



Innovation in Transport Review

ISSUE#
4

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Welcome

Welcome to the 2025 edition of the INNOVATION IN TRANSPORT REVIEW from CIMNE’s transport innovation unit, CENIT. Since its creation in 2001 as a partnership between the Catalan Government and the Universitat Politècnica de Catalunya–BarcelonaTech, CENIT has been dedicated to finding sustainable and innovative solutions for transport and mobility. Over the past two decades, the transportation landscape has undergone significant changes, emphasising the increasing need for innovation, technology, and flexibility to create a sustainable model that protects the well-being of future communities and the environment.

In this issue, we present insights and findings from some of our recent research, focusing on topics such as electrification in public transport systems, how 5G can help European ports achieve climate neutrality, and the impact of future mobility trends on public transport financing.

Our Bali e-bus article highlights the role of a multidimensional feasibility study that assesses data-driven route selection and demand forecasting, vehicle and charging specifications, financial and institutional frameworks, procurement pathways, and risk management to deliver evidence-based recommendations for a pilot aligned with Bali’s mobility and environmental goals.

The Jakarta low-emission zone article provides insights on a phased, “learn and adapt” approach where early pilot areas deliver visible emissions and public-health benefits while informing parallel equity and economic-impact studies and guiding scaled implementation across the city.

CENIT’s involvement in PIONEERS is also featured, with an article on how the pilot at the Port Authority of Barcelona is testing 5G connectivity to support more precise vessel monitoring, improve maritime operations management, and contribute to emissions reduction.

At CENIT, we remain enthusiastic, dedicated and flexible as we continue to tackle one of the most significant challenges of the 21st century: delivering efficient, sustainable transportation to communities and equipping policymakers with research-driven knowledge.

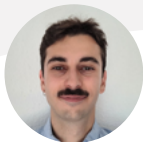
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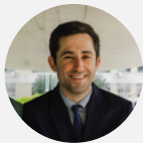
DR. SERGI SAURÍ MARCHÁN
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Dr. Sergi Saurí has been the Director of CENIT since 2013. He also serves as Associate Professor at the Department of Civil and Environmental Engineering of UPC-BarcelonaTech and President of the University Network RUIITEM (Ibero-American University Network of Territory and Mobility). He holds a PhD in Civil Engineering from UPC-Barcelona Tech, a Master's in Shipping Business from UPC-Barcelona Tech, and a Bachelor's in Economics from the University of Barcelona. He is currently a member of the Infrastructure Committee of Infrastructure Financing of the Professional Association of Civil Engineers of Catalonia and was previously a member of the Board Committee of this association. He also served as Assistant Professor in Transportation at UPC and Director of the Master's in Supply Chain, Transportation, and Mobility at the same institution. His PhD thesis on Optimisation of Regulation for Public-Private Partnerships in Container Port Concessions was awarded the IV Abertis Transport Infrastructure Management Award and he was a Visiting Scholar at the Massachusetts Institute of Technology (MIT) in 2008. An expert in the areas of transport modelling and transport economics, he is the author of a number of scientific publications and has led multiple projects in both the public and private sectors.



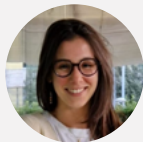
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Alex Mumbrú has a degree in Industrial Engineering from UPC – Polytechnic University of Catalonia, where he is currently pursuing a Master's degree in Civil Engineering with a specialty in Transportation Engineering. Currently, as a Trainee Engineer at CENIT, his areas of focus include transport policy and economic assessments at regional, national and international levels, performing cost-benefit assessments, and participating in projects such as the Bus Network Electrification Project in Fiji and the freight demand study for the northern region of Argentina. He is also involved in the HORIZON project RAIL4CITIES, focusing on green and socially inclusive urban development around railway stations. Alex also works as a Consultant for the Generalitat de Catalunya, focusing on cost-benefit assessments and transport planning.



GENÍS MAJORAL OLLER
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Genís Majoral is a Civil Engineer specialising in transport and urban planning from the Polytechnic University of Catalonia (UPC). He is a Researcher at the Centre for Innovation in Transport (CENIT) where his areas of specialisation are modelling, transport demand and transport economics. Currently, he is a PhD candidate in Civil Engineering at the UPC and studying for a Master's degree in Economic Research at the National University of Distance Education (UNED). He is also an Assistant Professor in Maritime Economics at the Tecnocampus of Mataró in Catalonia (UPF). In the field of transport modelling, he has contributed to updating the transport demand model for Catalonia (Department of Territory), developed mobility models for the Sustainable Urban Mobility Plan (SUMP) of Ankara, Türkiye, including an activity-based model (ABM), and updated a freight model for Argentina (CAF). In terms of transport economics, he has worked on the analysis of the financial statements and financial model of highway concessions (MITMA) and service areas, as well as financial models for the implementation of electric buses in Costa Rica (World Bank) or the evaluation of the impact of a tax on e-commerce deliveries (ATM) and the definition of financial aid for the digitalisation of road transport companies (passengers and goods, for MITMA). Other notable projects include Study on the potential future impact of 5G on ports and the development of the national maritime policy of Trinidad and Tobago (Government of the Republic of Trinidad and Tobago). Regarding electromobility, he has participated in the definition of business and financial models for mass implementation of e-buses in San José, Costa Rica, (The World Bank) and e-bus prioritisation for Fiji (GGGI). He is the author of the scientific articles (SCI) “Application of a Tax to e-commerce delivery in Barcelona.”; “Lessons from Reality on Automated Container Terminals: What Can Be Expected from Future Technological Developments?” and co-author of “Analysis of superblocks during the transition phase from traditional vehicles to a fully automated vehicle environment: A case-study of Barcelona City”.



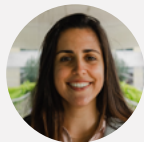
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Chiara Saragani is an Industrial Engineer from the *Alma Mater Studiorum* – University of Bologna, specialising in logistics, production systems, operations research and transportation. In 2022, she joined the Centre for Innovation in Transport (CENIT) as a PhD candidate, focusing on the digitalisation of the Port of Barcelona. During her undergraduate studies, Chiara spent a semester at *Instituto Tecnológico de Buenos Aires* (ITBA) in Argentina, deepening her knowledge of logistics and transportation systems. She went on to pursue her Master's degree at the University of Bologna, with an exchange semester at *École Supérieure d'Ingénieurs en Électronique et Électrotechnique* (ESIEE) in Paris. There, she completed her dissertation on distribution logistics and operations research, culminating in a Master's thesis titled: “*Crowd-shipping and Autonomous Vehicles: An Optimization Model for Last-Mile Delivery.*” Currently, as part of her PhD research in collaboration with the Port of Barcelona, Chiara explores cutting-edge technologies such as real-time monitoring systems, Digital Twins, and AI applications in port logistics, leveraging 5G connectivity. She is actively involved in the PIONEERS project, where she contributes to the development of several pilot initiatives. Her insights and findings are regularly shared through articles published in the *PierNext* newsletter.



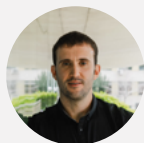
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Matteo Boschian Cuch holds a Bachelor's degree in Aerospace Engineering and a Master's in Mobility Engineering from the *Politecnico di Milano*. He joined the Centre for Innovation in Transport, CENIT, in 2023 as PhD candidate in Transport and Sustainable Mobility in the port sector at the Port Authority of Barcelona. During his Bachelor's degree, he gained a foundational understanding of the aerospace sector, acquiring essential technical skills and knowledge. In his Master's program, he expanded his expertise to the mobility sector, studying various aspects such as the technical requirements of transportation systems, their environmental and social impacts, transport assignment models, and the financing of transport infrastructure. During his studies, he had the opportunity to participate in academic projects in collaboration with major companies in the Italian mobility sector. His Master's thesis focused on Cost-Benefit Analysis and transport appraisal techniques. At CENIT, Matteo specialises in the maritime sector, specifically in ports. His PhD research focuses on the sustainability of the transport sector related to ports, with two interconnected areas of study. He works on intermodal transport, contributing to the development of the Multimodal Observatory of MEDports, while also focusing on road traffic by designing and implementing a model to calculate emissions from road vehicles visiting the port. Additionally, he has participated in several CENIT projects for international clients, focusing on port management models, regulatory assessments impacting ports, and exploring alternative fuels for the maritime sector.



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Clara Soler Bañuelos is a Civil Engineer. She obtained her Bachelor's degree from the Polytechnic University of Catalonia and obtained her Master's double degree with the Illinois Institute of Technology specialising in Transportation Engineering. Prior to starting her PhD, she worked as an Associate Project Manager in a construction project for Ferrovial in Atlanta, Georgia. She is currently developing her PhD with the *Autoritat del Transport Metropolità de Barcelona* on the topic of sustainable and resilient financing models for public transportation. Research topics include identifying key trends in future mobility and analyzing how these will affect the funding of public transport; maximising revenue by assessing new funding sources and adjusting fare policy; studying the most appropriate mix of revenue sources to ensure long-term sustainability; modelling the costs of public transport and analysing the resilience of the funding model.



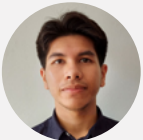
PACO GASPARÍN CASAJUST
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Urban Mobility and Freight Transport

Paco Gasparín is a graduate in Statistics from the University of Barcelona (UB) and from the Polytechnic University of Catalonia (UPC). He also completed a Master's degree in Statistics and Operations Research from UPC, specialising in Operational Research, with his thesis focusing on the “Analysis of mobile phone data for modelling transport demand.” His areas of expertise include data analysis, advanced statistical methods, mathematical modelling and operational research. He joined CENIT in 2018 as a Researcher in the Urban Mobility and Freight Transport department, working on mobility and freight transport projects at national and European level.



TOMAS ALFREDO HENRIQUE GILARRANZ
Researcher. Sustainable Transport Transitions

Tomas Henriquez is a Computer Scientist (BSc Georgia Institute of Technology (USA)) and a Sustainable Transport Transitions Scientist (MSc Universitat Politècnica de Catalunya (ES), MSc Eindhoven University of Technology (NL)) working as a Researcher at the Centre for Innovation in Transport (CENIT). At CENIT, Tomas has mainly focused on the development of activity-based transport demand models (ABM) for the planning of sustainable urban mobility transitions. Most recently, Tomas has worked on the translation of an existing activity-based model from a US context to a Turkish context to support the development of a sustainable urban mobility plan (SUMP) in Ankara, Türkiye. Prior to joining CENIT, Tomas worked on and led many transport and non-transport related initiatives in European and North American contexts. Tomas worked to develop a tool to estimate the feasibility and potential savings of transitioning existing lines to or operating new lines as autonomous electric vehicle fleets and designed and programmed the UI/ UX for the tool. Additionally, Tomas helped to define a strategy and policy objectives for public and road safety for the city of Atlanta and led the development of a centralisation and expansion strategy for the housing non-profit Habitat for Humanity. Tomas also led various software implementations in the public sector, including enterprise resource planning (ERP) software rollouts and cybersecurity design and management. Tomas has worked for large enterprises such as Microsoft and Accenture, taking on a variety of roles in strategy, management, and technology consulting. His focus has been and continues to be to help the public sector adapt to and get ahead of big technological and societal changes. In the latest iteration of his career, Tomas focuses on leveraging cutting-edge technologies to develop strategies and ease the burden on sustainable transportation transitions for public and private sector as they answer societal pressures and aim to mitigate transportation's impact on climate change.



MULIA ANDREAS PASARIBU
Transport and Urban Mobility Specialist

Mulia Andreas Pasaribu is a Civil Engineer with two Master's degrees in Urban Mobility from the UPC – Polytechnic University of Catalonia and in Transport, Mobility, and Innovation and the KTH Royal Institute of Technology. He also holds a degree in Civil Engineering from the Bandung Institute of Technology (ITB). Currently, he is a Researcher at the Centre for Innovation in Transport (CENIT) in Barcelona, where he applies his skills in Python and GIS tools such as QGIS and VISUM to analyse and model urban transport systems. His recent project involves developing an Activity-Based Model for Ankara, Türkiye. Previously, Mulia worked at the Institute for Transportation Development and Policy (ITDP) Indonesia in Jakarta as a Transport Engineer Assistant. There, he co-wrote the Inception Report of the E-mobility Implementation Roadmap for Indonesia's Public Transit Program (UK PACT) and collaborated with ITDP China on designing transport infrastructure projects for the city of Bandung.



EVGENII PRONIN
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Evgenii Pronin earned his Specialist degree in Vehicle Engineering from Bauman Moscow State Technical University in 2013. Currently, he works as a Transport Researcher at CENIT – CIMNE in Barcelona, Spain, where he focuses on advancing research in transport modeling and analysis. Prior to his current role, Evgenii worked as a Senior R&D Consultant at Moscow Metro from 2021 to 2024, where he contributed to the development of innovative transport solutions and optimisation strategies for urban transit systems. Earlier in his career, Evgenii held various roles at MosTransProekt, progressing from an Analyst to Deputy Head of Department between 2014 and 2021. During this time, he managed transport projects, developed transport models, and led teams in analyzing and improving transport infrastructure. His expertise also extends to teaching, having delivered a course at the Higher School of Economics in Moscow, focusing on developing city transport service schemes for Russian regional cities.



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Arnau Sedeño is an Oceanographic Engineer. He began his academic career studying Marine Sciences and Technologies, completing international semesters at the Autonomous University of Baja California (Mexico) and the Norwegian University of Science and Technology (NTNU). He later returned to Barcelona, where he obtained a Master's degree in Oceanography and Marine Environment Management. His master's thesis, carried out at the Institute of Marine Sciences (ICM-CSIC) in 2024, focused on assessing marine lobster stocks by training an artificial intelligence model to automatically count individuals using ROV-based imagery. He has taken part in scientific expeditions across the Mediterranean, the Atlantic, and the Arctic, contributing to studies on water mass characterization, satellite calibration, and the determination of Arctic sea-ice thickness (banquise), among other research activities. In 2025, Arnau joined the Centre for Innovation in Transport (CENIT) as a PhD candidate, in collaboration with the Port Authority of Barcelona, focusing on the Blue Economy. His research adopts a holistic perspective on the sectors and subsectors of the blue economy, analyzing their interconnections and evolution at local, national, and global scales to advance understanding and foster sustainable growth in ocean-related economic activities. Parallel to his academic and research work, Arnau has a longstanding background in the recreational nautical sector, having been sailor and coach for over ten years. He remains closely linked to the maritime community and is an enthusiast of various water sports such as diving and fishing. At the innovation department of the Port of Barcelona, he contributes to the development of the Blue District of the Port of Barcelona, providing technical support to startups and strengthening the innovation ecosystem that enables blue economy hubs to accelerate their projects and promote a more sustainable, digital, and resilient port model.

Bali Feasibility Study on E-buses

BY MULIA ANDREAS PASARIBU, EVGENII PRONIN AND GENIS MAJORAL

Electromobility in public transport is rapidly gaining momentum in Indonesia, driven by the Government's vision for greener mobility. Presidential Regulation No. 55/2019 marks a key milestone by promoting the adoption of battery-electric vehicles, including buses, as an essential part of a low-emission transportation future.

However, current market penetration remains limited, and policy frameworks still require reinforcement to ensure accelerated uptake.

In Bali, where over **4.3 million residents rely heavily on motorcycles and private vehicles**, nearly matching the number of registered vehicles to inhabitants, **traffic congestion and pollution are serious concerns**.

Trans Metro Dewata and Trans Sarbagita are the main public bus operators in Bali, providing essential but still limited coverage across the island. While services are affordable and connect key areas, restricted hours and reach hinder their full potential.

Meanwhile, growing public interest in e-mobility, boosted by the 2022 G20 Summit and EV-exclusive zones, has brought strong momentum for electrification. To meet Bali's mobility and climate goals, expanding and electrifying bus services is crucial. With national support, international finance, and PPP models, **the island has a real chance to build a cleaner, more accessible public transport network**.

CENIT's role

As part of the broader effort led by the Government of Indonesia and GGGI (Global Green Growth Institute) to accelerate electric vehicle adoption, CENIT - Innovation Unit in Transport at CIMNE - contributed to the feasibility study on e-bus implementation in Bali. CENIT formed a consortium with HATCH and Bali-based local partners Professor Alit Suthayana and Yudi Arsawan.

The study, supported by the Republic of Korea, aimed to assess the **techno-operational, economic, and institutional viability of deploying electric buses and charging infrastructure in the province**. CENIT's role focused on identifying suitable pilot routes, vehicle and charger specifications, and developing financial and Institutional schemes to support an inclusive and scalable transition towards sustainable public transport in Bali.

The project was structured around several key phases: data collection and analysis of Bali's public transport system, development of a demand forecasting model, a multi-step route selection process including Multi-Criteria Analysis (MCA); an E-bus and charging stations market assessment; the development of financial and institutional schemes; procurement and asset transfer planning; environmental benefit analysis; an assessment of potential feeder systems; and a comprehensive risk assessment to support implementation.

Route selection

During the data collection and preprocessing, relevant information was gathered from open sources and local stakeholders, including government agencies and transport operators. This included transport system data, demographic trends, and operational figures. Where gaps existed, targeted field surveys were carried out. The data was validated and contextualised with the support of local expert Dr. Putu Alit Suthanaya, ensuring alignment with on-the-ground conditions in Bali.

One of the key factors for successful e-bus deployment is, undoubtedly, passenger demand. To establish a reliable tool for assessing potential ridership, a predictive model was developed. The process began with a GIS-based estimation of building-level population using disaggregated demographic data. Catchment areas around existing bus stops were then defined using 700-metre buffers to assess accessibility. A multiple regression model was subsequently built to predict passenger demand, incorporating inputs such as population, POI coverage, trip frequency, and current ridership data. The resulting model achieved a high explanatory power ($R^2 = 0.88$), providing a robust analytical foundation for identifying the routes with the highest potential for e-bus deployment.

The selection of a suitable route for electric bus deployment in Bali was conducted through a structured multi-step process (Figure 1). The initial phase involved a preliminary multi-criteria analysis aimed at identifying routes with baseline feasibility for e-bus integration. This step highlighted Trans Sarbagita corridors as the most promising due to their connectivity, existing infrastructure, and operational readiness.

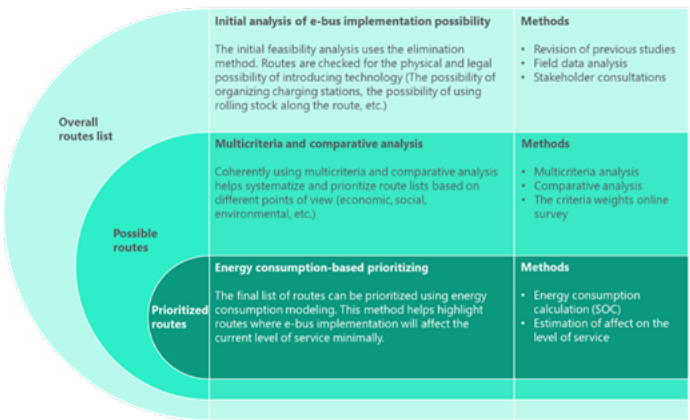


Figure 1. Multi-step route selection process

In the second phase, two Trans Sarbagita routes and five adjusted variants were proposed to meet specific goals, such as expanding service coverage and improving access to tourist destinations. These options were evaluated during a stakeholder workshop (Decision Point 1), resulting in four shortlisted routes for detailed analysis.

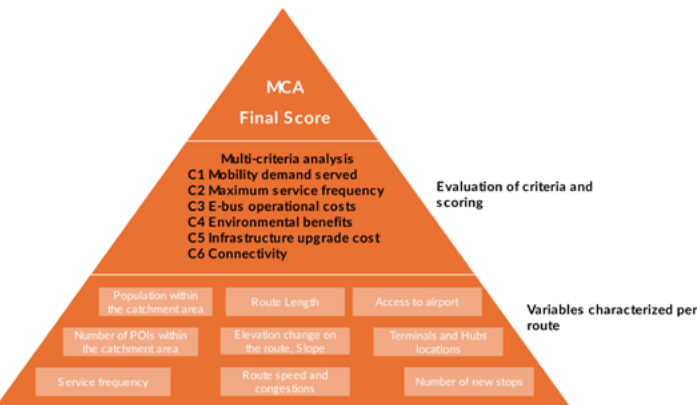
A refined multi-criteria analysis was then applied, using six key indicators derived from operational, technical, demographic, and environmental considerations (Figure 2). Weights for each criterion were informed by a stakeholder survey to ensure alignment with local priorities. The selected criteria provided a robust basis for final route selection, balancing practical constraints with policy and service objectives.

To support the main route and ensure more inclusive, widespread coverage, six feeder lines were also designed. Five target densely populated areas currently underserved by public transport, while one connects an electrified route to Garuda Wisnu Kencana Cultural Park, a major tourist attraction. These feeders are planned with synchronised headways to minimise transfer times and extend service reach, thus enhancing the pilot's overall catchment area and potential ridership.

Electric buses and charging stations market assessment

As part of the e-buses and charging stations market assessment, the study evaluated the technical requirements. Given Bali's narrow streets and frequent turning patterns, mini electric buses (<10 m) from a single manufacturer were recommended to ensure manoeuvrability, streamline maintenance, and enable parts standardisation. Charging needs were estimated based on energy consumption along the selected pilot route and its specific operational characteristics. The proposed configuration includes two 100 kW overnight slow chargers at the depot, sufficient to serve five operational buses and one spare, and three additional 100 kW chargers installed at a layover point to enable opportunity charging during midday and peak-hour breaks.

Figure 2. The final prioritisation of routes is carried out based on a large number of parameters



Financial and institutional modeling scenarios

As part of the development of financial and institutional schemes, the study examined several operational scenarios for electric bus deployment along the selected route. These ranged from maintaining the current service frequency to introducing a fleet of nine e-buses operating at maximum feasible service levels—30-minute headways during the day and 20-minute intervals during peak hours. For each scenario, a State of Charge (SoC) profile was developed to assess battery performance and energy requirements throughout the service cycle (Figure 3). In parallel, comprehensive calculations of both capital and operational expenditures (Figure 4) were conducted to evaluate the financial implications of each scenario. This analysis aimed to provide the Bali government with a clear understanding of the costs associated with various pilot implementation options, supporting informed decision-making on future investment and service planning.

An equally important component of the study was the development of an institutional scheme to govern the electrified route (Figure 5). This framework mapped out the roles and responsibilities of all stakeholders involved in the planning, operation, and maintenance of the e-bus system—including government agencies, transport operators, energy providers, and regulatory bodies.

Figure 3. State of charge of the nine buses during the whole day.

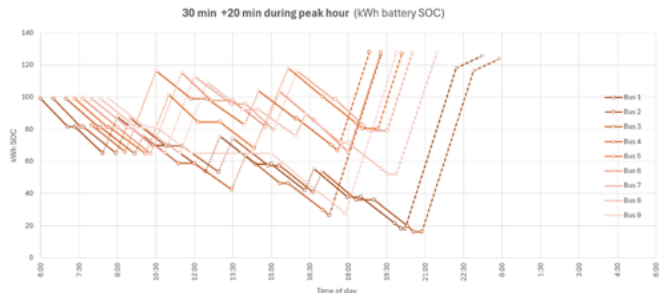


Figure 4. Operational expenditures for the 5 scenarios implementation

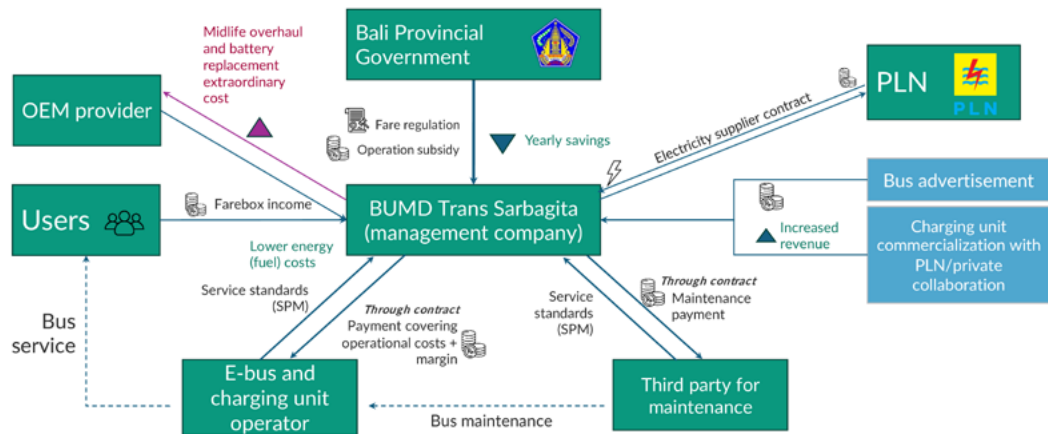
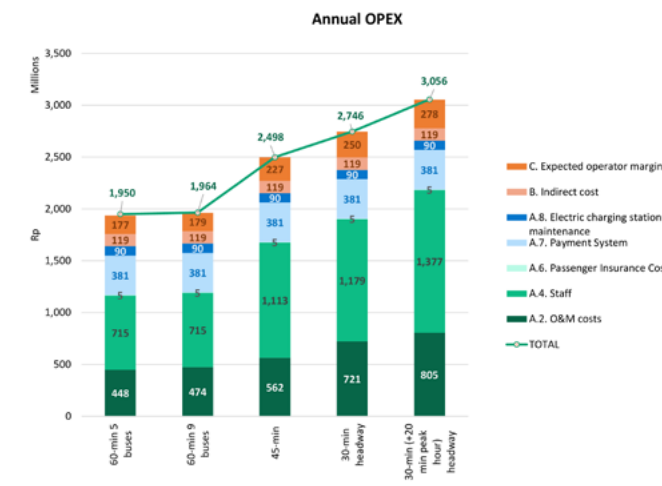


Figure 5. The projected operational model of E-buses by BUMD Trans Sarbagita. Clarification: OEM meaning Original Equipment Manufacturer.

Final steps: Procurement and asset transfer analysis and risk assessment

The procurement strategy ensures that e-buses and chargers are acquired through a direct grant from GGGI, following Indonesian regulations and GGGI policies. A main contractor will manage procurement, logistics, and compliance, including tax exemptions and customs. Asset transfer will occur in three phases: initial delivery under GGGI, formal transfer to the central government, and final handover to the Bali government for operation and maintenance.

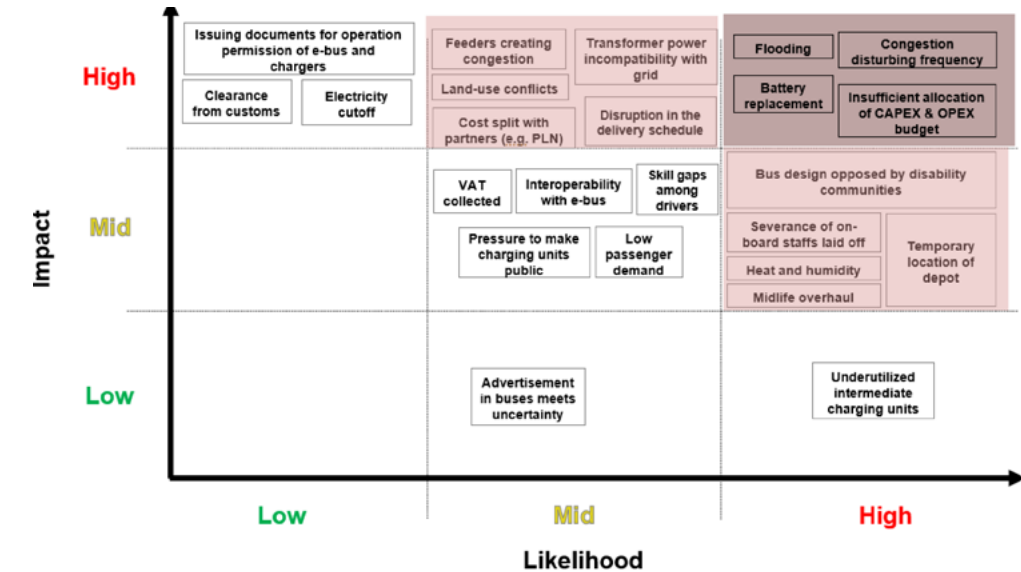
The risk assessment identified and ranked key risks by their impact and likelihood, highlighting flooding, battery replacement, and congestion as the most probable and critical (Figure 6). Mitigation measures were then proposed to minimise these risks and ensure reliable e-bus operations.

Project summary

In conclusion, this comprehensive feasibility study offered a robust and multidimensional assessment of electric bus deployment in Bali. From data-driven route selection and demand forecasting to detailed analysis of vehicle specifications, charging infrastructure, financial and institutional frameworks, procurement pathways, and risk management, the research provided a holistic foundation for implementation. The findings highlight not only the technical and economic viability of the proposed e-bus pilot but also its alignment with Bali's environmental and mobility goals. By addressing local constraints and engaging stakeholders throughout the process, the study equipped the Bali government with practical, evidence-based recommendations to guide future investments in sustainable urban transport.

This feasibility study was the last step before starting the procurement and operation of electric buses, expected to arrive in 2026. This work was curated and engaged by GGGI to become a reference for future fleet electrification projects.

Figure 6. Risk mapping



How future mobility trends could reshape public transport financing

BY CLARA SOLER BAÑUELOS

Urban public transport systems are under increasing pressure to deliver accessible, low-emission mobility while navigating chronic funding constraints. In many cities, fare revenues cover only a portion of operating costs, and large-scale investments depend heavily on public subsidies. These financing challenges are not new – but they are evolving fast.

A growing set of structural trends, from vehicle electrification and climate adaptation to demographic change and digitalisation, is redefining how transport systems are used, delivered, and funded. While many of these trends have been analysed in isolation, their combined impact on public transport financing remains largely unexplored.

To address this gap CENIT developed an **integrated assessment framework to identify and prioritise key mobility trends and understand their structural impact on cost, demand, and financing mechanisms**. The study combines a systematic literature review, expert-based prioritisation using a fuzzy Analytic Hierarchy Process (AHP), and a system dynamics model to visualise interdependencies and feedback loops.

Understanding the financial foundations of public transport

Urban transport systems are typically financed through three main channels: fare and commercial revenues, dedicated taxes or charges, and public subsidies. Most systems remain structurally underfunded. According to international benchmarks, farebox recovery ratios for public transport operators range from 40% to 60%, leaving significant gaps in capital and operating budgets.

At the same time, cities are facing long-term shifts in demographics, travel behaviour, vehicle technologies, and environmental pressures. These shifts affect both the cost structure and the revenue base of public transport systems. For instance:

- Ageing populations may increase demand for accessible transport but also reduce fare revenue due to concessions.
- Vehicle electrification reduces emissions and long-term operating costs, but requires high upfront investment.
- Digitalisation improves service quality and efficiency but raises questions about infrastructure, data management, and governance.

The question is not whether these trends will affect public transport finance – but how, and to what extent.

Mapping trends: From literature to expert validation

The first step was to compile a comprehensive list of trends affecting urban mobility. A systematic literature review covering over 140 peer-reviewed articles and technical reports identified 17 relevant trends, grouped into five domains:

- **Demographic** (e.g. ageing population, decline in youth car ownership)
- **Economic** (e.g. carsharing, e-commerce, sustainable finance)
- **Environmental and resilience-related** (e.g. electrification, health crises, natural disasters)
- **Technological** (e.g. ICT, AI, autonomous vehicles)
- **Mobility-related** (e.g. on-demand services, micromobility, multimodality)

To validate and prioritise these trends, a fuzzy Analytic Hierarchy Process (AHP) was conducted through a structured expert survey. The fuzzy AHP method allows for subjective expert judgments under uncertainty by converting linguistic preferences into triangular fuzzy numbers and calculating relative importance.

Out of 70 invited experts, 59 valid responses were collected, primarily from public transport operators, research centres, and urban mobility agencies. The results yielded the following top five trends:

1. Ageing population
2. Information and Communication Technologies (ICT)
3. Vehicle electrification
4. Natural disasters (climate-related)
5. Multimodal mobility

These trends were identified as the most likely to affect long-term financial sustainability through their combined effects on demand, operational cost, investment needs, and externalities.

System Dynamics: Visualising Interdependencies

To complement trend prioritisation, a qualitative **system dynamics model** was developed to map how these trends influence core transport variables. The model is structured around two main subsystems: **public transport (PT)** and **private vehicle (PV)** use, linked by modal shift dynamics and shared externalities such as emissions and congestion. It can be seen in Figure 1.

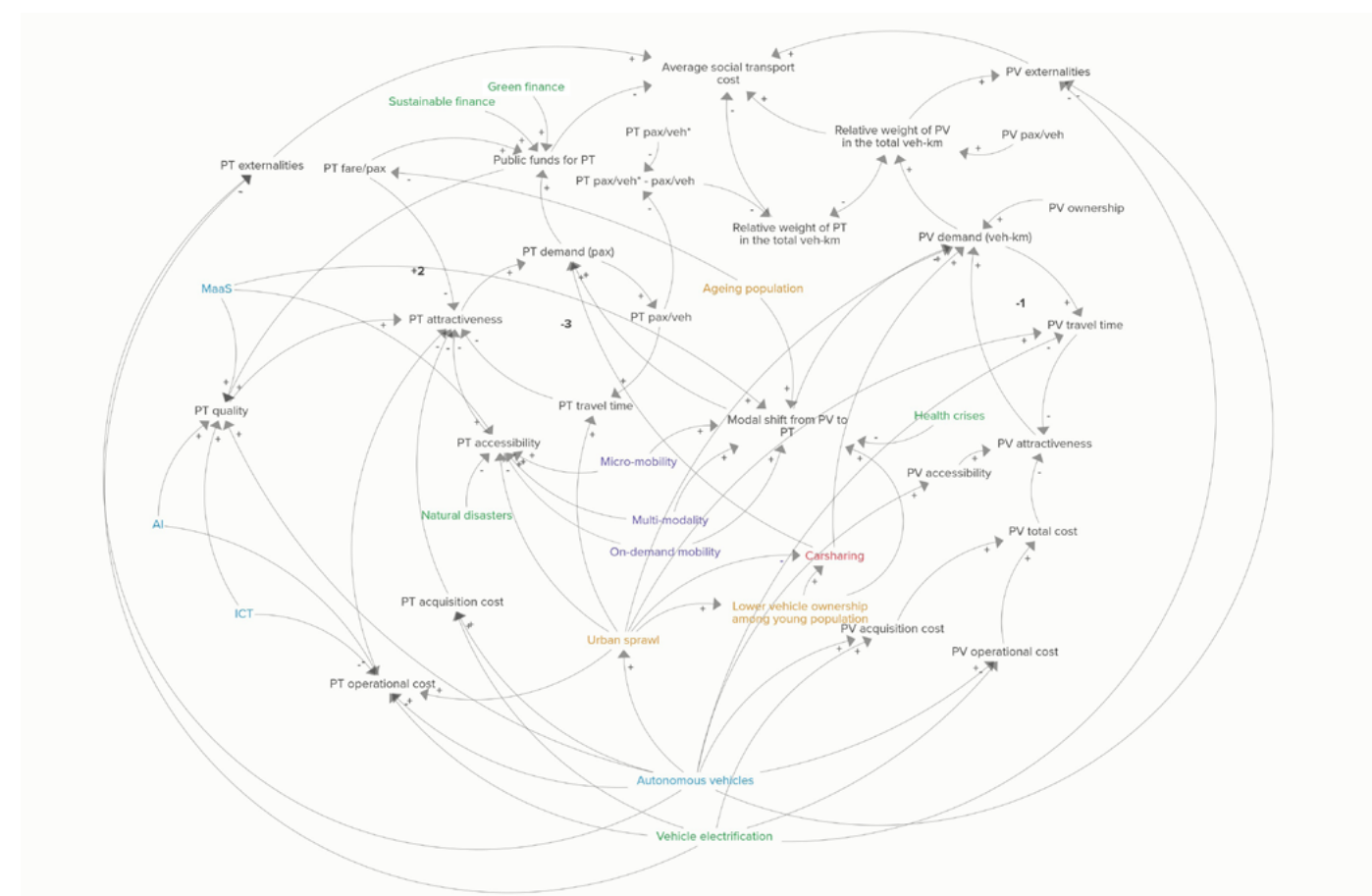
At the centre of the model is the average social transport cost – a proxy variable encompassing user costs, public expenditure, and social externalities. Three key feedback loops are highlighted:

- **Loop 1: Congestion feedback** – Increased PV use leads to congestion, lowering travel speed and discouraging further PV uptake (balancing effect).
- **Loop 2: PT reinvestment loop** – Improved PT quality increases demand, which enhances political support and unlocks investment (reinforcing loop).
- **Loop 3: PT capacity loop** – Higher PT demand may cause crowding and longer travel times, reducing attractiveness unless system capacity scales accordingly (balancing loop).

The influence of each trend was then mapped against these loops. For example:

- **ICT and AI** improve PT efficiency and service quality, reinforcing demand and enabling reinvestment (Loop 2), but may trigger crowding (Loop 3) if capacity isn't expanded.
- **Electrification** reduces operational costs and emissions, positively affecting both user costs and externalities – though it may increase acquisition costs.
- **Natural disasters** disrupt PT accessibility, weakening demand and public confidence in the system, and thereby affecting long-term funding reliability.

Figure 1. System dynamics model



Strategic implications for financing models

The study's integrated framework highlights the importance of understanding not only the scale of a given trend, but its position in the wider system.

- Trends like **ageing** and **multimodality** have strong systemic effects but may weaken the financial link between demand and revenue if fare structures are not adapted.
- **Digital and green technologies** offer opportunities for cost efficiency and service improvement, but their deployment requires upfront investment and new governance models.
- **Resilience-related risks**, such as health crises or extreme weather, require flexible funding mechanisms that can respond to disruptions without compromising service continuity.

This suggests that future-proof financing models must balance **predictable revenue streams** with **adaptive policy tools** – such as dynamic fare policies, climate finance instruments, and performance-based subsidies.

Conclusion and next steps

As mobility systems evolve, so too must the way we think about financing them. Public transport authorities will need to navigate an increasingly complex landscape where demographic, technological, and environmental shifts interact in unexpected ways.

This research provides a structured tool for anticipating these interactions. By combining expert prioritisation with system modelling, it helps policymakers visualise which trends carry the most financial risk – and where intervention could have the most impact.

Future work will focus on stress-testing financing models under combined trend scenarios, and exploring quantitative extensions of the system dynamics model to support long-term planning under uncertainty.

Health crises like the COVID-19 pandemic require flexible funding mechanisms that can respond to disruptions without compromising service continuity.



KRE-T Jakarta: Revolutionizing urban sustainability through integrated Low Emission Zones

BY TOMI HENRIQUEZ AND STEFANO BRAGA

Jakarta, a vibrant metropolis of over 10 million, faces the dual pressures of air pollution and rapid urbanisation. **Chronic congestion, frequent flooding, and persistent social divides make clear the need for transformative approaches that can improve urban health, climate resilience, and the overall quality of life.**

The **Kawasan Rendah Emisi Terpadu (KRE-T)**, or Integrated Low Emission Zone initiative, is a flagship of the Breathe Jakarta program, itself part of C40's Breathe Cities initiative. At the heart of the project is a unique partnership between CENIT, CIMNE's transport innovation unit, Techne Praxis – a Jakarta-based team that ensures local knowledge and vital networks on the ground, C40, and Jakarta's government.

Importantly, this initiative is being developed in tandem with two other major studies: an Equity and Inclusion Assessment & Strategy and a Cost-Benefit Analysis (CBA), each led by separate expert organisations. These parallel efforts are deeply interlinked, with KRE-T analysis shaping, and being shaped by, both the equity findings and the CBA, guaranteeing a cross-pollination of research, strategy, and local priorities.

While low emission zones are traditionally limited to transport sector interventions, KRE-T is not limited by traditional, single-sector boundaries. Instead, it envisions true integration across interconnected domains:

- **Transport:** Fostering cleaner, safer public and active mobility.
- **Built environment:** Upgrading energy efficiency and resilience in housing, commercial spaces, and infrastructure.
- **Green and blue infrastructure:** Expanding access to parks, water management systems, and nature-based solutions.
- **Waste and resource management:** Promoting circular models and cleaner neighbourhoods.
- **Governance and equity:** Centering vulnerable communities and building robust, participatory institutions.

Rather than focusing only on emission cuts, KRE-T's integrated approach targets lasting advances in public health, climate resilience, and social inclusion across Jakarta, with interventions that will reduce air pollution and create a more livable and more resilient city.

Site selection using geospatial multicriteria analysis.

Pilot sites were selected through a rigorous geospatial multicriteria data analysis. This approach allowed the team to objectively weigh environmental, social, and urban indicators across the various relevant sectors to recommend the zones with the highest potential impact and highest viability for KRE-T interventions.

Stakeholder validation through in-person workshops.



Findings and proposed solutions were not developed in isolation. Instead, CENIT and partners organised two in-person workshops, bringing city officials, community representatives, and NGOs together. These engagements ensured that technical recommendations were stress-tested and refined in light of the lived realities, challenges, and ambitions of local stakeholders. Quantitative analysis was supplemented with qualitative observations, as stakeholders used physical maps and specific measures to envision how a KRE-T pilot might look at each recommended location based on its unique characteristics.



Workshops in Jakarta led by the CENIT team brought stakeholders together

Dynamic framework for Transformation

Leveraging this analytical foundation, CENIT developed a highly adaptable KRE-T framework in which strategies are bundled at the zone and neighbourhood level, prioritizing interventions that reinforce one another; planning is phased to balance immediate wins with deep, lasting change; digital monitoring, data sharing, and transparent evaluation are embedded at every step; equity and public participation are not afterthoughts, but key design drivers.

KRE-T positions Jakarta to demonstrate practical progress on emissions, public health, and institutional reform, with early pilot areas aiming to deliver visible benefits within a few years. Lessons from existing related projects throughout Jakarta will guide the phased scaling of KRE-T and help inform parallel studies in equity and economic impact. This dynamic “learn and adapt” model helps ensure that both technical outcomes and community priorities advance hand-in-hand.

KRE-T is charting a new course not only for Jakarta, but also for megacities throughout the world, particularly in the Global South. By merging global best practices with rigorous local engagement, and by intertwining its work with parallel studies in equity and economic feasibility, this initiative offers a holistic blueprint for sustainable, equitable, and resilient urban transformation.

Participants at the second workshop

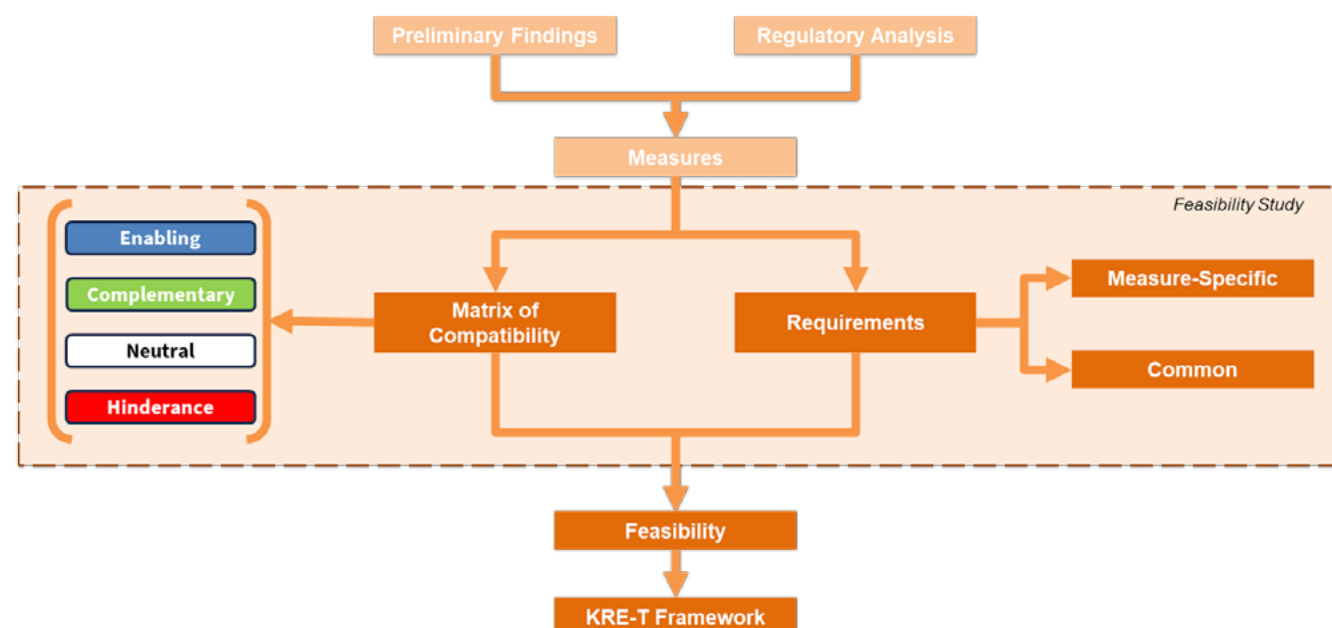


Figure 1. Building of the feasibility analysis and KRE-T framework.

Maritime 5G for intelligent vessel location

BY CHIARA SARAGANI

The **Maritime 5G** pilot is part of the **European-funded PIONEERS project**, developed in the **northern zone** of the **Port Authority of Barcelona**. This northern zone is characterised by its **heterogeneity**, as it accommodates a **diverse range of vessels**. Specifically, it is utilised by **ferries** operating from the **Grimaldi terminal**, while the **opposite side** of the area is home to a **yacht marina**. **Leisure boats** regularly navigate through this zone to reach the **old section of the port**, where their **berths** are located.

Additionally, during the pilot's development, the **America's Cup (AC)** took place at the **Port of Barcelona**, with the **AC bases** temporarily occupying the **same area**.

To enhance **environmental monitoring**, the Port Authority of Barcelona relies on two primary technologies to track vessel manoeuvres: **AIS** and **RADAR**.

The first, **AIS (Automatic Identification System)** functions similarly to **GPS for vessels**. It is a **maritime communication system** that transmits a vessel's **position, speed, and navigational status** at regular intervals. However, for **leisure boats**, AIS is generally **not mandatory**, although regulations may vary depending on the **country** or **specific waterways**. Furthermore, AIS does **not deliver continuous updates**, typically broadcasting data every **2–3 seconds**.

In contrast, the **RADAR system** faces challenges in providing **comprehensive coverage**, especially due to **physical obstructions** such as **buildings**, which can interfere with detection. Moreover, the **accuracy** of vessel location data via RADAR is often **suboptimal**.

In summary, the **current monitoring system** does **not provide precise, real-time information** on vessel activity within the **port's boundaries**.

To enhance the current **geolocation system**, the **5G Maritime project for Intelligent Vessel Location** introduces a **novel multi-camera technology** designed to deliver **more precise and real-time information**. This innovative solution is composed of three core components: an **AI algorithm**, **5G connectivity**, and a **network of cameras**. The AI algorithm leverages multiple cameras to detect key points on vessels—specifically the **stern, bow, and a central reference point**. This real-time data is transmitted to an **interactive dashboard**, which offers a comprehensive view of the monitored area and all active vessels. The AI system identifies and sends **critical information** such as the **type of vessel, direction, velocity**, and coordinates to the system which controls the final dashboard, in order to show data to the final user.

All components are interconnected through **5G**, enabling **low latency** and **high-quality service**, which significantly enhances system responsiveness and data accuracy.

The **dashboard** not only displays the **active cameras** within the system but also **differentiates between various vessel types** navigating the area. Additionally, it integrates **multiple GIS (Geographic Information System) layers**, enriching the spatial data and allowing for **context-aware monitoring**.

In conclusion, the adoption of a **more precise vessel monitoring system** within the **port's boundaries** will support **improved maritime operation management** and contribute to **emission reduction**. By optimizing **manoeuvring processes**, the system helps eliminate **inefficient operational time**, promoting a **greener and smarter port**.

Following the **development of the pilot**, a **calibration phase** was conducted to evaluate the **accuracy and precision** of the AI algorithm. Based on the collected data, the following **key findings** were observed:

- The **relative error** remains fairly **consistent** and does **not increase significantly with distance** for **Cameras 0 and 4**, which are installed at a **sufficient elevation**.
- While the **relative error** is generally **low**, over **long distances** it can still lead to **deviations of several tens of metres**, potentially making the system **unsuitable** for use in **areas requiring high precision**.
- Despite the **short footage** recorded by **Camera 2**, it clearly showed a **higher margin of error**. This is likely due to its **lower mounting height**, resulting in a **narrower field of view**. The **error increases** as the **observed point** moves farther from the camera.
- Although only **four frames** involved **data fusion** between **Cameras 4 and 2**, the system was able to **successfully resolve the vessel positions** by selecting data from the camera in which it had **greater confidence**—in this case, **Camera 4**.

Overall, the **pilot project successfully demonstrated the feasibility and benefits of using 5G technology and AI for real-time vessel monitoring** in a port environment. The results highlighted the importance of collaboration between different stakeholders and the potential for future improvements and expansions. In summary, the **key data reported** from the pilot are as follows:

- **More than 25 vessels were detected** simultaneously during the AC.
- The area, covering approximately 396 square metres, was **monitored by 5 cameras**. The system successfully processed an average of **292 requests per minute, 12,437 per hour, and 171,082 per day**.
- There was **no significant difference in latency** between 5G and fibre optic with 4K camera resolution streaming.
- **A frame rate of 3-4 fps** was necessary to ensure accurate vessel detection.
- **The relative error is constantly around 2%** independent of the distance of the camera relative to the object to be detected. For example, with a distance of 1000 metres from the camera, the position of the detected vessels has an error of 20 metres at most.

The implementation of the decision-making system based on vessel location at the Port of Barcelona has demonstrated significant improvements in maritime operations. The **key findings** from the pilot project are as follows:

- 1. Enhanced safety and efficiency:** The visual assistance for pilots and RADAR assistance with tablets can significantly improve the precision of manoeuvres and reduce the possibility of accidents. This leads to safer and more efficient operations within the port.
- 2. Reliable connectivity:** The new 5G connection has provided reliable and continuous operability, minimising downtime during both expected and unexpected stops. This has ensured smooth and uninterrupted new communication methods between vessels and port authorities.
- 3. Flexibility and scalability:** The system's architecture has proven to be flexible and scalable, allowing for easy adaptation to technical updates and future expansions. This ensures that the system can meet the growing demands and incorporate new functionalities as needed.

A view of the World Trade Centre at the Port of Barcelona and part of the yacht marina.
Source: BCN Port Innovation Foundation



Towards a New European Maritime Era

BY ARNAU SEDEÑO GOMEZ

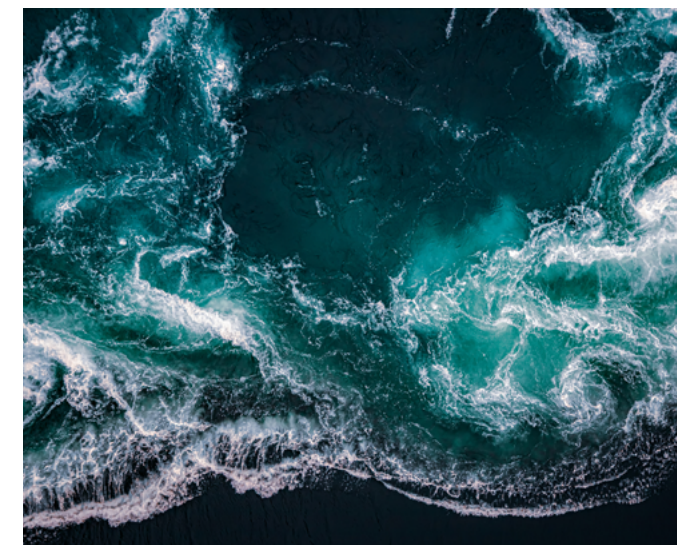
On 5 June 2025 the European Union presented the European Ocean Pact, a common strategy to accelerate the sustainable development of Europe's coastal and maritime areas and to address mounting pressures such as climate change, pollution and the over-exploitation of marine resources.

The importance of this pact can be better understood with some key facts about the European maritime environment:

- The EU has about 70,000 km of coastline, and 40% of its population lives within the first 50 km of the sea.
- The Blue Economy (all activities linked to seas and coasts) generates 5 million jobs and more than €250 billion in gross added value annually in the EU.
- 74% of EU foreign trade is carried out by sea, and 99% of global internet traffic is transmitted via submarine cables.

Despite this importance, oceans remain largely unexplored, and their ecosystems face increasing threats, including warming and sea level rise, plastic pollution, acidification of the water, among others.

In recent years, pressure on marine ecosystems has intensified, a trend that will worsen in the coming decades unless action is taken. Halting this deterioration requires that we all row in the same direction to protect ocean resources. The EU's political will has been made clear with ambitious goals: Commission President Ursula von der Leyen has emphasized the necessity of cutting plastic and nutrient pollution within five years and reviving 20% of Europe's marine ecosystems by 2030. The new Ocean Pact aims to channel that will into concrete actions.



Source: Envato

An Integrated Pact for a Sustainable Ocean Future

Maritime experts see this pact as a step forward towards a more integrated vision of ocean governance, innovation and research, helping to align fragmented efforts and avoid duplications across Europe. In a single roadmap, the EU has gathered directives on governance, investment, research and even diplomacy, articulated into six key priorities:

- **Protect and restore ocean health.** Expanding marine protected areas, restoring coastal habitats, and reducing marine pollution, in line with initiatives such as the EU's Zero Pollution Action Plan.
- **Boost the sustainable competitiveness of the blue economy.** Reinforcing traditional sectors (fisheries, aquaculture) and fostering emerging ones (offshore renewable energy, blue biotechnology, underwater robotics), ensuring long-term sustainability.
- **Promote research, knowledge and innovation related to the ocean.** Building new scientific and technological capabilities through investments in ocean observation, creating a European digital twin of the ocean before 2030 to improve forecasting and planning, and better connecting science with innovative solutions.
- **Support coastal and island communities.** Helping coastal, island and outermost regions adapt to climate change and seize new economic opportunities through tailored strategies that enhance resilience and sustainable development.
- **Strengthen maritime security and defense.** Addressing emerging threats (from cyberattacks to risks to critical infrastructure) through greater European cooperation and advanced technologies.
- **Reinforce ocean diplomacy and international governance.** Leading and shaping global ocean governance with sustainable rules, promoting international agreements (e.g., high seas protection treaties, combating illegal fishing, phasing out of harmful subsidies) under active EU leadership.

These priorities demonstrate the holistic approach of the pact: it is not only about environmental conservation, but about transforming the role of the ocean in the European strategy. For this purpose, the European Commission foresees proposing an Ocean Law in 2027 to give the pact legal force, as well as creating a high-level Ocean Council to oversee and support its implementation.

These steps aim to shape an authentic "Union of the Oceans" within the European Union, where all member states move in coordination towards a sustainable and competitive blue future.

Ports: Strategic Infrastructures for Maritime Security

As oceans become increasingly essential to Europe, ports are consolidating their role as strategic infrastructures. As gateways to the sea, ports are much more than logistics nodes. They are nerve centers where trade, energy, digital communications, security and defense considerations converge. The European Ocean Pact highlights this role, placing ports at the heart of measures to protect coastlines and maritime routes against the possible risks.

Within the framework of the EU Maritime Security Strategy, coastal surveillance and cooperation among European coast guards will be reinforced to respond quickly to incidents or threats in EU waters. Ports will be hubs where information and coordination of these surveillance networks converge. The EU is also promoting the adoption of advanced monitoring technologies: for instance, deploying marine and aerial drones, remote sensors and real-time surveillance systems to protect critical infrastructures (port facilities, pipelines, submarine cables,...). Given that much of Europe's digital economy depends on submarine cables that land in ports, their protection is already a geostrategic priority. Work is also underway on common protocols against cyberattacks and other hybrid threats that may affect maritime transport or port logistics chains. In short, the pact recognizes that a secure port is synonymous with a safer ocean for Europe.

Ports as Blue Innovation Laboratories

Another key dimension of the pact is innovation in the maritime domain, and here ports stand out as living laboratories (LivingLabs) for testing and developing new blue technologies. Many of the research and development initiatives, find in ports the ideal environments to pilot them. Indeed, the EU plans to create networks of ocean technology test centers located in ports, linked with European R&D programs like Horizon Europe and flagship projects such as the Mission "Restore Our Ocean and Waters". These centers will allow real-world trials of innovations in offshore renewable energy, autonomous underwater systems, new marine fuels for shipping, water quality sensors,...

The different ports authorities, are working on this. In the Mediterranean, we can find the 'BlueTechPort', in the port of Barcelona. But we can also find similar initiatives around EU, for example RDM campus in Rotterdam, to support startups. Or the 'Hub do Mar' in Lisbon, coworking spaces. There are places designed to incubate startups and give the facilities and the ecosystem to grow.

Port authorities across Europe are creating dedicated blue economy innovation spaces. In the Mediterranean, the Port of Barcelona has the BlueTechPort, an innovation hub to accelerate blue economy startups and projects. In Rotterdam, the RDM Campus hosts innovative companies, test facilities and field labs that nurture solutions for the "smart port of the future." And Lisbon is developing the Sea Hub (Hub do Mar) as part of the city's blue economy strategy, including coworking and innovation space.

A particularly ambitious initiative is the European Ocean Digital Twin, which the Commission aims to have operational before 2030. This model will integrate real-time marine data to simulate scenarios and support decision-making (from weather forecasting and early warning of extreme events to coastal infrastructure planning). Equipped with monitoring and connectivity systems, ports will be key nodes both for collecting data and for applying the tools derived from this digital twin in their daily management. Ports can also act as platforms for ocean literacy and citizen science initiatives, bringing innovation and environmental awareness closer to local communities.

The pact also strengthens public-private-academic collaboration around ports. For example, a European Knowledge and Innovation Community (KIC) specialized in water and maritime sectors is being prepared under the European Institute of Innovation and Technology. Different ports in EU, are also joining forces with companies, research centers and universities to develop innovative solutions that can be scaled up across the continent. Such initiatives show the potential of ports as technology hubs.

Source: Envato



Source: Envato

Regional Engines of the Blue Economy

Beyond their role in security and innovation, ports are presented by the EU as drivers of blue economy development in their regions. A major port acts as an industrial, logistics and energy hub, generating employment and attracting investment. The European Ocean Pact seeks to harness this dynamism. Ports are expected to spearhead the transition towards a sustainable blue economy, leading projects in decarbonization, circular economy and digitalization in the maritime sphere. In fact, many European ports are already transforming into clean energy nodes, electrifying docks installing OPS (Onshore Power Supply), promoting alternative fuels for ships (such as hydrogen or green ammonia),...

To support these transformations, the pact will mobilize financial resources through specific programs. Initiatives like BlueInvest and InvestEU are already channeling funds and guarantees to innovative blue businesses and projects. Likewise, the future maritime KIC will provide financing and expertise to scale solutions across the EU. These tools aim to attract private investment into greener port infrastructures, offshore renewable energy development, and new sustainable value chains.

For example, the Port of Barcelona's strong commitment to innovation and sustainability has positioned it in international alliances and allowed it to compete for European funding, showcasing how a port can lead change at the regional level. Collaborations in networks such as BlueNetCat (Catalonia's maritime R&D&I network) underline the importance of translating Europe's broad goals into local action, linking port stakeholders to the strategies of the pact.

Another major step is the European Commission's preparation of a new EU Port Strategy, aligned with the pact and the future Ocean Law. This strategy will strengthen the role of ports in maritime spatial planning (balancing diverse activities in coastal waters) and foster their integration with other key sectors such as fisheries, offshore energy or environmental protection. In short, ports will become the nexus linking the multiple dimensions of the blue economy in each territory.

Conclusion

The European Ocean Pact marks the beginning of a new era for the maritime domain in Europe. It is not merely a political agreement, but a transformative roadmap that recognizes the ocean as a strategic pillar of the European project in the 21st century. If its measures are successfully deployed, by the end of this decade we could see greener, more digitalized European ports, coasts more resilient to climate change, and marine ecosystems on the path to recovery. Europe would thus be laying the foundations of a prosperous yet responsible blue economy, balancing growth with ocean health.

Of course, turning the pact into tangible reality will require coordination across multiple actors and levels of governance. It will be crucial to establish clear leadership to ensure compliance and coherence.

The success of the European Ocean Pact will be measured by how it has transformed Europe's maritime future. Consolidating more innovative and secure ports, more sustainable coastal communities, and a healthier ocean. The vision of a "Union of the Oceans" suggests a Europe leading by example in protecting and responsibly using the sea. The path ahead is ambitious, but the course is already underway.



Source: Envato

Railway Stations as Sustainable City Promoters. Assessing Social, Environmental & Economic Impact with S-ROI

BY PACO GASPARÍN & ALEX MUMBRÚ

Railway stations today are far more than just entry and exit points for trains. They lie at the heart of our cities, functioning as vibrant hubs that connect people, communities, and modes of transport. Their transformation influences not only mobility, but also social inclusion, sustainability, and the overall vitality of urban life.

Traditional evaluation tools often focus narrowly on economic metrics. Yet in the face of today's challenges—climate change, social inequality, and urban fragmentation—this is no longer sufficient. We need evaluation frameworks that measure the full spectrum of impacts to ensure that our investments lead to greener, fairer, and more resilient cities.

The goal of the RAIL4CITIES project (RAILway stations for green and socially inclusive CITIES) is to accelerate the transformation of European railway stations into active promoters of sustainable cities and to guide them toward a new urban paradigm in the context of the climate emergency.

CENIT's role

CENIT, CIMNE's transport innovation unit, developed an integrated methodology that goes beyond traditional financial metrics by incorporating economic, social, and environmental dimensions. This approach combines **Sustainable Return on Investment (S-ROI) with Multi-Criteria Analysis (MCA)** to support decision-makers in evaluating and balancing diverse priorities effectively.

A central innovation of this methodology is the monetisation of intangible impacts—such as **mental well-being, accessibility, and social inclusion**. By applying financial proxies, these non-market effects can be quantified and incorporated into investment decision-making processes.

The methodology was tested in four Living Labs under the RAIL4CITIES project. In Ottignies (Belgium), the focus was on social inclusion and sustainability. In Milano Rogoredo (Italy), the lab explored circular economy strategies and the development of an energy hub. Toulouse Matabiau (France) concentrated on creating an inclusive, energy-efficient mobility hub, while Tomaszów Mazowiecki (Poland) worked on a multifunctional hub integrating mobility, sustainability, and social inclusion.

The framework integrates several components. MCA allows for the comparative evaluation of alternatives based on cost, social, and environmental performance. S-ROI quantifies the social and

environmental value generated per euro invested. The Theory of Change (ToC) is used to establish clear links between interventions and their expected long-term outcomes. Finally, financial proxies are employed to assign monetary values to non-market impacts, enabling a comprehensive assessment of project value.

Case Study: Ottignies railway station

Ottignies Station holds the potential to become a socially inclusive transport hub, fully integrated into the urban fabric through the principles of Transit-Oriented Development (TOD). This vision prioritises accessibility, social equity, and community engagement, while promoting sustainable growth and urban revitalisation. By combining public and private services and supporting multimodal transport, Ottignies Station can become a key node in the city's shift toward sustainability and inclusion.

Impact assessment

Two redevelopment solutions were analysed:

1. Community Social Allotment: Transformation of a 300 m² elevated parking lot into a public park and community allotment, serving a dual function as both green space and social venue.
2. Youth Cultural Centre: Construction of a 300 m² indoor space dedicated to cultural and youth-centered activities.

To evaluate these proposals, we applied both MCA and S-ROI. MCA enables comparison across multiple indicators, including social, environmental, and economic dimensions, while S-ROI quantifies both tangible and intangible benefits. Together, these tools provide a comprehensive assessment of the interventions' effectiveness and long-term sustainability.

MCA assessment

Multi-Criteria Analysis (MCA) was conducted to compare the two solutions based on environmental impact, social benefits, and cost. Criteria weights were determined via pairwise comparison and normalised, assigning 40% each to social and environmental factors and 20% to cost. KPI weights were similarly derived using the adapted Saaty scale and expert judgment.

Results indicate that the Community Social Allotment outperforms the Youth Cultural Centre across all KPIs, including cost (implementation and maintenance), social (accessibility and mental and physical health benefits), and environmental metrics (CO₂ reduction, resource efficiency, and sustainability promotion). Final solution weights were derived by multiplying normalised KPI scores by their corresponding criterion weights (see Table 1).

The Community social allotment would be prioritised opposite the Youth cultural centre in all categories, especially cost-effectiveness, accessibility, health impact and environmental sustainability.

KPIs	Community social allotment	Youth cultural centre
C1: Cost	0.57	0.43
C2: Social	0.57	0.43
C3: Environmental	0.60	0.40
Global weights	58.30%	41.70%

Table 1: Matrix of the weights of the solutions for each criterion and the overall weights for each solution for Ottignies

S-ROI assessment

The solution for Community Social Allotment incorporates the Theory of Change (TOC), as illustrated in Fig. 1. Long-term outcomes related to the environmental and social pillars have been identified based on previous studies of community social allotment users.

The S-ROI analysis shows that the Community Social Allotment generates environmental benefits valued at €224,475 and social benefits of €2,994,915. These benefits are achieved against a total investment cost of €555,141. This results in an S-ROI ratio of 5.80:1, meaning that for every euro invested, society gains €5.80

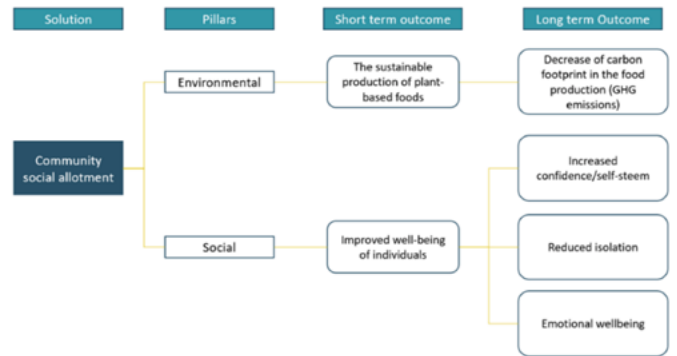


Fig. 1. Community social allotment: TOC outcomes

in combined social and environmental returns, confirming the solution's sustainable profitability.

To implement the S-ROI methodology, the Youth Cultural Centre solution incorporates the TOC framework, as illustrated in Fig. 2.

As shown, the long-term outcomes are consistent with those of the Community Social Allotment, given their similar social nature. This enables a more reliable comparison between the two solutions.

The S-ROI analysis for the Youth Cultural Centre estimates social benefits of €4,444,068 against costs of €1,687,960. This yields an S-ROI ratio of 2.63:1, indicating that for every euro invested, society gains €2.63 in social benefits. This confirms that the solution is sustainably profitable.

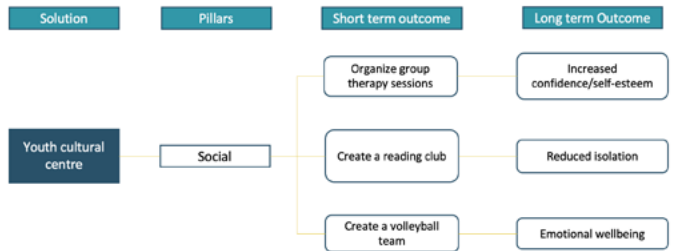


Fig. 2. Youth cultural centre: TOC outcomes

Conclusions

The results of the MCA and S-ROI clearly point to the Community Social Allotment as the superior investment option. With a high return (5.80:1), this solution delivers substantial benefits across the social and environmental spectrum. It is also cost-effective and aligns well with the principles of sustainable urban development.

The Youth Cultural Centre is also a viable initiative, offering a positive return (2.63:1), but with comparatively lower overall impact. It could be considered as a complementary investment if resources allow.

Recommendation: Prioritise the Community Social Allotment for funding and implementation, as it offers the greatest overall value in terms of sustainability, inclusiveness, and urban transformation.

Acknowledgements

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Road Traffic Emission Methodology: Port of Barcelona Case Study

BY MATTEO BOSCHIAN CUCH

The transport sector is both a driver of economic activity and a major source of global greenhouse gas (GHG) emissions. The global transport sector is responsible for about a quarter of greenhouse gas (GHG) emissions. In the EU, road transport alone contributes 72% of inland transport emissions, with heavy-duty trucks and buses accounting for 61% of that total (EEA, 2022). To address this, the **European Green Deal targets a 90% reduction in transport emissions by 2050**, aiming for carbon neutrality. The EU's "Sustainable and Smart Mobility Strategy" supports this goal by **promoting cleaner transport modes, reducing fossil fuel dependence, and internalizing the sector's external costs**. As key hubs in the supply chain, ports play a strategic role in enabling this transition. Their connection to hinterland transport—by road, rail, and sea—makes them critical in addressing both freight and passenger emissions. Understanding the sources of emissions within port areas is essential for prioritizing effective decarbonization actions.

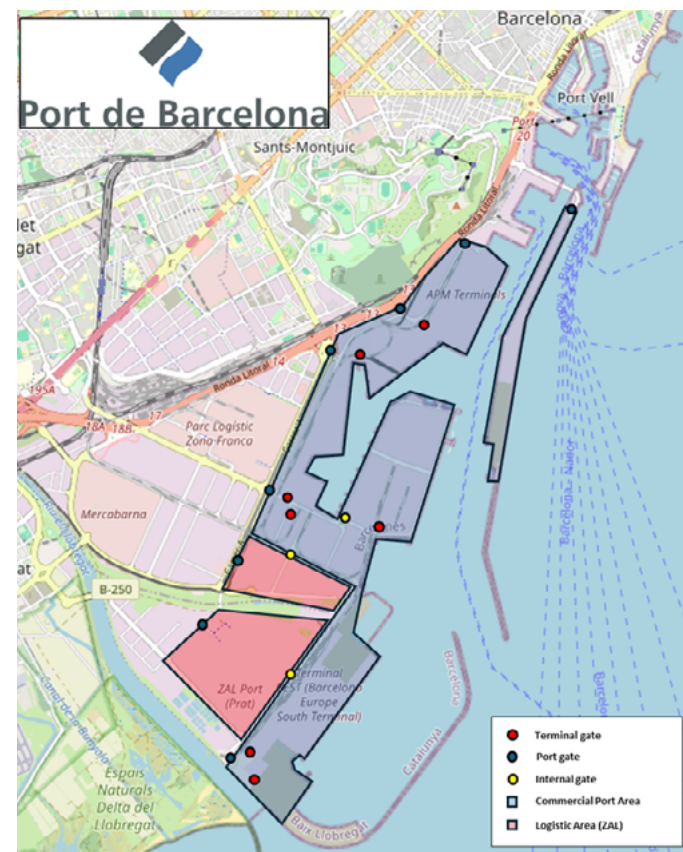


Figure 1: Map of the Port of Barcelona

Aligned with these goals, the **Port Authority of Barcelona has committed to significant GHG reduction targets and is implementing an energy transition strategy**. One of its key actions is to quantify total GHG emissions within the port area and verify them through the ISO 14064-1 certification scheme. This article presents a methodology developed to **calculate road transport emissions within the port**, applied to the Barcelona case study. As a multipurpose port, Barcelona handles diverse traffic—containers, vehicles, bulk, ro-ro (including Short Sea Shipping), cruise passengers, and daily commuting workers. This complexity requires a comprehensive emissions approach that includes all vehicle types for freight and passenger transport.

Looking at the literature, there is a clear need for standardized, practical methods to estimate road transport activity in port areas. Existing approaches often overlook vehicle diversity and depend on sensor-based data. **This study fills that gap by introducing a bottom-up methodology using Automatic License Plate Recognition (ALPR) cameras at port and terminal gates to generate trip matrices**. This approach enables accurate estimation of travel distances by vehicle type and supports comprehensive GHG emissions calculations. Its main advantage lies in its scalability and inclusivity, providing port authorities with a practical, sensor-free tool to inform emissions reduction strategies and support sustainability efforts. The area of the port included in the calculation is shown in Figure 1.

Methodology

In order to implement the model, the first essential step is the scope definition of the emissions inventory in both spatial and temporal dimensions.

The three main ingredients for calculating the road vehicles emissions are as follows:

- The **vehicle fleet composition** accessing the port, including the type of vehicle, fuel and EURO standards.
- The **distance travelled by each vehicle category** within the port boundaries.
- The **emission factors** corresponding to each vehicle type.

The proposed methodology accounts for emissions produced during both the cruise phase and idle periods, such as the queuing time at terminal gates, where vehicles are typically stationary but still consuming fuel.

Figure 2 presents a schematic overview of the methodology. First,

it is necessary to calculate the number of trips made by each vehicle category, then the distance travelled and finally the total emissions generated. The main source of information is the ALPR dataset, including gate number and type (if it is a port gate or terminal gate), date, time and license plate number. Then, a dataset that provides information on the vehicle is important to correlate the license plate number with the vehicle type characteristics. Finally, the dataset with the emissions factors for the different vehicle categories are applied to estimate total emissions.

The dataset from the ALPR cameras is merged with the vehicle-characteristics dataset (license plate attributes) to generate a trip matrix with an algorithm that detects two consequent actions of a single vehicle at different port locations. The trip matrix in each cell contains the number of trips detected from two specific positions. The last step, once the distance travelled is calculated for each vehicle category, is the calculation of emissions using the selected emissions factors.

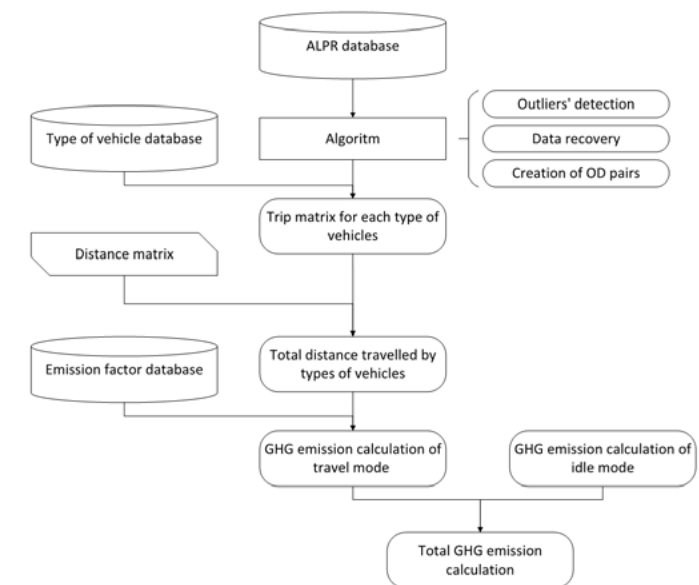


Figure 2: Methodology for the road transport GHG emissions in seaports.

Emission Calculation

The total emissions inside the port are composed of two contributions: the total emissions of all the vehicle categories due to the cruise mode and the emissions generated by the vehicles in idle mode in queues.

$$E_{tot} = E_{cruise} + E_{idle}$$

- **Cruise Mode Emissions:** a trip matrix is generated for each vehicle category, such as cars or heavy-duty vehicles, which records the number of trips made. This is combined with a distance matrix that indicates how far each vehicle travels within the port area. Additionally, the analysis considers the composition of the vehicle fleet, which is broken down into subcategories based

on characteristics like fuel type, vehicle size, and EURO emission standards. Each subcategory contributes differently to overall emissions. Lastly, emission factors—values that represent the amount of CO₂ emitted per kilometre—are applied to calculate the total emissions.

- **Idle Mode Emissions:** The idle emissions depend on the time vehicles spend waiting to access terminals for loading or unloading freight. To calculate idle mode emissions, it is necessary to calculate the time difference between the actual time registered between entry into the terminal and the preceding reading (which could be the entry into the port or the exit from another terminal) and the reference time, calculated in free flow mode. This calculation yields the time exceeding the minimum necessary to cover the given distance. Then, the median value is selected. Finally, the total waiting time is calculated as the product of the median time for accessing the terminal and the total number of entries to the specific terminal.

Results

The total GHG emissions from vehicles in cruise mode within the Port of Barcelona during a single month in 2022 amounted to 1,267 tCO₂e. These results, broken down by vehicle category, are presented in Figure 3. To refine the analysis, distances travelled by each vehicle category were further disaggregated into subcategories based on fuel type, size, and EURO classification, depending on the availability of emission factors. The emission factors used for GHG calculations are sourced from the EMEP/EEA air pollutant emission inventory guidebook.

As shown, **heavy-duty vehicles account for the largest share of emissions, reflecting the intense demand for freight transport between the port and its hinterland**. Cars represent the second-largest category, which includes commuters and taxis. Emissions from undefined vehicles—those for which detailed characteristics are unavailable—were estimated proportionally based on the distance travelled. This was done by dividing the known emissions by the total kilometres travelled by defined vehicles, then multiplying the resulting emission factor by the kilometres travelled by undefined vehicles.

Approximately 10% of the total distance was travelled by undefined vehicles. This group includes license plates with missing data or special vehicle types not classified under standard categories.

To complete the GHG inventory from road transport within the Port of Barcelona, emissions from vehicle idle time—specifically at the gates of container terminals—must also be considered. Fuel consumption during these waiting periods results in an additional 78 tCO₂e, calculated using idling fuel consumption factors for trucks from *Puertos del Estado* guidelines.

In total, GHG emissions from road vehicles within the port reach 1,345 tCO₂e, with 94% originating from cruising and the remaining 6% from idling at terminal gates.

In addition, **it is possible to analyse the composition of the heavy-duty vehicles' GHG emissions depending on the different freight sectors**. This is possible by classifying the license plates that enter the different types of terminals at the port (i.e., container, automotive, bulk, etc). In Barcelona, the container sector contributes the most to emissions, due to the high volume of containerised

import/export traffic and the complexity of related logistics. Conversely, the automotive sector accounts for the smallest share of emissions. Despite the port's significant new vehicle throughput, two main factors explain this: automotive terminals are located near the port's external gates, and the modal share of rail transport is high in the automotive supply chain.

Conclusions

This study highlights **the critical importance of accurately estimating greenhouse gas (GHG) emissions** from road transport within port environments. The framework requires a fully enclosed network equipped with automatic license plate recognition (ALPR) cameras at all entry/exit points and internal nodes (e.g. checkpoint gates and terminals).

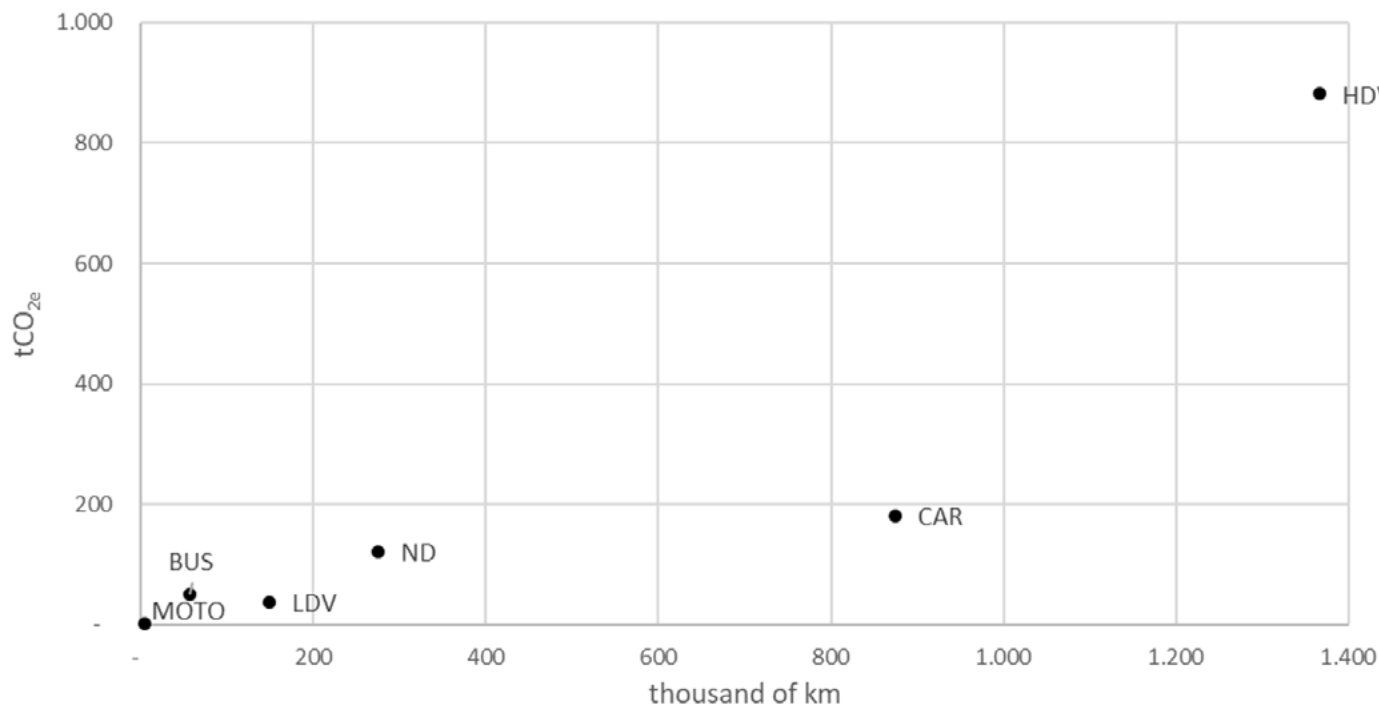
A key strength of this approach is its flexibility: it applies to all vehicle categories and sectors, enabling the monitoring of fleet characteristics. The findings demonstrate that this methodology effectively estimates the distance travelled by each vehicle within the port, allowing for accurate GHG emissions calculations. This was validated through a practical case study at the Port of Barcelona, where the approach was incorporated into the port's overall GHG emissions methodology, which achieved ISO 14064-1 certification.

Despite its comprehensive scope—including all vehicle types—several enhancements could improve the system's accuracy:

- Expand the number of cameras in the port's terminals. It allows us to have more accurate information for estimating the total traveled distance.
- Incorporate average vehicle speed in emissions calculations.
- More accurately model waiting times and congestion at terminal access points.
- Integrate AI-powered cameras at access points to automatically identify vehicle types, reducing reliance on supplemental datasets and minimising uncategorized license plate entries.

Beyond emissions monitoring, **the proposed framework also holds promise for applications in transport planning and digital twin development.** The generated trip matrices offer valuable insights into fleet dynamics and can guide emission reduction strategies within the port and its hinterland. Future research could expand the framework to track vehicle journeys from origin to destination, enabling a more holistic understanding of the environmental impact of port-related logistics.

Figure 3: GHG emissions and distance travelled by each vehicle category





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