Bird’s eye view

Caya Hein of AIVP explains how the MAGPIE project could offer a roadmap for European ports’ decarbonisation strategies


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MAGPIE (sMArt Green Ports Integrated and Efficient) is a collaborative research and innovation project funded by the European Commission (EC) under the Horizon 2020 Green Deal call. The Port of Rotterdam coordinates a consortium of 42 partners, including ports, research institutes, universities, small and medium enterprises (SMEs), and large commercial companies.

In 2021, the MAGPIE project set out to accelerate the introduction of green energy carriers for transport to, from, and in ports, combined with the realisation of logistic optimisation in ports. The project covers a span of five years and is set to end in September 2026. It is implementing 10 technological demonstrations, four digital tools and eight non-technological solutions across mainly the Port of Rotterdam and as well as in the fellow ports of Sines, DeltaPort and HAROPA and studying the transferability of the solutions between these ports. MAGPIE not only tests innovations, but also analyses the enabling conditions needed to move from isolated pilots to systemic transformation at the European port level.

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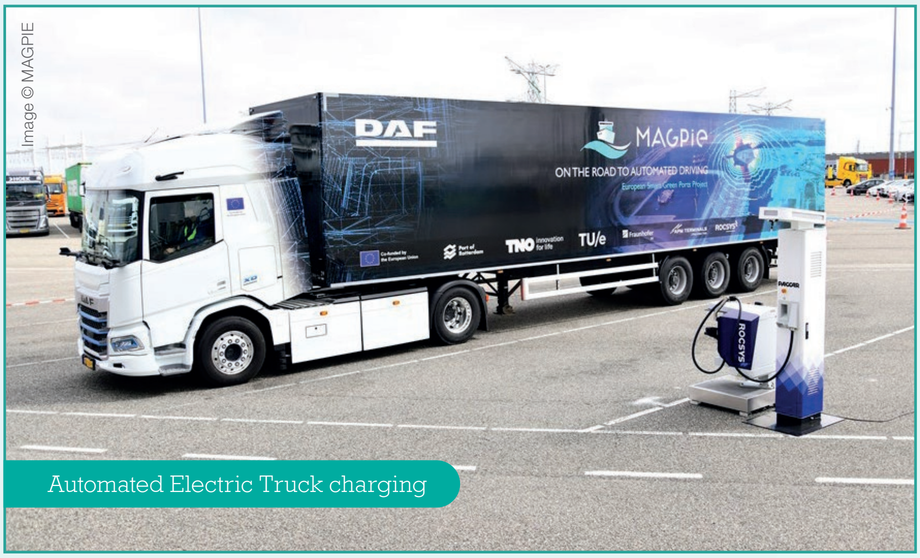
MAGPIE was created based on an ever-growing need to decarbonise transport and reduce greenhouse gas (GHG) emissions. In Europe, ports are vital in energy value chains and central to the low-carbon transition, especially with transport accounting for 25% of the European Union’s (EU) GHG emissions. They can take a leading role in the energy transition by becoming testing grounds for pilot solutions and thus facilitating the implementation of European and international regulations. The EC launched the European Green Deal in 2019, with the aim of a 90% reduction in the EU’s greenhouse gas emissions from transport by 2050. The “Fit for 55” package, introduced by the EC in 2021, aims to reduce GHG emissions by 55% from 1990 levels by 2030 and includes measures such as setting a GHG cap for ships entering EU ports and extending the EU Emission Trading Scheme (EU ETS) to maritime transport. The Renewable Energy Directive (RED) seeks to increase the EU’s renewable energy target to 40% by 2030, with an emphasis on the transport sector. Decarbonisation initiatives at the European level converge in their objectives with the recent efforts of the International Maritime Organization (IMO), which revised its strategy in July 2023 to reach carbon neutrality for international shipping around 2050.

The overall objective of the MAGPIE project is to demonstrate technical, operational, and procedural energy supply and digital solutions in a living lab environment to stimulate green, smart, and integrated multimodal transport and ensure roll-out through the 'European Green Port of the Future' Master Plan and dissemination and exploitation activities. This should lead to results that help attain the goals set in European and international regulations. The Master Plan will consist of three elements: a Vision document providing an outlook on an ideal future green European port in 2050; a Roadmap for the implementation of sustainable solutions developed in the framework of the project, with a timeline establishing ideal developments for 2030, 2040, and 2050; and a Handbook on how to become a future green European port with concrete guidance on planning, implementation, replication and scaling-up of MAGPIE demonstrators. The vision highlights a holistic approach to ensuring safer, more secure, more efficient, circular ports that also have a happy workplace, are in sync with people, local authorities, and nature and contribute to the regional economic value. Supported by the MAGPIE programme, European smart green ports will take the lead in enabling the building of a sustainable, climate-resilient and nature-positive future together.



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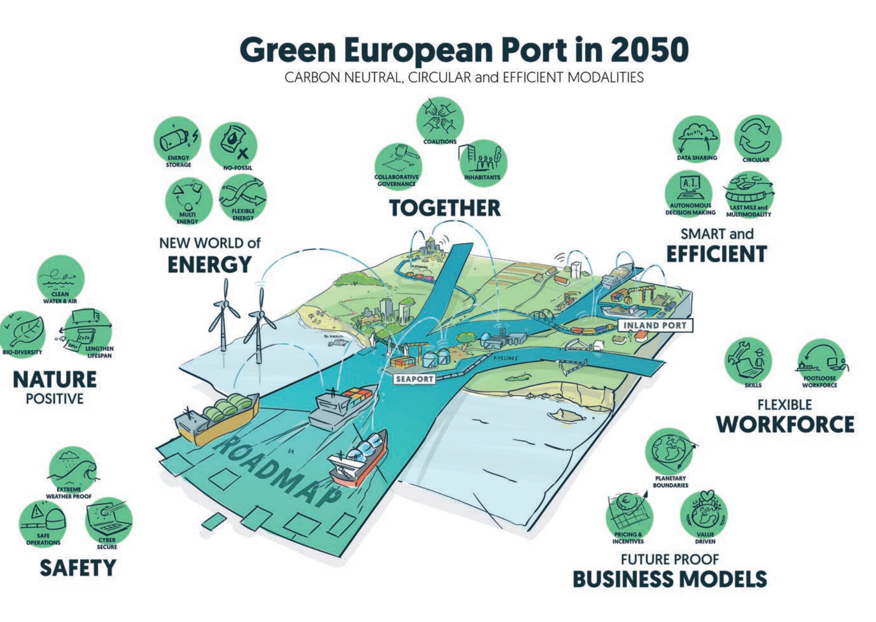
Automated Electric Truck charging

A SUSTAINABLE, MULTIMODAL APPROACH

The MAGPIE project considers all the main modes of transportation passing through ports – notably seagoing vessels, inland barges, rail, and trucks – in its decarbonisation efforts. It was important to both the consortium members and the EC to consider various modes of transport in ports, as European ports have a variety of geographic contexts and connections to the hinterland. Within the consortium, there exists already a variety of ports with different access to certain modalities. The ports of Rotterdam and HAROPA both make use of all four types of modalities, while Deltaport is an inland port and the Port of Sines does not have an inland waterway access.

Several of the project's solutions have already yielded results and garnered interest with relevant stakeholders. For instance, the two technological demonstrators focused on trucking are in their final stages and are ready to be replicated and upscaled. The first solution is focused on automated electric driving and automated charging. Many ports rely greatly on trucks for last-mile logistics, which contributes to congestion, air and noise pollution in port cities, and can create logistical sprawl to accommodate for parking areas, multimodal terminals, and refuelling stations. Berte Simons, COO of the Port of Rotterdam, stated that the reduction of CO_2-emissions by trucks is a step in the right direction for the port authority to reach its 2030 climate targets and is in line with the port's energy transition strategy, showcasing the importance of considering road transport decarbonisation for ports. The combination of electric driving and automated driving is an interesting combination as it helps avoid time consuming activities during charging, allows for improved data-driven planning, and addresses challenges in the logistical sector concerning sustainability, reliability, and productivity.

Similarly, a data-driven, smarter road traffic management and sustainable logistics solution was also developed. The Port of Rotterdam and its partners have demonstrated how targeted road traffic spreading and off-peak distribution can improve operational efficiency and support green transition goals. 10 major pilots have been completed including collaboration with leading food and agricultural importers. The shift to seamless on-board computer data enabled the analysis of over 3,000 truck trips within 18 months – marking a substantial step toward scalable and robust, data-driven decision-making. The analysis revealed an average 10-minute reduction in travel time during off peak hours and a significant flattening of warehouse workload peaks, while stakeholders benefited from real-time operational insights through tailored PowerBI dashboards. Emissions modelling carried out with partner IFPEN showed that more balanced road usage can help reduce emission peaks by about 30% and locally improve air quality – especially along busy truck routes. A practical industry toolkit offering best practices, digital templates and



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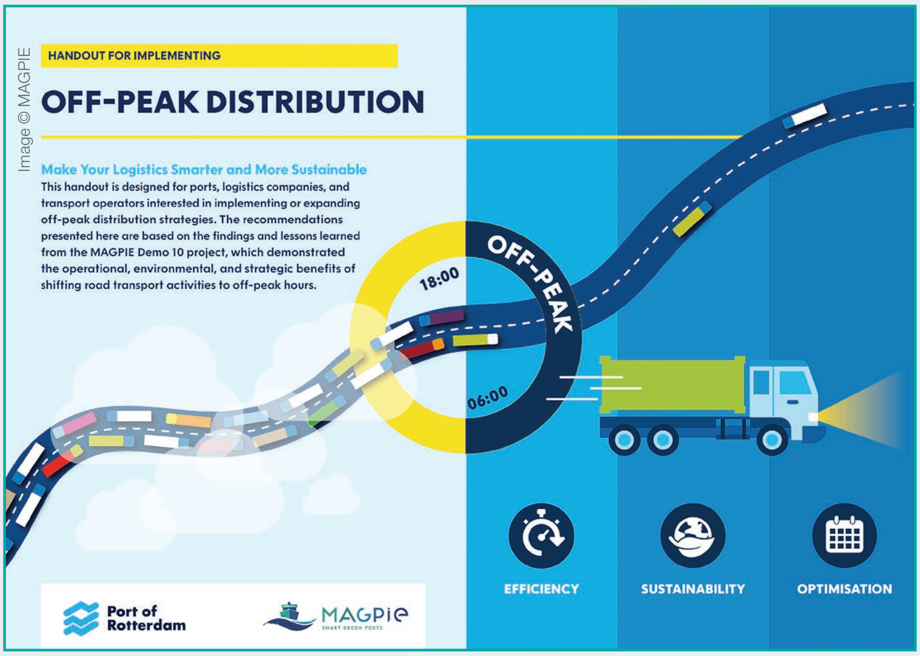

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resources, and data dashboards to facilitate off-peak distribution as a standard industry practice is available on the MAGPIE website.

The MAGPIE project is also testing a new built zero-emission shunting locomotive in a real life situation with different loads and weather conditions. The tests are being done in shunting operation and in short haul operation. The aim is to show that even the last mile of rail transportation on non-electrified railways can be done with zero emission locomotives. A diesel shunting locomotive in the Port of Rotterdam consumes about 100,000 litres of diesel yearly with a carbon footprint of around 270 tonnes of CO_2 per year. With the zero-emission locomotive, charged with green electricity, these greenhouse gas emissions will be avoided. There will also be noise reduction as electric traction produces less noise than diesel traction. A barrier to overcome is the approval for the homologation process, before the locomotives are allowed on the European railway network. A successful pilot will be noticed by other railway companies and ports. In the Port of Rotterdam there are now about 40 old diesel locomotives which could be replaced with zero emission locomotives.

> 'Zero emission transport by inland shipping is more energy-efficient per TEU than zero emission road transport, as a barge can replace dozens of trucks'

For inland shipping, the 'Autonomous e-barge and transshipment' solution is being considered. This solution aims to demonstrate how autonomous, small-sized barges and terminal cranes can contribute to making port operations for multi-modal hinterland transport more efficient and flexible. The solution is paired with an electric barge solution to reduce emissions. Zero emission transport by inland shipping is more energy-efficient per TEU than zero emission road transport, as a barge can replace dozens of trucks.

ALTERNATIVE FUELS AND ELECTRIFICATION

Ports can play an important role in the handling and production of biofuels, as circularity gains traction, although they are generally not directly linked to the production of renewable energy. The MAGPIE project has the ambition to demonstrate the usage of green energy supply chains/vectors in the logistics sector.

The electrification process is crucial to achieve a low-carbon future and reducing greenhouse gas emissions. The increased demand for sustainable energy has led to a growing interest in the electricity supply chain, from production to distribution. Electrification is often the first step in the energy transition strategies adopted by ports. Concerning the transport modalities coexisting in a port ecosystem, electrification is still in its early stages. For some specific transport, a fully electric powered propulsion may not even occur due to technical and economic constraints. In the maritime shipping sector, vessels almost entirely rely on fossil fuels to power their engines, propellers, and auxiliary systems.

For the maritime sector, the MAGPIE project has elaborated a solution titled 'Shore Power Peak Shaving', which sets out to increase utilisation of an existing shore power hub facility supplying two large crane vessels of Heerema Marine Contractors in the Port of Rotterdam, aiming to reduce greenhouse gas emissions and costs. The solution implements a battery on a heavy lift vessel when the crane is in operation to reduce their impact on the energy grid during peak energy demand times in the port. The battery can be charged with the existing shore power hub during off-peak hours. A nearby wind farm from ENECO feeds in through the same grid connection point as the shore power facility. While the vessel demand is fully determined by the crane lifting operations, the battery operation allows some flexibility, i.e. to prioritise recharging when sufficient renewable production is available. In general, co-locating renewable generation, when enabled to directly supply power to the vessel, can further reduce the energy procurement costs while reducing indirect emissions by partly replacing the grid electricity generation mix with renewables.

The 'Shore Power Peak Shaving' solution has the potential to increase the implementation of batteries on vessels, improving the shore power system architecture by lowering the overall grid demand and smart system integration within ports. Mock-up tests have shown that peak shaving of the vessel electricity demand with an on-board Battery Electricity Storage System (BESS) lowers the grid demand, allowing for a reduction of the contracted 15-minute peak load. It creates additional time periods of shore power supply during high load demand, and helps save operational costs. The peak load is lowered by 25%. Using a BESS for peak shaving can also prevent the need for additional diesel generators providing power while being connected to the shore power when two cranes operate simultaneously. Port minimum requirements for implementation of the solution include shore power installations with a grid connection matching the base load and a smart energy system to optimise the charging and discharging of the local energy storage.

A solution currently being analysed for its feasibility in the Mediterranean and in the North Sea is the offshore charging buoy. Its goal is to demonstrate offshore charging of electricity to vessels moored in waiting areas or near offshore wind farms, so that they can turn off their engines and thereby reduce emissions. This solution can benefit workers on these ships, due to reduced air and noise pollution. This has been tested in a model basin mimicking the North Sea extreme environments. The motion analysis of the tested E-buoy model was found not suitable for the North Sea context but potentially for the Mediterranean. Discussions are currently being held to test it at another port.

For inland shipping, the MAGPIE project developed a technological solution that demonstrates the feasibility and effectiveness of green energy containers, specifically lithium-ion batteries and low-pressure hydrogen, in real port operations. This includes safety assessments, technical requirements, and the interoperability of both energy sources. It aims to implement a certification process for green hydrogen and optimise container usage in the logistics chain. Additionally, it intends to develop a rollout plan that incorporates potential scalability. Electrification of intraport container traffic is highly visible in a port and can have a flywheel effect for more zero-emission shipping. CO_2 emission reduction in port area is potentially comparable to the installation of shore power in the Rotterdam port area, circa 800,000 tonnes per year.

The energy supply mix of ports can vary depending on location, available resources, and economic factors. For the wider port ecosystem, since most port authorities do not have ownership of the electricity grid, real-time information about energy consumption is either unavailable, or not duly exploited. Given the urgent need for green transition, port authorities could exploit the available information and further promote digitalisation to optimise operations, reduce emissions and energy consumption at the port level, and gain a better understanding about how ports may foster the transition to more sustainable energy vectors.

It is widely accepted that there will not be a single low-carbon fuel of the future. There will be competing fuels for each demand segment, and their commercial availability will impact their adoption. A variety of alternative fuels and their uptake are being assessed by the MAGPIE project, notably ammonia bunkering safety and e-methanol production. Ports can work with stakeholders to make low-carbon and carbon-free alternative fuels available for international shipping, helping to reduce emissions further. To move from theory to practice and allow the upscaling of alternative fuels, many uncertainties need to be tackled. Public and private stakeholders need long term stability, certainty and balance between risk and return in investments. Possessing a clear vision of how a mature and future-proof supply chain will look like is a first step in that direction. Indeed, it is unlikely that one alternative fuel will completely replace the others, as each has its own strengths and weaknesses, and the best approach will depend on the specific circumstances of each country and region.

> ‘The demonstration validated the ammonia bunkering safety framework, showing that such operations can be conducted safely and without release into the environment’

TNO, a MAGPIE Consortium partner, developed a Qualitative Risk Assessment (QRA) and a risk mitigation plan to ensure safety during ammonia bunkering between two vessels. Ammonia vapour clouds can travel long distances at ground level posing significant risk to populations in the vicinity of the release. Safety procedures at European ports will help to mitigate the risk. A release onboard a vessel poses a greater challenge. Just small concentrations of ammonia into the sea are sufficient to kill marine life. The effects of large spills of ammonia on people and ecosystems are still relatively unknown and based on limited case studies. One potential gap in the supply chain is the challenge of testing large spills considering the toxicity. With the support of the QRA, ammonia bunkering between two ships was tested successfully at the Port of Rotterdam in spring 2025. In this pilot, 800 cubic metres of cold liquid ammonia (-33°C) were transferred between two vessels over 2.5 hours. The demonstration validated the ammonia bunkering safety framework, showing that such operations can be conducted safely and without release into the environment. The pilot represents an important step in preparing the port for future ammonia-fuelled vessels.

Ammonia bunkering

Image © MAGPIE

Rotterdam is the world’s second-largest bunker port, supplying around 10 million tonnes of fuel annually. To manage fuel innovation, the Port of Rotterdam uses the international Port Readiness Level (PRL) assessment tool. This approach evaluates regulatory, safety, infrastructure, and supply-chain preparedness for new marine fuels. The port has already reached high readiness levels for LNG and methanol. With the ammonia pilot now completed, the port has advanced from PRL 6 to PRL 7, meaning it is ready to conduct ammonia bunkering operations on a project basis.

Regarding the production of e-methanol in the port, the aim is to demonstrate a TRL 6 level through the use of a membrane assisted reactor for more efficient methanol production from CO_2 and H2 feed. Methanol production from CO_2 hydrogenation is a thermodynamically limited reaction, and at lower pressures (35bar) conversion per pass is typically up to 23 mol%. By selective removal of reaction products via membrane, the conversion per pass can be increased significantly, hence decreasing energy demand for a recycle and reducing CAPEX and OPEX. The multi-tubular membrane reactor will be designed and constructed by TNO and tested in the Fieldlab Industrial Electrification (FLIE). This reactor will be sized for and connected to a 100 kW PEM electrolysis unit already available at FLIE. The testing will take place in the first half of 2026.

> 'This simulator showcases the current state of the electricity grid, identifies congestion points and flexibility needs, and anticipates its evolution under future energy transition scenarios'

GOVERNANCE OF THE ENERGY TRANSITION

Central to the ports' energy transition is governance, which ensures that strategies align with overarching sustainability objectives and provides a structured framework for transition, directing ports to incorporate renewable energy, enhance operations, and cut emissions. The transition governance is influenced by both internal and external factors. Internally, the benefits of sustainable operations, such as operational efficiencies and cost savings, are main drivers. Externally, regulatory mandates from governmental and international bodies, along with societal pressures from nearby communities, guide ports towards sustainable practices. Stakeholder collaborations, like those between port authorities, shipping firms, and energy suppliers, have fostered renewable energy initiatives within ports.

MAGPIE's non-technological solutions play a vital role in enabling progress in innovation upscaling. They provide policy, market, and informational solutions designed to mitigate the risks, costs, and uncertainties faced by commercial actors when adopting green technologies. These measures will offer market and regulatory support, helping new low emission solutions compete with entrenched carbon-intensive alternatives. The solutions being developed include price-based incentives, green corridors, voluntary agreements, governance for data-sharing platforms and energy-matching tools, stakeholder consensus building methods, and split incentive alignment frameworks. These are not optional 'add-ons' but essential tools for overcoming complex, multi-actor challenges in port environments. Green business models are still immature and need clear long-term stimulation policies they can rely on.

DIGITALISATION

A key way to simplify the analysis of the data generated and gathered from all these different stakeholders and to support decision-making is through digitalisation. The MAGPIE project has developed numerous digital tools to support the governance of the energy transition.

A 'Smart Energy Systems Simulator' was developed to understand energy systems both in their current state and under future scenarios. This simulator showcases the current state of the electricity grid, identifies congestion points and flexibility needs, and anticipates its evolution under future energy transition scenarios. It also considers future plausible scenarios of peak and flexible load demand, analyses the flexibility needs of the port, and then provides a decision support tool for port congestion, and efficient and economical operation based on the potential scenario. The Port of Sines has acted as a base case study and has completed a simulation with the tool. Due to data sensitivity, data unavailability, and data ownership issues, the base case study was shifted from the Port of Rotterdam to the Port of Sines

Several developed tools can also be combined to create a Port Digital Twin, whose implementation could create a modular architecture and interoperable digital representations for the port ecosystem to allow ports and related stakeholders to manage and plan their operations. These include the Greenhouse Gas tool, which bases itself on real-world data and has modelling and prediction capabilities to estimate GHG emissions. It also assesses the impact of reduction measures, both for the level of a port and on different transport corridors to and from the port. This tool will enable users to calculate the GHG emissions of logistics supply chains in compliance with ISO standard 14083. Ports and other stakeholders can use this tool for emission reporting purposes and strategic decision-making to comply with legislation. The initial model is targeted to the Port of Rotterdam. Using the same datasets, it can be transferred to other Dutch maritime ports. The methodology can also be transferred to other European ports.

Another tool is the 'Energy Matching tool', which is based on operational data. An optimisation model balances hourly energy supply and demand over a 24-48 hour horizon by leveraging local flexibility, storage, and renewable generation. It is a decision support tool that increases self-consumption and optimises the use of assets and operational flexibility, leading to lower costs and improved sustainability. The 'Smart and Green Logistics' tool's objective is to optimise the hinterland transportation planning of the arriving containers. The tool will provide an interface for port authorities to balance cost, time and emissions while testing the impact of certain policies on the hinterland transportation network. A shared interface for the port authorities and the shippers is proposed for the 24-48 hour operational transportation planning. An additional interface for the port authorities for the tactical level planning is proposed.

POLICY ADVICE BASED ON LESSON LEARNED

MAGPIE has assessed what works, what needs to change, and how European policy can accelerate the desired progress. These lessons can be separated into six categories: economic, knowledge-based, regulatory, technological, infrastructural, and social.

One of the key economic barriers encountered in MAGPIE is the immature state of markets for zero-emission solutions, which is inherent to low TRL research. There are mismatches between demonstrated technologies and the existing port environment, which could be addressed by pre-commercial test beds and interoperability labs for ports, where different suppliers and systems can test integration prior to real-world deployment. Another barrier is the persistent delay in physical delivery and deployment of project infrastructure. To address this, the EC should consider financial instruments that de-risk deployment of port decarbonisation solutions at all TRLs and create streamlined approval pathways for innovation pilots in ports. Instruments such as green public procurement, volume guarantees, or minimum uptake quotas for large freight forwarders could help stimulate demand and accelerate market maturity.

MAGPIE also encounters knowledge-related barriers, particularly regarding data transparency and availability. A lack of standardised, transparent data across port systems remains a barrier to both operational efficiency and innovation scaling. The absence of clear safety standards and regulatory guidance, particularly for alternative fuels, is another barrier. The development of harmonised safety standards by the EC for the bunkering, storage, and use of alternative fuels such as ammonia, methanol, and hydrogen should be encouraged. In parallel, standards for infrastructure should be accelerated through collaboration between port authorities, classification societies, and national regulators.

Social acceptance and workforce participation emerged as non-negligible barriers to the success of several MAGPIE demonstrations. Technological change in ports must be accompanied by proactive efforts to build trust, communicate risks, and engage workers early in the process. It is important to realise that this approach and the necessary tools highly depend on the social structure of each port.

CONCLUSION

The MAGPIE project shows that achieving a sustainable port ecosystem in Europe will require more than just advanced technology. It will demand a coordinated European strategy that addresses economic de-risking, regulatory standardisation, spatial and infrastructure planning, and social licence for change. Ports sit at the intersection of trade, energy, and climate policy, and MAGPIE has shown that systemic innovation in these environments is both possible and urgent. Many European ports do not have a clear master plan regarding the energy transition. They are testing out technological solutions that they have seen in other ports that they believe may be of use to them, but they do not have all the necessary elements (infrastructure, regulations, economic incentives, etc.) to scale them up afterwards. Therefore, the possibilities of a long-term effect of innovation is decreased. The MAGPIE project aims to propose the technological, digital, and governance solutions, the methodology to implement and upscale them, and the masterplan to do so effectively.

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