-time energy consumption dashboards—can further increase transparency and empower stakeholders to actively contribute to sustainability goals.

When designed and executed effectively, awareness campaigns can deliver tangible outcomes through changes in behavior and operational practices. The key benefits include:

- Reduced Energy Waste: Increased awareness encourages stakeholders to adopt energy-efficient habits, such as minimising unnecessary lighting or optimising HVAC use.
- Lower Carbon Emissions: Promoting responsible energy consumption directly contributes to emission reductions by limiting resource overuse.
- Enhanced Stakeholder Engagement: Broad participation across employees, tenants, and service providers fosters a shared sense of environmental responsibility.

- Operational Cost Savings: Behavioral shifts reduce utility expenses, enhancing the financial sustainability of airport operations.
- Regulatory Compliance and Brand Reputation: Active engagement in sustainability enhances public image and ensures alignment with national and international environmental standards.

The timeline for developing and executing an awareness campaign depends on its scope and level of integration with existing environmental strategies:

- Short-Term (3–6 months): Campaign planning, message development, and initial launch through digital channels and static signage.
- Mid-Term (6–18 months): Expansion to include stakeholder workshops, interactive energy dashboards, and cross-departmental engagement.
- Long-Term (18–36 months): Integration into the airport's Environmental Management System (EMS), enabling continuous improvement, monitoring, and long-term sustainability alignment.

Awareness campaigns are relatively low-cost interventions compared to physical infrastructure projects, yet they offer high returns in efficiency and engagement. Main cost components include:

- Communication Materials: Design and production of posters, stickers, digital media, and terminal displays (low to moderate cost).
- Training Programmes: Energy-efficiency workshops for operational staff (moderate cost, offset by long-term gains in energy performance).
- Technology Enhancements: Implementation of real-time energy tracking systems for transparency and motivation (moderate investment with high engagement potential).
- Incentive Schemes: Financial or recognition-based rewards to departments or tenants demonstrating exemplary performance (flexible cost structure).
- Despite modest investment requirements, these campaigns are highly manageable and adaptable, making them ideal for phased implementation or pilot testing.

Awareness campaigns generate both immediate and long-term returns, driven by improved energy use behaviors and stakeholder alignment:

Immediate Impact: Rapid changes in practices—such as more efficient use of lighting and HVAC systems—can yield visible energy savings within months.

- Short-Term ROI (1–3 years): Quantifiable reductions in electricity and fuel use contribute to cost savings and improved operational efficiency.
- Medium-Term ROI (3–7 years): Increased stakeholder buy-in enhances the effectiveness of broader sustainability programmes and supports deeper carbon reduction efforts.
- Long-Term ROI (7–15 years): Cultural transformation within the airport ecosystem creates lasting commitments to sustainability, further reducing emissions and ensuring policy compliance.

Awareness-raising campaigns represent a cost-effective and impactful strategy for promoting energy efficiency within airports. When integrated with broader environmental goals and EMS frameworks, these initiatives can drive lasting behavioral change, reduce environmental impacts, and create a unified, sustainability-focused airport culture. By investing in well-designed and inclusive campaigns, airport operators can significantly enhance both their operational efficiency and their leadership in climate action.

4.2.1.3. Investing in newer equipment

Investing in modern, energy-efficient equipment is a vital component of airport sustainability strategies. Continuous modernization of key systems—including lighting, heating, ventilation, and air conditioning (HVAC), baggage handling, and Ground Support Equipment (GSE)—is necessary to reduce energy consumption, lower carbon emissions, and meet international sustainability targets. Facilitating these upgrades through financial incentives, grants, and regulatory support can significantly accelerate the transition to a more efficient and climate-resilient airport infrastructure.

Upgrading legacy systems with advanced, energy-efficient alternatives generates measurable benefits across operational, environmental, and financial dimensions:

- Lower Energy Consumption: High-efficiency lighting, HVAC, and power systems significantly reduce electricity use.
- Reduced Carbon Footprint: Replacing outdated equipment directly contributes to emissions reductions and supports climate targets.
- Extended Equipment Lifespan: Modern systems typically require less maintenance and offer greater durability, reducing lifecycle costs.
- Improved Operational Efficiency: Automation and digital controls streamline workflows, enhance reliability, and reduce delays.
- Regulatory Compliance: Modern equipment is aligned with international environmental regulations and energy efficiency standards.

The transition to energy-efficient infrastructure requires strategic planning and phased execution:

- Short-Term (6–12 months):
    - Conduct energy audits and feasibility studies;
    - Develop investment plans and identify priority systems for replacement.
- Mid-Term (1–5 years):
    - Roll out targeted upgrades, such as LED lighting, smart HVAC systems, and energy-efficient baggage handling equipment.
- Long-Term (5–15 years):
    - Achieve full-scale modernization;
    - Integrate energy-efficient systems with renewable energy sources and energy management systems (EMS).

While upfront costs for modern equipment can be substantial, long-term benefits justify the investment. Financial support mechanisms—including public funding, tax incentives, and green financing tools—can ease capital burdens. Key cost elements include:

- LED Lighting Systems: High initial costs are offset by long operational life and substantial energy savings.
- Smart HVAC Systems: Investment in AI-enabled climate control systems offers dynamic efficiency improvements.
- Automated Baggage Handling Systems: Energy-efficient conveyors and smart logistics reduce labor and energy costs over time.

- Electric GSE Fleets: Transitioning to electric-powered GSE requires vehicle procurement and charging infrastructure, but significantly reduces fuel and maintenance costs.

The return on investment (ROI) for upgrading to newer, energy-efficient equipment is primarily driven by reductions in energy costs, improvements in operational efficiency, and lower maintenance expenditures.

- Short-term ROI (1–5 years): Immediate financial savings are typically achieved through reduced energy consumption, particularly from the installation of LED lighting systems and optimised HVAC technologies.
- Medium-term ROI (5–10 years): Additional benefits arise from lower maintenance requirements and streamlined operations, resulting in consistent cost reductions and performance enhancements.
- Long-term ROI (10–20 years): Full recovery of capital investments is realised through sustained energy savings, improved compliance with environmental standards, and increased infrastructure resilience.

By promoting the use of targeted incentives and structured investment frameworks, airports can expedite the transition toward energy-efficient infrastructure, securing long-term economic and environmental advantages.

4.2.1.4. Expansion of central systems

The expansion and modernization of central energy systems in airports is essential for optimising electricity usage, enhancing operational efficiency, and achieving long-term sustainability goals. Centralized power management, smart-grid technology, and the integration of renewable energy sources are fundamental components in building a resilient, low-emission energy infrastructure. By advocating for supportive mechanisms such as government grants, tax incentives, and public-private partnerships, airports can accelerate investment in energy-efficient systems that provide both environmental and economic benefits.

Modernized central energy systems offer a range of benefits that contribute to airport sustainability and efficiency:

- Improved Energy Efficiency: Upgraded systems reduce energy loss, enhance distribution accuracy, and increase the effectiveness of power management across airport facilities.
- Lower Operational Costs: Smart-grid and automation technologies help optimise energy consumption, leading to long-term financial savings.
- Resilience and Reliability: Centralized systems provide greater control over energy flows, reducing the risk of outages and operational disruptions.
- Support for Renewable Integration: Expanded infrastructure facilitates the deployment and efficient use of renewable sources such as solar, wind, and battery storage.
- Regulatory Compliance: Aligning with international energy efficiency mandates and environmental standards supports airports in meeting climate targets and securing funding opportunities.

The development and deployment of central energy systems involve phased planning and infrastructure upgrades:

- Short-Term (6–12 months):
    - Conduct feasibility studies;
    - Establish budgets and timelines;
    - Identify financial incentives and funding sources.

- Mid-Term (1-5 years):
    - Retrofit and upgrade legacy systems;
    - Deploy automation technologies (e.g., AI-enabled energy management systems);
    - Begin integration of renewable energy technologies.
- Long-Term (5–15 years):
    - Implement smart-grid frameworks across airport infrastructure;
    - Optimise energy distribution through continuous monitoring and AI-driven adjustments;
    - Expand renewable energy capacity and storage systems to achieve partial or full self-sufficiency.

Although initial investments are substantial, the long-term economic and environmental returns justify the costs. Key areas of expenditure include:

- Smart Grid Implementation: AI-based tools for demand forecasting, load balancing, and predictive maintenance.
- Renewable Energy Infrastructure: Solar panels, wind turbines, and energy storage systems tailored to airport energy demand profiles.
- HVAC and Electrical System Modernization: High-efficiency equipment for thermal management and updated power distribution networks.
- Monitoring and Control Systems: Real-time data analytics platforms for energy consumption tracking and automated optimisation.

Cost manageability improves through phased implementation, utilization of existing infrastructure, and leveraging of external funding opportunities. The ROI from expanding central energy systems materializes through energy savings, enhanced reliability, and deferred maintenance costs:

The return on investment (ROI) for expanding central energy systems is influenced by multiple factors, including energy savings, improvements in operational efficiency, and reductions in maintenance costs.

- Short-term ROI (1–5 years): Immediate benefits arise from the implementation of automated energy controls and smart power distribution, leading to enhanced system efficiency and reduced waste.
- Medium-term ROI (5–10 years): Financial gains are realised through decreased maintenance requirements, increased system reliability, and strengthened energy resilience.
- Long-term ROI (10–20 years): Full capital recovery is achieved through sustained reductions in energy expenditures, broader integration of renewable energy sources, and enhanced infrastructure durability.

Through strategic planning and the pursuit of financial support mechanisms—such as public funding, tax incentives, or industry partnerships—airports can successfully implement and expand centralized energy systems, thereby advancing both economic efficiency and environmental sustainability over the long term.

4.2.2. Energy and resources - fossil fuels

4.2.2.1. Constant modernization of vehicle fleet

Modernizing an airport’s vehicle fleet is a key initiative in reducing fossil fuel consumption and improving overall energy efficiency. Airports rely on a variety of ground support vehicles and equipment, including shuttle buses, baggage transporters, aircraft pushback tractors, fueling trucks, special services vehicles and maintenance vehicles. By transitioning to energy-efficient and low-emission alternatives, such as electric, hybrid, and hydrogen-powered vehicles, airports can significantly cut emissions and fuel costs. In some cases, due to technological or infrastructural reasons, airport's might need to keep relying on the fossil fuel vehicles and equipment, but in such cases, it's necessary to acquire new vehicles with better characteristics and improved energy efficiency.

To encourage this transition, airports can advocate for government grants, tax incentives, and regulatory policies that support the adoption of alternative fuel technologies. Additionally, partnerships with vehicle manufacturers and energy providers can accelerate the deployment of sustainable ground transportation solutions. The modernization of an airport's vehicle fleet has far-reaching benefits:

- Lower Carbon Emissions: Replacing diesel and gasoline-powered vehicles with better performance internal combustion engince, electric or hybrid alternatives reduces CO_2 output.
- Improved Energy Efficiency: Electric motors are more efficient than internal combustion engines, leading to lower energy consumption. New internal combustion engines (when used) have better energy efficiency.
- Reduced Operating Costs: While the initial investment is high, new diesel and gasoline powered vehicles, or electric and hybrid vehicles have lower fuel and maintenance costs over time.
- Enhanced Public Image: Sustainable transportation practices improve an airport's reputation and align with global environmental standards.
- Regulatory Compliance: Many governments are tightening emissions regulations, making early adoption of clean energy vehicles a proactive compliance strategy.

The transition to a fully modernized vehicle fleet requires careful planning and a phased implementation approach:

- Short-term (6-12 months): Conduct feasibility studies, assess existing fleet efficiency, and secure funding for pilot programs.
- Mid-term (1-5 years): Begin phased replacement of older vehicles, install necessary charging or fueling infrastructure, and train staff on new technologies.
- Long-term (5-15 years): Achieve full fleet electrification or conversion to alternative fuels, integrate predictive maintenance systems, and optimise vehicle deployment for maximum efficiency.

Modernizing an airport's vehicle fleet requires substantial investment in both vehicles and infrastructure. Key cost factors include:

- Vehicle Procurement: Electric and hydrogen-powered vehicles have higher upfront costs but lower lifetime operating expenses. New internal combustions vehicles are high investment also, but lower costs then electric vehicles in short term.
- Charging and Fueling Infrastructure: Charging stations for electric vehicles and hydrogen refueling stations require significant capital investment.
- Maintenance and Training: Staff need specialised training to maintain and operate alternative fuel vehicles.
- Regulatory Compliance: Meeting emissions regulations may require additional monitoring and reporting systems.

Despite these costs, financial incentives such as tax credits, government grants, and manufacturer subsidies can help offset initial expenditures. ROI for fleet modernization is realised through a combination of energy savings, operational efficiencies, and regulatory compliance:

- Short-term ROI (1-5 years): Reduced fuel expenses and initial efficiency gains from optimised vehicle usage.
- Medium-term ROI (5-10 years): Lower maintenance costs, improved vehicle longevity, and increased energy efficiency.
- Long-term ROI (10-20 years): Full cost recovery through significant reductions in fuel consumption, emissions, and maintenance costs.

By strategically modernizing their vehicle fleets, airports can reduce their environmental footprint, improve cost efficiency, and future-proof their ground transportation operations against evolving sustainability regulations.

4.2.2.2. Helpful maps and programmes

Efficient fuel management is a key pillar of sustainable airport operations. The implementation of digital mapping systems and fuel optimisation programmes can lead to significant reductions in fuel consumption, greenhouse gas emissions, and operational inefficiencies. By investing in AI-powered taxiway guidance, optimised refueling logistics, and real-time vehicle tracking, airports can streamline ground operations and support airlines in achieving greater fuel efficiency.

To accelerate deployment, airports can pursue government grants, leverage regulatory incentives, and establish partnerships with aviation technology providers. These collaborations foster innovation and ensure the integration of intelligent systems aligned with broader environmental objectives.

Deploying advanced mapping and fuel management technologies delivers multiple operational and environmental benefits:

- Reduced Fuel Consumption: Intelligent routing for aircraft and ground vehicles minimises idle time and inefficient movement, significantly lowering fuel use.
- Lower Carbon Emissions: Shorter taxiing distances and optimised vehicle flow reduce emissions from both aircraft and airport ground support equipment (GSE).
- Enhanced Operational Efficiency: Digital tools improve coordination among air traffic controllers, ground crews, and fueling operators, reducing delays and congestion.
- Cost Savings: Fuel efficiency translates to direct financial savings for both airlines and airport operators.
- Regulatory Alignment: These initiatives support compliance with international emissions reduction goals and environmental reporting standards (e.g., ICAO's CORSIA, EU ETS).

Implementing helpful maps and fuel optimisation programmes involves a phased and scalable approach:

- Short-Term (6–12 months):
  - Conduct feasibility studies and baseline energy audits;
  - Develop initial mapping models and identify priority inefficiencies.
- Mid-Term (1–5 years):
  - Deploy AI-enabled taxiway and routing solutions;

   - Integrate digital systems with live operational data;
   - Train staff to operate new systems effectively.
- Long-Term (5–15 years):
   - Expand system integration with autonomous ground vehicle technologies;
   - Continuously optimise algorithms and routing strategies;
   - Scale program to cover entire airport operations.

The cost of implementing digital mapping and fuel optimisation technologies varies depending on the airport's scale and technological readiness. Key cost components include:

- Software Development and Integration: Custom AI and GIS platforms for navigation and predictive analytics.
- Sensor and Tracking Infrastructure: IoT deployment for real-time vehicle and equipment monitoring.
- Training and System Maintenance: Capacity building for staff and ongoing software/hardware support.
- Compliance and Cybersecurity: Ensuring adherence to data protection regulations and environmental reporting frameworks.

While the initial investment can be moderate to high, long-term manageability is enhanced through phased implementation and external funding opportunities. The return on investment is realised through energy savings, improved operations, and sustainability gains:

- Short-Term ROI (1–5 years): Immediate fuel savings from reduced taxi times and improved GSE routing.
- Medium-Term ROI (5–10 years): Increased airside efficiency, fewer delays, and measurable emissions reductions.
- Long-Term ROI (10–20 years): Full integration with automated and autonomous systems, achieving maximal operational efficiency and emissions reductions.

Investing in digital mapping systems and fuel optimisation programmes presents a strategic opportunity for airports to reduce energy consumption, enhance operational coordination, and demonstrate climate leadership. These technologies not only yield immediate cost savings but also contribute to the long-term transformation of the aviation sector into a more efficient and environmentally responsible industry.

4.2.2.3. Promotion of micro-mobility

Micro-mobility solutions—such as e-scooters, bicycles, and shared electric vehicles—are increasingly adopted in urban transportation systems but remain underutilized in the context of air travel. One of the main barriers is the geographical location of most airports, which are typically situated at considerable distances from city centers and separated by major roadways. This spatial separation limits the practicality of micro-mobility as a mode of access. Nevertheless, some airports have begun to support first- and last-mile connectivity through the development of bike lanes, designated parking facilities, and links to public transport systems.

Empirical evidence suggests that bike lane planning in relation to airport accessibility is generally most effective within a 12–15 kilometer radius of the city center. Beyond this range, cycling becomes less viable for the majority of passengers and staff, especially those carrying luggage. Consequently, the uptake of micro-mobility remains limited in the air transport sector and is primarily feasible for employees and passengers with minimal baggage. Additionally, micro-mobility is often seasonally constrained, with reduced usability in regions experiencing harsh winter conditions.

Given the vast spatial layout of most airports, micro-mobility offers an efficient and sustainable alternative for internal movement between terminals, administrative offices, and maintenance areas. For airport employees, bicycles, e-scooters, and small electric vehicles can reduce reliance on shuttle buses or private vehicles, enhancing both energy efficiency and operational convenience.

However, safety remains a critical concern. To ensure secure integration, designated micro-mobility routes must be carefully planned to avoid high-risk areas such as runways, taxiways, and zones with limited visibility or active aircraft movement. Infrastructure should include clearly marked pathways, speed limits, signage, and dedicated crossings to separate micro-mobility users from ground support vehicles and airside traffic. These measures can facilitate a structured, safe, and efficient transport network within the airport environment.

The overall sustainability impact of micro-mobility in air transport is moderate, largely due to infrastructural and spatial limitations. Nonetheless, where feasible, micro-mobility can contribute to reduced emissions, lower road congestion, and enhanced employee accessibility. Although passenger usage may remain limited, employees—particularly those living within cycling distance—represent a key user group. Targeted incentives such as secure bike parking, subsidies for e-scooter purchases, and dedicated cycling infrastructure can encourage more sustainable commuting behaviors.

Micro-mobility yields the greatest environmental benefit when it replaces short-distance travel in gasoline or diesel-powered vehicles. However, its long-term success depends on infrastructure investment and collaboration with local authorities, particularly in ensuring connectivity beyond the airport perimeter. Seasonal climate considerations must also be addressed through complementary sustainable transport options for winter periods.

Implementation timelines vary based on existing infrastructure, local regulations, and stakeholder coordination:

- Short-Term (6–12 months): Airports with pre-existing bike lanes and transport connections can introduce micro-mobility solutions quickly through parking stations, charging docks, and promotional campaigns.
- Medium-Term (1–2 years): Development of cycling lanes, signage systems, and better integration with public transport hubs requires coordination with municipalities and mobility providers.
- Long-Term (2-3+ years): Major infrastructure projects such as bridges over highways or comprehensive regulatory adjustments demand extensive planning, construction, and cross-sectoral cooperation.

Stakeholder collaboration—including airport authorities, municipal governments, transport agencies, and mobility providers—is critical to managing complexity, clarifying jurisdictional responsibilities, and ensuring long-term maintenance.

Cost varies significantly depending on the level of implementation:

- Low-cost options include bike racks, parking zones, and basic signage;
- Moderate to high-cost investments involve infrastructure upgrades, scooter-sharing systems, app integration, and safety enhancements;
- Ongoing costs relate to maintenance, security, and promotion.

Airports can promote adoption among employees through incentive programmes, mobility partnerships, and targeted communication campaigns. Co-branded marketing and user engagement strategies can further support uptake. While direct financial returns are generally low to moderate, micro-mobility offers several indirect benefits:

- Reduced internal traffic congestion;
- Decreased emissions and environmental footprint;
- Enhanced airport accessibility for staff;
- Positive impact on public perception and sustainability branding;
- Potential ancillary revenue through advertising and partnerships.

These benefits can enhance the airport's alignment with environmental goals and appeal to eco-conscious travelers and business partners.

In summary micro-mobility is not a universal solution for airport access but can provide meaningful environmental and operational benefits in specific contexts. Its viability is greatest for employees and passengers with minimal baggage and within a 12–15 km range of urban centers. Seasonal constraints and infrastructure gaps limit year-round application in some regions, but targeted investments and strategic integration with other transport modes can enhance its role in sustainable airport mobility. A multi-modal, flexible approach, supported by strong stakeholder collaboration, will be key to realising micro-mobility's full potential in the air transport sector.

4.2.2.4. Promoting and advocating for new incentives

The transportation sector is among the most energy-intensive globally, contributing significantly to greenhouse gas emissions. Within this context, the air transport sector plays a critical role in the transition toward a more energy-efficient and low-emission future. The introduction and promotion of well-designed incentive mechanisms are key to facilitating this transition. Incentives may take the form of financial subsidies, regulatory advantages, carbon pricing schemes, **or** operational privileges, encouraging airlines, airport operators, and fuel suppliers to invest in energy-efficient technologies, alternative fuels, and innovative propulsion systems.

The implementation of structured incentive programmes can generate substantial benefits, including:

- Reduction in Fuel Consumption and Emissions: Incentives can accelerate investment in fuel-efficient aircraft, sustainable aviation fuels (SAF), and alternative propulsion technologies, contributing to immediate and long-term environmental gains.
- Acceleration of SAF Adoption: Policies such as tax incentives, subsidies, and mandatory blending targets can improve the economic viability of SAF, making it competitive with conventional jet fuels.
- Operational Efficiency Gains: Incentives that promote improved air traffic management (ATM) and flight optimisation can reduce fuel consumption and emissions.
- Fostering Technological Innovation: Financial support for research and development (R&D) encourages the advancement of electric, hybrid, and hydrogen-based propulsion technologies.
- Strengthened Market Position: Early adopters of sustainable practices can gain competitive advantages, appealing to environmentally conscious passengers and stakeholders.
- Enhanced Industry Collaboration: Incentive frameworks can align the goals of airlines, airports, governments, and manufacturers, fostering a coordinated effort toward decarbonizing aviation.

The time required to introduce new incentives depends on their type and complexity:

- Short-Term (1–2 years): Regulatory measures such as emissions-based landing fee reductions or carbon pricing can be implemented relatively quickly, especially with strong governmental or industry support.
- Medium-Term (3–5 years): Financial incentives for SAF production, or infrastructure investments for alternative fuel systems, require legislative processes, stakeholder engagement, and capital planning.
- Long-Term (5+ years): Large-scale shifts—such as the deployment of hydrogen or electric aircraft—depend on R&D maturity, technological readiness, and extensive infrastructure development.

The cost of promoting and advocating for new incentives is largely manageable, especially compared to infrastructure investments. Primary cost areas include:

- Regulatory Advocacy: Includes policy development, lobbying, and coordination with regulatory bodies. These typically require administrative resources rather than large financial outlays.
- Public Awareness and Stakeholder Engagement: Costs related to communication strategies, forums, workshops, and industry consultations.
- Research and Feasibility Studies: Essential for generating data-driven policy proposals; moderate investment required for environmental and economic impact assessments.
- Collaboration with Industry Bodies: Involves participation in working groups, co-funded initiatives, and the development of promotional and informational materials.
- Financial Incentives: Subsidies for SAF, R&D funding, or infrastructure support require substantial investment but can be balanced with carbon levies, public-private partnerships, or green bond schemes.
- Monitoring and Compliance: Implementation requires performance tracking, reporting systems, and auditing to ensure effectiveness and transparency.

The ROI of advocacy and incentive promotion varies by measure but offers substantial potential:

- High ROI:
  - Operational incentives such as optimised flight planning and ATM improvements yield immediate fuel and cost savings.
  - Regulatory advocacy can result in industry-wide energy efficiency improvements with relatively low investment.
- Moderate ROI:
  - Awareness campaigns and stakeholder engagement foster voluntary adoption of sustainability measures.
  - SAF incentives may initially be cost-intensive but can lead to long-term savings and emissions reductions as production scales.
- Long-Term ROI:
  - Research, policy development, and collaborative initiatives lay the foundation for systemic change and enable future technology integration.
  - Technology shifts toward electric or hydrogen aircraft offer extended payback periods but are vital for deep decarbonization.

The strategic promotion and advocacy of incentive mechanisms in the air transport sector is an essential component of the broader energy transition. When effectively designed and implemented, incentives can drive immediate operational improvements while supporting long-term innovation and sustainability goals. Importantly, this approach not only facilitates environmental performance but also enhances the sector's resilience, competitiveness, and alignment with international climate targets.

4.2.2.5. Investing and exploring the trend of hydrogen use for vehicles

Hydrogen represents a promising avenue for reducing emissions in the airport sector, particularly in ground service operations such as baggage handling, internal passenger transport, and aircraft servicing. While the potential environmental benefits are considerable, the adoption of hydrogen technology remains at an early developmental stage, accompanied by significant regulatory, technical, and infrastructural uncertainties.

Key barriers include the need for dedicated refueling infrastructure, the adaptation of ground vehicles to hydrogen powertrains, and the absence of fully established regulatory frameworks in many jurisdictions. These factors contribute to a complex implementation landscape, requiring coordinated strategic planning and stakeholder engagement.

Although hydrogen may ultimately play a role in decarbonizing aviation more broadly, this document focuses specifically on its application within airport ground operations, excluding potential use in aircraft propulsion.

Hydrogen-powered ground vehicles generate zero tailpipe emissions, presenting a clear opportunity to reduce greenhouse gas (GHG) emissions and local air pollutants in airport environments. The extent of these benefits depends largely on the source of hydrogen production:

- Green hydrogen, produced via electrolysis using renewable energy, offers the most significant emissions reductions.
- Grey or blue hydrogen, produced from fossil fuels with or without carbon capture, offer fewer environmental advantages.

Despite its theoretical potential, empirical data on hydrogen's environmental impact in airport ground operations remains limited. Outcomes are highly dependent on technology maturity, energy sourcing, and deployment context. Further pilot projects and case studies are necessary to generate reliable benchmarks and assess real-world feasibility.

Given the current regulatory uncertainties and technological constraints, accurately estimating an implementation timeline for hydrogen vehicle deployment in airport environments remains highly speculative. In the absence of a clearly defined regulatory framework, progress is likely to be limited to exploratory and preparatory activities. Moreover, as the use of hydrogen-powered vehicles in airports is still emerging, comprehensive testing will be essential to ensure safety, operational feasibility, and system reliability. Critical safety considerations—including hydrogen handling, storage protocols, and emergency response measures—will require thorough risk assessments and regulatory alignment. Even following regulatory approval, the implementation process would likely involve several years of pilot testing and gradual rollouts, positioning hydrogen integration as a long-term undertaking that could extend over a decade.

Initial investment costs for hydrogen integration in airport ground operations are substantial, primarily due to the need for dedicated infrastructure, procurement of hydrogen-powered vehicles, and specialised training for personnel. Key cost drivers include the construction of hydrogen refueling stations, implementation of comprehensive safety protocols, and adaptation or replacement of existing ground service equipment. Nevertheless, these costs are expected to decline over time as technological maturity increases and economies of scale are realised across the hydrogen value chain.

In the long term, operational costs for hydrogen-powered vehicles may be lower than those associated with conventional diesel vehicles, particularly as green hydrogen becomes more accessible and competitively priced. The manageability of these investments is influenced by several factors, including the existing infrastructure base, organisational capacity for innovation, and the ability to establish strategic partnerships with technology providers and energy suppliers.

Estimating a precise return on investment (ROI) at this stage remains complex due to significant uncertainties related to regulatory developments, market dynamics, and the evolving cost of hydrogen infrastructure. Nonetheless, early adopters may benefit from non-financial returns, such as enhanced environmental performance, improved alignment with Environmental, Social, and Governance (ESG) criteria, and strengthened institutional reputation. Airports that lead in hydrogen implementation may also gain a first-mover advantage, attracting public funding, green investment, or subsidies earmarked for low-carbon transition efforts.

While the financial profitability of hydrogen integration is not yet guaranteed, early investments can lay the groundwork for long-term sustainability gains, operational resilience, and strategic leadership in the aviation sector's transition toward decarbonization.

4.2.3. Environment

4.2.3.1. Regular maintenance of infrastructure

The air transport sector is highly reliant on robust and well-maintained infrastructure to ensure operational efficiency, safety, and environmental sustainability. Airports must adhere to stringent regulatory frameworks, including those set by the International Civil Aviation Organisation (ICAO) and the European Union Aviation Safety Agency (EASA). Routine and systematic maintenance of key infrastructure elements—such as runways, taxiways, lighting systems, heating and cooling systems, and Ground Support Equipment (GSE)—is critical to minimising energy consumption and sustaining long-term performance.

By proactively maintaining and upgrading facilities and equipment, airports can reduce energy losses, prevent system failures, and extend the service life of critical assets. These efforts contribute not only to operational resilience but also to substantial cost savings and emissions reductions.

Regular maintenance significantly enhances energy efficiency through several mechanisms:

- Prevention of energy waste: Well-maintained HVAC systems, lighting networks, and power distribution systems operate at optimal efficiency, minimising unnecessary energy usage.
- Extension of asset lifespan: Routine servicing of key equipment—including ground power units (GPUs), baggage handling systems, and jet bridges—reduces wear and tear, delaying the need for costly replacements and mitigating the environmental impact associated with new manufacturing.
- Minimisation of unplanned downtime: Infrastructure failures often lead to increased energy use, operational delays, and higher costs. Preventative maintenance helps ensure continuous and efficient operations.
- Increased airport resilience: Properly maintained infrastructure is better equipped to integrate emerging sustainability technologies, such as renewable energy systems and electrified GSE fleets.

The timeline for implementing a comprehensive maintenance framework varies based on airport size, complexity, and existing infrastructure. The process typically involves:

- Assessment and Asset Inventory: Identification of all infrastructure components requiring routine maintenance.

- Definition of Procedures and Schedules: Establishment of detailed maintenance protocols, including frequency and scope.
- Personnel Training or Contracting: Ensuring that in-house teams or external service providers possess the necessary expertise and resources.
- Implementation and Monitoring: Execution of scheduled maintenance tasks and systematic performance tracking.
- Audit and Optimisation: Periodic evaluations of effectiveness, with adjustments made to improve efficiency and coverage.

While basic frameworks can be initiated within 6 to 12 months, full operational maturity and integration into broader Environmental Management Systems (EMS) typically require 3 to 5 years. The cost of implementing a structured maintenance program depends on various factors, including airport scale, infrastructure complexity, and regulatory obligations. Based on insights from the Transnational Technical Working Group (TWG) discussions, this measure is classified as medium in manageability. Major cost components include:

- Initial setup costs for maintenance scheduling systems, baseline audits, and staff training.
- Ongoing expenses related to labor, spare parts, and performance monitoring tools.
- Targeted infrastructure upgrades, such as LED lighting installations or integration of advanced energy management platforms.

Although recurring, these maintenance costs are significantly lower than those incurred through emergency repairs, unplanned downtime, or premature asset replacement. Structured maintenance programmes deliver multiple financial and operational returns:

- Reduced energy consumption: Optimised performance of HVAC, lighting, and power systems lowers electricity and fuel use.
- Extended asset longevity: Regular servicing delays the need for major capital expenditures on replacements.
- Improved operational stability: A well-maintained airport experiences fewer technical disruptions, reducing delays and their associated financial impacts.
- Regulatory compliance: Adherence to maintenance standards helps avoid penalties and supports alignment with sustainability and ESG commitments.

Although precise ROI varies by airport context, typical payback periods range from 3 to 7 years, with longer-term savings accruing from improved efficiency and asset preservation.

Regular infrastructure maintenance is a cornerstone of sustainable airport operations and a fundamental element of any effective **Environmental Management System (EMS)**. While it requires ongoing investment, the benefits—including enhanced energy efficiency, reduced operational costs, and improved environmental performance—are both measurable and enduring. By prioritising preventative maintenance, airports can strengthen their resilience, improve service continuity, and contribute meaningfully to the broader decarbonization of the aviation sector.

4.2.3.2. Measures taken to address noise pollution

Noise pollution represents a significant environmental and operational challenge for airports. The cumulative impact of aircraft takeoffs, landings, taxiing, and ground support operations contributes to elevated noise levels, which can adversely affect both surrounding communities and local ecosystems. To effectively mitigate these impacts, airports must adopt proactive and integrated noise management strategies, including the adoption of quieter aircraft technologies, optimised flight paths, and sound insulation programmes for high-exposure areas.

To support implementation, airports should advocate for regulatory incentives, targeted funding, and operational policies that encourage the use of quieter aircraft and more sustainable procedures. Moreover, collaboration with local authorities, aviation regulators, and community stakeholders is essential to ensure the effectiveness and social acceptance of noise reduction frameworks.

Comprehensive noise mitigation strategies provide a broad range of environmental, social, and operational benefits:

- Improved Community Relations: Lower ambient noise levels foster stronger ties with local communities and reduce the frequency of complaints or opposition to airport operations.
- Enhanced Passenger Experience: Reduced noise contributes to a more comfortable and appealing airport environment for travelers.
- Regulatory Compliance: Alignment with national and international noise standards helps avoid legal penalties and maintains operational legitimacy.
- Operational Efficiency: Flight path optimisation and better ground management practices can reduce delays and streamline movements.
- Environmental Protection: Limiting excessive noise contributes to the preservation of local biodiversity by minimising disruption to wildlife habitats.

The implementation of noise pollution reduction strategies requires a structured approach:

- Short-term (6-12 months): Conduct noise impact assessments, engage stakeholders, and introduce minor operational changes (e.g., modifying runway use during nighttime hours).
- Mid-term (1-5 years): Implement sound insulation programmes, optimise flight paths, and introduce incentives for airlines using quieter aircraft.
- Long-term (5-15 years): Complete fleet modernization efforts, integrate advanced noise-reduction technologies, and establish permanent community engagement programmes.

While noise mitigation measures require both capital investment and operational reform, their long-term manageability is enhanced through structured planning and access to funding. Key cost areas include:

- Noise Monitoring Systems: Deployment of real-time tracking and data analysis tools to measure and respond to noise emissions.
- Sound Insulation Programmes: Investment in retrofitting homes, schools, and commercial spaces located in high-exposure zones.
- Flight Path Optimisation Tools: Upgrading air traffic systems to enable environmentally and acoustically optimised routing.
- Fleet Transition Support: Financial incentives or landing fee discounts to encourage airlines to operate quieter, next-generation aircraft.
- Community Engagement: Ongoing communication initiatives, including public forums, impact assessments, and feedback channels.

The long-term benefits of implementing comprehensive noise reduction measures extend beyond environmental performance, contributing to regulatory compliance, strengthened stakeholder relationships, and improved operational efficiency:

- Short-term ROI (1-5 years):
    - Immediate decrease in noise-related community complaints;
    - Enhanced compliance with national and international noise regulations.
- Medium-term ROI (5–10 years):
    - Increased airport capacity through more efficient and noise-sensitive flight scheduling;
    - Improved public perception and community support for airport operations.
- Long-term ROI (10–20 years):
    - Sustainable reductions in noise levels foster long-term trust and cooperation with surrounding communities;
    - Increased passenger satisfaction due to a more comfortable acoustic environment;
    - Greater operational resilience and efficiency through integrated noise management practices.

By adopting structured and proactive noise reduction strategies, airports can achieve a more sustainable operational model, fulfill regulatory obligations, and foster positive relationships with key stakeholders—laying the foundation for long-term environmental and economic success.

4.2.3.3. Reducing the use of plastic where possible

Airports are significant generators of plastic waste due to the high volume of passenger activities, retail operations, food services, and routine maintenance. Minimising plastic use is a critical component of sustainable airport management and contributes to broader global efforts to reduce environmental pollution. By adopting policies that phase out single-use plastics, encourage the use of biodegradable alternatives, and promote recycling, airports can play a leadership role in advancing circular economy principles.

Strategic collaboration with government agencies, vendors, and logistics providers, alongside financial incentives and regulatory frameworks, can significantly accelerate the transition to a low-waste, plastic-free operational environment. Implementing plastic reduction strategies delivers numerous environmental, reputational, and operational benefits:

- Lower Environmental Footprint: Minimising plastic consumption reduces the accumulation of waste in landfills and marine environments.
- Enhanced Brand Image: Demonstrating commitment to sustainability appeals to environmentally conscious travelers and strengthens stakeholder trust.
- Regulatory Compliance: Early alignment with emerging policies on plastic reduction mitigates legal risks and positions the airport as a policy leader.
- Improved Recycling Outcomes: Reducing plastic waste facilitates better waste segregation, improves recycling efficiency, and enhances resource recovery.
- Cost Savings in Waste Management: Decreased reliance on disposable plastics lowers long-term disposal costs and improves overall operational sustainability.

The transition to a plastic-free airport requires a phased approach:

- Short-term (6-12 months): Identify key sources of plastic waste, introduce initial reduction policies, and engage stakeholders.

- Mid-term (1-5 years): Implement plastic-free alternatives, establish recycling stations, and incentivize businesses to reduce plastic dependency.
- Long-term (5-10 years): Complete phase-out of single-use plastics, integrate circular economy principles, and maintain continuous improvement efforts.

While the transition to plastic-free operations involves upfront investment, these costs are manageable and diminish over time. Key areas of expenditure include:

- Biodegradable Alternatives: Initial procurement costs may be higher, but prices are expected to decline as adoption scales.
- Recycling and Waste Infrastructure: Investments in sorting stations, composting units, and optimised logistics.
- Vendor Support: Offering financial or logistical assistance to on-site retailers and food service providers transitioning to sustainable packaging.
- Awareness and Training Campaigns: Educating passengers and staff to encourage behavioral change and support successful implementation.

Investing in plastic reduction initiatives leads to long-term environmental and financial benefits:

- Short-term ROI (1-3 years): Increased passenger awareness and reduced single-use plastic consumption.
- Medium-term ROI (3-7 years): Lower waste management costs and enhanced reputation as a sustainable airport.
- Long-term ROI (7-15 years): Full integration of circular economy practices, regulatory compliance, and significant environmental impact reduction.

By systematically reducing plastic use, airports can contribute to global sustainability efforts while improving operational efficiency and passenger experience.

4.2.3.4. Introduction of oil/water separators

Oil and water separation is a vital environmental protection measure for airports, given the significant volumes of wastewater generated through aircraft maintenance, fueling, runoff from aprons, and ground support activities. Without adequate treatment, oil-contaminated water can pose severe risks to local water bodies and ecosystems. The installation of oil/water separators ensures compliance with environmental regulations, mitigates pollution risks, and supports the airport’s long-term sustainability objectives.

To facilitate widespread adoption, airports can advocate for regulatory incentives, government grants, and industry partnerships that support infrastructure upgrades. Additionally, meeting rigorous wastewater discharge standards can contribute to eligibility for tax benefits and sustainability certifications.

The implementation of oil/water separation systems offers several strategic advantages across environmental, regulatory, and financial domains:

- Environmental Protection: Prevents oil, fuel, and chemical residues from entering water bodies, thereby protecting aquatic ecosystems.
- Regulatory Compliance: Ensures adherence to national and international environmental standards, reducing the risk of legal action or penalties.
- Improved Wastewater Management: Facilitates the safe treatment and discharge of wastewater produced during routine airport operations.

- Enhanced Public Image and Certification Potential: Demonstrates environmental stewardship, contributing to improved stakeholder perception and eligibility for green airport certifications (e.g., Airport Carbon Accreditation).
- Cost Avoidance: Reduces the need for costly remediation efforts by preventing contamination at the source.

The implementation of oil/water separators requires proper planning, investment, and regulatory alignment:

- Short-term (6-12 months): Conduct environmental impact assessments, obtain permits, and design infrastructure solutions.
- Mid-term (1-5 years): Install oil/water separation systems at key airport locations, integrate monitoring systems, and train staff on maintenance and compliance.
- Long-term (5-10 years): Optimise separation efficiency, expand coverage, and establish continuous improvement programmes for wastewater management.

The implementation of oil/water separation systems entails initial capital investment, which can be managed through external funding and long-term planning. Key cost drivers include:

- Infrastructure Development: Installation of oil/water separators and associated drainage systems at critical airport locations.
- Monitoring and Compliance: Acquisition of sensor systems for water quality monitoring and regulatory reporting.
- Operational and Maintenance Costs: Routine cleaning, filter replacements, and safe disposal of separated waste products.
- Regulatory and Certification Expenses: Fees related to permitting, inspections, and environmental compliance documentation.

Despite the initial investment, these systems are highly manageable over time, especially when supplemented by financial incentives **or** public-private partnerships. Investing in oil/water separation technology provides significant long-term returns through regulatory compliance, environmental protection, and operational efficiencies:

- Short-term ROI (1-5 years): Immediate regulatory compliance and risk reduction.
- Medium-term ROI (5-10 years): Lower cleanup costs, fewer fines, and improved wastewater management.
- Long-term ROI (10-20 years): Sustainable environmental practices, long-term financial savings, and enhanced airport reputation.

By integrating oil/water separators into airport infrastructure, operators can protect the environment, comply with regulations, and achieve long-term cost savings while enhancing their sustainability credentials.

4.2.4. Management system - implementing an EMS

4.2.4.1. Data analysis and reporting

Data analysis and reporting represent foundational components of an effective Environmental Management System (EMS) in the aviation sector. By utilizing real-time monitoring technologies, airports can systematically track energy consumption, emissions, and operational performance. These data-driven insights enable more precise decision-making, enhance regulatory compliance, and support long-term sustainability targets.

To encourage the adoption of advanced analytical capabilities, airports should advocate for government funding, the establishment of industry-wide reporting standards, and incentives that facilitate the integration of artificial intelligence (AI) and machine learning within environmental monitoring systems. These tools not only enhance operational efficiency but also promote transparency and continuous environmental improvement.

Deploying advanced data analysis and reporting tools within EMS frameworks yields multiple strategic benefits:

- Improved Energy Efficiency: Real-time data capture enables early detection of inefficiencies, leading to immediate corrective action and energy savings.
- Regulatory Compliance: Automated monitoring and structured reporting ensure adherence to national and international environmental regulations, minimising the risk of penalties.
- Enhanced Decision-Making: Comprehensive datasets support evidence-based resource allocation, investment planning, and process optimisation.
- Operational Cost Savings: Improved visibility of resource usage leads to reductions in waste, inefficiency, and overall utility expenses.
- Stakeholder Transparency: Public sustainability reports strengthen trust among airlines, regulators, passengers, and local communities.

The deployment of data analysis and reporting frameworks involves several phases:

- Short-term (6-12 months): Identify key performance indicators (KPIs), assess existing data collection methods, and develop a reporting strategy.
- Mid-term (1-5 years): Implement real-time monitoring systems, integrate AI-based analytics, and establish automated reporting tools.
- Long-term (5-10 years): Continuously optimise data collection, expand reporting capabilities, and integrate predictive analytics for sustainability planning.

Although initial investments in data infrastructure and training may be significant, these costs are manageable and often offset by long-term efficiency gains. Major cost elements include:

- Software and Infrastructure: Acquisition of cloud-based analytics platforms, sensor networks, and AI applications for predictive insights;
- Staff Training and Development: Capacity-building initiatives for personnel responsible for EMS implementation and performance monitoring;
- Regulatory Compliance and Auditing: Resources for aligning with environmental reporting obligations and maintaining cybersecurity standards;
- System Integration: Costs related to merging new technologies with existing operational and IT frameworks.

Access to green funding, public-private partnerships, and EU-level sustainability grants can significantly reduce the financial burden of implementation. ROI for data analysis and reporting systems is realised through cost savings, improved efficiency, and regulatory benefits:

- Short-term ROI (1-5 years): Immediate efficiency gains from automated monitoring and reporting.

- Medium-term ROI (5-10 years): Reduction in energy waste and enhanced compliance with environmental regulations.
- Long-term ROI (10-20 years): Fully optimised sustainability planning, lower operational costs, and stronger industry leadership in environmental management.

By integrating advanced data analysis and reporting into EMS frameworks, airports can enhance sustainability efforts, improve transparency, and drive long-term cost savings while ensuring regulatory compliance.

4.2.4.2. Integration of renewable energy

The integration of renewable energy into airport infrastructure is a vital measure for advancing environmental sustainability and energy independence. By harnessing sources such as **solar, wind**, and **geothermal energy**, airports can significantly reduce dependence on fossil fuels, decrease greenhouse gas emissions, and align with national and international climate targets. Through **government incentives**, **grants**, and **industry collaborations**, airports can overcome financial and technical barriers, facilitating a timely and cost-effective transition to clean energy.

The implementation of renewable energy systems provides a broad range of environmental, economic, and operational benefits:

- Reduced Carbon Footprint: Transitioning from conventional fuels to renewables significantly decreases greenhouse gas emissions.
- Operational Cost Savings: Renewable energy systems—particularly solar photovoltaics and wind turbines—offer long-term reductions in electricity costs.
- Enhanced Energy Resilience: On-site energy generation and storage reduce reliance on external grids and improve energy security during peak demand or outages.
- Regulatory Alignment: Early adoption supports compliance with national renewable energy mandates and international decarbonization frameworks.

Reputation and Stakeholder Engagement: Airports that lead in renewable energy adoption enhance their public image, attract environmentally conscious travelers, and gain favor with investors and regulators.

Renewable energy integration should follow a structured, phased approach tailored to site conditions, available funding, and policy frameworks:

- Short-term (6-12 months): Conduct feasibility studies, secure funding, and engage stakeholders.
- Mid-term (1-5 years): Install small-scale renewable energy projects, such as rooftop solar panels and battery storage systems.
- Long-term (5-15 years): Expand renewable energy infrastructure, integrate microgrids, and achieve energy self-sufficiency.

While renewable energy infrastructure entails substantial upfront investment, these costs are increasingly mitigated by declining technology prices, government incentives, and long-term savings. Key cost elements include:

- Infrastructure Development: Installation of solar panels, wind turbines, inverters, and associated grid hardware
- Energy Storage Systems: Battery banks for load shifting and backup power

- Grid Modernization: Upgrades to airport power distribution systems to accommodate two-way energy flows
- Permitting and Compliance: Regulatory approvals, environmental impact studies, and alignment with energy standards (e.g., ISO 50001)

Manageability is enhanced through public-private partnerships (PPPs), performance-based contracts, and access to EU green transition funding mechanisms. The ROI from renewable energy investments depends on system size, energy pricing structures, and financing mechanisms:

- Short-term ROI (1-5 years): Immediate energy cost reductions and enhanced sustainability reputation.
- Medium-term ROI (5-10 years): Increased energy independence and further cost reductions.
- Long-term ROI (10-20 years): Full cost recovery through energy savings, government incentives, and enhanced operational efficiency.

By strategically integrating renewable energy, airports can reduce long-term operational costs, minimise environmental impact, and ensure compliance with global sustainability standards.

4.2.4.3. Predictive maintenance

Predictive maintenance, when embedded within an Environmental Management System (EMS), offers a data-driven approach to optimising maintenance operations, reducing energy waste, and enhancing overall operational efficiency in the airport environment. Leveraging technologies such as real-time sensors, Internet of Things (IoT) devices, and artificial intelligence (AI), predictive maintenance enables early detection of potential equipment failures, thereby minimising unscheduled downtime and unnecessary energy consumption.

At airports, this approach applies to a wide range of systems and operations, including Ground Support Equipment (GSE), airfield lighting, baggage handling systems, HVAC systems, emergency response vehicles (e.g. police, fire, ambulance), and fueling operations. For airlines, ground handlers, and other service partners, predictive maintenance facilitates better equipment performance monitoring, reduces inefficiencies, and lowers fuel and energy consumption. When fully integrated into an EMS, predictive maintenance becomes a key tool for enhancing sustainability, improving energy efficiency, and minimising environmental impact.

Predictive maintenance delivers a wide range of measurable benefits, including:

- Energy Efficiency Gains: Enables optimal operation of airport systems, reducing energy losses from idle or inefficient equipment.
- Extended Equipment Lifespan: Minimises wear and tear, reducing the frequency of replacements and the energy burden associated with new production and disposal.
- Lower Carbon Footprint: Enhances the environmental performance of both airport-owned infrastructure and third-party service operations.
- Improved Safety and Reliability: Anticipates failures before they occur, reducing operational risk and avoiding energy-intensive disruptions.
- Reduced Operational Costs: Lowers the cost associated with emergency maintenance and unscheduled downtime.
- Risk and Opportunity Management: Supports the early identification of environmental risks and benefits under various scenarios, enabling proactive mitigation planning.

The timeline for implementing predictive maintenance varies based on airport size, digital maturity, and data availability. A phased approach typically includes:

- Short-Term (3-6 months): Conducting a feasibility study, selecting appropriate systems, and identifying priority assets for monitoring.
- Mid-Term (6–18 months): Pilot implementation, training of maintenance staff, refinement of predictive models, and early integration into EMS processes.
- Long-Term (18–36 months): Full-scale deployment, institutionalisation within the EMS, and ongoing performance optimisation based on real-time data and feedback loops.

The cost of implementing predictive maintenance is influenced by the scope of deployment and existing digital infrastructure. Major cost elements include:

- Hardware Investment: Installation of IoT sensors, connectivity infrastructure, and data storage systems (typically front-loaded, with high scalability over time);
- Software and AI Integration: Development or acquisition of predictive analytics tools and integration into EMS platforms (moderate and often available as a subscription or service);
- Training and Auditing: Upskilling of maintenance personnel and routine audits to ensure system effectiveness (ongoing costs that improve long-term efficiency);
- Operational Adjustments: Minor costs associated with initial integration and potential temporary service disruptions, which can be minimised through effective planning.

While initial expenditures may be significant, costs can be mitigated through phased implementation, leveraging existing infrastructure, and exploring public-private partnerships or funding opportunities.

Predictive maintenance delivers a high return on investment, typically within 3-5 years, through:

- Energy Savings: Decreased energy usage across lighting systems, HVAC operations, and GSE fleets;
- Reduced Maintenance Expenditures: Fewer unplanned repairs and component replacements;
- Extended Equipment Longevity: Delays capital expenditures by maximising the useful life of assets;
- Enhanced Operational Efficiency: Minimises flight disruptions and supports consistent service delivery.

Beyond financial gains, predictive maintenance strengthens an airport's alignment with climate action goals, regulatory compliance (e.g., ICAO and EU sustainability standards), and Environmental, Social, and Governance (ESG) commitments.

In summary, the integration of predictive maintenance into EMS frameworks offers substantial long-term advantages in terms of **energy efficiency, cost reduction, equipment reliability**, and **sustainability**. While initial investments in technology, training, and infrastructure are required, the operational and environmental benefits far outweigh the costs. Airports and aviation stakeholders that adopt predictive maintenance early will not only improve their internal performance but also lead the industry toward **climate-resilient and low-emission operations**.

4.2.4.4. Automated controls for lighting and HVAC

Automated control systems for lighting and HVAC (heating, ventilation, and air conditioning) are essential for improving the energy performance of airport facilities. These smart technologies—including motion sensors, AI-driven temperature regulation, and real-time energy monitoring—enable dynamic environmental management, reducing energy consumption while maintaining comfort and operational efficiency. As airports face increasing pressure to meet environmental targets, automation offers a scalable and impactful solution for advancing sustainability.

To facilitate adoption, airports may leverage government grants, tax incentives, and public-private partnerships to reduce upfront costs and ensure long-term cost-effectiveness. Collaboration with energy management firms and smart technology providers can also enhance system design and implementation quality. The adoption of automated systems provides a range of environmental, financial, and operational benefits:

- Reduced Energy Consumption: Motion and occupancy sensors prevent energy waste by activating lighting and HVAC systems only when needed.
- Lower Operational Costs: Automated systems enable precise energy use, which translates to significant savings on utility expenses.
- Enhanced Passenger Comfort: AI-enabled HVAC systems adjust indoor climates in real-time based on occupancy and external conditions, improving passenger satisfaction.
- Regulatory Compliance: Meeting international energy efficiency standards (e.g., ISO 50001) and contributing to national climate goals.
- Prolonged Equipment Lifespan: Reduced system runtime decreases wear and tear on lighting and HVAC units, lowering maintenance and replacement costs.

The implementation of automated control systems can be structured in incremental phases, depending on the airport's infrastructure readiness and investment capacity:

- Short-term (6-12 months): Identify high-energy-use areas, conduct feasibility studies, and install pilot automation systems in select locations.
- Mid-term (1-5 years): Scale up automated controls across terminals and integrate AI-driven optimisation software to improve efficiency.
- Long-term (5-15 years): Achieve full automation with continuous improvements based on energy consumption data, incorporating predictive analytics for long-term sustainability.

While initial investments in automation technology can be substantial, these systems are financially manageable and increasingly supported by external funding mechanisms. Primary cost drivers include:

- Sensor and Automation Infrastructure: Procurement and installation of motion detectors, smart thermostats, actuators, and centralized controllers;
- System Integration: Compatibility upgrades with existing HVAC and lighting infrastructure;
- Training and Support: Staff education, system maintenance, and software updates;
- Compliance and Permitting: Alignment with national efficiency codes and international sustainability benchmarks.

Cost efficiency is further enhanced through energy service contracts (ESCOs), green bonds, or EU-funded climate initiatives. The ROI for automated lighting and HVAC systems is realised through energy savings, operational cost reductions, and enhanced environmental performance:

- Short-term ROI (1-5 years): Immediate reductions in energy waste and lower electricity bills.
- Medium-term ROI (5-10 years): Enhanced efficiency through AI-driven automation and optimised climate control.

- Long-term ROI (10-20 years): Full integration with airport-wide smart systems, maximising energy efficiency and cost savings.

By adopting automated lighting and HVAC controls, airports can significantly reduce energy consumption, enhance operational efficiency, and align with global sustainability goals, making it a strategic long-term investment.

4.2.5. Other climate change measures - implementation of warning systems

The implementation of advanced warning systems is a vital component of modern airport infrastructure, aimed at enhancing safety, improving risk mitigation, and strengthening emergency preparedness. These systems provide real-time alerts for a wide range of threats—including extreme weather events, air quality deterioration, security incidents, and other operational hazards—that can significantly disrupt airport functionality.

To accelerate deployment, airports can advocate for government funding, industry partnerships, and regulatory support. The integration of AI-driven analytics, IoT-enabled sensors, and automated communication platforms can significantly enhance system accuracy and responsiveness, supporting a resilient and future-proof operational environment. The adoption of modern warning systems offers critical operational, safety, and economic advantages:

- Enhanced Safety and Risk Management: Early detection of hazards such as thunderstorms, fog, runway icing, or unauthorised airspace breaches improves decision-making and mitigates risk to passengers, personnel, and infrastructure.
- Operational Efficiency: Timely alerts enable airports to proactively adjust operations, reducing delays, minimising diversions, and facilitating more efficient resource allocation.
- Improved Passenger Experience: Clear and prompt communication during disruptions fosters traveler trust and reduces anxiety, particularly in high-stress scenarios.
- Regulatory Compliance: Integration with international aviation safety frameworks (e.g., ICAO, EASA) ensures legal adherence and may be a prerequisite for operational certification.
- Cost Avoidance: Proactive mitigation of operational disruptions—such as equipment damage, terminal closures, or emergency evacuations—results in lower insurance costs and reduced financial losses.

The rollout of warning systems typically follows a multi-stage deployment strategy based on operational complexity and existing infrastructure:

- Short-term (6-12 months): Conduct feasibility studies, identify critical risk areas, and secure initial funding.
- Mid-term (1-5 years): Install sensor networks, develop AI-based predictive systems, and integrate automated alert mechanisms.
- Long-term (5-10 years): Optimise warning systems, expand coverage, and integrate them with broader airport management platforms.

The cost of implementing airport-wide warning systems varies based on airport size, hazard profile, and technology scope. Primary cost elements include:

- Infrastructure Development: Installation of sensors, weather radars, and secure communication systems

- Software Integration: Customisation and integration of AI algorithms, cloud-based platforms, and user interfaces for operations staff
- Human Capital: Training programs for staff, emergency services, and air traffic controllers on the use and response to alerts
- System Maintenance: Ongoing calibration, software updates, and cybersecurity safeguards to ensure system resilience

Despite moderate to high initial investments, public-sector funding, insurance discounts, and climate adaptation grants can significantly improve manageability. The return on investment for airport warning systems is typically realised across three key phases:

- Short-term ROI (1-5 years): Immediate safety enhancements and improved decision-making during emergency situations.
- Medium-term ROI (5-10 years): Reduced financial losses from operational disruptions and lower insurance premiums due to risk mitigation measures.
- Long-term ROI (10-20 years): Increased airport resilience, regulatory compliance, and enhanced reputation as a safe and reliable transportation hub.

By investing in advanced warning systems, airports can proactively manage risks, ensure regulatory compliance, and enhance passenger safety, making them a critical component of a modern and sustainable airport infrastructure.

4.3. Urban transport

Urban transport plays a crucial role in ensuring the efficiency, accessibility, and sustainability of cities by facilitating the movement of people and goods while reducing congestion and environmental impact. As urbanisation continues to increase, well-planned transport systems are essential for enhancing economic productivity, improving quality of life, and minimising greenhouse gas emissions through the integration of sustainable mobility solutions. In the REDU-CE-D project the Municipality of Krakow (Krakow Transport Authority) and BKK Centre for Budapest Transport represented the sector of urban transport; the following chapter is based on their experiences.

4.3.1. Energy and resources - electrical energy

4.3.1.1. Constant modernization of the electrical vehicle fleet

The modernization of electric vehicle (EV) fleets in public transport—including electric buses, trams, trolleybuses, and metro systems—represents a critical step towards the sustainable development of urban mobility. While such investments are characterised by high initial capital costs, they yield substantial long-term economic, environmental, and operational benefits. It is therefore prudent to evaluate both the costs and anticipated returns associated with the modernization of electric vehicle fleets.

Categories of Electric Fleet Modernization:

1. Electric buses are gaining widespread adoption across cities globally. Modernization efforts in this category may include:

   a. Battery Upgrades: Replacing or upgrading batteries to increase vehicle range. Advanced lithium-ion batteries and emerging technologies offer improved capacity and energy efficiency.
   b. Enhanced Charging Infrastructure: Installing faster charging systems (e.g., opportunity charging at bus stops or end terminals) to increase vehicle availability during peak hours.
   c. Advanced Energy Management Systems: Integrating systems that optimise energy usage during operation, thereby lowering running costs.

2. Trams - Despite being one of the most established forms of urban transport, tram systems are also subject to modernization:
   a. Replacement of Propulsion Systems: Upgrading to energy-efficient electric motors.
   b. Control System Modernization: Incorporating advanced control systems for improved integration with other public transport modes and for optimising fleet performance.
   c. Infrastructure Upgrades: Modernizing overhead contact systems (e.g., replacing cables, poles, and substations) to ensure reliable power supply and improved operational efficiency.
3. Trolleybuses - Like trams, trolleybuses benefit from systematic upgrades:
   a. Drive System Modernization: Replacing outdated electric drive systems and energy management modules to improve efficiency and reduce energy consumption.
   b. Infrastructure Enhancements: Upgrading the traction power infrastructure, including wiring and support structures, to ensure supply continuity and reliability.
4. Metro Systems:
   a. Propulsion and Control Systems: Updating these components to increase energy efficiency and reduce consumption.
   b. HVAC and Lighting: Modernizing ventilation, air conditioning, and lighting to reduce operational costs and enhance passenger comfort.

Modernization costs vary considerably depending on the type of vehicle, scale of the upgrade, and specific operational requirements of the transport authority.

1. Procurement of Components and Technologies:
   a. Battery Replacement: A critical cost element in electric bus modernization. Although modern lithium-ion batteries remain expensive, their prices are gradually declining.
   b. Electric Motors and Drives: Replacement costs vary by vehicle type and energy demand.
   c. Charging Systems: Cost depends on the charging technology (e.g., fast versus standard charging) and required power capacity.
2. Infrastructure Modernization:
   a. Overhead Lines (Trams and Trolleybuses): Modernization costs depend on the technical condition and are typically calculated per kilometre of track.
   b. Charging Infrastructure (Electric Buses): Establishing charging stations, particularly in major depots or terminals, involves substantial investment depending on the number of vehicles and charging capacity.
3. Labour and Training:

   a. Staff Training: Essential for both drivers and maintenance personnel to ensure safe and efficient operation of modern vehicles and systems.
   b. Maintenance Costs: Although lower than for internal combustion vehicles, electric systems still require regular servicing, particularly energy management and propulsion components.
4. Costs Due to Downtime:
   a. Operational Disruptions: Fleet modernization can lead to temporary service interruptions, resulting in lost ticket revenue and additional costs related to alternative service provision.

Despite the substantial upfront expenditure, the long-term advantages of modernizing electric fleets are extensive:

- Fuel Savings: Electric vehicles have significantly lower operating costs, with electricity being less expensive than fossil fuels.
- Lower Maintenance Costs: Electric drivetrains consist of fewer moving parts than combustion engines, thereby reducing wear and associated repair costs.
- Enhanced Energy Efficiency: Modern battery technologies and energy management systems facilitate more effective energy use, lowering operational expenditures.
- Environmental Benefits: Utilising electricity—particularly from renewable sources—reduces air pollutants and greenhouse gas emissions, improving urban air quality.
- Long-Term Cost Efficiency: Technological advancements and falling equipment costs contribute to increasing affordability over time.

In the short term (0–2 years), the introduction of electric vehicles in public transport offers clear benefits including environmental compliance, enhanced passenger experience, and reduced operating costs, though it is accompanied by high upfront costs and infrastructure investment. Over the medium term (2–7 years), operational savings from lower fuel and maintenance costs, combined with improved fleet management and reduced emissions, begin to outweigh these initial challenges, although ongoing infrastructure development and staff training remain necessary. In the long term (beyond seven years), the return on investment (ROI) becomes substantial, as cumulative savings on fuel and maintenance offset the original capital outlay, while improved operational efficiency, environmental benefits, and cost stability support both fiscal sustainability and public wellbeing.

The modernization of electric vehicle fleets in public transport constitutes a strategic investment in the transition towards sustainable urban mobility. Although it requires significant capital outlay, the long-term financial and environmental returns justify the expenditure. Investments in advanced battery systems, energy-efficient propulsion technologies, and supporting infrastructure significantly enhance service quality, operational efficiency, and environmental performance.

With effective financial planning and support from the European Union and national funding mechanisms, such investments not only become economically viable but are also instrumental in achieving long-term sustainability objectives in the public transport sector.

4.3.1.2. Awareness raising campaigns

Awareness raising campaigns should aim to promote sustainable mobility options and influence travel behavior among both residents and visitors, thereby contributing to increased energy efficiency and reduced consumption. Another objective could be to enhance the visibility and attractiveness of public transport across the urban area—both in physical space and through digital channels—by engaging influencers and media professionals. These campaigns can support energy efficiency in urban transportation through various thematic areas:

1. Encouraging modal shift - promoting a transition from private car use to more energy-efficient modes like walking, cycling, and public transport.
2. Educating on eco-driving **- p**otentially including information on energy-efficient driving practices for those who must use cars.
3. Promoting shared mobility **-** increasing awareness of car-sharing and bike-sharing options, which can reduce overall energy consumption.
4. Enhancing safety **-** by improving road safety, these campaigns indirectly support the adoption of more energy-efficient transportation modes like walking and cycling.

These campaigns can be implemented relatively quickly and may yield immediate to short-term behavioral impacts. While sustained influence requires ongoing funding, costs can be mitigated through strategic partnerships and the use of digital platforms. Digital campaigns, in particular, offer scalable and cost-effective outreach, enabling wide dissemination at a low cost per impression. Targeting specific demographic groups or travel behaviors with high energy-saving potential, as well as incorporating elements of gamification, can further enhance the effectiveness and reach of these initiatives.

4.3.1.3. Investing in newer equipment

Investing in modern repair equipment for public transport represents a strategic decision that can yield substantial operational and financial benefits. However, it requires a comprehensive cost-benefit analysis to ensure that the investment aligns with long-term organisational goals. High-quality tools and equipment in maintenance facilities are essential to ensuring the efficiency, safety, and reliability of vehicle fleets—factors that directly influence the quality of public transport services.

Outlined below are the key considerations that should inform decisions regarding the acquisition of new maintenance equipment for public transport operations.

1. Enhancing Maintenance and Repair Efficiency:
   a. Fault Prevention: Investment in advanced diagnostic equipment facilitates the early detection of mechanical and electronic issues, enabling quicker and less costly repairs. Contemporary tools such as diagnostic computers, telematics systems, and vehicle health sensors can anticipate potential malfunctions, allowing for preventative interventions that avert major breakdowns.
   b. Reduced Repair Time: Modern workshop tools—including pneumatic screwdrivers, hydraulic lifts, tyre changers, and brake testers—accelerate the repair process. This reduces vehicle downtime and increases fleet availability, thereby improving operational efficiency.
2. Prolonging Fleet Lifespan:
   a. Improved Repair Quality: Up-to-date tools enable more precise and reliable repairs, reducing the likelihood of recurring faults. Vehicles that are regularly and properly maintained retain their functional value for longer, postponing the need for replacement.
   b. Reduced Capital Expenditure on Fleet Renewal: Extending the operational lifespan of vehicles can significantly reduce expenditure on fleet replacement—a crucial consideration for urban transport authorities managing extensive vehicle inventories.
3. Passenger Safety and Comfort:

   a. Higher Safety Standards: Modern diagnostic and repair tools—such as brake and suspension testers—enable thorough inspection and servicing of critical systems, ensuring vehicles meet the highest safety standards. Consistent maintenance minimises the risk of failures that could jeopardise passenger safety.
   b. Enhanced Travel Comfort: Regular servicing with modern equipment (e.g., for suspension systems, HVAC units, and drivetrains) contributes to improved ride quality. This has a direct impact on passenger satisfaction and may encourage greater use of public transport.

4. Optimising Operational Costs:
   a. Reduced Operating Expenditure: Early identification and resolution of technical issues prevent escalating damage, which reduces repair costs. Moreover, a well-maintained fleet is typically more energy-efficient, consuming less fuel (in the case of combustion engines) or electricity (for electric vehicles).
   b. Minimised Emergency Repair Costs: Up-to-date workshops are better equipped to conduct scheduled maintenance, thereby reducing the need for costly emergency interventions arising from neglected wear and tear.
5. Adapting to Technological Advancements:
   a. Support for Electric and Hybrid Vehicles: With the increasing adoption of electric public transport vehicles, specialised diagnostic and repair tools for electric drivetrains, battery management systems (BMS), and charging infrastructure are becoming indispensable.
   b. Readiness for Emerging Technologies: Investing in tools compatible with autonomous vehicle systems, advanced telematics, and smart maintenance platforms positions transport operators to respond proactively to future market developments.
6. Environmental Benefits:
   a. Emission Reduction: Diagnostic tools such as exhaust gas analysers ensure that internal combustion engines meet emissions standards, contributing to air quality improvements.
   b. Energy Conservation: For electric vehicles, precision maintenance tools facilitate better energy management, such as optimising charging cycles, which reduces overall energy consumption and operational costs.
7. Passenger Satisfaction and Public Image
   a. Improved Service Quality: A well-maintained fleet provides a higher level of service, which positively affects passenger satisfaction and retention. Reliable transport encourages greater public use, thereby improving cost recovery through fare revenues.
   b. Reputational Gains: Cities and operators that invest in state-of-the-art maintenance infrastructure are perceived as progressive and committed to quality service provision. This can enhance the public image of local authorities and transport providers.

The procurement of advanced maintenance equipment—such as diagnostic platforms, tyre changers, and lifting systems—can involve considerable upfront costs. However, these investments tend to yield long-term returns through lower repair costs, reduced breakdowns, and enhanced fleet performance. Modern equipment often requires specialised training for maintenance personnel and periodic servicing of the tools themselves. Although these entail additional costs, they are generally marginal in comparison to the long-term savings realised.

In the short term (0–2 years), investing in modern repair equipment for public transport yields benefits such as reduced vehicle downtime, enhanced fleet reliability, and lower service costs, although it requires significant initial capital expenditure, staff training, and infrastructure adaptation. Over the medium term (2–5 years), further gains include fewer breakdowns, reduced spare parts usage, and increased operational efficiency, despite ongoing maintenance and equipment depreciation costs. In the long term (beyond five years), such investments result in substantial savings on repairs, increased fleet availability, prolonged equipment lifespan, and extended vehicle service life. While periodic reinvestment and continuous staff training remain necessary, the overall return on investment (ROI) is favourable, as long-term financial and operational benefits outweigh the initial and ongoing costs.

While investing in new repair equipment for public transport entails significant initial expenditure, the long-term returns are substantial. Modern tools enhance maintenance efficiency, lower operating costs, extend the operational lifespan of vehicles, and improve both safety and passenger experience. These investments also yield environmental advantages and ensure preparedness for technological advances, such as the shift towards electric and autonomous vehicles.

Nonetheless, any investment decision should be grounded in a detailed assessment of the specific needs of the transport system, ensuring that the selected equipment aligns with fleet characteristics and organisational objectives. When appropriately managed and supported by national or European funding instruments, such investments can play a pivotal role in advancing sustainable and high-quality public transport systems.

4.3.1.4. Expansion of central systems

In the context of urban transportation, central systems can encompass a wide range of components, including operations and dispatch centers, infrastructure management platforms, ticketing and vending machines, and passenger information systems. While the direct impact of these systems on energy efficiency is often indirect and difficult to quantify systematically, their expansion provides significant benefits. By enabling greater control and coordination across various elements of the urban transport network, these systems create opportunities for large-scale interventions and the integration of energy management tools.

The implementation of a Mobility as a Service (MaaS) system represents a particularly promising approach to improving energy efficiency. MaaS enhances the attractiveness of intermodal and public transport by integrating a variety of service providers—including micromobility solutions, regional transit, and taxi services—into a single, user-friendly platform. This integration can encourage citizens to shift towards more sustainable transport options. Moreover, the data generated by such centralized systems can be harnessed to design optimised routes and schedules, leading to more energy-efficient operations. Additionally, these systems can be used to promote healthier and more sustainable travel behaviors, further contributing to reduced energy consumption.

From a temporal and financial perspective, establishing a MaaS system requires both infrastructural investments and advanced technological solutions. In urban environments characterised by fragmented service provision and multiple transport operators, the development of a coherent regulatory framework may take several months or even years. Consequently, the expansion of central systems should be viewed as a medium- to long-term intervention, typically associated with substantial upfront costs. However, these investments can yield significant long-term benefits. For instance, the integration of contactless payment technologies—such as NFC-enabled readers on vehicles—not only enhances user convenience but also supports energy efficiency by streamlining fare collection and encouraging increased public transport usage.

4.3.2. Energy and resources - fossil fuels

4.3.2.1. Constant modernization of vehicle fleet

Fossil fuel-powered vehicles—such as diesel buses—will continue to constitute a significant proportion of urban public transport fleets for the foreseeable future. Although the electrification of public transport is gaining momentum globally, the modernization of existing internal combustion engine (ICE) fleets remains crucial from both operational and economic standpoints. In this context, retrofitting fossil fuel vehicles and investing in appropriate technologies presents a cost-effective and pragmatic solution.

1. Optimisation of Fuel Consumption - Modernizing ICE vehicles can lead to a substantial reduction in operating costs associated with fuel usage. The adoption of advanced technologies facilitates improvements in efficiency, including:
    a. High-efficiency engines: Replacing outdated engines with newer, more efficient alternatives can reduce fuel consumption and emissions, significantly enhancing overall energy performance.
    b. Energy recovery systems: Installing regenerative braking systems enables energy to be recovered during deceleration, decreasing fuel demand and improving energy efficiency.
    c. Optimised powertrains: Incorporating modern automatic transmissions improves adaptability to road conditions, resulting in more economical fuel usage.
2. Enhancing Operational Efficiency:
    a. Advanced diagnostic systems: Investment in contemporary diagnostic tools allows for early identification of technical issues, such as those related to ignition, fuel injection, or engine performance. Preventative maintenance based on accurate diagnostics reduces vehicle downtime and sustains fuel efficiency.
    b. Improved fleet management: Fleet management platforms—utilising GPS and telematics—facilitate real-time performance monitoring, enabling optimised routing, reduced idle time, and minimised fuel consumption.
3. Emission Reduction and Environmental Compliance - Even as ICE vehicles remain in service, targeted upgrades can achieve significant environmental benefits:
    a. Reduced exhaust emissions: Retrofitting vehicles with emissions control technologies—such as diesel particulate filters (DPF), selective catalytic reduction (SCR) systems, and advanced fuel injection systems—can substantially reduce emissions of nitrogen oxides (NO_x), particulate matter (PM), and carbon dioxide (CO_2).
    b. Regulatory compliance: Upgrades enable vehicles to meet increasingly stringent emissions standards, thereby avoiding potential penalties and ensuring alignment with municipal environmental policies.
4. Enhanced Reliability and Safety- Modernizing internal combustion vehicles also improves operational reliability and passenger safety:
    a. Advanced safety systems: Implementing driver assistance systems (ADAS)—such as blind spot detection, automatic emergency braking, and electronic stability control—enhances vehicle safety.
    b. Updated braking and suspension systems: Upgrades to braking technologies (e.g., ABS, EBD) and suspension systems contribute to improved handling and stability, thereby increasing safety for passengers and other road users.

5. Improved Passenger Comfort - Investments in modern technologies positively impact passenger experience, which is vital to service quality:
    a. Noise and vibration reduction: Engine and drivetrain upgrades reduce in-vehicle noise and vibration, contributing to a more pleasant journey.
    b. Advanced climate control: Upgrading air conditioning and ventilation systems enhances thermal comfort—particularly in warmer months—and improves overall passenger satisfaction.
6. Social and Reputational Benefits:
    a. Sustainability leadership: Retrofitting supports environmental objectives and demonstrates a commitment to sustainability, thereby enhancing the image of transport operators and municipal authorities. This can also help attract environmentally conscious passengers.
    b. Passenger satisfaction: Enhanced vehicle comfort, safety, and reliability contribute to a higher quality of service, promoting passenger loyalty and encouraging modal shift towards public transport.

Cost Considerations: Retrofitting Versus Fleet Replacement

- Lower capital expenditure: The replacement of an entire fleet with electric vehicles entails considerable financial outlay, including vehicle acquisition and the development of charging infrastructure. In contrast, retrofitting existing ICE vehicles—through engine replacement, emissions control installations, and fuel system optimisation—is a significantly more affordable option.
- Long-term operational savings: Although retrofitting incurs upfront costs, these are offset by long-term reductions in fuel consumption, maintenance expenditure, and extended vehicle lifespans. Improved fuel efficiency translates into lower operating costs for transport providers.

In the short term (0-2 years), fleet modernization yields immediate benefits such as reduced fuel consumption, improved vehicle reliability, enhanced passenger comfort, and compliance with emission standards, although it requires considerable investment and may result in temporary service disruptions. Over the medium term (2–5 years), the operational cost savings from lower fuel use and maintenance, combined with improved efficiency and reduced emissions, begin to offset the initial expenditure, despite ongoing infrastructure and component replacement needs. In the long term (beyond five years), the return on investment (ROI) becomes increasingly evident through sustained reductions in fuel and maintenance costs, extended vehicle lifespan, and environmental compliance, while also enhancing the reputation of the transport operator and contributing to long-term sustainability goals.

While the electrification of public transport fleets remains a long-term goal, the retrofitting of fossil fuel vehicles represents a viable and cost-effective interim strategy. It enables improvements in fuel efficiency, emission reductions, operational reliability, and passenger comfort, while also aligning with evolving environmental regulations. Despite the initial capital requirements, the long-term economic and ecological advantages make retrofitting a strategic choice for urban transport operators seeking to modernize their fleets within budgetary constraints.

4.3.2.2. Helpful maps and programmes

A variety of digital tools and programmes have emerged to enhance the efficiency of urban transportation systems and promote sustainable mobility options. These initiatives aim to optimise travel routes, provide real-time information to users, and encourage the adoption of energy-efficient transport modes. By supporting smarter travel choices and improving operational coordination, such technologies contribute significantly to reducing energy consumption and enhancing the overall sustainability of urban mobility.

An integrated mobility platform represents a comprehensive solution by offering route planning, real-time travel updates, and digital ticketing for public transport. Functioning as a multi-modal journey planner, it allows users to combine various transport modes—such as buses, trams, metro, cycling, and walking—to identify the most efficient and sustainable travel options. Real-time information on traffic conditions, delays, and service disruptions enhances user experience while promoting more efficient use of public transport networks. Systems like the Traffic Control and Passenger Information System (e.g., FUTÁR in Budapest) further exemplify this approach by enabling real-time tracking of public transport vehicles, displaying accurate arrival information, and prioritising public transport at intersections through traffic signal control. These features help improve punctuality and reduce idling time, thereby enhancing energy efficiency.

Digital solutions also support active and micromobility. For example, public bike-sharing systems, when integrated into a MaaS platform, provide users with digital maps and station locators that display real-time availability of bikes and docking spaces. These tools make active travel modes more accessible and convenient, reinforcing a shift away from private car use.

These digital tools contribute to urban energy efficiency by minimising unnecessary trips, promoting public transport use, facilitating multimodal travel, and optimising vehicle operations. Although the development and deployment of comprehensive digital systems may require several years and involve ongoing maintenance and updates, the long-term benefits are substantial. Once the foundational infrastructure is in place, extending functionalities or expanding geographic coverage can be achieved relatively cost-effectively. While direct profitability is difficult to quantify, the impacts include increased ridership and revenue due to improved service quality, reduced fuel consumption through optimised routing, valuable data generation for urban planning, and overall improvements in economic activity due to enhanced mobility.

4.3.2.3. Promotion of micro-mobility

Bike-sharing systems hold significant potential for reducing the energy consumption of urban transportation networks. In many instances, they replace individual car trips, offering a low-energy alternative with minimal environmental impact compared to conventional motorised transport modes. The successful implementation of such systems requires cross-sectoral collaboration, and their design is highly dependent on the specific municipal, political, economic, geographical, and regulatory context of a city. Consequently, while a universal blueprint for implementation is not feasible, several key principles and strategic guidelines can be identified.

- Establishing Partnerships and Cross-Sector Collaboration: Whether operated by public authorities or private companies, the long-term success of a bike-sharing system relies on strong collaboration between the public and private sectors. Private investment is often essential, with returns potentially generated through advertising, sponsorships, and service contracts.
- Creating a Supportive Regulatory Framework: Effective regulation is critical to ensuring smooth operation and user satisfaction. Without appropriate policies in place, bike-sharing systems may face logistical and safety challenges, which can negatively impact user experience and diminish public trust, leading to a shift back to less sustainable transportation modes.
- Continuous Development and Modernization: The expansion and modernization of the system are crucial. This includes enlarging the service area, maintaining and upgrading the bicycle fleet, and incorporating new models such as cargo bikes and electric bicycles to meet diverse mobility needs.
- Integration into the Urban Transport Network: Micromobility services should be fully integrated into the broader public transport system. Access through Mobility as a Service (MaaS) platforms enhances

convenience and usability, encouraging more citizens to opt for bike-sharing as part of their daily commute, thereby contributing to reduced energy consumption.

A notable example is the MOL Bubi system in Budapest, which has become a central element of the city's micromobility strategy. As of now, the system includes nearly 2,500 bicycles distributed across more than 200 docking stations and has recorded over 10 million trips. It is estimated that MOL Bubi contributes to daily carbon savings of over 90,000 kilograms of CO_2, underscoring its significant role in promoting sustainable urban mobility and reducing energy demand.

Budapest has successfully integrated various shared micromobility services into its urban transport system, supported by targeted policies and infrastructure planning. The city has introduced regulations to manage the deployment of e-scooters and similar devices, ensuring organised usage through the creation of Mobi-Points—designated parking zones for shared micromobility vehicles. In collaboration with service providers, the municipality has worked to maintain high compliance with parking regulations, improving the orderliness and accessibility of public spaces. Efforts have also been made to seamlessly integrate micromobility options with traditional public transportation, with Mobi-Points strategically located near transit stops to promote easy and efficient multimodal travel.

The Mobi-Points Concept envisions a dense network of designated micromobility parking areas, ideally spaced one to two minutes apart in high-demand urban areas such as city centers and district hubs. These points are situated close to key destinations—such as public institutions, retail areas, and major transport nodes—to maximise convenience and accessibility. By concentrating pick-up and drop-off locations, the system facilitates flexible travel, encourages the use of shared services, and maintains the visual and functional integrity of public spaces. Each Mobi-Point typically occupies the space of a single car but accommodates up to ten micromobility vehicles, thus significantly increasing the efficiency of space use. Importantly, Mobi-Points are designed to avoid obstructing movement, particularly for people with disabilities, older adults, and other individuals with reduced mobility.

As an advanced level of the concept, E-Mobility Points have been established in major transport hubs. These points integrate multiple functions, including charging stations for electric vehicles, designated car-sharing parking, optional kiss-and-ride (K+R) facilities, MOL Bubi public bike-sharing stations, and Mobi-Points for micromobility services. This multi-functional approach enhances intermodality and reflects a systems-level integration of sustainable transport services within the city's mobility framework.

The promotion of micromobility contributes to energy efficiency by offering an attractive alternative to short car trips, thus reducing fuel consumption and greenhouse gas emissions. These services serve as effective "last mile" solutions that complement public transport, increasing its overall accessibility. Most micromobility options, such as bicycles and e-scooters, produce zero direct emissions during use and require significantly less space than automobiles, potentially reducing the demand for energy-intensive parking infrastructure.

Compared to large-scale transport infrastructure projects, micromobility systems can be implemented more rapidly and at lower cost. The network of services and infrastructure can be incrementally expanded in response to demand, allowing for flexible adaptation over time. However, the continued effectiveness of such systems requires consistent oversight, stakeholder coordination, and responsive management practices.

4.3.2.4. Promoting and advocating for new incentives

Advocating for and promoting new incentives can play a critical role in shaping strategic development guidelines and regulatory frameworks for urban transport operators. Stakeholder engagement is essential in this process, particularly given the fragmented nature of the urban transport sector, which often includes both public and private entities. Active promotion and advocacy efforts help to sustain ongoing dialogue around energy efficiency and sustainable mobility, encouraging innovation and alignment across various stakeholders. These efforts can foster a shared vision for future-oriented urban transport systems that prioritise environmental performance and operational effectiveness.

The promotion and advocacy of new incentives are typically low-cost and can be implemented relatively quickly. Urban transport operators are already required to maintain robust passenger and travel information systems, which can serve as effective platforms for communicating and disseminating new policy incentives and sustainability initiatives. Leveraging existing communication infrastructure allows for efficient outreach to both stakeholders and the public, enhancing awareness and encouraging behavioral change in support of energy-efficient and sustainable transport practices.

4.3.2.5. Investing and exploring the trend of hydrogen use for vehicles

Hydrogen-fueled vehicles present a promising pathway to significantly reduce the energy consumption and environmental impact of urban public transport systems. Compared to traditional diesel or compressed natural gas (CNG) buses, hydrogen fuel cell vehicles offer higher energy efficiency and emit only water vapor as a byproduct. Their operational advantages—such as extended range and fast refueling times—make them particularly suitable for high-frequency, long-distance routes within urban networks. Cities like Tokyo, Hamburg, and Los Angeles have already incorporated hydrogen buses into their fleets, demonstrating the technological viability and environmental benefits of this emerging mobility solution. Ongoing advancements in hydrogen fuel cell efficiency, vehicle design, and the decreasing cost of hydrogen production—especially green hydrogen generated from renewable sources—further enhance the attractiveness of hydrogen as a sustainable transport fuel.

Urban transport operators can pursue a phased approach to adopting hydrogen-fueled vehicles. Initial steps include conducting feasibility studies to assess infrastructure requirements, such as hydrogen refueling stations (HRS), and identifying suitable operational contexts. Collaboration with energy providers, research institutions, and technology developers is critical for establishing a robust hydrogen ecosystem. Pilot programmes can provide valuable insights into real-world vehicle performance, maintenance needs, and cost dynamics, thereby informing large-scale deployment strategies. Hydrogen-powered fleets require purpose-built infrastructure for production, storage, distribution, and refueling. Hydrogen must be stored at high pressures (typically 350–700 bar for buses) and handled with advanced safety systems, including leak detection technologies and ventilation infrastructure. Proper training for personnel across operations and emergency services is essential to ensure safe implementation.

Hydrogen buses typically offer a range of 300-450 kilometers per refueling—comparable to diesel and significantly higher than the 150–250 kilometers achieved by most battery-electric buses. Refueling hydrogen buses takes approximately 5–15 minutes, providing operational advantages for routes with high turnaround demands. However, the financial and infrastructural barriers remain substantial. The capital cost of a hydrogen-powered bus is currently 30-50% higher than that of a battery-electric bus, although economies of scale are expected to reduce this margin over time. Hydrogen refueling stations entail high upfront investment—ranging from €1.5 to €2.5 million per station—and hydrogen fuel itself often costs two to three times more per refueling compared to electricity, depending on regional energy prices and hydrogen sourcing.

In Central Europe, cities face additional challenges in adopting hydrogen transport. These include limited hydrogen infrastructure, greater reliance on imported or grey hydrogen, lower national subsidies compared to Western Europe, and higher financing barriers due to weaker access to private capital and public-private partnerships. While the return on investment for hydrogen buses currently ranges from 10 to 15 years—longer than the 5 to 10 years typical of battery-electric buses—the technology offers unique advantages in terms of operational flexibility and scalability. Strategic investment, regional cooperation, and access to

EU funding mechanisms can help Central European cities overcome these barriers and gradually integrate hydrogen mobility into their urban transport systems.

4.3.3. Environment

4.3.3.1. Regular maintenance of infrastructure

Road maintenance and management are fundamental components of sustainable road infrastructure development. Routine and systematic maintenance is essential to ensure the longevity, safety, and functional performance of road networks. Neglect in this area can lead to surface deterioration, the formation of potholes, and structural damage, which in turn reduces travel comfort and heightens the risk of road traffic accidents.

Effective road management encompasses planning, design, monitoring, and maintenance activities. When implemented correctly, such management enhances road capacity, improves safety outcomes, and reduces long-term maintenance expenditure. One of the principal challenges facing road maintenance and management is the requirement to adapt strategies in response to changing environmental conditions and variable road usage. Key influencing factors include traffic intensity, adverse weather events, heavy goods vehicle loads, and the ageing of infrastructure, all of which necessitate timely and targeted interventions.

Furthermore, the consistent availability of financial resources remains a critical challenge for the regular upkeep and enhancement of road infrastructure. Equally important is the efficient coordination of maintenance works to avoid unnecessary disruption to traffic and minimise inconvenience for road users.

Well-maintained road infrastructure underpins efficient and safe transport systems. Regular inspection and upkeep are not only legal obligations but represent prudent long-term investments—delivering cost savings, enhanced safety, and improved serviceability.

Key Benefits of Systematic Road Infrastructure Maintenance

- Enhanced Safety - Routine inspections facilitate the timely identification of surface damage and structural issues, thereby preventing accidents. Repairing carriageways and ensuring adequate visibility of road signage are essential measures for safeguarding all road users.
- Cost Optimisation - Preventative maintenance reduces the incidence of severe structural failures that require costly remediation. Early interventions for issues such as surface cracking, potholes, or damage to bridges mitigate the financial burden associated with emergency repair work.
- Reduced Traffic Disruption - Unscheduled repair activities often result in traffic congestion and disruption. Regular condition monitoring enables maintenance works to be strategically scheduled during off-peak periods, thus minimising their impact on road users.
- Environmental Protection - Well-maintained roadways contribute to lower vehicle emissions by enabling smoother traffic flow and reducing the need for frequent braking and acceleration, particularly on damaged road sections. Moreover, properly maintained surfaces demonstrate greater resistance to climate-related wear, thereby supporting environmental resilience.
- Extended Pavement Lifespan - Ongoing maintenance activities, including crack sealing, surface treatments, and structural reinforcements, significantly prolong the service life of pavements and bridges. This, in turn, reduces the frequency and cost of major rehabilitation works.
- Improved Budgetary Planning - A systematic maintenance regime enables local and national authorities to forecast and allocate resources more accurately. This allows for more efficient budgeting and avoids the need for reactive spending in response to infrastructure failures.

- Enhanced User Comfort - The quality of road surfaces directly affects the experience of all users. Smooth, well-maintained roads, pavements, and cycle paths contribute to the comfort and satisfaction of drivers, pedestrians, and cyclists alike.

In the short term (0–3 years), regular maintenance incurs high operational costs due to inspections and part replacements, alongside investments in condition monitoring systems. However, it delivers immediate benefits such as fewer breakdowns, enhanced safety, and improved public perception. In the medium term (3-7 years), the return on investment (ROI) becomes more pronounced through reduced emergency repair costs, extended infrastructure lifespan, improved budget predictability, and increased passenger revenue. Over the long term (beyond seven years), substantial capital cost savings are achieved by avoiding full system replacements, alongside sustained environmental and energy efficiency gains, with the potential to reinvest in innovation and system development.

In the context of rail-based urban transport, regular rail grinding is an essential maintenance practice. It ensures the correct technical condition of tram tracks and significantly contributes to the reduction of noise emissions. A quieter tram environment enhances passenger comfort and is indicative of a well-managed, sustainable transport system. Rail grinding represents one of several cyclical maintenance measures that should be routinely implemented across tram networks.

4.3.3.2. Measures taken to address noise pollution

Among the various environmental impacts of urban traffic, noise pollution is one of the most detrimental to human health and well-being. Numerous studies have demonstrated that chronic exposure to traffic noise can result in adverse health outcomes, including cardiovascular diseases, sleep disturbances, and psychological stress.

The principal determinants of road traffic noise emissions include:

a) the type and technical condition of vehicles;

b) traffic volume and flow characteristics;

c) vehicle speed;

d) the proportion of heavy vehicles in traffic (including particularly noisy vehicles, such as motorcycles);

e) the type and condition of the road surface;

f) the longitudinal gradient of the road.

While these factors exert a fundamental influence on noise emissions, they are not the only contributors. Other significant elements include the number of traffic lanes, the presence and location of bus or tram stops, intersections and junctions, as well as the design and regulation of traffic signals. The complexity of road infrastructure further complicates the identification and mitigation of noise sources. Additionally, environmental and structural conditions—such as the proximity of residential buildings or intervening land use—significantly influence the propagation of noise (immission).

A comprehensive noise mitigation strategy should incorporate the following components:

- Urban Planning and Traffic Management in Densely Built-Up Areas:
    - Designation of traffic-calmed zones;
    - Creation of no-entry or restricted parking areas;
    - Traffic reorganisation to prevent the use of local or internal roads as bypass routes for through traffic;

    - Enforcement of speed limits through effective monitoring and supervision;
    - Traffic light coordination (e.g. “green wave” systems) to reduce idling near intersections, particularly prioritising public transport;
    - Restrictions on heavy vehicle traffic, with the exception of public transport vehicles;
    - Road redesign to include geometric improvements, installation of chicanes, roundabouts, and optimised surfaces to minimise noise while maintaining traffic functionality.
- Technical Noise Control Measures:
    - Use of low-noise road surfaces;
    - Replacement or resurfacing of degraded roadways;
    - Modernization and grinding of tram tracks;
    - Installation of automatic rail lubrication systems;
    - Maintenance of wheel profiles on rail vehicles;
    - Construction of noise barriers (e.g. acoustic screens, earth embankments);
    - Implementation of intelligent traffic management systems.
- Organisational and Operational Improvements:
    - Enforcement of traffic regulations aimed at reducing noise;
    - Traffic calming interventions, such as:
        - reallocation of road space for parking,
        - alternating parking edges,
        - traffic disruption strategies to reduce through-traffic,
        - introduction of one-way streets to reduce congestion;
    - Progressive replacement of rolling stock, particularly for tram systems, with quieter and more efficient models.

Protecting the urban population from transport-related noise is demonstrably cost-effective, from both economic and social perspectives. While the initial capital expenditure may be considerable, the long-term advantages of these interventions often outweigh the upfront costs. The key areas to consider include:

1. Health and Social Benefits:
    a. Improved quality of life: Prolonged exposure to traffic noise is associated with numerous health issues, including cardiovascular conditions, sleep disorders, elevated stress levels, and mental health problems. Lowering noise levels in residential neighbourhoods enhances quality of life and reduces noise-induced illnesses.
    b. Legal compliance: In many jurisdictions, specific noise limits are mandated, particularly in residential zones. Investment in noise reduction measures facilitates compliance with such legislation and helps to avoid legal sanctions or penalties.
2. Economic Benefits:
    a. Reduction in healthcare costs: Noise abatement efforts can reduce the incidence of noise-related illnesses, lowering the demand for medical services and associated expenditures.

   b. Increased property values: Properties located near noisy transport corridors tend to depreciate. Mitigation measures such as the installation of noise barriers can increase real estate values by improving local environmental quality.

   c. Public acceptance: Reducing noise can increase public support for expanding and modernizing public transport networks, especially in densely populated areas with historically high noise levels.

3. Environmental Benefits - Adoption of quieter technologies, including electric vehicles and noise-reducing infrastructure, contributes to environmentally sustainable urban development and supports broader climate and air quality objectives.

4. Investment and Operational Costs:

   a. Initial expenditure: The procurement and implementation of noise barriers, track and vehicle upgrades, and engine modifications may incur significant initial costs.

   b. Maintenance: Infrastructure elements such as acoustic screens and damping systems require ongoing maintenance. Likewise, rolling stock must be routinely serviced to maintain low-noise performance.

5. Long-Term Profitability:

   a. Operational savings: Low-noise electric vehicles and well-maintained transport systems tend to incur lower maintenance costs and may yield energy savings, improving the financial performance of public transport operators.

   b. Improved passenger experience: Reduced noise levels enhance the attractiveness of public transport, potentially increasing ridership and boosting the sector's reputation.

6. Funding Opportunities - National and EU-level funding programmes provide financial support for noise mitigation initiatives. These subsidies can substantially reduce the financial burden of implementation.

7. Challenges and Limitations:

   a. Implementation difficulties: Densely built urban areas with legacy infrastructure may face challenges in fully deploying noise reduction solutions, necessitating extensive and prolonged investment.

   b. Technological constraints: While electric and noise-reducing technologies are promising, they often require further research, development, and adaptation to suit specific urban contexts.

In the short term (0–2 years), noise mitigation measures such as barriers can quickly enhance resident comfort and reduce social pressure, yielding political and public relations benefits, though they often involve high initial investment without immediate financial return and present challenges in quantifying effects. In the medium term (2–5 years), improvements in public health and reductions in associated social costs begin to emerge, alongside rising property values and opportunities for integration with broader urban projects. In the long term (beyond five years), the return on investment (ROI) becomes more substantial through significant reductions in healthcare and urban planning costs, long-term enhancements in quality of life, and increased attractiveness of districts for development, tourism, and local engagement, albeit requiring periodic modernisation and infrastructure adaptation.

Noise mitigation in urban transport systems constitutes a sound long-term investment. Despite significant initial outlays, the multifaceted benefits—including health improvements, operational cost reductions, enhanced urban quality of life, and strengthened public trust in public transport—justify such efforts. When combined with targeted funding and policy support, noise reduction strategies can facilitate a transition to quieter, healthier, and more sustainable urban environments.

4.3.3.3. Reducing the use of plastic where possible

A public transport operator such as BKK can enhance the overall energy efficiency of the urban transport system by reducing plastic use through both direct and indirect measures. One of the most impactful strategies involves transitioning from plastic-based paper tickets and passes to digital alternatives, such as mobile applications and contactless payment systems. This shift not only reduces plastic waste but also lowers the energy required for the production, distribution, and disposal of physical fare media. Additionally, public transport operators can influence vendors operating in stations and transport hubs to adopt biodegradable or reusable packaging, thereby minimising the environmental footprint of associated commercial activities.

Even in cases where operators do not directly manage vehicles, collaboration with fleet owners can promote the use of sustainable materials in vehicle interiors—such as recycled or eco-certified components for seat upholstery, handrails, and signage. Operators can also support or align with broader municipal regulations that aim to reduce plastic use in public spaces, indirectly shaping the behavior of public transport users. Installing water refill stations at major transit hubs offers another practical measure to reduce single-use plastic bottles, encouraging more sustainable passenger habits.

Public awareness initiatives—including visual campaigns, social media outreach, and educational materials—can further encourage passengers to reduce plastic consumption, contributing to lower waste collection and processing demands, and thus reducing energy use in the waste management sector. Finally, operators can integrate sustainability principles into procurement practices by engaging suppliers to minimise plastic packaging and prioritise eco-friendly materials for uniforms, office supplies, and maintenance equipment. Taken together, these actions form a comprehensive approach to plastic reduction that supports environmental sustainability and enhances the energy efficiency of public transport systems.

4.3.3.4. Introduction of oil/water separators

A public transport operator may significantly reduce energy consumption by incorporating oil/water separators to facilitate closed-loop water recycling within vehicle washing facilities. This approach diminishes the reliance on fresh water and lowers the associated energy demands required for pumping, heating, and treatment. Furthermore, the use of oil/water separators prevents hydrocarbons and grease from entering the municipal sewage system, thereby alleviating the operational burden on wastewater treatment plants and contributing to broader reductions in urban energy consumption. Within maintenance zones, such systems help preserve the efficiency of drainage infrastructure by minimising blockages, which would otherwise necessitate energy-intensive mechanical pumping and cleaning operations.

Oil/water separators offer tangible benefits across various components of an urban public transport network. First, bus depots and maintenance facilities can utilise these systems to treat effluent arising from vehicle cleaning and routine maintenance. This reduces the pollutant load on public treatment infrastructure and enhances local environmental performance. Second, rail yards—particularly those incorporating fuelling and repair operations—can deploy separators to manage hydrocarbon-laden runoff, thus protecting local watercourses and reducing the energy required for downstream purification. Third, tram and light rail depots benefit similarly by treating contaminated wastewater at the point of origin, thereby mitigating the energy footprint of transport operations and supporting sustainable water resource management.

From an economic and operational perspective, the adoption of oil/water separators entails a combination of capital and recurring costs. Beyond the initial procurement price, substantial investment is required for system installation and ongoing maintenance. The installation period may range from several weeks to a few months, contingent upon system complexity and site-specific conditions. Regular maintenance is essential to ensure optimal functionality, prevent performance degradation, and avoid costly reactive repairs. Although maintenance expenses may vary, they are justified by the potential for long-term operational savings. The return on investment (ROI) for such systems in public transport settings typically spans three to seven years, influenced by factors such as maintenance frequency, regional water treatment tariffs, and prevailing environmental regulations. Notably, investing in high-quality separators constructed from durable materials can reduce maintenance frequency and extend service life, thus enhancing overall cost-effectiveness and strategic viability.

4.3.4. Management system – implementing an EMS

4.3.4.1. Data analysis and reporting

To support the reduction of energy consumption within the urban transport system, the implementation of a unified data collection system could offer significant benefits. In many cities, the degree of centralization within the urban transport sector varies, often resulting in fragmented data collection practices. Different public and private transport operators may use inconsistent methodologies for reporting sustainability-related key performance indicators (KPIs), including energy consumption, emissions, and operational efficiency.

A centralized data collection framework would be highly valuable in addressing these inconsistencies. By defining a standardised set of data requirements and enabling both public and private stakeholders to report their energy-related metrics in a unified system, cities can obtain a comprehensive overview of the sector's energy performance. Such a system would help identify inefficiencies and critical pressure points, enabling the development of targeted strategies to improve energy management and optimise resource use across the urban transport network.

This measure is relatively feasible within a short to medium timeframe. The initial phase would involve an assessment of existing data collection methods and the identification of relevant data types. With adequate coordination and resource allocation, the system could be established within approximately one to two years. Following the collection of baseline and historical data, informed strategies and interventions could be developed to enhance the sector's energy efficiency and contribute to broader urban sustainability objectives.

4.3.4.2. Integration of renewable energy

An Energy Management System (EMS) in urban transport constitutes an integrated technological framework designed to monitor, control, and optimise energy consumption across transport networks—particularly those incorporating electric vehicles and renewable energy sources such as photovoltaic (PV) systems. The primary objective of such systems is to enhance energy efficiency, reduce pollutant emissions, and lower the operational costs of public transport. The following outlines the key functionalities and benefits of EMS implementation in urban mobility systems:

1. Energy Management and Optimisation - An EMS collects real-time data on the energy consumption of electric transport modes (e.g. buses, trams, trolleybuses, e-bikes, and e-scooters), as well as auxiliary infrastructure such as charging stations, photovoltaic installations, and energy storage systems. This enables:

   a. Optimised energy consumption: The system analyses consumption patterns to identify peak usage locations and times. Based on this data, it can recommend energy-efficient route planning, prioritise off-peak charging, and adjust operational strategies to minimise energy use.

   b. Energy resource allocation: EMS enables intelligent utilisation of diverse energy sources—including solar energy, battery storage, and energy recovered through regenerative braking—ensuring optimal energy flow and minimal waste.

2. Integration of Renewable Energy Sources - A critical component of EMS in urban transport is the incorporation of renewable energy systems, especially photovoltaic panels. The EMS facilitates:

   a. Utilisation of solar energy: Solar-generated electricity may be used directly for vehicle charging or auxiliary infrastructure. EMS monitors PV output and, based on supply and demand, determines whether to store, distribute, or sell surplus energy to the grid.

   b. Surplus energy management: When production exceeds immediate demand, surplus energy is stored in batteries or fed back into the energy network, thereby enhancing system resilience and delivering potential financial returns.

3. Optimisation of Electric Vehicle (EV) Charging - An EMS enables intelligent control over vehicle charging, ensuring both efficiency and sustainability:

   a. Smart charging management: Charging schedules are managed in accordance with renewable energy availability, vehicle battery levels, and overall grid demand, thereby reducing stress on the network during peak hours.

   b. Priority charging from renewables: The EMS prioritises charging during periods of surplus solar energy generation, especially in daylight hours, thus maximising the utilisation of clean energy.

4. Energy Storage Management - Effective energy storage is integral to the EMS framework:

   a. Stationary storage systems: Strategically placed storage facilities (e.g. at bus depots or transport hubs) store excess renewable energy for later use during demand peaks or at night.

   b. Vehicle-to-grid (V2G) integration: EMS can support bidirectional charging, where electric vehicles act as mobile storage units capable of feeding energy back to the grid during high demand, thereby enhancing flexibility and grid stability.

5. Demand-Side Management and Cost Optimisation - EMS supports real-time demand-side management, aiming to reduce energy consumption and costs:

   a. Dynamic demand management: Charging schedules and system operations can be shifted to off-peak periods to minimise grid load and energy expenditure.

   b. Cost-effective energy use: The system continuously monitors electricity prices and dynamically adjusts usage patterns to minimise costs, favouring renewable energy sources when available.

6. Monitoring, Forecasting, and Reporting - Comprehensive monitoring and predictive capabilities are core EMS functions:

   a. Data acquisition: EMS gathers data on energy usage, renewable energy generation, battery status, and infrastructure performance. This data informs both short-term decision-making and long-term strategic planning.

   b. Forecasting and analytics: Through advanced analytics, EMS forecasts future energy demand based on historical trends and projected operational conditions, thereby facilitating efficient planning and optimisation.

7. Key Benefits of EMS Implementation in Urban Transport - The deployment of an EMS offers numerous operational, economic, and environmental advantages:
   a. Operational cost reductions: Improved energy efficiency and integration of cost-effective renewable sources significantly lower day-to-day operating costs.
   b. Enhanced energy efficiency: The system enables public transport fleets to operate with higher energy productivity, reducing reliance on fossil fuels and enhancing long-term sustainability.
   c. Environmental gains: By promoting renewable energy use and reducing emissions, EMS contributes to improved air quality and the mitigation of climate change impacts.

In the short term (0–2 years), integrating renewable energy sources (RES) such as photovoltaics into urban transport systems can yield immediate environmental benefits, reduced fuel costs, and access to national and EU subsidies, although these gains are tempered by high initial investment and infrastructure upgrade requirements. In the medium term (2–5 years), benefits expand to include considerable savings in fuel and maintenance, greater energy independence, and improved system efficiency through data-driven optimisation, despite ongoing infrastructure demands and network management challenges. In the long term (beyond five years), the return on investment (ROI) becomes substantial, typically achieved within 6–10 years, resulting in markedly lower operational costs, enhanced public health, compliance with climate targets, and even revenue generation through surplus energy sales, though continued technological updates and equipment renewal remain necessary.

An Energy Management System (EMS) in urban transport represents a sophisticated and future-oriented solution to the pressing challenges of energy consumption, environmental sustainability, and economic efficiency. Its implementation supports the transition towards low-emission mobility, delivering measurable benefits to both transport operators and the broader urban population. As cities strive to meet ambitious climate targets, EMS will increasingly become a cornerstone of integrated, resilient, and sustainable transport planning.

4.3.4.3. Predictive maintenance

Predictive maintenance is a proactive strategy aimed at maintaining equipment in optimal condition through continuous monitoring and analysis of its operational parameters. This approach enables the early detection of faults and the forecasting of potential failures, thereby facilitating timely intervention before a breakdown occurs. In the context of public transport, and specifically tram systems, predictive maintenance plays a pivotal role in improving vehicle reliability, reducing downtime, and lowering overall maintenance costs.

Predictive maintenance in tram operations involves the systematic monitoring and assessment of critical vehicle components, with maintenance tasks scheduled based on predefined operational thresholds—most commonly distance travelled. These maintenance intervals and procedures are typically prescribed by the tram manufacturer, which provides detailed guidance on inspections, component replacements, and performance evaluations. Adhering to such schedules ensures that rolling stock operates safely and efficiently, minimising the likelihood of unplanned breakdowns and extending asset lifespan.

A structured predictive maintenance process also includes data acquisition from sensors and control systems, performance diagnostics, certification and calibration of key components, as well as historical data analysis. This continuous cycle of monitoring, intervention, and optimisation forms a core element of advanced maintenance regimes in modern urban transport systems.

Regular and predictive maintenance enhances energy efficiency through several key mechanisms:

- Prevention of energy waste: Well-maintained propulsion systems, lighting, and electrical infrastructure operate more efficiently, thereby reducing unnecessary energy losses.
- Extension of asset lifespan: Systematic servicing mitigates wear and tear, deferring costly replacements and reducing the environmental impact associated with manufacturing and disposing of equipment.
- Minimisation of unplanned downtime: Failures in critical systems often lead to inefficiencies, service disruptions, and increased fuel or energy use. Predictive maintenance supports continuous and stable operations.
- Increased resilience: Robust infrastructure is more adaptable to emerging sustainability measures and technological innovation, including integration with energy management systems.

Steps to Establish a Structured Maintenance Framework:

1. Assessment and Inventory: Identification of all infrastructure components requiring regular inspection and upkeep.
2. Definition of Maintenance Procedures and Schedules: Establishing maintenance frequencies, performance thresholds, and task specifications based on usage data and manufacturer guidelines.
3. Training and Resourcing: Recruiting or training qualified personnel (or external contractors) to execute maintenance activities in compliance with safety and quality standards.
4. Implementation and Monitoring: Executing maintenance tasks according to the schedule, while employing monitoring tools to track performance indicators and detect anomalies.
5. Audit and Optimisation: Periodic review of maintenance outcomes to assess efficiency, update procedures, and improve scheduling based on operational data.

According to discussions held by the Technical Subgroup of the Transnational Working Group, the cost of implementing predictive maintenance falls within the category of moderate manageability. Key cost drivers include:

- Initial investment: Planning activities, system audits, staff training, and procurement of monitoring equipment.
- Recurring operational costs: Labour, spare parts, and diagnostic services.
- Infrastructure upgrades: Enhancements that improve energy performance, such as retrofitting with LED lighting or integrating advanced energy management systems.

While maintenance represents a continuous cost, it is significantly less expensive than emergency interventions or premature asset replacement.

Investing in predictive maintenance yields substantial long-term financial and operational returns:

- Reduced energy expenditure: Optimal operation of lighting, HVAC, and power systems leads to decreased electricity and fuel consumption.
- Asset longevity: Preventative care prolongs the functional lifespan of critical equipment, reducing capital expenditure.

- Regulatory compliance and risk mitigation: Meeting maintenance standards helps avoid regulatory penalties and underscores an organisation's commitment to sustainability and operational excellence.

Predictive maintenance constitutes a fundamental pillar of an effective Environmental Management System (EMS) within the urban transport sector. Although it entails ongoing operational investment, the long-term benefits—spanning energy efficiency, cost reduction, service reliability, and regulatory compliance—far outweigh the associated costs. By embedding predictive maintenance into their operational strategy, transport operators can significantly contribute to the sustainability, resilience, and performance of urban mobility systems.

4.3.4.4. Automated controls for lighting and HVAC

Implementing automated controls for lighting and HVAC (heating, ventilation, and air conditioning) systems across vehicles, stations, and depots presents a valuable opportunity to reduce energy consumption in urban transport systems. These technologies, when piloted and tailored to the specific infrastructure of a city, can lead to significant energy savings. The effectiveness of such interventions depends on their scale, the technological readiness of the infrastructure, and the level of integration with existing systems.

- Smart HVAC Controls in Public Transport Vehicles: HVAC systems in buses, trams, and metro cars can be enhanced with smart sensors that adjust heating, cooling, and ventilation based on real-time passenger load and external weather conditions. For example, during low-occupancy periods, the system can automatically reduce output to avoid unnecessary energy use. Similarly, temperature adjustments can be made in response to outdoor climate conditions, preventing excessive heating in winter or cooling in summer.

- Automated Lighting Systems in Vehicles: Interior lighting systems can be optimised through automation to reduce unnecessary energy use. In vehicles with large windows, lighting can be dimmed or deactivated during daylight hours. Motion sensors may also be installed to reduce lighting in unoccupied sections of vehicles, particularly on longer trams or articulated buses.

- Smart HVAC and Lighting in Stations, Depots, and Support Infrastructure: In stations and depots, HVAC and lighting systems can be programmed to respond to occupancy patterns. Heating and cooling can be minimised during off-peak hours or in unoccupied spaces using motion and occupancy sensors. In some metro systems, innovative technologies are already in use—such as reusing filtered exhaust air from train tunnels to preheat station ventilation. Artificial intelligence (AI) and smart monitoring systems offer additional potential for optimising energy usage across these facilities by learning usage patterns and adjusting settings accordingly.

The implementation costs and return on investment (ROI) for these technologies depend on several factors, including the complexity of the system, the scale of deployment, and the existing efficiency of the infrastructure. Retrofitting older vehicles and buildings may require substantial initial investment, whereas integrating automated systems into newly procured infrastructure tends to be more cost-effective. Basic automation systems, such as motion-sensitive lighting, typically offer a short ROI period of approximately 3–5 years due to immediate energy savings. More advanced systems—especially those incorporating AI-driven optimisation—entail higher costs and longer implementation times, with expected ROI periods ranging from 5 to 10 years. Nevertheless, the long-term benefits in energy savings, operational efficiency, and environmental sustainability make these investments highly worthwhile for urban transport operators.

4.3.5. Other climate change measures – implementation of warning systems

The implementation of Intelligent Transport Systems (ITS) in public transport represents a key advancement in enhancing the safety, efficiency, and sustainability of urban mobility networks. ITS integrate modern information and communication technologies to support dynamic traffic management and real-time decision-making. Their use is particularly beneficial in the development of advanced warning systems, enabling better responsiveness to hazards and improving operational continuity in complex transport environments.

ITS comprise a range of interconnected subsystems, which together support the optimal functioning of public transport. These include devices and applications deployed across mobile networks, spatial information systems, Geographic Information Systems (GIS), satellite navigation tools, electronic display units, weather monitoring instruments, traffic databases, and vehicle tracking systems.

These technologies offer comprehensive and timely data for both transport operators and road users, covering elements such as incident reports, weather conditions, and real-time public transport departures. The benefits of ITS are far-reaching, encompassing improvements in service reliability, reduced congestion, enhanced passenger information, and increased public satisfaction. Crucially, these systems support both local authorities and stakeholders by promoting informed decision-making and more efficient resource allocation.

The core components of an ITS framework in Public Transport are:

- In-Vehicle Visual and Audio Passenger Information Systems - These systems typically consist of an onboard computer, LED information displays, and a voice module. The onboard computer facilitates integration with other digital systems, enabling real-time service updates, vehicle location tracking, and coordination with traffic signal priority systems. The system is programmable and can be tailored to the needs of specific operators or cities.
- Traffic Signal Priority Systems - This subsystem enables automatic priority for public transport vehicles at signalised intersections. It involves the installation or upgrading of traffic signal controllers, system calibration, and the provision of GSM/GPRS communication modules within vehicles to enable remote coordination with urban traffic control centres.
- Online Passenger Information Services - Real-time service data can be made accessible via web-based platforms, allowing users to check up-to-date departure information and service disruptions from any internet-enabled device.
- Real-Time Passenger Information Displays - Dynamic electronic stop displays provide real-time arrival predictions based on live vehicle tracking. These displays are connected to a central control system via GPRS or GSM networks and are programmable to include service alerts or operational messages sent from traffic management centres.

The cost of implementing ITS varies widely depending on factors such as city size, system scope, technology selection, and project objectives. Key cost categories include:

- Infrastructure Costs:
    - Monitoring and Detection Systems: Deployment of CCTV, motion detectors, GPS tracking, and road condition sensors.
    - Traffic Management Centres: Construction or modernization of facilities for real-time monitoring and coordination.
    - Traffic Signal Equipment: Upgrades to traffic lights and integration of intelligent control mechanisms.

- Software and Management Systems:
  - Traffic and Data Platforms: Acquisition or development of software for real-time traffic analysis, incident detection, and performance reporting.
  - Mobile Applications: Development of passenger-facing apps for journey planning, service alerts, and dynamic route tracking.
- System Integration Costs:
  - Compatibility with Existing Systems: Integration with ticketing platforms, fleet management systems, and surveillance networks.
  - Cybersecurity Measures: Investment in data encryption, access controls, and threat mitigation technologies.
- Vehicle and Equipment Costs:
  - Onboard ITS Equipment: Installation of GPS, communication modules, diagnostic sensors, and digital displays in vehicles.
  - Fleet Upgrades: Purchase or retrofitting of vehicles to meet technical specifications compatible with ITS infrastructure.
- Training and Technical Support:
  - Staff Training: Programmes for drivers, technicians, and control centre staff in system usage and emergency protocols.
  - Maintenance and Servicing: Regular hardware maintenance and software updates to ensure long-term system reliability.
- Operational Costs:
  - System Management: Ongoing operational expenses, including cloud storage, analytics platforms, and system licensing.
  - Dynamic Traffic Response: Costs associated with adaptive signal control and real-time route optimisation in response to traffic conditions.
- Research and Pilot Testing - Proof-of-Concept Trials: Testing in selected areas prior to full deployment to validate performance and gather user feedback.
- Legislative and Administrative Costs - Compliance and Certification: Ensuring adherence to data protection laws, national regulations, and industry standards, including the acquisition of necessary permits and approvals.

Despite potentially high initial investment, ITS offer considerable long-term value by improving traffic flow, enhancing public transport reliability, reducing fuel consumption, and lowering emissions. The resulting improvements in air quality, commuter experience, and operational efficiency contribute significantly to urban sustainability objectives. ITS also support broader smart city goals, offering scalable, future-proof solutions to evolving mobility challenges.

In the short term (0–2 years), the implementation of advanced safety and monitoring systems in urban transport leads to a rapid reduction in accidents, lower insurance and repair costs, and improved traffic flow, though these benefits are accompanied by high initial expenditures, infrastructure upgrades, and the need for staff training. Over the medium term (2–5 years), the sustained decrease in incidents enhances public safety, increases passenger numbers, reduces operating costs, and provides valuable data for traffic planning, albeit requiring continued investment in system integration and updates. In the long term (beyond five years), the return on investment (ROI) becomes substantial, encompassing both financial and societal gains, including lower public health and emergency costs, improved public trust in transport systems, and the potential for exporting developed technologies, despite challenges such as technological obsolescence and evolving data protection requirements.

4.4. Waterway transport

Waterway transport, which includes both inland and maritime navigation, plays a key role in global and regional trade by enabling the efficient and cost-effective movement of large volumes of goods. Compared to other transport modes, it contributes significantly to reducing environmental impacts, offering lower energy consumption and greenhouse gas emissions per ton-kilometer. Furthermore, the development of sustainable waterway transport infrastructure enhances multimodal connectivity, supports economic growth, and strengthens resilience in supply chains, especially within strategic corridors such as the Danube and along major maritime routes. Freeport of Budapest Logistics Ltd and Port of Ploče Authority represented the waterway sector in the REDU-CE-D project, and the following chapter is built on their expertise.

4.4.1. Energy and resources - electrical energy

4.4.1.1. Constant modernization of the electrical vehicle fleet

Waterway transport is a fundamental pillar of sustainable and energy-efficient logistics, and the integration of electric propulsion technologies is gaining increasing importance. This action aims to procure and commission a small electric boat to support the daily operations of a port authority and enhance the overall efficiency and sustainability of port and shipping services. The electric vessel will complement existing conventional boats and will be tasked with:

- Nautical supervision of vessels moored at the port, including oversight of anchoring, lighting, and general security.
- Inspection and verification of ship documentation during patrol rounds, such as checking certifications and barge logbooks.
- Emergency first aid response for onboard crew in case of medical incidents or accidents.

In addition to supporting operational needs, the adoption of this electric boat represents a clear commitment to environmentally responsible practices in inland and port navigation. The introduction of an electric boat is expected to deliver multiple positive impacts across environmental, economic, operational, and safety domains:

- Environmental Benefits: The vessel will operate with zero emissions and minimal noise, thereby reducing air and noise pollution within the port area and contributing to a lower ecological footprint.
- Economic Efficiency: Electric propulsion offers significantly lower energy and maintenance costs compared to internal combustion engines, resulting in long-term savings.
- Operational Advantages: The compact size and high maneuverability of the electric boat make it ideal for fast, responsive movements in confined port areas.
- Safety Improvements: Enhanced capacity for vessel monitoring, documentation control, and on-water emergency response will improve the overall safety of port and waterway operations.

The procurement and deployment of the electric boat will follow a structured three-phase timeline:

1) Preparation and Planning (3–6 months):
    a) Conduct needs assessment and market analysis.
    b) Evaluate available electric boat technologies.
    c) Prepare technical specifications and procurement documentation.
2) Procurement and Commissioning (6–9 months):
    a) Execute the purchase of the electric vessel.
    b) Prepare supporting port infrastructure (e.g., docking and charging facilities).
    c) Conduct test operations and system integration.
3) Deployment and Optimisation (3 months):
    a) Fully integrate the vessel into operational routines.
    b) Provide staff training on vessel operation, safety, and maintenance.
    c) Monitor performance and adjust procedures as necessary.

The overall cost of implementing this action includes several key components:

- Vessel Procurement: Estimated between €300,000 and €1,500,000, depending on vessel size, equipment, and technical capabilities.
- Port Infrastructure Development: Includes installation of charging stations and designated docking areas, ranging from €50,000 to €200,000.
- Operational and Maintenance Costs: Electric boats typically incur lower long-term costs due to reduced fuel needs and fewer mechanical maintenance requirements.
- Training and Operational Preparation: Estimated between €10,000 and €50,000, covering training for staff in electric propulsion technology and emergency response procedures.

The investment in a small electric boat is expected to yield cost-effective and sustainable returns over the short, medium, and long term:

- Short Term (1–3 years): Immediate savings on fuel and routine maintenance.
- Medium Term (3–7 years): Improved operational efficiency and reliability of port operations.
- Long Term (7–15 years): Full return on investment, enhanced environmental performance, and long-lasting benefits for sustainable port and shipping practices.

4.4.1.2. Awareness raising campaigns

Waterway transport is among the most energy-efficient modes of freight movement, offering substantial environmental benefits over road-based alternatives. A single cargo vessel carrying approximately 1,200 tons of goods can replace up to 40 trucks, resulting in significantly lower energy consumption per ton-kilometer, reduced CO_2 emissions, and minimised environmental strain. An awareness campaign dedicated to promoting inland waterway and maritime freight transport should aim to inform stakeholders about these advantages and encourage modal shift from road to waterborne logistics.

Key campaign messages should emphasise:

- Lower Energy Demand: Inland and coastal shipping requires considerably less energy per ton-kilometer than road freight, positioning it as a more sustainable and cost-effective option.

- Reduced CO_2 Emissions: Waterway transport emits significantly less CO_2 per transported ton, supporting local, national, and EU-level climate objectives.
- Minimal Noise Pollution: Unlike road freight, waterborne transport contributes little to urban and residential noise levels, enhancing quality of life.
- No Road Infrastructure Strain: Unlike trucks, ships do not contribute to road wear and congestion, reducing maintenance costs and traffic-related externalities.

A well-structured awareness campaign can deliver both environmental and economic benefits by:

- Increasing Public and Industry Awareness: Educating logistics operators, policymakers, and the public about the environmental and operational advantages of water transport.
- Encouraging Policy and Industry Support: Building momentum for policy incentives and strategic investment in inland waterway infrastructure.
- Promoting Sustainable Logistics Choices: Influencing supply chain decision-makers to adopt more energy-efficient freight alternatives.
- Realising Long-Term Cost Savings: Highlighting the potential for reduced fuel costs, lower maintenance expenditures, and optimised freight logistics through modal shift.

The campaign is envisioned in three key phases:

1) Preparation (1–2 months):
   a) Define key messages and identify target stakeholder groups.
   b) Select appropriate communication channels (e.g., digital platforms, industry events, printed materials).
2) Execution (2–3 months):
   a) Launch online campaigns, social media content, and educational videos.
   b) Organise professional forums, roundtables, and public outreach events.
   c) Collaborate with industry associations, ports, and freight operators.
3) Evaluation and Follow-Up (1 month):
   a) Monitor campaign performance using key performance indicators (KPIs).
   b) Assess impact and adapt messaging or strategies as needed.

Campaign costs will vary depending on the scope, communication tools, and media used. To ensure financial feasibility:

- Phased Implementation is recommended, starting with cost-effective digital outreach (e.g., social media, webinars) and expanding to print media, conferences, and stakeholder engagement sessions as resources allow.
- Collaborative Funding from public and private stakeholders, as well as potential support from EU programmes, can help ensure sustainability.

Though difficult to quantify in the short term, the long-term return on investment can be considerable. Expected benefits include:

- Reduced Environmental Impact: Greater uptake of water transport leads to decreased greenhouse gas emissions and energy consumption.

- Lower Operational Costs: Efficient freight systems reduce fuel use and vehicle wear, offering long-term financial savings.
- Increased Access to Incentives: A more informed and engaged sector can better leverage national and EU funding opportunities for sustainable logistics.
- Enhanced Corporate Image: Companies that support greener transport modes can improve their public reputation and align with ESG (Environmental, Social, and Governance) standards.

4.4.1.3. Investing in newer equipment

Energy efficiency and sustainability are becoming increasingly critical in the water transport sector. The growing use of electric energy—particularly through investments in modern, energy-efficient equipment—offers considerable potential to reduce operational costs, lower emissions, and mitigate environmental impacts. Key areas for such investments include:

- Installation of energy-efficient port infrastructure, such as electric cranes and charging stations;
- Modernization of onboard systems, including high-efficiency batteries, LED lighting, and intelligent energy management systems to optimise a vessel's internal power supply;
- Deployment of electric vessels or drones in emergency response scenarios, such as oil or chemical spills, where rapid intervention is required to prevent the spread of pollutants by deploying absorbent materials.

The primary objective of these measures is to optimise energy consumption, decrease dependence on fossil fuels, and enhance long-term cost-efficiency in maritime operations. The adoption of electric or hybrid technologies yields multiple environmental, economic, and operational benefits:

- Fuel Savings: Electric propulsion systems significantly reduce the consumption of conventional fuels, leading to lower operational costs.
- Emission Reduction: The use of electric ships and port equipment dramatically decreases greenhouse gas emissions and other pollutants.
- Reduced Maintenance Costs: Electric systems typically have fewer mechanical components, resulting in lower failure rates and reduced maintenance expenses.
- Enhanced Competitive Advantage: Improved energy performance and sustainability credentials can strengthen an organisation's market position.
- Improved Environmental Response: Electric vessels and drones enable fast, effective management of pollution incidents, reducing environmental damage and associated liabilities.

The implementation timeline for the investment varies depending on the type and complexity of the equipment involved:

- Energy-efficient port equipment (e.g., cranes, charging stations) - 18–24 months;
- Onboard system upgrades (e.g., LED lighting, batteries) - 3-6 months;
- Electric vessels or drones for emergency response - 6–12 months.

The financial viability of these investments can be enhanced through:

- Utilization of national and EU-level funding programmes, including green transition and innovation grants;

- Long-term operational savings stemming from improved energy efficiency and reduced maintenance costs.

While ROI varies depending on the type and scale of investment, several factors can shorten the payback period:

- Fuel cost reductions through decreased consumption of fossil fuels;
- Lower maintenance expenditures, with electric systems often requiring 30–40% less maintenance;
- External subsidies and incentives, which can significantly offset initial capital expenditures.

Long-Term Strategic Benefits should be also not left out:

- Increased energy independence, with more stable and predictable energy supply costs;
- Enhanced environmental performance and corporate reputation, contributing to a greener public image;
- Competitive advantage, particularly among stakeholders and customers with sustainability-driven procurement policies.

4.4.1.4. Expansion of central systems

In the context of waterway transport, the role of electric energy is gaining increasing prominence, both in vessel operations and port infrastructure. Expanding central electrical systems is a strategic measure aimed at transitioning toward more sustainable, efficient, and resilient energy use in ports and related facilities. Key elements of this measure include:

- Development of Port Power Supply Networks: Upgrading and expanding electrical infrastructure to meet the rising demand for high-capacity electricity supply in ports.
- Installation and Expansion of Shore Power Supply Systems: Enabling docked vessels to connect to the grid, thereby eliminating the need to run onboard generators and reducing emissions.
- Integration of Energy Storage Systems: Enhancing load balancing and enabling the storage of excess energy for use during peak demand periods.
- Incorporation of Renewable Energy Sources: Utilizing solar panels, wind turbines, and other clean energy technologies to reduce fossil fuel dependency.

The overarching goal is to enhance energy efficiency, support decarbonization objectives, and improve the competitiveness and environmental performance of the sector. The expansion of centralized electrical systems is expected to yield a wide range of benefits:

- Environmental Sustainability: Shore-side electricity reduces emissions from docked ships, helping to improve air quality in port areas and contributing to climate goals.
- Operational Cost Savings: By replacing onboard fuel generators with electric power, ports and ship operators can realise significant reductions in fuel expenses.
- Energy Optimization: Energy storage systems allow for efficient use of renewable energy, minimising energy loss and enabling cost-effective operations.
- Infrastructure Resilience: Modernized power supply systems reduce the risk of outages, enhance reliability, and increase the flexibility of port energy management.

In the long term, these improvements can strengthen the position of inland and maritime ports within the global logistics network, making them more attractive partners in sustainable international shipping. The timeline for implementing this measure varies depending on project scale and site conditions, but it generally includes the following phases:

- Phase 1: Planning and Approval (6–12 months)
    - Conducting needs assessments and evaluating technological alternatives
    - Performing cost-benefit and return-on-investment analyses
    - Securing permits and regulatory approvals
- Phase 2: Procurement and Installation (12–24 months)
    - Construction and connection of upgraded electrical grid infrastructure
    - Installation of shore power supply systems at berths
    - Deployment and integration of energy storage systems and renewable energy technologies
- Phase 3: Testing and Commissioning (3–6 months)
    - System calibration, performance testing, and fine-tuning
    - Staff training and development of operational procedures

Total time required to implement: 18 months to 3 years, depending on project complexity.

The expansion of central electrical systems entails substantial capital investment, particularly in infrastructure development and technology integration. However, long-term operational and maintenance savings can significantly offset initial costs. Potential financing mechanisms include:

- National and EU-level green infrastructure funding programmes;
- Preferential loans for sustainable energy investments;
- Public-private partnerships (PPP) and private sector investment.

Phased implementation may also support better financial manageability and funding acquisition. The ROI is influenced by several key factors, including port energy demand, vessel traffic volumes, system scale, and energy pricing. Benefits contributing to a favorable ROI include:

- Fuel Cost Reductions: Substituting onboard generators with shore power significantly lowers annual fuel expenditures.
- Lower Maintenance Costs: Modern electrical systems are more durable, experience fewer breakdowns, and require less frequent maintenance.
- Savings through Renewable Integration: On-site energy generation reduces reliance on external energy providers and enhances long-term energy security.

4.4.2. Energy and resources - fossil fuels

4.4.2.1. Constant modernization of vehicle fleet

Continuous modernization of the vehicle fleet is essential for enhancing operational efficiency, reducing costs, improving safety, and mitigating environmental impacts. In the context of inland and maritime waterways, this modernization refers to the systematic upgrading of vessels used for transport, logistics, and maritime services. It encompasses the integration of advanced technologies, compliance with evolving environmental regulations, and strategic innovation to ensure competitiveness and sustainability within the sector. Key elements of fleet modernization include:

- Automation and Artificial Intelligence (AI): The implementation of automated systems for navigation, cargo handling, and predictive maintenance significantly enhances operational precision. AI-based route optimisation can lower fuel consumption and improve safety by adjusting routes in response to environmental and traffic data.
- Electrification and Hybridisation: The transition to electric, hybrid, or hydrogen-powered vessels contributes to decarbonization efforts. These technologies reduce greenhouse gas emissions and decrease reliance on conventional fossil fuels.
- Advanced Materials: The adoption of lightweight and durable materials, such as carbon composites, contributes to reduced fuel consumption, increased vessel speed, and extended service life.
- Energy-Efficient Engines and Renewable Energy: Modern propulsion systems and the integration of auxiliary renewable energy sources (e.g., solar panels) support lower overall energy consumption and operating costs.

The modernization of a waterway fleet is a phased, long-term process, influenced by fleet size, technology readiness, and regulatory frameworks:

- Initial Planning and Strategy Development (6–12 months): This phase includes a comprehensive assessment of the existing fleet, technology benchmarking, objective-setting, and budgetary planning.
- Pilot Testing and Evaluation (12–24 months): Selected vessels are retrofitted or newly constructed using advanced technologies. Their performance is monitored, and training is provided to crews and technical staff.
- Ongoing Upgrades and Monitoring (5+ years): Continuous updates are made based on technology availability, environmental regulations, and organisational financial capacity.

Modernization entails a range of capital and operational expenditures:

- Assessment and R&D: Includes fleet diagnostics, technology research, and prototype development.
- Infrastructure Upgrades: New technologies may require complementary infrastructure investments at ports, such as charging stations or refueling systems.
- Operational Adaptation: Training for personnel, maintenance adjustments, and temporary operational disruptions contribute to transitional costs.

Costs vary widely depending on whether vessels are retrofitted or newly constructed, the degree of technology integration, and the extent of regulatory compliance required. Despite the significant initial capital outlay, long-term benefits justify the investment:

- Fuel and Maintenance Savings: Hybrid and electric vessels offer lower fuel costs and reduced mechanical wear, translating into lower maintenance expenditures and extended asset lifespan.
- Operational Efficiency: Predictive maintenance and AI-driven route planning reduce downtime and increase service reliability, supporting revenue growth.
- Environmental Compliance and Incentives: Investing in low-emission technologies reduces regulatory risk, avoids penalties, and may attract incentives or subsidies from national and EU-level sustainability programs.

The continuous modernization of waterway transport fleets is vital for achieving environmental, operational, and economic objectives. By investing in advanced technologies and aligning with international sustainability standards, operators can significantly reduce CO_2 emissions, lower lifecycle costs, and enhance service competitiveness. In a maritime sector increasingly shaped by climate policy and digital innovation, modernization is not only an opportunity—it is a strategic necessity.

4.4.2.2. Helpful maps and programmes

Water transport plays a pivotal role in global trade, enabling the movement of goods and people across rivers, lakes, and oceans. Efficient navigation, environmental monitoring, and infrastructure management are critical for ensuring safe and sustainable waterway operations. A range of digital tools and programs have been developed to support professionals in transportation, environmental sciences, and engineering, enhancing the effectiveness of decision-making and resource management in the sector. Key categories of helpful tools include:

- Navigation and Mapping Tools (e.g., Navionics, OpenStreetMap, Google Earth, C-Map, MarineTraffic): These facilitate real-time navigation, route planning, and maritime traffic monitoring.
- Environmental Monitoring and Management Tools (e.g., EPA Watershed Monitoring, USGS Hydrography Program, RiverWare, National Wetlands Inventory): These systems support the assessment and maintenance of ecosystem health in aquatic environments.
- Flood Prediction and Waterway Management Tools (e.g., FEMA Flood Map Service Center, Floodplain Mapper, Coastal & Marine Spatial Planning): These tools are essential for risk mitigation and spatial planning.
- Water Quality Monitoring Applications (e.g., Water Quality Exchange (WQX), Water Quality Application (WQApp)): These are used to track and manage water quality metrics relevant to compliance and sustainability objectives.

The time required to implement digital maps and management programs varies depending on the complexity and scale of the project, as well as the goals of the organisation:

- Navigation Charts and Mapping Systems: A few weeks to several months.
- Geographic Information System (GIS) Tools: Several months to one year.
- Automatic Identification System (AIS) Integration: 3–6 months.
- Port Management Systems (PMS): 6 months to 1 year.
- Simulation and Modeling Software: 6 months to 1 year or more.
- Real-Time Vessel Traffic Management Systems: 6 months to 2 years.

In general, simpler systems (e.g., basic map overlays or tide predictions) can be deployed within weeks, while comprehensive solutions may require up to two years for full implementation. The cost of implementing mapping and management programs in water transport is influenced by system complexity, required customisations, and long-term support needs:

- Navigation and Mapping Systems: Costs include initial licensing, software customisation, and maintenance.
- GIS Tools: May involve software subscriptions (e.g., ArcGIS), hardware, data acquisition, and personnel training.
- AIS Systems: Require investment in hardware, data services, and system integration.
- Port Management Systems (e.g., NAVIS N4, PortCall): Include licensing fees, infrastructure upgrades, training, and change management processes.

While small-scale applications may involve modest expenses, comprehensive systems used in large ports or regional navigation networks can cost several million euros. Despite the high initial costs, the ROI for digital mapping and management systems can be considerable, with both quantitative and qualitative returns:

- Operational Efficiency and Cost Reduction: Optimised scheduling, better fuel usage, and reduced delays lead to significant savings.
- Increased Throughput and Revenue: Faster vessel turnaround and improved port capacity can generate higher revenues.
- Enhanced Safety and Risk Mitigation: Real-time data reduces the likelihood of accidents, environmental incidents, and operational disruptions.
- Regulatory Compliance and Environmental Impact: Systems help ensure adherence to environmental regulations, avoid fines, and qualify for sustainability incentives.

For large-scale ports, the payback period can be as short as 1–2 years, with ongoing annual returns potentially reaching millions of euros through efficiency gains and enhanced safety.

4.4.2.3. Promotion of micro-mobility

The concept of promoting micro-mobility within the waterway sector represents an emerging and innovative approach to sustainable urban transportation. Traditionally associated with small, lightweight, and often electric vehicles such as e-scooters or e-bikes, micro-mobility, when adapted to waterways, includes the integration of compact, energy-efficient vessels—such as electric ferries, water taxis, and small autonomous boats—into existing urban and regional transport systems. This initiative is particularly relevant for cities and regions with developed water infrastructure, where the strategic use of inland waterways can alleviate congestion, reduce emissions, and enhance multi-modal connectivity.

The promotion of micro-mobility on waterways offers a broad spectrum of environmental, social, and economic benefits. Environmentally, it contributes to reducing carbon emissions, lowering noise pollution, and maintaining cleaner water bodies through the adoption of low-emission or zero-emission vessels. From a mobility standpoint, waterborne micro-mobility solutions can ease road congestion, promote intermodality by integrating with land-based public transport systems, and reduce pressure on traditional ferry and transport services. Economically, such initiatives can stimulate job creation, foster tourism-related revenue, and offer commuters cost-effective alternatives. Furthermore, they drive technological innovation, enabling the development of smart infrastructure, real-time navigation systems, and new business models aligned with the principles of the circular and digital economies. From an urban planning perspective, integrating micro-mobility into water transport necessitates the rethinking of public space use, the construction of docking and charging infrastructure, and the alignment with broader smart city strategies.

The implementation of waterborne micro-mobility systems typically unfolds over multiple phases, each influenced by factors such as urban scale, existing infrastructure, and regulatory environments:

- Initial Planning and Feasibility (6–12 months): Involves stakeholder engagement, policy alignment, market research, and legal groundwork.
- Design and Infrastructure Development (12–24 months): Includes technological development, vessel procurement, and construction of docking and charging stations.
- Pilot Testing (6–12 months): Conducting small-scale trials to evaluate user experience, operational efficiency, and safety.

- Full-Scale Deployment (12–18 months): Expansion of fleet operations, staff training, marketing, and full integration into public transport networks.

The manageability of micro-mobility promotion in the waterway sector is shaped by both capital and operational expenditures. Key cost categories include:

- Infrastructure Investment: Construction of docking stations, installation of charging points, and integration with existing transport terminals.
- Fleet Procurement and Management: Acquisition of electric or hybrid vessels, along with ongoing maintenance and fleet tracking systems.
- Compliance and Safety: Regulatory certification, safety equipment, and insurance-related expenses.
- Operational Expenses: Staffing, training, maintenance, and service operations.
- Technology Systems: Booking applications, payment gateways, and digital monitoring platforms.

While initial capital costs can be substantial, opportunities exist to mitigate them through public-private partnerships, EU funding instruments, and green innovation subsidies.

The ROI of micro-mobility systems in the waterway sector is multifaceted, encompassing environmental, economic, and social dimensions:

- Environmental Benefits: Lower emissions, enhanced water quality, and alignment with urban climate goals.
- Economic Gains: Increased tourism, job creation, operational savings in road infrastructure, and revenue through fare collection and commercial partnerships.
- Social Impact: Improved accessibility, reduced commute times, public health benefits, and stronger civic engagement.

Although the short-term financial returns may be modest, the medium- to long-term outcomes (5–10 years) can be substantial, particularly if the system achieves widespread adoption and scales effectively. As awareness and ridership increase, the service can generate steady income, reduce public transport pressure, and contribute to broader sustainability targets.

4.4.2.4. Promoting and advocating for new incentives

Promoting and advocating for new incentives in waterway transport represents a strategic approach to improving the efficiency, sustainability, and competitiveness of this crucial sector. As one of the most fuel-efficient modes of transport, inland and coastal waterway navigation offers substantial opportunities for reducing carbon emissions, mitigating road congestion, and lowering overall transportation costs. Advocating for incentive mechanisms—particularly those targeting sustainability, innovation, and environmental protection—can catalyse policy reform and drive transformative industry developments. These incentives may encompass pollution reduction, the adoption of clean technologies, enhanced energy efficiency, and the promotion of community and environmental well-being.

The timeframe for introducing advocacy measures and new incentive frameworks in the waterway sector varies depending on the complexity of the proposed initiatives, the geographical and operational scope of the waterway, and the diversity of stakeholders involved. The process can be broken down into the following phases:

- Research and Planning (3–6 months): Conducting baseline assessments, identifying relevant stakeholders, and reviewing applicable regulations and policy frameworks.

- Designing Incentives (2–4 months): Developing tailored incentive structures based on feasibility studies and public consultations.
- Advocacy and Awareness Campaigns (6–12 months): Building coalitions with stakeholders, launching public education initiatives, and engaging in targeted lobbying efforts.
- Implementation (1–3 years): Rolling out pilot projects, securing regulatory approvals, and scaling up successful programs.
- Monitoring and Evaluation (Ongoing): Establishing mechanisms for measuring effectiveness and refining strategies over time.

The costs associated with promoting and implementing incentive programs are influenced by their scale and complexity. Key expenditure categories include:

- Research and Analysis: Market studies, data collection, and environmental impact assessments.
- Stakeholder Engagement and Advocacy: Public relations campaigns, stakeholder outreach, and lobbying efforts.
- Program Development: Designing and piloting incentive schemes, as well as technology adaptation and infrastructure planning.
- Monitoring and Reporting: Establishing systems for performance tracking and regulatory compliance.
- Personnel and Legal Support: Hiring qualified personnel and obtaining legal expertise for regulatory alignment.

Despite potential upfront costs, many activities—such as advocacy and research—are relatively manageable and can be supported through public funding, international cooperation, or private-sector partnerships. The ROI from promoting and advocating for new incentives in the waterway sector can be substantial, though it often involves both direct financial and broader socio-environmental returns:

- Economic Development: Enhancing efficiency in waterborne logistics may reduce transport costs, stimulate trade, and improve the competitiveness of the broader economy.
- Environmental Benefits: Encouraging modal shift from road to waterways can lead to significant reductions in greenhouse gas emissions and support water quality improvements.
- Employment Generation: New investments in infrastructure and service development can create both direct and indirect employment opportunities across the maritime and logistics sectors.
- Operational Cost Savings: Improved port operations, navigational efficiency, and reduced delays can significantly lower costs for businesses and public operators.
- Private Sector Leverage: Incentives can stimulate private investment, including contributions to modernization and decarbonization efforts, thereby amplifying long-term economic gains.

In summary, the strategic promotion and advocacy of new incentives in the waterway sector can yield long-term dividends in economic growth, environmental sustainability, and operational performance. The cumulative return on investment—particularly when considering indirect and societal benefits—can be substantial over time, reinforcing the value of such initiatives as part of broader transport and environmental policy agendas.

4.4.2.5. Investing and exploring the trend of hydrogen use for vehicles

Investing in and exploring the trend of hydrogen use for waterway transport represents a forward-looking and transformative opportunity for the maritime industry. As the global energy landscape shifts toward cleaner and more sustainable alternatives, hydrogen-powered vessels are emerging as a viable solution to decarbonize maritime transport. Offering a zero-emission alternative to traditional marine fuels such as diesel and bunker oil, hydrogen can play a pivotal role in reducing the environmental footprint of ships, ferries, tugboats, and other waterborne vehicles.

The integration of hydrogen into the maritime sector has the potential to generate significant economic, environmental, and technological impacts. While the promise of hydrogen is clear, the realisation of this potential requires overcoming various technical, infrastructural, and regulatory challenges.

The transition to hydrogen-fueled maritime transport is expected to unfold across multiple phases, reflecting advancements in technology, regulatory readiness, infrastructure development, and market dynamics:

- Short-Term (1–5 years): Research, Development, and Early Adoption (Research and Development, Government Policy and Regulatory Framework, Infrastructure Planning)
- Medium-Term (5–10 years): Expansion and Market Scaling (Commercial Deployment of Hydrogen-Powered Vessels, Expansion of Hydrogen Infrastructure, Technological Improvements)
- Long-Term (10–20 years): Full Integration and Global Adoption (Widespread Adoption and Mainstreaming, Full Regulatory Alignment, Technological Maturity)

From a manageability standpoint, the deployment of hydrogen in the maritime sector involves substantial capital expenditure and operational costs. Key cost components include:

- Infrastructure Investment: Hydrogen production facilities, high-pressure storage units, fueling stations, and associated port upgrades.
- Vessel Retrofitting or Procurement: Adapting existing vessels or commissioning new hydrogen-powered fleets.
- Fuel Supply Chain: Development of logistics for hydrogen production, distribution, and refueling.
- Operation and Maintenance: Costs for maintaining hydrogen-compatible components, such as fuel cells and safety systems.
- Regulatory Compliance: Meeting evolving safety and environmental standards, including risk management protocols and certification processes.

To manage these expenses, it is essential to leverage public-private partnerships, access government grants, and utilize innovative financing tools that spread risk and promote cost recovery over time. While the financial returns from investing in hydrogen-powered waterway vehicles are long-term in nature, the multifaceted benefits contribute to a compelling ROI over a 10–15-year horizon. These include:

- Environmental Impact and Regulatory Compliance (Reduced Emissions, Government Incentives (For example, the EU, Norway, and other countries have launched funding programs for green shipping technologies, which can boost ROI));
- Fuel Cost Savings and Efficiency (Fuel Cost Savings, Operational Efficiency, Cost of Maintenance);
- Long-Term Savings on Environmental Penalties and Regulations (Carbon Tax and Emissions Penalties, Regulatory Incentives);
- Competitive Advantage and Market Demand (Market Differentiation, Industry Trends and Funding);
- Technological Innovation and Scaling (Technological Maturity, Mass Adoption and Network Expansion).

Investing in hydrogen-powered vessels within waterborne transport systems offers a high-potential pathway toward achieving climate-neutral maritime operations. While the initial investment and long payback periods present challenges, the long-term benefits—in terms of emissions reduction, operational efficiency, and regulatory compliance—are substantial. With appropriate support through government incentives, infrastructure development, and international collaboration, hydrogen has the capacity to redefine sustainable maritime transport in the decades ahead.

4.4.3. Environment

4.4.3.1. Regular maintenance of infrastructure

Regular maintenance of infrastructure in the waterway sector refers to the systematic, ongoing upkeep and repair of physical assets, technologies, and systems that support inland and coastal waterway transportation and associated services. This continuous process is essential for ensuring infrastructure safety, operational functionality, and long-term efficiency. By institutionalising proactive maintenance practices, waterway systems can achieve enhanced safety, economic sustainability, and environmental performance.

Implementing a structured maintenance regime yields a range of benefits across operational, financial, and environmental dimensions:

- Improved Safety and Reliability
  - Reduces the risk of structural failures and accidents.
  - Enhances confidence among passengers, operators, and stakeholders.
- Enhanced Operational Efficiency
  - Minimises unplanned downtime through timely inspections and interventions.
  - Extends the lifespan of infrastructure and equipment, ensuring optimal asset utilization.
- Cost Savings
  - Prevents major failures and high-cost emergency repairs.
  - Enables better allocation of financial and human resources through planned interventions.
- Environmental Protection
  - Reduces the risk of infrastructure-related environmental damage, such as spills or erosion.
  - Supports broader sustainability targets and regulatory compliance.
- Financial Viability
  - Contributes to predictable and stable operational expenditures.
  - Increases the attractiveness of the sector for public and private investment.

The introduction and execution of regular maintenance is a continuous process, requiring both initial setup and sustained operational management:

- Initial Setup and Planning (1-3 months)
  - Infrastructure condition assessments.
  - Development of preventive maintenance schedules.
  - Allocation of human and financial resources.

- Ongoing Maintenance Activities (Immediate and continuous)
  - Daily and weekly inspections of critical assets.
  - Preventive and corrective maintenance operations based on asset condition and usage.
- Quarterly and Annual Reviews (Every 3–12 months)
  - Detailed inspections, performance evaluations, and overhauls of key infrastructure.
  - Updating schedules and documentation.
- Feedback and Adjustment (6–12 months post-implementation)
  - Review of effectiveness and operational efficiency.
  - Optimisation of scheduling, resource allocation, and task prioritisation.

The costs associated with implementing and managing a regular maintenance strategy can be broadly categorised as follows:

- Labor Costs - Salaries for maintenance personnel, engineers, and support staff.
- Material and Equipment Costs - Procurement of tools, spare parts, and repair equipment.
- Maintenance Scheduling and Management Software - Costs of implementing digital solutions for tracking tasks and monitoring infrastructure conditions.
- Compliance and Regulatory Costs - Expenses related to inspections, certifications, and adherence to environmental and safety regulations.
- Emergency Repairs and Contingency Funds - Allocations for unforeseen issues requiring immediate response.
- Capital Investments for Upgrades - Strategic funding for major system renewals and modernization efforts.
- Administrative Overheads - Coordination, planning, and reporting costs incurred by the managing authority.

The ROI of a comprehensive maintenance program can be realised through multiple tangible and intangible benefits:

- Operational Efficiency - Minimisation of disruptions and delays improves reliability and throughput.
- Extended Asset Lifespan - Reduces the frequency and cost of capital-intensive infrastructure replacements.
- Enhanced Safety and Compliance - Prevents accidents, environmental incidents, and regulatory penalties.
- Improved Customer and User Satisfaction - Reliable service contributes to increased public trust and ridership.
- Lower Emergency Repair Costs – Timely maintenance mitigates the risk of catastrophic failures and unplanned shutdowns.
- Environmental Sustainability - Maintains compliance with environmental regulations and reduces ecological harm.

In summary, while regular maintenance requires consistent investment and resource commitment, the long-term gains in safety, efficiency, cost savings, and sustainability make it one of the most cost-effective measures in the waterway sector. When properly managed, maintenance programs offer substantial financial returns and support broader policy goals related to resilient and sustainable transport infrastructure.

4.4.3.2. Measures taken to address noise pollution

Noise pollution in ports and waterways is a critical concern that affects not only the health and well-being of workers and surrounding communities but also the sustainability of marine ecosystems. Ports are inherently high-activity zones with multiple noise sources, including ship engines, cranes, loading/unloading equipment, and associated land-based transport (e.g., trucks and trains). In waterways, noise impacts extend further, disrupting aquatic habitats and biodiversity.

Mitigating noise pollution in maritime environments requires a multifaceted approach involving regulatory frameworks, technological innovation, and adaptive operational practices. The benefits of such interventions extend across environmental, social, regulatory, and economic domains. The key impacts are:

- Environmental Impact (Protection of Marine Life, Silent Ship Technology, Vessel Speed Reduction, Quieting Propeller Designs, Improved Marine Habitat Quality);
- Public Health and Social Impact (Reduced Impact on Human Communities, Zoning Regulations and Buffer Zones, Enhanced Vessel Noise Monitoring, Influence on Human Populations);
- Regulatory and Policy Measures (Implementation of Noise Standards);
- Technological Innovation (Quiet Vessel Technology);
- Economic Influence (Costs of Noise Mitigation).

The adoption of noise reduction measures varies according to complexity, technological maturity, and regulatory readiness:

- International and National Regulations - Timeframe: 1-5 years (depending on the jurisdiction and regulatory complexity);
- Quiet Ship Technologies (Hull and Propeller Designs, Hybrid Engines, etc.) - Timeframe: 2-10 years (depends on technological maturity and adoption rates);
- Real-time Noise Monitoring Technologies - Timeframe: 1–3 years (for implementation of monitoring systems);
- Vessel Speed Reduction Measures - Timeframe: 1-3 years (depends on enforcement and voluntary compliance);
- Creation of Quiet Zones or Buffer Zones - Timeframe: 2–5 years (depending on local governance and stakeholder collaboration).

While the costs of addressing noise pollution in waterways can be significant, particularly in early phases, they are manageable and offset by long-term returns. Key cost areas include:

- Regulatory and Compliance Costs - Drafting and implementing regulations, monitoring compliance, and enforcement.
- Technological Investments - Retrofitting or procuring quieter ship technologies and installing acoustic monitoring systems.
- Operational Adjustments - Managing and enforcing vessel speed limits and routing measures.

- Zoning and Infrastructure Development - Establishing marine protected areas, quiet zones, and noise buffer corridors.
- Industry Training and Awareness - Educating operators and port authorities on best practices for noise reduction.

Although initial investments may be high, the long-term ROI is substantial, both financially and in terms of sustainability:

- Environmental ROI - Enhanced biodiversity and ecosystem services valued in billions of euros globally.
- Economic ROI - Increased tourism and sustainable fisheries can result in millions of euros in annual revenue.
- Compliance ROI - Reduced risk of non-compliance fines, litigation, and reputational damage.
- Technological ROI - Market leadership in sustainable maritime solutions and competitive advantage in green shipping lanes.

Mitigating noise pollution in ports and waterways is essential for achieving sustainable waterborne transport. Through a combination of policy, innovation, and community engagement, noise reduction strategies yield long-term environmental, social, and economic gains. Early adopters stand to benefit from regulatory alignment, improved public perception, and operational resilience in an increasingly environmentally conscious global economy.

4.4.3.3. Reducing the use of plastic where possible

Reducing plastic use in waterway transport involves a comprehensive set of practical and strategic measures targeting shipping companies, ports, and regulatory bodies. These initiatives focus on replacing plastic materials, minimising waste, and embedding sustainability into operational practices. By integrating such measures, the maritime sector can significantly mitigate its environmental impact and contribute to broader sustainability goals.

Concrete actions to reduce plastic use in waterborne transport include:

- Substitution of plastic items onboard vessels (e.g., cutlery, packaging) with biodegradable or reusable alternatives.
- Implementation of recycling programs and onboard waste segregation systems.
- Development of port infrastructure to manage and process plastic waste sustainably.
- Collaboration with suppliers to minimise packaging and promote eco-friendly materials.
- Crew training and awareness programs to foster a culture of plastic reduction and environmental responsibility.

The adoption of plastic reduction strategies in waterway transport generates multifaceted benefits:

- Environmental Impact
    - Reduction of marine pollution and microplastics entering aquatic ecosystems.
    - Protection of marine biodiversity, reducing entanglement and ingestion risks.
    - Improved ecosystem health, supporting long-term water quality and biodiversity resilience.
- Economic Impact

    - Operational cost savings from reduced waste disposal and improved efficiency.
    - Compliance with emerging international regulations, avoiding fines and reputational risks.
    - Stimulation of the green economy through demand for sustainable alternatives and innovation.
- Social and Health Impact
    - Improved public health through cleaner waterways and less contamination.
    - Enhanced tourism and recreation in cleaner marine environments.
    - Increased environmental awareness, promoting responsible consumption across the supply chain.
- Innovation and Technological Impact
    - Fostering of R&D in sustainable maritime technologies.
    - Sustainability as a competitive differentiator, enhancing corporate image and stakeholder trust.

The timeline for implementing plastic reduction measures can be segmented into short, medium, and long-term phases:

- Short-Term (1-2 Years) (Regulatory Framework and Industry Engagement, Pilot Programs and Research, Research into Sustainable Alternatives, Crew Training and Education);
- Medium-Term (3-5 Years) (Expansion of Sustainable Alternatives, Port Infrastructure for Plastic Waste Management, Regulatory Enforcement and Incentives, Financial Incentives for Green Technologies, Adoption of Plastic-Free Shipping Practices);
- Long-Term (5-10+ Years) (Full Implementation of Plastic-Free Operations, Widespread Adoption Across the Industry, Continuous Innovation and Adaptation, Ongoing Technological Innovation, International Agreements on Plastic Reduction).

While initial investments may be substantial, long-term manageability and savings are achievable. Cost components include:

- Initial Investments: Procurement of biodegradable materials, development of port waste management facilities.
- Operational Costs: Training programs, ongoing maintenance of waste systems, awareness campaigns.
- Compliance Costs: Meeting new standards, reporting, and auditing.
- Technology Development: Adoption of alternative packaging and processing solutions.
- Revenue Opportunities: Potential increases from eco-branding and sustainability-driven customer loyalty.

The return on investment from plastic reduction measures encompasses direct financial returns and broader strategic advantages:

- Environmental ROI:
    - Tangible reduction in plastic waste and marine pollution.
    - Strong alignment with global environmental and corporate social responsibility (CSR) goals.

- Economic ROI:
  - Reduced operational costs through less waste and more efficient waste handling.
  - Revenue from sustainable services or waste-to-energy initiatives.
- Operational ROI:
  - Lower risk of marine debris-related incidents, fines, or operational disruptions.
  - Enhanced regulatory compliance and resilience to future legal changes.
- Strategic ROI:
  - Future-proofing business models against increasing global sustainability demands.
  - Strengthening stakeholder relationships and public image.

Reducing plastic use in waterway transport presents a high-impact opportunity for the maritime industry to align with global sustainability goals. Despite initial costs, the long-term environmental, economic, and operational returns are significant. As plastic pollution continues to threaten marine ecosystems, adopting a proactive and systematic approach to plastic reduction will not only improve industry practices but also position waterborne transport as a leader in sustainable logistics. Through innovation, regulation, and collaboration, the sector can pave the way for a cleaner, more resilient future.

4.4.3.4. Introduction of oil/water separators

The implementation of oil/water separators in waterways—particularly in ports, marinas, and industrial zones—represents a vital measure for protecting aquatic ecosystems, enhancing operational efficiency, and complying with environmental regulations. These systems are engineered to remove oil, hydrocarbons, and other pollutants from wastewater before discharge, thereby safeguarding marine environments and promoting sustainable maritime practices. Key impacts are:

- Environmental Impact (Reduction of Water Pollution, Safeguarding Wildlife, Ecosystem Restoration);
- Economic Impact (Cost Savings from Pollution Prevention, Improved Operational Efficiency, Enhanced Corporate Image and Marketability);
- Social Impact (Community Health and Well-Being, Enhancing Public Awareness and Trust, Public Relations Benefits).

The time required to implement oil/water separation systems depends on project scale, infrastructure readiness, and regulatory conditions. A typical implementation timeline includes:

- Feasibility Study and Planning (1-3 Months)
- Procurement and Selection of Oil/Water Separators (1-2 Months)
- Installation and Infrastructure Setup (2-6 Months)
- Training and Staff Preparation (1 Month)
- Ongoing Maintenance and Monitoring (Continuous)

Total estimated implementation time: 4 to 12 months. Costs associated with oil/water separators vary based on the scale of deployment, level of pollution, and complexity of the site:

- Small-Scale Systems (e.g., marinas or light industry): Lower cost, manageable with modest capital outlay.

- Medium-Scale Systems (e.g., mid-sized ports or industrial terminals): Moderate investment with tailored infrastructure adjustments.
- Large-Scale Systems (e.g., major ports or petrochemical hubs): High capital costs, including extensive monitoring and treatment capabilities.
- Additional cost factors include: Equipment procurement and installation, Civil and plumbing works, Training and operational adjustments, Maintenance and sludge disposal, Compliance-related documentation and audits.

The Return on Investment (ROI) when introducing oil/water separators into waterways can be significant, as it often leads to cost savings, improved operational efficiency, compliance with environmental regulations, and enhanced reputation. Below, we'll break down the key factors that contribute to the ROI of implementing these systems.

- Direct Financial Benefits (Reduced Environmental Cleanup Costs, Compliance with Regulations and Avoiding Fines, Reduced Maintenance Costs for Infrastructure);
- Indirect Financial Benefits (Improved Reputation and Corporate Social Responsibility, Avoiding Legal Liabilities, Long-Term Savings on Wastewater Treatment);
- Break-Even Point (For smaller systems or operations with lower annual benefits, the break-even period could be 1-2 years, depending on the scale of the operation and the efficiency of the separators).

The integration of oil/water separators into waterway infrastructure is a highly effective strategy for improving environmental stewardship, ensuring compliance with regulatory standards, and reducing long-term operational costs. While initial investments can vary based on scale and complexity, the return on investment is generally substantial—both in financial terms and reputational value. As environmental pressures mount and global regulations tighten, adopting such systems represents a prudent and forward-looking choice for stakeholders in maritime and industrial sectors.

4.4.4. Management system - implementing an EMS

4.4.4.1. Data analysis and reporting

The implementation of an Energy Management System (EMS) is a critical step toward increasing the sustainability, operational efficiency, and environmental responsibility of waterborne transport systems. The EMS aims to optimise energy use, reduce ecological impact, and lower operational costs through the integration of smart infrastructure and environmentally conscious practices. Key areas of development within this framework include:

- Environmentally Conscious Waste Management: Proper handling and treatment of polluted waste—such as oily water and bilge water—as well as wastewater discharged from ships at port facilities, in accordance with environmental protection standards, to minimise the risk of water pollution.
- Installation of Electric Ship Charging Stations: Development of port infrastructure to support electric ship charging, prioritising the use of renewable energy sources, such as solar power, to promote zero-emission operations.
- Implementation of Smart Metering Systems: Deployment of advanced water meters with remote reading and automated data transmission capabilities, enabling more accurate and timely tracking of consumption and resource use.

The introduction of an EMS in the water transport sector is anticipated to deliver a broad range of benefits:

- Environmental Impact: Reduction of harmful emissions, improved waste and water management practices, and decreased risk of pollution from port operations.
- Economic Impact: Enhanced energy efficiency leads to significant reductions in operational costs, contributing to the long-term financial sustainability of port and shipping activities.
- Operational Efficiency: Modernized infrastructure and data-driven processes improve system reliability, enable predictive maintenance, and allow for faster incident response.
- Regulatory Compliance: Advanced monitoring and reporting tools support compliance with environmental regulations and international maritime standards.

The deployment of the EMS will be conducted in several phases to ensure systematic integration and effective implementation:

- Preparation (3–6 months): Conducting needs assessments, technical planning, and reviewing environmental and regulatory requirements.
- Installation and Integration (6–12 months): Developing the physical infrastructure (e.g., charging stations, metering systems), installing smart systems, and implementing data collection frameworks.
- Testing and Optimisation (3–6 months): Verifying system functionality, running trial operations, and fine-tuning performance settings.
- Commissioning and Continuous Development: Launching the full system and initiating continuous performance monitoring and improvement processes based on collected operational data.

The implementation of the EMS involves substantial upfront investments in infrastructure, including the installation of electric charging facilities, smart metering systems, and digital management tools. To ensure financial viability and manageability, the rollout can be phased, prioritising high-impact areas and expanding as additional funding becomes available. The return on investment for the EMS is influenced by multiple factors:

- Short-Term Benefits: Immediate cost savings through reduced energy loss, improved water use efficiency, and more precise consumption tracking.
- Operational Improvements: Decreased incidence of system malfunctions, faster diagnostics, and better resource allocation.
- Regulatory Advantages: Enhanced capacity for compliance with evolving environmental and reporting standards through automated, accurate data collection.

The estimated payback period ranges between 5 and 10 years, with measurable benefits—particularly in energy and maintenance cost savings—expected as early as the first year of implementation.

4.4.4.2. Integration of renewable energy

Waterborne transport is characterised by substantial energy demands, particularly in port operations and onboard vessel systems. To reduce operational costs and mitigate environmental impacts, increasing attention is being directed toward the integration of renewable energy sources and the implementation of Energy Management Systems (EMS). The adoption of renewable energy technologies and EMS can be realised through the following key measures:

- Installation of solar and wind energy systems at ports to enable local electricity generation.

- Deployment of onboard solar panel systems on ships to reduce reliance on internal combustion generators and decrease fuel consumption.
- Implementation of energy storage solutions to ensure stable power supply by storing excess energy for later use.
- Provision of shore-side power from renewable sources, allowing docked vessels to operate without using fossil fuel-based energy.
- Introduction of Energy Management Systems (EMS) to optimise energy consumption, monitor energy efficiency indicators, and balance production and usage patterns.

The overarching objective of these interventions is to enhance energy autonomy, promote sustainable practices, and reduce operational expenditures within the water transport sector. The integration of renewable energy and EMS offers a range of benefits, including:

- Reduction in CO_2 emissions: Transitioning to renewable sources significantly lowers greenhouse gas emissions.
- Fuel savings: EMS facilitates the optimisation of energy usage in ships and port operations, reducing fuel dependency.
- Improved cost efficiency: By minimising unnecessary energy use, EMS contributes to lower energy-related operational costs.
- Reduced strain on the power grid: Locally generated and efficiently managed energy alleviates demand on external electrical networks.
- Enhanced sustainability: EMS supports regulatory compliance and fosters a more environmentally responsible energy management approach.

The implementation timeline is largely dependent on the scale and technological complexity of the project. However, EMS can generally be deployed in a comparatively shorter timeframe:

- Planning and permitting: 6–12 months;
- Procurement and installation: 12–24 months;
- Testing and commissioning: 3–6 months.

The deployment of EMS can yield immediate cost savings through improved energy efficiency, while the integration of renewable energy sources ensures long-term energy cost stability and supports the sector’s transition toward climate neutrality.

4.4.4.3. Predictive maintenance

Predictive maintenance is a contemporary, data-driven approach to maintenance that, when applied to the waterborne transport sector, offers substantial technical and economic advantages. The integration of a comprehensive Energy Management System (EMS) facilitates the optimisation of energy consumption on vessels by reducing waste and improving overall efficiency. Through the use of sensors and artificial intelligence, the system continuously analyses energy usage data, identifies inefficiencies or emerging technical issues, and enables timely interventions. This proactive approach minimises unplanned downtimes and reduces operational costs.

The expansion of predictive maintenance systems in waterborne transport can support several critical operational functions:

- Integration of weather stations and water level forecasting tools to optimise navigation routes and enhance maritime safety.
- Implementation of riverbed depth surveys to maintain safe draft levels and mitigate risks associated with fluctuating water levels.
- Continuous monitoring and maintenance of shoreline conditions, reducing the likelihood of structural degradation at ports and loading sites.
- Predictive maintenance of electrical systems and vessel charging infrastructure, ensuring efficient energy use and maximising the benefits of alternative energy sources.

Expected Impacts of the Measure:

- Technical Benefits: Enhanced optimisation of vessel energy use, leading to reduced energy consumption and maintenance requirements for electrical systems.
- Economic Impact: Lower expenditures on energy and maintenance improve fleet-wide cost-efficiency and profitability.
- Operational Impact: Fewer mechanical failures and more consistent vessel performance reduce downtime and improve service reliability.
- Environmental Benefits: Increased energy efficiency and greater integration of renewable energy sources contribute to lower emissions and improved environmental performance.

The full deployment of a predictive maintenance and EMS system is estimated to take approximately 42 months, structured into the following phases:

- Preparation (9-12 months): Needs assessment, system architecture design, and supplier selection.
- Installation and Integration (18–24 months): Deployment of sensors, integration of AI-driven software with existing systems, and the installation of weather and water-level forecasting infrastructure.
- Testing and Optimisation (6 months): System calibration, data validation, shoreline condition inspections, and riverbed depth assessments.
- Commissioning and Continuous Development: Activation of full system functionality and ongoing refinement based on operational data and user feedback.

The initial capital investment required for predictive maintenance implementation varies depending on the size of the fleet and the technologies selected. Additional costs may arise from the procurement of weather stations, forecasting systems, riverbed survey tools, and upgrades to portside electrical infrastructure. However, these expenditures are justified by the resulting gains in operational reliability and energy efficiency. Government grants, incentive programmes, and EU-level subsidies may help offset the initial financial burden. The estimated return on investment is projected within 3 to 5 years, supported by measurable reductions in fuel consumption, maintenance costs, and operational inefficiencies. Long-term benefits include:

- Extended fleet lifespan, due to timely maintenance and reduced mechanical strain;
- Improved business continuity and operational stability;
- Greater competitiveness, especially in sustainability-conscious markets and regulatory environments.

Utilizing available funding mechanisms can significantly accelerate the payback period and facilitate broader adoption of predictive maintenance technologies across the sector.

4.4.4.4. Automated controls for lighting and HVAC

The deployment of automated lighting and HVAC (heating, ventilation, and air conditioning) control systems in the water transport sector is a strategic measure aimed at optimising energy consumption and enhancing operational efficiency across shipping fleets and port infrastructure. These systems are particularly relevant in large vessels and port facilities, where lighting and HVAC systems operate continuously and represent a significant share of total energy consumption. Given the growing importance of energy conservation and environmental sustainability, automated control technologies offer a high-impact solution.

Automated control systems utilize real-time environmental data to adjust lighting and HVAC operations dynamically, thereby minimising energy waste. These systems monitor conditions in various zones—such as cabins, corridors, and technical areas—enabling adaptive climate and lighting management based on occupancy and ambient conditions. In port settings, energy-efficient operation of port wall lighting is a regulatory priority; automated solutions employing timers and twilight sensors can ensure legal compliance while reducing unnecessary energy use.

In maritime applications, automated roof systems equipped with rain and wind sensors further enhance operational efficiency by responding to changing weather conditions, providing both environmental protection and energy savings. The implementation of automated lighting and HVAC systems in the water transport sector brings multiple benefits:

- Energy savings: Real-time optimisation significantly reduces unnecessary energy use, particularly in high-demand environments such as large vessels and port facilities.
- Environmental impact reduction: Lower energy consumption directly translates to reduced CO_2 emissions, supporting broader sustainability goals.
- Operational efficiency: Automation reduces the need for manual adjustments, decreases the likelihood of human error, and ensures consistent system performance.
- Enhanced comfort and safety: Automated systems contribute to a more comfortable environment for crew and passengers, and can incorporate safety features such as motion detection and fire prevention protocols.

The implementation process can be divided into three main phases:

1) Planning and Preparation (3-6 months):
   a) Conducting needs assessments and selecting suitable automation technologies;
   b) Designing system architecture, including selection of sensors, controllers, and software;
   c) Securing necessary permits and ensuring compliance with maritime and port regulations.
2) Installation and Integration (6–12 months):
   a) Installing hardware components;
   b) Integrating systems with existing infrastructure;
   c) Conducting initial testing and adjustments to ensure system compatibility and effectiveness.
3) Training and Commissioning (3 months):
   a) Providing staff training and operational workshops;
   b) Full system deployment, with ongoing monitoring and optimisation.

The full implementation is typically achievable within 1 to 2 years, depending on system complexity, fleet size, and infrastructure readiness. Costs associated with implementation can be categorised as follows:

- Initial Investment:
  - Establishment of automation infrastructure for lighting and HVAC systems;
  - Procurement and installation of automation infrastructure, including sensors and smart controllers;
  - Software integration and data management systems.
- Operational Costs:
  - Routine maintenance and updates for automated systems;
  - Regular system inspections and troubleshooting.
- Training Costs:
  - Workshops and educational materials for system operators and technical personnel.

While the upfront investment may be substantial, ongoing operational costs are expected to decrease due to reduced energy use and lower maintenance needs. The financial ROI is influenced by energy savings, system efficiency, and operational scale. Key factors include:

- Energy Efficiency Gains: Potential energy savings of 20–40% across vessels and port facilities, depending on the existing infrastructure and the scope of implementation.
- Reduced Operational Costs: Automation lowers maintenance needs, reducing long-term expenditures.

The estimated ROI period ranges from 2 to 4 years, with potential acceleration through the use of public subsidies and incentive programmes targeting energy efficiency in the transport sector.

4.4.5. Other climate change measures - implementation of warning systems

Addressing the impacts of climate change in the water transport sector is increasingly critical, as waterborne transportation is particularly vulnerable to extreme weather events, fluctuating water levels, storms, and the degradation of riverbanks. These conditions pose risks to vessel navigation, port infrastructure, and environmental sustainability. The deployment of advanced warning systems and sensor networks enables water transport operators to proactively respond to dynamic environmental conditions, enhancing operational safety, resilience, and efficiency. The proposed warning system integrates a suite of advanced technologies:

- Depth Sensors: Facilitate safe navigation by detecting siltation and underwater obstacles.
- Water Level Sensors: Provide real-time data on river and sea levels, enabling timely route adjustments.
- Meteorological Stations: Deliver hourly weather forecasts for vessels and port operations, including alerts for wind, rainfall, and storms.
- Riverbank Condition Monitoring: Supports the structural integrity of port infrastructure and mitigates the risk of erosion-related collapses.
- Pollution Detection Systems: Enable early warning and rapid response to oil or chemical spills, minimising ecological damage.

- Smart Camera Systems: Offer real-time visual surveillance of vessel movements and port conditions, enhancing safety and security.

The integration of climate-responsive sensor networks and warning systems is expected to yield multiple benefits:

- Increased Safety: Continuous environmental monitoring reduces the likelihood of vessel accidents and infrastructure damage.
- Reduced Operational Disruptions: Accurate weather and water-level forecasts support improved voyage planning and minimise delays.
- Enhanced Environmental Protection: Early detection of pollutants enables swift action to prevent large-scale contamination.
- Operational Efficiency: Real-time data facilitates optimised decision-making, improving the use of resources and energy.

The deployment of the advanced warning system will follow a phased approach:

- Planning and Needs Assessment (2–3 months);
- Installation and Integration (6–12 months);
- Testing and Fine-Tuning (3–4 months);
- Training and Commissioning (1–2 months).

Estimated total implementation period: 12 to 24 months, depending on system scale and complexity. The implementation of advanced warning systems yields both short- and long-term economic and strategic benefits:

- Risk Mitigation: Real-time monitoring enhances decision-making and prevents damage to vessels and infrastructure.
- Operational Cost Savings: Data-driven planning reduces fuel waste, unnecessary downtime, and unplanned maintenance.
- Sustainable Development: The system supports environmentally responsible operations and aligns with broader climate adaptation goals.

Estimated ROI period: 2 to 4 years, depending on the scale of implementation and technological efficiency.

4.5. Rail transport

Rail transport is a key element of sustainable mobility, offering a high-capacity and energy-efficient alternative to road and air transport for both passengers and freight. It plays a critical role in reducing greenhouse gas emissions and alleviating road congestion, thereby contributing to climate goals and improving air quality. In addition, investment in modern rail infrastructure enhances regional connectivity, economic competitiveness, and the integration of multimodal transport systems. Adriafer s.r.l (Italy) and Ecco-Rail Gmbh (Austria) represented the rail sector in the REDU-CE-D project, which means that the following chapter is based on their experience and expertise.

4.5.1. Energy and resources - electrical energy

4.5.1.1. Constant modernization of the electrical vehicle fleet

Fleet renewal and modernization constitute a strategic imperative for railway operators aiming to remain competitive, sustainable, and efficient over the long term. Operating with ageing rolling stock leads to increased maintenance costs, higher energy consumption, elevated emissions, and a decline in service reliability. In a European context that increasingly prioritises decarbonisation and digital transformation, the transition to modern, efficient rolling stock is essential—not only to comply with evolving environmental regulations and qualify for public funding, but also to meet rising passenger expectations around quality, punctuality, and comfort.

The renewal process involves the gradual replacement of electric locomotives, electric multiple units (EMUs), and service vehicles with high-performance, low-impact electric alternatives. Additionally, support and auxiliary vehicles—such as shunters, inspection trolleys, and maintenance units—will be electrified, replacing diesel-powered systems. This transformation is accompanied by the adoption of advanced technologies, including regenerative braking systems that recover energy during deceleration, lightweight and aerodynamic vehicle designs to reduce energy demands, and highly efficient traction systems with optimised converters. Furthermore, solutions such as eco-driving assistance tools, automated train operation, and onboard energy management systems for heating, ventilation, air conditioning (HVAC), lighting, and auxiliary functions will contribute to overall efficiency. Real-time monitoring, predictive maintenance, and operational optimisation will be enabled by integrating digital tools and IoT-based platforms into the fleet management ecosystem.

The benefits of this strategy are significant and multifaceted. Energy consumption and emissions will be substantially reduced thanks to improved system efficiency and the phasing out of outdated technologies. Asset lifespans will be extended, reducing waste and the need for premature replacements. The introduction of a modern fleet will also bring improvements in reliability and punctuality, translating into better service delivery and customer satisfaction. From an economic standpoint, operating and maintenance costs will decrease, as new rolling stock requires fewer unplanned interventions and benefits from longer maintenance intervals. Moreover, this strategic shift ensures full alignment with EU climate policies and rail decarbonisation targets.

The implementation of this strategy involves several key cost areas. Rolling stock procurement is estimated to range between €3 million and €10 million per trainset or locomotive, depending on energy systems, technical specifications, passenger capacity, and onboard equipment. Infrastructure adaptation—including upgrades to depots, workshops, and electrical systems such as charging stations for battery-powered shunters—is expected to cost between €500,000 and €2 million per site. The integration of digital systems, encompassing telematics platforms, energy management technologies, and IoT-enabled maintenance tools, represents an investment estimated at €100,000 to €500,000, depending on the size of the fleet and the digital maturity of the operator. In parallel, the transition requires investment in workforce training, including upskilling in predictive maintenance, eco-driving, and the use of new technologies, with associated costs ranging between €50,000 and €300,000 for mid-sized operators.

The return on investment can be assessed over three distinct timeframes. In the short term—within one to three years—operators will benefit from reduced energy consumption due to regenerative braking and more efficient traction systems, along with an immediate decrease in corrective maintenance needs and improved fleet availability. Over the medium term, spanning three to seven years, service reliability, punctuality, and passenger satisfaction are expected to improve steadily, while maintenance costs become more predictable and cost-effective through condition-based and predictive maintenance models. In the long term—within a horizon of seven to fifteen years—the investment is expected to be fully recovered through cumulative savings in energy and operations. Additionally, there will be a marked reduction in greenhouse gas emissions and other environmental externalities, contributing to modal shift and ensuring compliance with EU climate and transport strategies.

4.5.1.2. Awareness raising campaigns

Awareness-raising campaigns are a critical part of sustainability strategies in the freight railway sector, especially when implementing or strengthening an Environmental Management System (EMS). While infrastructure upgrades and energy-efficient technologies play a fundamental role in reducing environmental impact, their effectiveness increases significantly when complemented by behavioural change. These campaigns aim to promote a culture of energy awareness among all internal and external stakeholders—train drivers, depot staff, rolling stock maintenance teams, administrative personnel, logistics partners, and even energy providers—encouraging responsible electricity use across all operations.

In rail freight, energy consumption primarily relates to electric traction, depot operations (including lighting, ventilation, and HVAC), and maintenance equipment. Campaigns help teams understand their impact on the company's energy footprint and engage them in identifying ways to improve efficiency. For example, locomotive drivers can be trained and encouraged to adopt energy-saving driving techniques, such as coasting, using regenerative braking effectively, and avoiding unnecessary acceleration. Depot and yard staff can be reminded to turn off lighting, chargers, and ventilation equipment when not in use. Maintenance personnel can be made aware of the link between early diagnostics, optimised workflows, and electricity savings.

Campaigns can take multiple forms, including digital signage in depots and control rooms, printed materials near workstations and technical rooms, energy-saving reminders near HVAC units, and email campaigns showcasing best practices. More interactive approaches may include workshops focused on energy-efficient operations, team challenges with rewards for energy reductions, and real-time dashboards displaying electricity use by department or depot. These tools enhance transparency, give ownership to staff, and demonstrate how individual actions contribute to collective energy performance.

The key benefits of such initiatives are significant. Firstly, reduced energy waste—especially in depots and traction operations—can be achieved by influencing day-to-day behaviours. Secondly, awareness campaigns contribute directly to reducing CO_2 emissions associated with electricity use, particularly when traction power still comes partly from non-renewable sources. Thirdly, stakeholder engagement improves internal communication, builds environmental responsibility across the workforce, and fosters collaboration between departments such as operations, IT, facilities, and sustainability. These changes also translate into operational cost savings over time, with more efficient practices reducing utility bills and equipment wear.

In freight operations, where energy costs represent a non-negligible share of operating expenses, even modest behavioural improvements can yield visible results. These campaigns are also valuable from a reputational and compliance perspective: demonstrating active engagement in energy efficiency supports EMS certification (e.g., ISO 14001), ESG reporting, and alignment with national and European climate goals. In increasingly competitive markets, it also strengthens the operator's image with clients and public authorities as a responsible, forward-looking logistics partner.

The timeline for developing and executing awareness campaigns varies by scope and target audience. Short-term campaigns (3 to 6 months) typically include message development, internal branding, and initial deployment through digital channels and signage across depots and offices. Over the medium term (6 to 18 months), these efforts can expand to include structured training programmes for train drivers and maintenance crews, integration with energy management dashboards, and the launch of internal incentive schemes to reward high-performing teams. In the long term (18 to 36 months), awareness initiatives can be fully embedded into the EMS framework, linked to energy KPIs, and integrated into procurement, safety, and HR policies.

From a cost standpoint, awareness campaigns are low to moderate investments when compared to infrastructure upgrades or digital system installations. Communication materials—posters, visual displays, internal newsletters, stickers, and dashboards—typically represent a low-cost component. Training programmes for operational teams involve moderate costs, which are often offset by measurable improvements in energy performance. The development of real-time tracking systems or mobile apps for internal energy monitoring may require slightly higher investments but provide high engagement value and long-term impact. Recognition or incentive schemes for staff or departments demonstrating exemplary energy-saving performance can be designed with flexible budgets and scaled based on organisational size.

Despite the modest investment, these campaigns offer a high return. Immediate impacts are often visible within a few months through reduced electricity usage in depots, more efficient traction patterns, and better equipment handling. Over the short term (1 to 3 years), energy savings translate into reduced operational costs and stronger EMS performance. Medium-term results (3 to 7 years) include improved staff engagement, greater alignment with environmental policies, and enhanced audit readiness. Over the long term (7 to 15 years), sustained behavioural change can lead to deep cultural transformation across the company, supporting ambitious energy efficiency goals and strengthening resilience to future climate challenges.

4.5.1.3. Investing in newer equipment

The modernization of railway electrical infrastructure is a key strategic measure for improving energy efficiency and reducing emissions in the transport sector. While innovations in rolling stock and user behaviour are vital, they must be supported by an updated, intelligent power supply system capable of sustaining modern rail operations.

This measure involves targeted investments in traction substations, overhead catenary systems, smart metering, and equipment at depots. The goal is to reduce transmission losses, optimise electricity use, and enhance both the reliability and capacity of rail services.

Smart metering technologies represent another cornerstone of this measure. The installation of intelligent meters and digital monitoring tools across the energy network allows operators to track electricity use by segment, identify inefficiencies, and adapt consumption patterns accordingly. These systems also support environmental reporting, audits, and alignment with energy certification protocols. Real-time consumption data opens possibilities for dynamic pricing schemes and demand-response agreements with utility providers.

Depots and maintenance centres are also energy-intensive components of the rail system. Retrofitting these facilities with high-efficiency lighting, heating and cooling systems (HVAC), electric tool upgrades, and charging infrastructure for electric shunters can lead to significant energy savings.

Across the rail sector, operators and infrastructure managers are gradually integrating this measure through modular upgrades and coordinated strategies. Common steps include:

- Replacing obsolete transformers and switchgear in key nodes of the energy network with modern, digitally controlled alternatives.
- Installing energy monitoring devices along traction substations, depots, and substations for real-time data acquisition and diagnostics.
- Upgrading catenary systems with high-conductivity wires and improved tensioning for better current collection and system reliability.
- Modernizing depot infrastructure by incorporating smart lighting, HVAC, electric vehicle (EV) charging units, and automation systems.

- Exploring renewable energy integration and microgrids to support operational self-sufficiency and reduce grid dependency.

Many of these initiatives are implemented as part of wider energy efficiency plans, infrastructure renewal programmes, or environmental management systems. Collaboration with technology providers and digital solution developers is essential for ensuring system interoperability, cybersecurity, and compliance with EU railway standards.

The financial and operational returns of investing in newer electrical equipment are substantial and multifaceted. Among the key benefits observed:

1. Operational Savings: Enhanced energy efficiency leads to a significant reduction in electricity consumption, with cost savings typically in the range of 10–20% depending on the scope and scale of interventions.
2. Improved Service Reliability: Real-time diagnostics and automation reduce system failures, enabling more frequent, dependable train operations and lower unplanned maintenance.
3. Lower Maintenance Costs: Predictive maintenance enabled by smart monitoring reduces the need for emergency interventions and extends the lifecycle of key infrastructure assets.
4. Carbon Emissions Reduction: Modernized systems reduce energy losses and support cleaner energy use, contributing directly to lower indirect emissions and aligning with national and EU decarbonisation goals.
5. Strategic Value: Upgraded infrastructure enhances long-term resilience, enabling integration with renewable energy, participation in smart grid networks, and future-ready digital platforms.

The timeframe of this measure is divided into 3 main categories:

Short-term (1-2 years):

- Feasibility studies, diagnostics, and pilot installations of smart metering and monitoring systems.
- Targeted upgrades in critical nodes (e.g. partial replacement of switchgear or substation components).
- Initial modernization of depot systems (lighting, HVAC, EV charging).

Medium-term (3–5 years):

- Full-scale deployment of modern traction substations and high-efficiency transformers.
- Large-scale renewal of overhead catenary systems on high-traffic corridors.
- Expansion of digital infrastructure and remote control systems across the network.
- Integration of renewable sources (solar, battery storage) into depots and maintenance hubs.

Long-term (5–10+ years):

- Full network integration of smart energy systems (smart grids, real-time energy trading).
- Progressive alignment with digital twins and predictive asset management platforms.
- Complete fleet compatibility with modernized infrastructure and dynamic energy systems.

Regarding the cost estimation, these measures are extremely expensive.

- Smart metering systems: €2,000–€10,000 per metering point (depending on complexity and integration with SCADA systems).

- Modern traction substation (upgrade/new build): €3–7 million per unit.
- Overhead catenary system renewal (including materials and installation): €300,000–€1 million per km.
- Depot energy system upgrades (lighting, HVAC, tools, EV charging): €500,000–€2 million per site.
- Digital control systems (monitoring, diagnostics, remote command): €100,000–€500,000 per corridor/section, depending on length and level of automation.

The Return on Investment (ROI) is so divided:

- Energy Cost Savings: about 10–20% reduction in energy consumption due to lower transmission losses, optimised load balancing, and smart scheduling.
- Maintenance Cost Reduction: up to 25% savings due to predictive maintenance, fewer failures, and longer asset life.
- Service Reliability Gains: the reduction of downtime and fewer delays, improving on-time performance and customer satisfaction—indirectly boosting ridership and freight contracts.
- Environmental ROI: reduction in indirect CO_2 emissions through reduced electricity waste and better integration with renewables.
- Payback Period: for this measure is typically 5–8 years, depending on the scale of investment and the price factors.

4.5.1.4. Expansion of central systems

The growing electrification of rail transport demands parallel upgrades in energy infrastructure. This measure focuses on expanding and modernizing traction substations, overhead lines, and control centres to ensure reliable, efficient power delivery. Integrating smart grid technologies enables real-time monitoring, load balancing, and fault detection, supporting higher traffic volumes and the integration of battery-electric trains.

Without these upgrades, energy infrastructure risks becoming a bottleneck for operational growth and sustainability objectives.

Railway operators contribute by:

- Identifying energy bottlenecks linked to service expansion.
- Coordinating with infrastructure managers for substation upgrades and smart grid integration.
- Supporting the installation of charging points for hybrid/battery trains.
- Providing energy consumption data to improve load forecasting and system planning.
- Operators also align their operational strategies with available grid capacity and energy optimisation tools to enhance efficiency and service continuity.

The timeframe is:

- Short-term: feasibility studies, pilot smart grid installations (1–3 yrs)
- Medium-term: substation upgrades, catenary extensions (3–6 yrs)
- Long-term: network-wide smart energy management (6–10 yrs)

The general costs are:

- Traction substation: €3–8 million
- Smart grid deployment: €2-5 million per corridor
- Catenary extension: €300,000–€1 million/km
- Charging hubs: €200,000–€1 million

The ROI proposed for this measure is 10–15% energy savings through loss reduction and load optimisation, the:

- increased service reliability and capacity;
- reduced maintenance and operating costs;
- typical payback: 6–10 years, shorter in high-demand areas.

4.5.2. Energy and resources - fossil fuels

4.5.2.1. Constant modernization of vehicle fleet

While full electrification or zero-emission solutions (hydrogen, battery-electric) remain long-term goals, many non-electrified rail lines—especially in rural or mountainous areas—still rely on diesel traction. This measure focuses on reducing emissions and improving efficiency in the medium term through the gradual modernization of diesel rolling stock.

Modernization includes:

- Procurement of new diesel or hybrid trains compliant with EU Stage V standards.
- Retrofitting existing fleets with emissions-reducing technologies (e.g. SCR, DPF) and digital energy management tools.

Both options improve fuel efficiency, reduce pollutants (NO_x, CO_2, PM), and enhance comfort and reliability.

Railway Operators are responsible for:

- Planning fleet renewal or retrofit strategies based on network characteristics and budget.
- Procuring or leasing new low-emission or hybrid vehicles.
- Installing retrofit kits (e.g. exhaust treatment, battery packs for hybridisation).
- Training staff in eco-driving and integrating digital monitoring systems.

Public transport authorities and rolling stock manufacturers support implementation through funding, co-design, and scalable solutions.

Timeframe:

- Short-term (1–3 yrs): retrofitting of existing vehicles.
- Medium-term (3–6 yrs): procurement of new Stage V diesel/hybrid trains.

Costs:

- Retrofit per vehicle: €200,000–€600,000
- New diesel/hybrid multiple unit: €5–9 million (depending on configuration)

ROI:

- Fuel savings: 5–15%
- Payback period: 5-8 years (shorter for retrofits)

4.5.2.2. Helpful maps and programmes

In the effort to reduce fossil fuel dependence and enhance energy efficiency across rail operations, especially on non-electrified lines, the deployment of digital tools and geospatial programs has become an essential strategy. This measure focuses on the use of software systems and mapping technologies to support railway operators in optimising fuel use, improving driving behaviour, and planning more energy-efficient services.

While the long-term goal remains full electrification or the adoption of zero-emission traction technologies, diesel-powered rail services continue to play a necessary role on secondary, regional, and low-density lines. Within this context, improving the operational efficiency of existing diesel services through digital innovation is a practical and cost-effective approach.

Key tools under this measure include eco-driving advisory systems, Geographic Information System (GIS)-based route planning, and real-time fuel tracking and performance platforms. These solutions enable operators to reduce fuel consumption, lower emissions, and achieve more consistent and sustainable rail operations without requiring immediate changes to infrastructure or rolling stock.

Railway undertakings implement this measure by integrating digital tools into their existing operational framework. Common approaches include:

- Eco-driving assistance systems that provide train drivers with real-time recommendations on optimal speed, braking, and acceleration. These systems are tailored to the route's topography and timetable, and can be deployed via in-cab devices or mobile tablets.
- GIS-based route planning and mapping tools that incorporate geospatial data—such as gradients, curves, and stop frequency—to optimise service planning and identify fuel-intensive route segments.
- Fuel monitoring platforms that use onboard sensors and telematics to collect and analyse data on fuel usage, enabling targeted interventions, maintenance planning, and informed decision-making.

Implementation typically begins with a pilot phase focused on high-consumption routes or rolling stock categories, followed by network-wide scaling. Staff engagement and training are critical, particularly for drivers, control room operators, and fleet managers. Training modules often include eco-driving techniques, interpretation of system feedback, and performance evaluation.

These tools are often integrated into broader energy and asset management systems, supporting predictive maintenance, carbon footprint monitoring, and environmental reporting under national or EU frameworks.

Implementation Timeframes:

- Eco-driving systems: Deployed within 3–6 months, including installation, configuration, and driver training.
- Fuel monitoring and dashboard platforms: Require 6–12 months for full deployment across a medium-sized fleet.
- GIS-based tools: Typically implemented within 6–18 months, depending on network coverage and required data integration.
- SCADA or energy dashboard integration: May take 12–24 months for full integration into control systems.

Cost Ranges:

- Eco-driving systems: €1,000–€5,000 per vehicle.
- Fuel tracking platforms: €100,000–€250,000 for fleet-wide implementation.
- GIS and route planning tools: €50,000–€200,000 depending on network size and complexity.
- Dashboard and energy management system integration: €250,000–€1 million+.

Return on Investment:

- Fuel savings: 5–15% reduction in diesel consumption, translating to immediate operating cost reductions.
- Payback period: Typically 1–2 years, especially where systems are deployed across high-usage routes.
- Environmental benefits: Lower emissions of CO_2, NO_x, and particulate matter; improved air quality near urban or ecologically sensitive areas.
- Operational impact: Improved driver behaviour, reduced mechanical stress on rolling stock, and enhanced service reliability.

4.5.2.3. Promotion of micro-mobility

One of the key challenges in promoting sustainable rail transport lies in resolving the "first and last mile" gap—the short, often car-dependent trips that connect passengers to and from railway stations. This reliance on private vehicles increases local congestion, greenhouse gas emissions, and limits the accessibility and appeal of rail, especially in suburban and peri-urban areas.

This measure focuses on promoting micro-mobility solutions—such as bicycles, e-bikes, e-scooters, and shared mobility services—as a strategic response to reduce fossil fuel use and enhance multimodal integration. By improving micro-mobility access to stations, the rail system becomes more attractive, inclusive, and energy efficient.

The measure involves coordinated action across three dimensions:

1. Infrastructure Adaptation: stations are equipped with cycling lanes, secure bike parking (short- and long-term), and e-mobility charging points. These interventions create safe, convenient, and visible pathways for active and light electric mobility.
2. Service Integration: shared mobility services—such as bike- and scooter-sharing—are introduced in partnership with private operators. These services must be aligned with urban mobility plans and be inclusive in coverage, pricing, and access. Public-private agreements should ensure quality, safety, and data sharing.
3. Digital Enablement: micro-mobility options are integrated into Mobility-as-a-Service (MaaS) platforms and journey planners, enabling users to plan, reserve, and pay for complete multimodal trips. Real-time availability of micro-vehicles, digital ticketing, and open data facilitate user uptake and behavioural change.

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Promoting micro-mobility around railway stations delivers substantial benefits:

- Environmental: replacing short car trips with cycling or e-mobility reduces fossil fuel use and air pollution, especially in urban areas with high health and climate vulnerability.
- Social: micro-mobility enhances access to rail for non-drivers and low-income groups, while supporting healthier, more active lifestyles.
- Operational: reduced car dependency eases parking pressure, lowers congestion near stations, and improves the quality and flow of intermodal connections.
- Systemic: encouraging sustainable first/last mile options contributes to modal shift from road to rail.

Implementation Timeframes:

- Cycle lanes and infrastructure adaptation: 6–12 months;
- Bike/e-scooter parking and charging facilities: 3-6 months per station;
- Deployment of shared micro-mobility services: 3–9 months depending on local approvals and provider selection;
- Integration with MaaS platforms: 6-12 months.

Cost Estimates:

- Cycling infrastructure near stations: €100,000–€500,000 per station area (depending on coverage and complexity);
- Secure bike parking (incl. smart lockers, surveillance): €1,000–€2,500 per unit;
- E-bike/e-scooter charging points: €2,000–€5,000 per station cluster;
- Integration with digital platforms: €50,000–€200,000 depending on interface and system integration;
- Shared micro-mobility service partnerships: Public-private models with minimal upfront public investment; costs vary depending on subsidy structure.

Return on Investment (ROI)

- Fuel savings: Reduction in short-distance car use can reduce urban fossil fuel demand by 5-10% in catchment zones;
- Carbon impact: Estimated CO_2 reduction of 0.1-0.3 tonnes per user annually when shifting short trips to e-mobility;
- Operational savings: Decreased demand for car parking, reduced road maintenance costs around stations;
- Payback period: Typically 1-3 years for infrastructure investments, faster for shared service rollouts;

- Non-monetary gains: Increased rail ridership, improved public health, enhanced user satisfaction.

4.5.2.4. Promoting and advocating for new incentives

For railway operators committed to reducing their environmental impact, the transition away from diesel traction presents both a strategic priority and a significant challenge. While technological alternatives—such as hybrid, electric, battery-electric, and hydrogen traction—are increasingly available, the financial and regulatory conditions needed to support their adoption are often insufficient or fragmented.

From the operator's perspective, the promotion and advocacy of new financial and policy incentives is essential to bridge this gap. This measure focuses on pushing for a more enabling environment—one that reduces investment risk, rewards sustainability, and ensures that operators have access to the tools and funding needed to lead the green transition.

As railway operators, we see several mechanisms as critical to supporting a feasible and timely decarbonisation path:

1. Green Public Procurement (GPP): Procurement rules should include environmental criteria such as lifecycle emissions, compatibility with alternative fuels, and energy performance. When these are embedded in public tenders, it ensures that sustainability becomes a standard, not a premium. For operators participating in such tenders, this creates a fairer and more innovation-friendly competitive landscape.
2. Targeted Tax Incentives: Tax benefits—such as accelerated depreciation for low-emission rolling stock, VAT reductions on clean technology, or investment tax credits—can significantly reduce the total cost of ownership. These tools are particularly important for regional and smaller operators managing tight margins and legacy diesel fleets.
3. Carbon Pricing and Emissions-Based Access Charges: Operators recognise the potential of carbon pricing to level the playing field between rail and road transport. However, these mechanisms must be calibrated to avoid penalising rail in areas where clean alternatives are not yet operationally viable. Ideally, revenues from carbon pricing should be reinvested into rail decarbonisation—such as innovation funds, pilot programs, or green infrastructure development.

The timeframe for introducing and benefiting from advocacy-led incentive reforms depends on the complexity of the initiatives and institutional processes. Typical phases include:

- Research and Positioning (3–6 months) – Baseline studies, regulatory gap analysis, internal needs assessments;
- Policy Proposal and Design (3-6 months) - Development of incentive models, stakeholder engagement, economic impact assessment;
- Advocacy and Institutional Engagement (6–12 months) - Position papers, participation in policy forums, joint lobbying activities;
- Implementation and Access to Incentives (1–3 years) - Pilot projects launched, funding applications submitted, incentive schemes activated;
- Monitoring and Policy Feedback (Ongoing) - Tracking programme uptake, emissions reductions, and operational impacts.

While advocacy work generally requires modest financial outlay compared to infrastructure or rolling stock investments, coordinated campaigns and technical design of incentive mechanisms may involve specific expenditures:

- Research and Analysis: €20,000–€100,000;
- Stakeholder Engagement and Policy Advocacy: €50,000–€150,000 annually (depending on the scale and geographic scope);
- Technical and Legal Advisory Services: €30,000–€100,000;
- Pilot and Demonstration Costs (where applicable): variable, often co-funded through EU or national programmes.

Funding for these activities can be mobilised through project-based support, internal sustainability budgets, or via cooperation with associations and public institutions.

Though indirect, the ROI for promoting new incentives is both strategic and cumulative, and includes:

- Lower Capital Costs: Through access to grants, tax benefits, and favourable depreciation rules;
- Improved Project Viability: Easier financing for clean technology and infrastructure upgrades;
- Competitive Advantage: Preferential conditions in public procurement and performance-based incentives;
- Operational Savings: Long-term reduction in fuel and maintenance costs as clean technologies scale;
- Environmental and Reputational Value: Enhanced compliance with EU Green Deal objectives and stronger ESG positioning for private and public operators.

4.5.2.5. Investing and exploring the trend of hydrogen use for vehicles

As part of the transition to climate-neutral rail transport, hydrogen traction offers a promising alternative to diesel, especially on non-electrified lines where full electrification is technically difficult or economically prohibitive. For railway operators, this measure represents a strategic opportunity to phase out fossil fuel use while maintaining operational flexibility and regional service continuity.

The adoption of hydrogen-powered trains—particularly fuel-cell electric multiple units (FCEMUs)—can support the decarbonisation of long-distance, low-density, or rural lines without the need for extensive catenary infrastructure. This technology is especially suitable for lines where battery-electric solutions may be limited by range or where service frequency does not justify electrification investment.

Hydrogen trains offer several advantages from an operator's perspective:

- Zero local emissions when using green hydrogen, supporting environmental performance targets and improving air quality in stations and depots.
- Lower noise levels compared to diesel, improving comfort for passengers and communities.
- Operational autonomy and faster refuelling compared to battery-electric units, especially on longer or more isolated routes.
- Modular investment: Hydrogen allows phased implementation without requiring full line electrification, making it a flexible and scalable option.

The introduction of hydrogen trains follows a phased approach:

- Feasibility Studies & Planning: 6–12 months (route analysis, stakeholder alignment, funding strategies);
- Pilot Project Launch: 1–2 years (rolling stock procurement, infrastructure setup, staff training);

- Full Deployment on Selected Lines: 3-5 years (scale-up, integration with wider hydrogen ecosystems);
- Monitoring and Scaling: ongoing (performance tracking, cost-efficiency analysis, fleet optimisation).

Costs vary by region, project scale, and whether hydrogen is produced on-site or transported. Indicative ranges include:

- Hydrogen Train Units: €5-10 million per unit (for FCEMUs);
- Retrofitting Diesel Units: €2-4 million per unit (depending on scope);
- Refuelling Station: €5–10 million per facility (can serve multiple trains);
- Green Hydrogen Production (Electrolyser): €800–1,200/kW installed capacity;
- Training and Safety Compliance: €100,000–€500,000 for initial roll-out.

Total pilot project costs can range from €15–50 million depending on scope and co-financing. While initial capital costs are high, the ROI improves over time as the hydrogen ecosystem matures:

- Fuel and Maintenance Savings: Lower mechanical wear, fewer emissions-related repairs, and stable long-term fuel prices when using renewable hydrogen.
- Regulatory Advantage: Improved compliance with emissions regulations and access to green finance instruments.
- Reputational Value: Enhanced public image and stakeholder support linked to zero-emission operations.
- Scalability and Resilience: Hydrogen traction can be scaled line by line and used flexibly across different service profiles.

Payback period varies but may range from 8–15 years, depending on hydrogen costs, infrastructure use levels, and access to funding or subsidies.

4.5.3. Environment

4.5.3.1. Regular maintenance of infrastructure

For rail freight operators, reliable infrastructure is a prerequisite for efficient, safe, and sustainable operations. While infrastructure management often lies with national or regional authorities, freight operators have a direct interest—and growing responsibility—in supporting and influencing maintenance practices that enhance both operational continuity and environmental performance.

Freight corridors often cross environmentally sensitive areas and are subject to greater wear due to heavy loads and high utilisation. Proactive engagement in maintenance planning helps reduce delays, avoid environmental incidents, and optimise long-term cost efficiency.

Unscheduled disruptions due to poorly maintained infrastructure—such as drainage failure, track degradation, or slope instability—can cause rerouting, delays, and increased energy use, all of which reduce service quality and reliability for freight customers.

In addition, infrastructure failures can lead to environmental damage (e.g. runoff contamination, embankment erosion), with reputational and regulatory consequences for operators.

For freight operators, supporting systematic maintenance—especially along key logistics corridors—means:

1. Minimising service interruptions and detours;

2. Ensuring access to terminals and sidings in all weather conditions;
3. Reducing stop-start movement patterns that increase fuel consumption and emissions;
4. Preserving competitive transit times against road alternatives.

Where freight trains operate on secondary or mixed-use lines, operators often have a frontline understanding of the infrastructure's physical condition and environmental vulnerabilities. Even without direct ownership of infrastructure, freight operators can follow some directions:

- Report early signs of degradation: Collaborate with infrastructure managers through shared reporting systems or joint inspections along frequently used corridors.
- Advocate for critical interventions: Highlight priority zones (e.g. sidings, intermodal terminals, industrial branches) where infrastructure weaknesses affect reliability and throughput.
- Collaborate on maintenance windows: Coordinate schedules to allow for works while minimising disruption to time-sensitive freight flows.
- Support monitoring technologies: Provide input on data collection (e.g. axle load stress patterns) that can help predict wear and optimise maintenance intervals.

Timeframe for Engagement and Impact:

- Issue Reporting and Coordination: Immediate to short term (weeks to months);
- Joint Planning with Infrastructure Managers: 6–12 months for integration into annual maintenance plans;
- Support for Monitoring Initiatives: 1–2 years depending on scale and digital readiness;
- Benefits Realised: Reduced disruption within 12–24 months; long-term operational and environmental savings over 3–5 years.

Though infrastructure managers typically fund and execute maintenance, operators may invest in:

- Monitoring Tools and Equipment (optional): €50,000–€150,000 for condition-monitoring systems or joint digital platforms;
- Training and Coordination Costs: €10,000–€30,000 annually for liaison staff, joint workshops, or incident analysis;
- Delays from Poor Maintenance: Hidden costs in fuel, penalties, and client dissatisfaction.

Freight operators benefit from proactive infrastructure maintenance through:

- Improved Reliability and Punctuality: Fewer track closures and detours reduce delays and scheduling complexity;
- Lower Operational Costs: Smoother running conditions cut fuel consumption and mechanical stress;
- Fewer Service Interruptions: Minimised unplanned downtime and simplified route planning;
- Environmental Risk Mitigation: Reduced exposure to fines or clean-up costs from runoff, derailments, or landslides linked to neglected assets.

Estimated payback period: 1–2 years for reduced delays and fuel use; longer-term savings through improved infrastructure durability and customer retention.

4.5.3.2. Measures taken to address noise pollution

While rail remains among the lowest-emission modes of freight transport, its acoustic impact—caused by rolling noise, braking, coupling operations, and engine vibration—can affect public health, quality of life, and social acceptance of rail infrastructure. As part of broader environmental responsibility, freight operators play a critical role in both mitigating and managing noise levels, even where infrastructure ownership lies with third parties. Key Measures Implemented:

1) Rolling Stock Modernization
   a) Deployment of low-noise freight wagons, compliant with noise regulations, especially those equipped with composite brake blocks (LL or K-type) that reduce wheel-rail interaction noise.
   b) Phased retrofitting of older wagons with noise-reducing technologies as part of fleet renewal programmes.
2) Operational Adjustments
   a) Speed management through noise-sensitive areas, particularly near residential zones or during night hours.
   b) Route planning optimisation to reduce night-time operations on lines adjacent to densely populated areas when feasible.
   c) Improved train handling practices to avoid abrupt braking or acceleration that can amplify acoustic peaks.
3) Maintenance Strategies
   a) Regular wheel and track grinding to prevent roughness-induced rolling noise.
   b) Maintenance of brake systems to ensure noise-reducing performance remains consistent over time.
   c) Collaboration with infrastructure managers to monitor and maintain track conditions, especially in curved sections.
4) Terminal and Yard Measures
   a) Use of low-noise shunting locomotives or battery-powered units where available.
   b) Operational limits on coupling/uncoupling activities during late-night hours in urban terminals.
   c) Installation of buffering and shock-absorbing devices to reduce impact noise from marshalling operations.
5) Monitoring and Stakeholder Engagement
   a) Participation in noise mapping and environmental monitoring in coordination with national rail infrastructure managers.
   b) Community engagement initiatives to inform residents of mitigation actions and receive feedback on perceived noise issues.
   c) Contribution to Environmental Impact Assessments and mitigation plans during the planning of new or upgraded services.

Timeframe:

- Immediate measures (e.g. speed adjustment, operational protocols) can be implemented in weeks.
- Medium-term actions (retrofitting, procurement of low-noise wagons) may require 1-3 years.

- Long-term gains (fleet replacement, terminal redesign) are realised over 5-10 years.

Costs:

- Retrofitting wagons with composite brake blocks: approx. €1,500–€3,000 per wagon;
- Wheel/track grinding (per km): €500–€1,000/km depending on scope;
- Shunting engine upgrades: €500,000–€1.5 million per unit;
- Noise barriers and yard modifications (if applicable): variable, project-specific.

ROI:

- Reduced risk of regulatory penalties or restrictions on night operations;
- Enhanced social licence to operate and improved community relations;
- Compliance with EU and national noise limits, avoiding future retrofit mandates;
- Improved asset performance through smoother operation and reduced wear.

4.5.3.3. Reducing the use of plastic where possible

Plastic waste is one of the most visible and persistent environmental challenges facing modern industries. In the freight transport sector, where packaging, wrapping, and consumables are widely used to protect goods and support daily operations, the overreliance on plastic presents both environmental and reputational risks. For railway freight operators, reducing plastic use is not just an ecological imperative—it is a business opportunity that aligns with growing expectations for circular economy practices, resource efficiency, and sustainable logistics.

Rail freight is already considered a low-emission alternative to road transport. Yet, the environmental advantages of rail can be further amplified by addressing waste generation within operational and supply chain processes. Freight operators are uniquely positioned to implement targeted, high-impact measures that reduce plastic consumption and waste, particularly in depots, intermodal terminals, and maintenance hubs. This contributes to the overall decarbonisation strategy of the transport sector while enhancing corporate responsibility and long-term cost savings. The benefits of reducing plastic use are multifaceted:

- Environmental: Less plastic waste reduces pollution risk in sensitive areas near tracks, terminals, and depots—especially those adjacent to waterways or natural habitats.
- Operational: Reusable solutions often lead to lower procurement and disposal costs over time.
- Reputational: Demonstrating leadership on waste reduction strengthens the operator’s brand and improves relationships with public stakeholders and logistics partners.
- Regulatory: Plastic use is increasingly regulated at EU and national levels. Proactive measures reduce exposure to future compliance risks.

Moreover, clients in sectors such as retail, manufacturing, and food logistics increasingly favour low-waste, environmentally aligned logistics partners—giving freight rail operators a competitive edge.

Implementation Timeline:

- Awareness and training: 1–3 months;
- Procurement and supply chain changes: 6–12 months;
- Depot and terminal transitions: 12–24 months;

- Monitoring system integration: 1–2 years.

Indicative Costs:

- Staff engagement and signage: €5,000–€15,000 (one-off);
- Reusable containers or wrapping systems: €10,000–€50,000 per site, depending on volume;
- Procurement policy updates and supplier engagement: Low cost, primarily internal labour.

Return on Investment (ROI):

- Cost recovery from avoided single-use materials and lower waste disposal fees within 1–2 years;
- Long-term savings and reputational returns through cleaner operations and reduced environmental liability;
- Higher scoring in ESG (Environmental, Social, Governance) assessments, aiding access to green financing and contracts.

4.5.3.4. Introduction of oil/water separators

Rail depots, maintenance yards, and fuelling stations are essential components of railway operations, yet they pose elevated environmental risks, particularly in relation to soil and water contamination. Activities such as fuelling, washing, lubrication, and mechanical repairs involve regular handling of hydrocarbons, increasing the potential for spills or leaks. Without proper treatment, these substances may enter stormwater drains or wastewater systems, polluting local water bodies and violating environmental regulations.

To mitigate this risk, the installation of oil/water separators is a fundamental measure. These systems remove hydrocarbons from wastewater before discharge into municipal networks or natural waterways. Their role is both preventive and regulatory, helping operators meet environmental standards while protecting surrounding ecosystems.

Oil/water separators are especially important in areas where diesel locomotives and rolling stock are serviced. Typical risk zones include:

- Refuelling and washing bays;
- Wheel cleaning pits;
- Underfloor maintenance channels;
- Drainage systems near depots and workshops.

Hydrocarbon runoff is common in these environments, and separators provide a first line of defence against pollution.

Timeframe:

- Assessment and Planning: 1–3 months to map high-risk zones (e.g. refuelling points, washing bays) and select appropriate separator types based on flow volume and hydrocarbon load.
- Installation: 3–6 months for procurement, civil works, and installation—depending on site conditions and the number of units required.
- Commissioning and Training: 1–2 months to calibrate the system, train depot staff, and integrate into site-level environmental monitoring protocols.

- Operational Use and Maintenance: Continuous. Maintenance cycles typically range from quarterly to biannual depending on usage intensity and system size.

Cost Estimates:

- Unit and Installation Costs (per site):
    - Small/medium-capacity units (e.g. gravity or coalescing separators): €10,000–€25,000;
    - Large-capacity or advanced systems with alarms and remote monitoring: €30,000–€60,000;
    - Civil works, drainage adaptation, and ancillary infrastructure: €10,000–€40,000 depending on site complexity.
- Annual Maintenance and Waste Disposal: €2,000–€10,000 per system (Includes inspections, sludge/oil removal, system cleaning, and basic servicing)
- Training and Staff Engagement: €3,000–€7,000 (one-time or recurring depending on turnover)

Return on Investment (ROI):

- Environmental Compliance: Avoidance of fines or shutdowns due to regulatory violations. In many jurisdictions, non-compliance with water discharge standards can result in penalties ranging from €5,000 to over €100,000 per incident.
- Pollution Mitigation: Preventing a single hydrocarbon spill from reaching soil or groundwater can save tens of thousands in remediation costs and protect operator reputation.
- Operational Continuity: Reliable drainage and wastewater management reduce the risk of service disruptions at depots and fuelling stations, particularly during heavy rainfall or high-traffic periods.
- Reputation and ESG Performance: Demonstrating active pollution prevention strengthens sustainability reporting, enhances public trust, and improves positioning in ESG ratings—important for access to green funding or long-term contracts.

Estimated Payback Period: 2–4 years depending on the scale of installation, site sensitivity, and frequency of use. ROI improves further when combined with digital monitoring and predictive maintenance to reduce long-term servicing costs.

4.5.4. Management system - implementing an EMS

4.5.4.1. Data analysis and reporting

For a railway freight operator, effective data analysis and reporting is not just a compliance task—it is a strategic tool to drive cost efficiency, reduce risks, and meet sustainability goals. At the core of any Environmental Management System (EMS) lies the accurate, systematic collection and analysis of environmental performance data. This includes energy consumption, emissions, waste, water use, land impacts, and noise—key concerns in rail freight operations.

A robust EMS requires digitalised data collection systems that track key indicators such as traction energy (electricity, diesel, hydrogen), GHG emissions, waste categories (plastic, hazardous, general), and noise levels near logistics hubs or along non-electrified lines. Real-time or automated monitoring—particularly at depots, intermodal terminals, and along high-traffic corridors—can significantly improve responsiveness and accuracy.

Digital dashboards and Key Performance Indicators (KPIs) enhance visibility and accountability. Freight operators benefit from tracking metrics such as CO_2 per train-kilometre, tonne-km per energy unit, or incident rates per route. These tools help prioritise interventions (e.g. retrofitting locomotives, optimising schedules) based on environmental and financial impact. Integration with ERP and GIS systems facilitates spatial analysis and fleet-wide benchmarking.

From a time and cost perspective, implementation of a basic EMS data platform (including sensors, dashboards, and reporting templates) may require 6–12 months and an initial investment of €100k–€300k, depending on fleet size and infrastructure complexity. Ongoing operational costs (maintenance, training, system upgrades) average 5–10% of the upfront investment annually. However, ROI is typically realised within 2–3 years through reduced fuel costs, lower emissions penalties, improved asset efficiency, and access to green finance or ESG-linked incentives.

Data-driven EMS reporting also supports compliance with EMAS, ISO 14001, and national regulatory frameworks. For operators managing publicly funded infrastructure or operating under concession agreements, transparent reporting enhances trust with authorities and stakeholders. It also supports participation in voluntary platforms or cross-sector benchmarking, further driving innovation.

Staff engagement and training are essential. Maintenance crews, operations personnel, and procurement officers must be trained to collect and validate data. Environmental managers should oversee data governance, while IT teams ensure systems are integrated, secure, and scalable.

Lastly, real-time monitoring enables proactive risk management—detecting anomalies, preventing non-compliance, and ensuring business continuity. By transforming data into actionable insights, this measure lays the foundation for operational excellence and long-term environmental leadership.

4.5.4.2. Integration of renewable energy

For a railway operator, managing environmental impact is becoming a core part of running a smart and efficient business. With rising energy costs, stricter regulations, and growing demand for sustainable transport, adopting an Environmental Management System (EMS) and using more renewable energy helps rail companies stay competitive, reduce risks, and improve long-term performance.

This measure describes how a rail freight or passenger operator can plan and benefit from both actions: setting up an EMS and integrating renewable energy in their operations. Rail is already a low-carbon mode of transport, but using clean energy sources makes it even greener. Operators can:

- Buy electricity from renewable sources (green energy contracts or PPAs);
- Install solar panels on depots, stations, or administrative buildings;
- Use hydrogen or battery-powered trains on non-electrified lines;
- Switch to electric or hybrid support vehicles (e.g., for shunting, maintenance).

These choices reduce CO_2 emissions and protect the company from fuel price fluctuations. Implementing an Environmental Management System (EMS) along with the integration of renewable energy typically unfolds over three main phases.

The first phase, which covers the initial six months, involves planning and design. During this period, the operator begins with a thorough environmental audit to understand the current status of energy use, emissions, and other environmental impacts across its facilities and operations. Based on this analysis, the EMS is designed by selecting the most relevant performance indicators—such as energy consumption per train-kilometre, carbon emissions, and depot-level waste production. In parallel, a technical assessment is carried out to identify where renewable energy solutions can be adopted, whether through solar installations, the purchase of certified green electricity, or other low-carbon technologies. It is also crucial at this stage to ensure commitment from senior management and to define responsibilities clearly across the organisation.

The second phase, typically spanning from the sixth to the eighteenth month, focuses on setting up the EMS and starting the integration of renewable energy solutions. This includes installing the necessary tools and systems for environmental monitoring, such as smart energy meters and digital dashboards. Staff involved in operations, maintenance, and reporting are trained to use these systems and apply sustainability practices in their daily work. Where feasible, the operator proceeds with the installation of renewable infrastructure—such as solar photovoltaic panels on depots or hydrogen refuelling systems on non-electrified lines. These installations are then connected to internal platforms, such as Enterprise Resource Planning (ERP) software or Geographic Information Systems (GIS), to allow seamless data integration and ongoing performance tracking.

The third and final phase, between the eighteenth and thirty-sixth month, involves operating the EMS, evaluating results, and obtaining certification. The system becomes fully functional, and performance data is monitored regularly. The operator applies for certification under recognised environmental standards such as ISO 14001 or the EU's EMAS. Environmental performance reports are produced and shared both internally and externally. At least once a year, the system is reviewed to assess progress, update objectives, and identify new areas for improvement.

For a medium-sized railway operator, the cost of implementing an EMS combined with renewable energy integration typically ranges from €700,000 to €1.2 million. This includes the design of the EMS and the deployment of monitoring software, staff training, certification costs, the installation of a solar photovoltaic system of approximately 500 kWp on one depot, and, optionally, a battery energy storage system. The full rollout generally takes between one and a half and three years.

Return on investment can usually be achieved within three to five years. This depends on the size of the investment, the scale of energy savings, and the availability of public funding or incentives. Savings come from reduced electricity bills—up to 30 to 40 percent with solar energy—as well as lower fuel costs when diesel-powered vehicles or locomotives are replaced with electric or hybrid alternatives. The operator also benefits from lower risks of fines or penalties thanks to improved regulatory compliance, easier access to green funding or ESG-linked loans, and stronger positioning in public tenders that require environmental credentials.

Several challenges may arise during implementation. The most common is the high upfront cost, which can be addressed by seeking funding from national or EU programmes and by phasing the rollout. Staff may be unfamiliar with new systems or resist changes in procedures; this can be managed with well-planned training and internal communication that highlights the long-term benefits.

4.5.4.3. Predictive maintenance

For a railway operator, combining an Environmental Management System (EMS) with predictive maintenance represents a strategic investment in efficiency, safety, and sustainability. An EMS provides the framework to monitor and reduce environmental impacts across the organisation, while predictive maintenance leverages data and technology to anticipate failures, optimise repairs, and reduce waste. When integrated, these two systems not only improve environmental performance but also deliver measurable cost savings and higher service reliability.

The process begins with a planning phase that usually spans the first three months. During this stage, the operator defines the environmental goals to be addressed by the EMS—such as reducing emissions, lowering fuel consumption, or cutting down on hazardous waste—and identifies the key assets that would benefit most from predictive monitoring. These typically include locomotives, rolling stock, depot systems, and key infrastructure components like switches and traction systems. A review of current maintenance practices and data availability is also conducted, laying the groundwork for system design.

Between the third and eighth month, the operator moves into the procurement and system design phase. At this point, the company selects the necessary technologies, including sensors for temperature, vibration, fuel efficiency, and emissions, as well as the software platforms for analytics and data visualisation. This is also the moment to design how predictive data will be integrated into EMS reporting tools, enabling a full picture of environmental and operational performance. Training for staff begins in parallel, preparing teams in maintenance, IT, and environment to use the new tools effectively.

From month eight to sixteen, installation and testing take place. Sensors are installed on trains and infrastructure components, data platforms are deployed, and testing is conducted to ensure that performance anomalies and warnings are being correctly identified and communicated. The EMS is now extended to include predictive indicators, linking maintenance alerts with environmental impacts—such as increased emissions from poorly tuned engines or oil leaks detected in early stages. Staff training continues, focusing on the use of dashboards, data interpretation, and preventive actions.

The final phase, between month sixteen and twenty-four, marks the beginning of full-scale operation. The predictive system becomes part of daily maintenance planning, feeding real-time information into the EMS. Environmental managers use this data to update sustainability reports and assess progress toward emissions and waste-reduction targets. At this stage, the company may also apply for external EMS certification, such as ISO 14001 or EMAS, strengthening its credibility and regulatory compliance. Annual system reviews ensure ongoing optimisation and the identification of new opportunities for improvement.

In terms of investment, a medium-sized rail operator can expect to spend between €540,000 and €1.2 million to implement this combined system. This includes the design and integration of the EMS, sensor and hardware installation, analytics software, staff training, and certification costs. While this may seem substantial, the return on investment is typically achieved within two to four years. The benefits are both financial and operational: fewer unplanned breakdowns mean lower maintenance costs and service disruptions; improved asset performance results in lower energy and fuel consumption; and more efficient resource use reduces waste disposal costs and environmental risk.

Beyond cost savings, the system delivers strategic value. With predictive maintenance in place, the operator can extend the lifespan of key assets, reduce the use of spare parts, and shift from reactive to proactive maintenance planning. These improvements feed directly into EMS goals, reinforcing a culture of performance monitoring and continuous improvement. Furthermore, the ability to demonstrate real-time environmental performance can support access to green funding, improve positioning in public tenders, and meet growing stakeholder expectations on sustainability.

4.5.4.4. Automated controls for lighting and HVAC

Improving energy efficiency across stations, depots, and offices is a practical and impactful step in implementing an Environmental Management System (EMS). One of the most effective ways to achieve this is through the automation of lighting and heating, ventilation, and air conditioning (HVAC) systems. These systems account for a significant share of energy consumption in non-traction operations. Automating them helps reduce unnecessary energy use, stabilise operational costs, and lower the overall environmental footprint.

The process begins with an assessment of current energy use in buildings and facilities. Typically, this includes stations, depots, warehouses, administrative buildings, and service areas. By monitoring consumption patterns—especially during off-peak hours or in underutilised spaces—it becomes clear where inefficiencies lie. Often, lighting and HVAC systems are found running when not needed, contributing to avoidable electricity and fuel costs. To address this, the operator implements a combination of occupancy sensors, smart thermostats, programmable lighting schedules, and building management systems. These technologies allow lighting and climate control to adjust automatically based on presence, time of day, weather conditions, or operational schedules. For example, lights in staff corridors or waiting rooms can dim or switch off when areas are unoccupied.

HVAC systems can reduce heating or cooling output overnight or during low-traffic periods, especially in administrative zones or auxiliary rooms. Implementation typically follows a staged approach over a period of 6 to 12 months. In the initial months, energy audits are conducted to map out current consumption and identify priority buildings. A tailored design is then developed, taking into account the layout, usage patterns, and integration requirements with existing infrastructure. Once the plan is approved and equipment is procured, installation begins, usually with minimal disruption to daily operations. Systems are then tested and fine-tuned to align with EMS objectives and comfort requirements for staff and passengers. For a mid-sized operator, the total investment in automated lighting and HVAC controls can range from €150,000 to €400,000, depending on the number of buildings, level of digitalisation, and system complexity. This cost includes sensors, control systems, installation, staff training, and EMS integration software.

Despite the initial outlay, the return on investment is generally achieved within two to three years. Automated systems can reduce energy consumption for lighting and HVAC by 20% to 40%, depending on baseline usage, with significant savings on electricity and heating bills. This not only cuts operational costs but also contributes directly to EMS targets related to CO_2 emissions, energy efficiency, and environmental impact reduction. Moreover, automation enhances data availability and transparency. Consumption trends from lighting and HVAC systems can be tracked in real time and fed into EMS dashboards. This allows environmental managers to monitor progress, detect anomalies, and report results more accurately to both internal and external stakeholders. It also strengthens the case for ISO 14001 or EMAS certification, as it demonstrates a clear link between system control, performance monitoring, and continuous improvement.

4.5.5. Other climate change measures - implementation of warning systems

As climate change increases the frequency and intensity of extreme weather events, railway operators must take proactive steps to ensure service continuity, infrastructure safety, and passenger protection. One critical climate adaptation measure is the implementation of early warning systems—digital or sensor-based platforms that provide real-time alerts for weather-related risks such as floods, landslides, extreme heat, storms, and strong winds.

From the perspective of a railway operator, these systems serve a dual purpose: they reduce the risk of infrastructure damage and operational disruption, while also enhancing the safety of passengers, staff, and rolling stock. Integrating these tools within the broader Environmental Management System (EMS) and operational control structures allows the operator to anticipate and respond to climate-related threats with greater precision and speed.

The first step involves identifying vulnerable assets and critical zones along the network—such as river crossings, tunnels, embankments, areas with known instability, or locations with a history of flooding or snow accumulation. The operator then deploys a mix of meteorological sensors, geotechnical monitoring equipment, and remote communication systems. These devices are installed at trackside locations, stations, depots, and intermodal hubs, and are connected to a centralised control centre that collects and processes data in real time. In many cases, the system is linked with national or regional weather forecasting services to enable anticipatory action, such as slowing or rerouting trains, suspending services, or activating emergency protocols.

Implementation typically takes between 12 and 18 months, depending on network size and terrain complexity. In the initial months, climate vulnerability mapping and risk assessments are carried out to prioritise installations. This is followed by the procurement of technology and the integration of the warning system into existing digital infrastructure—often via the operator's traffic control or maintenance platforms. Staff training is conducted in parallel to ensure that dispatchers, station personnel, and infrastructure teams understand alert protocols and response procedures. In the final stages, trial runs and simulations are performed to test system reliability under different scenarios.

For a medium-sized rail operator, the investment required to install a functional and integrated warning system typically ranges from €500,000 to €1.5 million. This includes the costs of sensors, software, communications systems, IT integration, and staff training. However, the return on investment can be substantial. The financial impact of a single major weather event—such as a flash flood damaging infrastructure or a landslide blocking a main line—can easily exceed several hundred thousand euros in repair costs, service interruptions, and compensation payments. By contrast, an effective warning system allows the operator to take preventive measures, reducing these losses significantly. The ROI for warning systems is often realised within three to five years, especially in regions prone to high-impact weather events. In addition to avoid damage, there are long-term gains in operational resilience, improved insurance ratings, and stronger credibility with regulators and public authorities. Furthermore, many warning systems contribute to climate-related performance reporting, aligning with EMS objectives and helping operators demonstrate preparedness in the face of growing climate risks.

Beyond cost and performance, the implementation of warning systems also improves safety outcomes. Early alerts enable better coordination with civil protection authorities, faster evacuation or rerouting of passengers, and more accurate decision-making in crisis situations.

5. Implementation plan

As a basis, the actors of the transport sector should integrate the specific goals and objectives set by the strategic European directives (EU GREEN DEAL, EU Climate plan). Then by the guidance of the assessment methodology (shown in chapter 3) the transport company is able to identify the gap between the current state and the specific goals, and the interventions needed to achieve them. But the number of best practices and the number of improvable areas indicate the need to handle and prioritise the measures systematically. This means that the most essential aspect of implementing REDU-CE-D best practices is adopting a strategic and long-term approach.

If a transport company aims to improve its energy efficiency and sustainability, the first step is to review the long list of best practices that are available to them and select those that best align with its objectives and long-term vision. The second step should involve a similar evaluation method to the one used by REDU-CE-D TWG experts during the subgroup meetings. This means assessing the selected measures based on their impact, implementation timeframe, and cost to ensure comparability. The evaluation process should involve operational and strategic decision-makers within the company to incorporate different aspects and interests. The results of the evaluation can help identify some key points for building up our implementation plan:

- We should start implementing those low cost measures that can be implemented in a short timeframe. These quick wins help us raise awareness and can also increase the commitment at company level towards a greener and more energy efficient future.
- We should focus on the most impactful measures, even if there is a possibility that these measures have plenty of difficulties and the costs do not seem manageable. If the most effective solution is not prioritised, achieving meaningful progress in energy transition will be difficult.
- We should identify measures that surely require external financing (e.g. loan or national/ EU subsidies). Even if funding is not immediately available, keeping these measures on the radar ensures that the company is well-prepared for funding opportunities, lobbying and grant applications.
- Developing a detailed implementation plan for long-term measures, breaking them down into manageable steps to facilitate execution.
- Allocating company resources or securing loans for measures with a strong return on investment (ROI) to maximise financial and environmental benefits.
- We should select the most suitable EMS that aligns with the size of the company and its strategic goals. Digitalization and monitoring will be key components, ensuring clear feedback on the effectiveness of implemented measures.

Stakeholder engagement will be crucial both in the planning phase and in the implementing phase, helping to build trust, improve decision-making, and enhance long-term success. With effective collaboration of stakeholders, the company can achieve better risk management and can increase the company's resilience to future challenges.

An effective Monitoring and Evaluation (M&E) framework is also a fundamental component of any sustainability strategy. It ensures that organisations systematically assess their progress towards environmental and energy efficiency goals, identify potential areas for improvement and take corrective actions where necessary. M&E is particularly crucial in the transport sector, where resource consumption and emissions have significant environmental impacts.

Monitoring and evaluation serve multiple purposes in the implementation of an environmental strategy. First, they provide data-driven insights into an organisation's performance, enabling decision-makers to make informed choices regarding energy consumption and environmental management. In addition, M&E frameworks help establish accountability, ensuring that sustainability goals are not only set but also effectively pursued. Finally, continuous monitoring allows for the early detection of inefficiencies, facilitating timely interventions that enhance energy savings and reduce environmental footprints.

To develop a reliable M&E system, organisations should adopt standardised data collection methodologies tailored to the transport sector. Key environmental indicators to monitor include fuel and electricity consumption, CO_2 emissions, water usage, waste production, and the share of renewable versus non-renewable energy sources. The data collection process should be structured, ensuring consistency across different measurement periods.

Technological tools play a vital role in the monitoring process. Data visualisation and analytics software such as Power BI can help process and interpret collected information, providing stakeholders with real-time insights and trend analysis. These tools allow companies to track performance indicators, compare them against benchmarks, and generate reports that support strategic decision-making.

Benchmarking is a valuable practice for assessing an organisation's performance relative to industry standards and best practices. In the energy sector, benchmarking allows companies to determine whether their consumption patterns align with sector-wide efficiency targets or if corrective actions are necessary. In the process of benchmarking energy efficiency, organisations should consider:

- Selecting relevant comparison groups, such as companies in the same industry with exemplary energy management practices.
- Establishing performance indicators that align with sustainability objectives.
- Interpreting results effectively, ensuring that deviations from benchmarks lead to actionable improvements rather than static assessments.

Benchmarking not only provides a performance snapshot but also serves as a motivational tool, encouraging companies to adopt best practices and stay competitive within the sector.

Pilot tests are an essential step in validating energy monitoring strategies before full-scale implementation. A well-structured pilot test helps organisations:

- Identify potential challenges in data collection and analysis.
- Ensure that the chosen methodologies are practical and effective.
- Gain stakeholder buy-in by demonstrating the benefits of the proposed energy management strategies.

During a pilot test, companies should focus on evaluating their infrastructure's energy consumption patterns and testing different monitoring tools. This phase provides an opportunity to refine data collection methods and assess whether the selected indicators accurately reflect energy efficiency improvements. Key aspects to consider during pilot tests include:

- The accuracy of collected data and its comparability with existing records.
- The feasibility of real-time monitoring versus periodic assessments.
- The potential impact on operational processes, ensuring that monitoring activities do not disrupt daily operations.

Evaluation and reporting are crucial to transforming data into actionable insights. A robust evaluation framework helps organisations understand whether their energy management efforts yield tangible benefits and where further adjustments are needed. Best practices for evaluation and reporting include:

- Defining clear Key Performance Indicators (KPIs) to assess progress in energy efficiency.
- Using validated data to ensure credibility and comparability across reporting periods.
- Generating comprehensive reports that summarise findings, highlight trends, and provide recommendations for improvement.
- Engaging stakeholders by sharing reports in accessible formats, fostering transparency, and encouraging continuous improvement.

Through structured evaluation and transparent reporting, organisations can drive long-term sustainability, demonstrating commitment to energy efficiency while ensuring compliance with environmental regulations. By leveraging data-driven approaches, companies can continuously refine their strategies, reducing their environmental impact and enhancing overall operational efficiency.

6. Stakeholder engagement

6.1. Identification of Key Stakeholders

Effective stakeholder engagement is fundamental to ensuring the success of any initiative aimed at improving energy efficiency in the transport sector. Stakeholders represent all parties that are directly or indirectly affected by the implementation of new energy management strategies and sustainability practices. Their involvement facilitates knowledge sharing, fosters collaboration, and enhances the adoption of best practices across the industry.

In the transport sector, stakeholders can include a wide range of actors. Public authorities and regulatory bodies play a crucial role in setting regulatory frameworks, enforcing environmental policies, and offering financial incentives for sustainable practices. Transport companies and fleet operators are directly responsible for implementing energy-saving solutions and optimising resource utilization. Infrastructure owners and service providers contribute by developing energy-efficient logistics and operational frameworks. Technology developers and research institutions offer innovative solutions, such as smart energy management systems and predictive maintenance tools, which can enhance efficiency and reduce carbon emissions. Employees and trade unions are key stakeholders, as they are directly involved in daily operations and require adequate training and incentives to support the transition towards sustainable practices. Finally, customers and the general public influence the sector's sustainability demand patterns by demanding environmentally friendly transport services and supporting companies that adopt green initiatives.

6.2. Strategies for Stakeholder Involvement

Engaging stakeholders effectively requires a structured approach to support active participation and commitment throughout the energy transition process. Establishing clear objectives for stakeholder involvement is essential to align expectations and define the benefits of participation. Open communication channels are needed to be developed to facilitate dialogue, ensuring that all stakeholders have access to relevant information and can provide valuable feedback.

Collaborative workshops and roundtable discussions serve as platforms for knowledge exchange, allowing stakeholders to share experiences and discuss challenges related to energy efficiency improvements. These interactive sessions encourage co-creation of solutions and foster a sense of shared responsibility for sustainability goals. Public-private partnerships can further enhance stakeholder engagement by combining resources, expertise, and investment in joint initiatives that promote energy-efficient transport solutions. Pilot projects provide practical insights by allowing stakeholders to observe the implementation of new technologies and assess their impact before full-scale adoption. Involving employees through training programmes and incentive schemes ensures that they are equipped with the necessary skills and motivation to support energy-saving initiatives within their organisations.

Regular performance reviews and transparent reporting mechanisms strengthen stakeholder trust and encourage continuous improvement. Setting measurable sustainability targets and regularly reporting progress helps maintain engagement and demonstrate the companies' commitment to energy efficiency. Adopting digital tools, such as online platforms and real-time data dashboards, facilitates stakeholder interaction and ensures continuous monitoring of key performance indicators.

6.3. Communication and Dissemination Plan

A well-structured communication and dissemination plan is essential to effectively engage stakeholders and promote best practices in energy efficiency. The primary goal is to raise awareness of the benefits of sustainable transport solutions and encourage the adoption of energy management strategies across the sector. This requires a combination of targeted communication strategies to different stakeholder groups.

Internal communication within transport companies should focus on educating employees about energy-saving initiatives and fostering a corporate culture that prioritises sustainability. Regular internal newsletters, training sessions, and workshops can help reinforce key messages and ensure alignment with organisational goals. External communication, on the other hand, should aim to inform the broader industry and the public about the progress of energy efficiency initiatives. Press releases, industry conferences, and participation in sectoral events provide opportunities to present case studies and share best practices.

Digital channels play a critical role in modern communication strategies. Websites, social media platforms, and dedicated online portals allow companies to disseminate information widely and interact with diverse audiences. Publishing reports, policy documents, and research findings on accessible digital platforms ensures that valuable insights reach policymakers, industry experts, and academic institutions. Interactive tools, such as webinars and online discussion forums, create opportunities for stakeholder engagement beyond physical meetings.

A strategic dissemination approach should also involve collaboration with media outlets and professional associations to amplify the visibility of sustainability initiatives. Engagement with policymakers through policy briefs and stakeholder consultations helps ensure that regulatory frameworks support the implementation of energy-efficient practices in the transport sector. Ultimately, a comprehensive and proactive communication plan reinforces the impact of stakeholder engagement efforts and contributes to the long-term success of energy management initiatives.

7. Expected contribution to the EUSDR Priority Areas (PAs)

The EU Strategy for the Danube Region (EUSDR) is a macro-regional strategy adopted by the European Commission in December 2010 and endorsed by the European Council in 2011. The Strategy was jointly developed by the Commission, together with the Danube Region countries and stakeholders, in order to address common challenges. The Strategy aims to create synergies and coordination between existing policies and initiatives taking place across the Danube Region. The REDU-CE-D Strategy mostly contributes to priority areas PA2 Sustainable energy, PA4 Water quality, PA5 Environmental risks, PA6 Biodiversity, Landscapes, Air and Soil Quality, PA10 Institutional capacity and Cooperation.

The improvements suggested by the strategy align most closely with the objectives of the EUSDR PA2 on Sustainable Energy by promoting energy efficiency, integrating renewable energy sources, and optimising resource management. The recommendations emphasise the modernization of electrical and fossil fuel-based systems, which directly supports the objective of PA2 to increase energy security and sustainability across the region. By recommending the expansion of energy tracking capabilities and the adoption of innovative technologies such as predictive maintenance and automated energy management systems, the proposed measures contribute to the efficient use of resources while reducing carbon emissions. Furthermore, the integration of renewable energy solutions, such as solar panels at public transport stations and geothermal energy systems, is consistent with the focus of PA2 on enhancing the share of clean energy in the Danube Region, thereby fostering a transition towards a low-carbon economy.

Additionally, the recommendations address wider environmental and infrastructural considerations that are crucial for the success of EUSDR PA2. By promoting the certification of energy-efficient buildings, the reduction of plastic waste, and the implementation of oil/water separators, these strategies contribute to minimising the environmental impact of energy production and consumption. Moreover, measures such as promoting micro-mobility and calling for the introduction of government incentives for sustainable energy transition align with PA2's emphasis on strengthening transnational cooperation and policy support for sustainable energy development. These improvements support the technical goals of PA2. They also promote a systemic approach to sustainability that integrates technological, regulatory, and behavioral changes to ensure long-term energy resilience in the Danube Region.

The outlined suggestions of REDU-CE-D strategy also contribute to the objectives of the EUSDR PA4 on Water Quality by promoting measures that reduce pollution and enhance water resource management. Initiatives such as the installing of oil/water separators, the reduction of single-use plastics, and the adoption of pesticide-free operations directly support PA4's goal of reducing hazardous substances and improving the ecological status of water bodies. By preventing contaminants from entering natural water sources, these measures help protect aquatic ecosystems and ensure cleaner water for human consumption and biodiversity conservation. Additionally, infrastructure maintenance strategies, such as regular track sanding and lubrication to minimise particulate pollution, further contribute to safeguarding water quality by reducing the spread of pollutants into waterways. These efforts align with PA4's emphasis on integrated water resource management, pollution prevention, and sustainable land-use practices, thereby fostering a more resilient and environmentally responsible Danube Region.

The proposed measures support the objectives of the EUSDR PA5 on Environmental Risks by enhancing resilience to climate change, preventing pollution, and mitigating risks associated with industrial and urban development. The implementation of warning systems for severe weather events is consistent with the priorities of PA5, which emphasise on disaster preparedness and early warning mechanisms, ensuring that communities and infrastructure are better protected against extreme weather conditions. Additionally, the introduction of oil/water separators and the reduction of pesticide use help to prevent the release of hazardous substances from contaminating soil and water sources, thereby reducing environmental and health risks. Measures such as the relocation of wildlife during construction projects demonstrate a proactive approach to minimising ecological disruptions and maintaining biodiversity, which is crucial for long-term environmental stability. Altogether, these initiatives support PA5's goals by promoting risk prevention, enhancing adaptive capacity, and ensuring the sustainable management of environmental resources in the region.

EUSDR PA6 on Biodiversity, Landscapes, Air, and Soil Quality is also subject of the proposed improvements by promoting sustainable practices that protect ecosystems, enhance air quality, and reduce soil contamination. Initiatives such as the reduction of single-use plastics and the transition to pesticide-free operations contribute to preserving biodiversity by minimising pollution and preventing harmful substances from entering natural habitats. Additionally, the relocation of wildlife during construction projects demonstrates a commitment to safeguarding species and maintaining ecological balance. Measures aimed at reducing fossil fuel consumption, such as promoting micro-mobility and investing in hydrogen-powered vehicles, support PA6's goal of improving air quality by lowering greenhouse gas emissions and particulate matter. Furthermore, the implementation of oil/water separators prevents hazardous substances from contaminating soil and water sources, ensuring the sustainable use of land and safeguarding environmental health. Collectively, these strategies advance PA6's overarching objective of fostering a healthier, more resilient natural environment in the Danube Region.

Finally, the proposed measures support the objectives of the EUSDR PA10 on Institutional Capacity and Cooperation by fostering cross-border collaboration, enhancing governance structures, and promoting knowledge exchange among project partners. Initiatives such as participating in pilot projects and adopting energy management systems encourage the sharing of best practices and innovative solutions, strengthening institutional networks across the region. Additionally, advocating for new incentives and policy support for sustainable energy transitions aligns with PA10's goal of improving institutional frameworks and public administration efficiency. Awareness-raising campaigns further contribute by engaging stakeholders, promoting a culture of cooperation, and ensuring the effective implementation of sustainability initiatives. By facilitating coordinated efforts among governments, businesses, and civil society, these measures enhance institutional capacity and reinforce transnational cooperation, ultimately supporting the successful implementation of sustainable development strategies in the Danube Region.

8. Conclusion

The REDU-CE-D Strategy represents a comprehensive and strategic framework to accelerate the energy transition of the transport sector in Central Europe. Developed through transnational collaboration, extensive assessments, and stakeholder engagement, the strategy highlights the urgent need to align transport systems with the European Union's climate objectives. By synthesising local insights, transnational data, and sector-specific expertise, the strategy offers both an analytical foundation and a practical roadmap for advancing sustainable energy practices across air, urban, waterway, and rail transport modes.

At its core, the strategy is rooted in the recognition that decarbonising transport is central to achieving climate neutrality by 2050, as stipulated in the European Green Deal. Transport remains a significant contributor to greenhouse gas emissions and fossil fuel dependency, thus necessitating transformative action. The REDU-CE-D Strategy addresses this challenge through a dual approach (combining technological development with institutional change): promoting technological innovation and embedding sustainability into institutional and behavioural norms.

The REDU-CE-D Strategy presents a structured, evidence-based framework for advancing sustainable energy transitions in the transport sector, built upon data gathered through localised assessments by transport organisations across six Central European countries and spanning four key transport modes: air, urban, waterway, and rail. The findings were synthesised into a Transnational Assessment Report, which was further enriched by expert insights from an interdisciplinary Transnational Technical Working Group, comprising representatives from public and private organisations within the transport industry. These inputs provided critical context for understanding the operational and strategic challenges of energy management across varying national and sectoral settings. To ensure broader relevance and applicability, the strategy integrates cross-sectoral benchmarks and practical case studies, focusing on implementation timelines, cost implications, and return on investment (ROI). It combines a common chapter for shared issues—such as energy use in buildings—with sector-specific guidance tailored to the unique needs of each transport mode. Beyond operational measures, the strategy addresses prioritisation, monitoring, and alignment with EU climate and energy targets, offering a comprehensive tool for policymakers and operators alike, and laying the groundwork for future funding instruments and long-term resilience planning.

The transnational assessment (Deliverable D1.1.3) provided critical insights into the current state of energy management across the participating transport companies. While basic measures such as energy efficiency upgrades, simple monitoring systems, and waste separation are widely implemented, the adoption of advanced energy management systems (EMS), climate adaptation strategies, and digital solutions remains limited. Furthermore, disparities in data collection and performance tracking hinder the development of strategic, evidence-based sustainability policies. These findings highlight the importance of expanding systematic monitoring, integrating renewable energy sources, and investing in staff training and stakeholder collaboration to build institutional capacity.

A particularly noteworthy feature of the REDU-CE-D Strategy is its emphasis on best practices with cross-sectoral applicability. The methodology for selecting these practices, grounded in Deliverables D1.2.1 and D1.2.2, ensures scalability and relevance across transport modes. Measures such as the installation of photovoltaic panels, the introduction of electric ground vehicles, and the digitalisation of energy usage monitoring exemplify initiatives with tangible environmental and economic benefits. Importantly, the strategy recognises that not all sustainability solutions yield immediate financial returns. Nevertheless, their long-term advantages—ranging from improved air quality to enhanced regulatory compliance—warrant sustained investment and policy support.

The contributions of the Transnational Technical Working Group further enriched the strategy by providing sector-specific evaluations of the feasibility, impact, and adaptability of the recommended measures. The collaborative workshops and subgroup discussions revealed that a one-size-fits-all approach is insufficient.

Instead, tailored interventions—supported by a common overarching framework—are necessary to address the unique challenges and opportunities within each transport sector. For instance, while sustainable aviation fuels may hold promise for air transport, modal shift and e-mobility are more pertinent to urban systems. Similarly, waterway and rail sectors benefit from optimised logistics and hybrid propulsion systems.

Looking forward, the successful implementation of the REDU-CE-D Strategy depends on several critical enablers. Firstly, institutional commitment at both national and local levels is paramount. Policymakers must adopt regulatory frameworks that incentivise sustainable practices, while transport authorities should be equipped with the technical and financial tools necessary to enact change. Secondly, capacity building is essential—not only for transport operators but also for supporting actors such as infrastructure managers and local communities. Training programmes, awareness campaigns, and multi-stakeholder partnerships will be vital to fostering a culture of sustainability.

Thirdly, consistent monitoring and evaluation must underpin all efforts. The strategy provides guidance on assessment and benchmarking methods that can support continuous improvement. Digital tools and data platforms will play a crucial role in enabling real-time tracking and transparent reporting of energy performance. In this context, the implementation of Energy Management Systems (EMS) emerges as a cornerstone of effective energy governance.

“An EMS is a set of management principles intended to identify, evaluate, monitor and reduce the negative environmental impacts of an organization’s activities. It benefits an organization by offering a systematic approach for assessing and controlling ongoing activities, increasing environmental awareness and complying with relevant regulations. EMS provides many different and useful tools for detecting, understanding, and managing the elements involved in its activities, products, and services that have the potential to impact the environment. The implementation of an energy management system is not an objective; what matters are the results of the system, which include energy performance improvement by anchoring attention to energy in daily practice. Whether an energy management system works depends on the willingness of the organization to manage energy use and energy costs and make the necessary changes to their day-to-day operations to facilitate these improvements and cost reductions.”

EMS not only facilitate the systematic collection, analysis, and interpretation of energy data but also provide structured pathways for setting objectives, verifying savings, and identifying inefficiencies across operational processes. Their adoption enables transport operators to move beyond ad-hoc improvements and toward a culture of continuous, data-driven optimisation. Furthermore, EMS support compliance with international standards such as ISO 50001, strengthening institutional accountability and enhancing credibility with stakeholders, including funders and regulators. By integrating EMS into their operations, transport entities can unlock greater energy savings, reduce greenhouse gas emissions, and build resilience against fluctuating energy costs and regulatory pressures. Moreover, pilot projects serve as vital testing grounds for innovative solutions, including EMS implementation, offering valuable feedback loops that inform broader policy and operational decisions.

Finally, the REDU-CE-D Strategy supports the implementation of the EU Strategy for the Danube Region (EUSDR), particularly in areas such as sustainable energy (PA2), environmental risk reduction (PA5), and institutional cooperation (PA10). By advancing integrated, cross-border solutions, the strategy fosters regional resilience and supports a just and inclusive energy transition.

In conclusion, the REDU-CE-D Strategy offers a forward-looking, actionable blueprint for transforming Central Europe’s transport sector into a low-carbon, energy-efficient system. It bridges policy with practice, combines strategic foresight with operational detail, and above all, places sustainability at the heart of mobility. As the transport sector embarks on this critical transition, the strategy stands as both a catalyst and a compass, guiding stakeholders toward a cleaner, more resilient future.

8.1. Policy recommendations

The REDU-CE-D Strategy identifies critical pathways to decarbonise the transport sector and reach the goals of the European Green Deal and the European Climate Plan across Central Europe. To effectively realise its vision, the following policy recommendations are proposed to support public authorities, policymakers, and sectoral stakeholders in implementing sustainable energy measures:

1. Institutionalise Energy Management Systems (EMS) Across Transport Modes

   Policymakers should prioritise the integration of Energy Management Systems (EMS) within all public and private transport operations. National and regional frameworks ought to incentivise EMS adoption through regulatory requirements and financial support mechanisms, including subsidies and tax relief for compliance with standards such as ISO 50001. Institutionalising EMS will establish a culture of continuous monitoring, verification, and optimisation of energy usage, thereby enabling more strategic, evidence-based decision-making.

2. Mandate the Use of Key Performance Indicators (KPIs) and Data Transparency

   The use of harmonised Key Performance Indicators (KPIs) should be made mandatory for transport operators, infrastructure managers, and local authorities. This data-driven approach will facilitate benchmarking and enhance accountability. Legislation should encourage transparent public reporting of energy consumption, emissions, and sustainability performance, supported by the deployment of digital platforms to enable real-time monitoring and centralised data collection.

3. Provide Targeted Funding for Sustainable Infrastructure and Innovation

   To overcome financial barriers and scale up successful pilot initiatives, targeted public funding should be allocated to sustainable transport infrastructure, including electrification, hybrid propulsion systems, renewable energy installations (e.g., photovoltaics), and smart logistics technologies. Calls for proposals should favour cross-border cooperation and innovative, replicable solutions aligned with REDU-CE-D's best practices. Dedicated funding instruments should also support retrofitting existing infrastructure for enhanced energy efficiency.

4. Enhance Technical Capacity and Human Resource Development

   The successful implementation of sustainable energy practices requires skilled professionals across all levels of the transport sector. Policymakers should develop national and regional programmes focused on capacity-building and vocational training in sustainable transport planning, digitalisation, and EMS management. Educational partnerships with academic institutions and the creation of professional certification schemes will be key to ensuring a qualified workforce capable of implementing complex energy transition strategies.

5. Integrate Sustainability into Public Procurement and Planning

   Sustainability criteria must be embedded into public procurement processes and strategic transport planning. Legislation should require public tenders to include environmental and energy efficiency benchmarks, thus incentivising suppliers and contractors to adopt greener practices. Urban mobility and regional development plans should explicitly align with climate and energy goals, integrating multimodal and low-emission transport options.

6. Facilitate Transnational Cooperation and Knowledge Exchange

   The transport energy transition must be approached as a transboundary challenge. EU Member States in Central Europe should be encouraged to formalise cross-border collaboration through intergovernmental working groups, joint investment schemes, and shared digital tools. Knowledge exchange platforms should be institutionalised to disseminate successful case studies and harmonise policy implementation across regions and transport modes.

7. Support Pilot Projects as Testbeds for Policy Development

   Pilot projects serve as critical experimental grounds for testing innovative energy solutions under real-world conditions. Policymakers should establish frameworks for the long-term monitoring and evaluation of pilot initiatives, ensuring lessons learned inform broader policy development. This includes mechanisms for scaling up successful pilots and adapting regulatory frameworks to accommodate novel technologies and business models.

8. Align Transport Energy Strategies with Broader EU Objectives

   National and regional transport policies should be harmonised with overarching EU frameworks such as the European Green Deal, Fit for 55 Package, and the EU Strategy for the Danube Region (EUSDR). Policymakers must ensure coherence between transport, energy, and climate policies, fostering integrated solutions that contribute to a just, inclusive, and regionally balanced energy transition.

8.2. Future of the REDU-CE-D project

Following the REDU-CE-D Conference, the project will enter a crucial phase focused on the practical testing and refinement of the customised Environmental Management System (EMS) support packages. Four pilot actions will be implemented across Central Europe—specifically in Croatia (air transport), Poland (urban transport), Hungary (waterway transport), and Italy (rail transport). These pilots will serve as the foundation for validating the EMS support tools tailored to each transport mode. Project partners will collaborate closely during this phase to evaluate the adaptability and efficacy of the developed packages, involving not only direct stakeholders but also external observers such as additional airports, port authorities, and urban mobility agencies.

Subsequent to the testing phase, the project will proceed with a comprehensive validation process through the Transnational Advisory Forum. This forum will synthesise insights gathered from the pilot activities and ensure the final EMS packages reflect the diverse needs of Central European transport systems. It will also play a strategic role in enhancing the packages' applicability and acceptance across different regulatory and operational contexts. These finalised EMS support packages will encapsulate strategic guidelines, monitoring tools, and key performance indicators tailored to each transport mode, thereby offering a scalable framework for energy efficiency improvements across the region.

The concluding stages of the REDU-CE-D project will focus on maximising uptake and transfer of the validated EMS support packages. This will be achieved through a series of targeted training sessions, awareness-raising campaigns, and lobbying efforts aimed at embedding these tools within both partner and external organisations. Roundtables involving transport authorities and policy-makers will be organised to facilitate institutional commitment and to explore pathways for incorporating the EMS frameworks into regional and national legislation. These activities are intended not only to promote adoption but also to build a durable legacy for the project by fostering a shared commitment to climate neutrality and energy transition in Central Europe's transport sector.

9. List of sources

During the elaboration of the REDU-CE-D strategy the partnership used the following sources:

- European strategic documents:
  - https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en
  - https://climate.ec.europa.eu/eu-action/climate-strategies-targets_en
  - https://danube-region.eu/about/priority-areas/
- The finished deliverables of REDU-CE-D project (where further references can be found):
  - D.1.1.1 - Assessment Grid for data collection
  - D.1.1.2 - Local assessment Reports
  - D.1.1.3 - Transnational assessment Report
  - D.1.2.1 - Methodology for selection of best practices
  - D.1.2.2 - Collection of best practices
  - D.1.3.1 - Transnational TWG follow-up report
  - D.2.2.1 - Guidelines for predefinition of EMS support packages
  - Transnational Communication Strategy for the REDU-CE-D project
- Measures of Chapter 4 were built on the own expertise and experiences of sectoral partners.