MAGPIE

SMART GREEN PORTS

VISION DOCUMENT FOR THE FUTURE GREEN EUROPEAN PORT WITH OUTLOOK TO 2050



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List of Abbreviations

AGVs	Automated Guided Vehicles
CBD	Convention on Biological Diversity
CRMs	Critical Raw Materials
DE	Germany
FR	France
NL	The Netherlands
PT	Portugal
PV solar	Photo Voltaic solar
SMRs	Small Modular Reactors
WFD	Water Framework Directive
WP9	Workpackage 9
XaaS	X as a service

Executive Summary

The MAGPIE vision for the future green European port is anchored in the Paris Climate Agreement's net-zero ambition, the emerging EU Port Strategy, and the planetary boundaries framework – seven of nine of which have already been exceeded (1). It was developed through a structured co-creation process involving four European port partners (Port of Rotterdam (NL), HAROPA Port (FR), Port of Sines (PT) and DeltaPort (DE)), nine research institutes and universities, and a range of expert partners. It combined desk research with iterative brainstorm and review sessions across the full Vision team.

The resulting vision is focused on the modalities in a port and organised around three dimensions: goals, major changes and conditions. The vision:

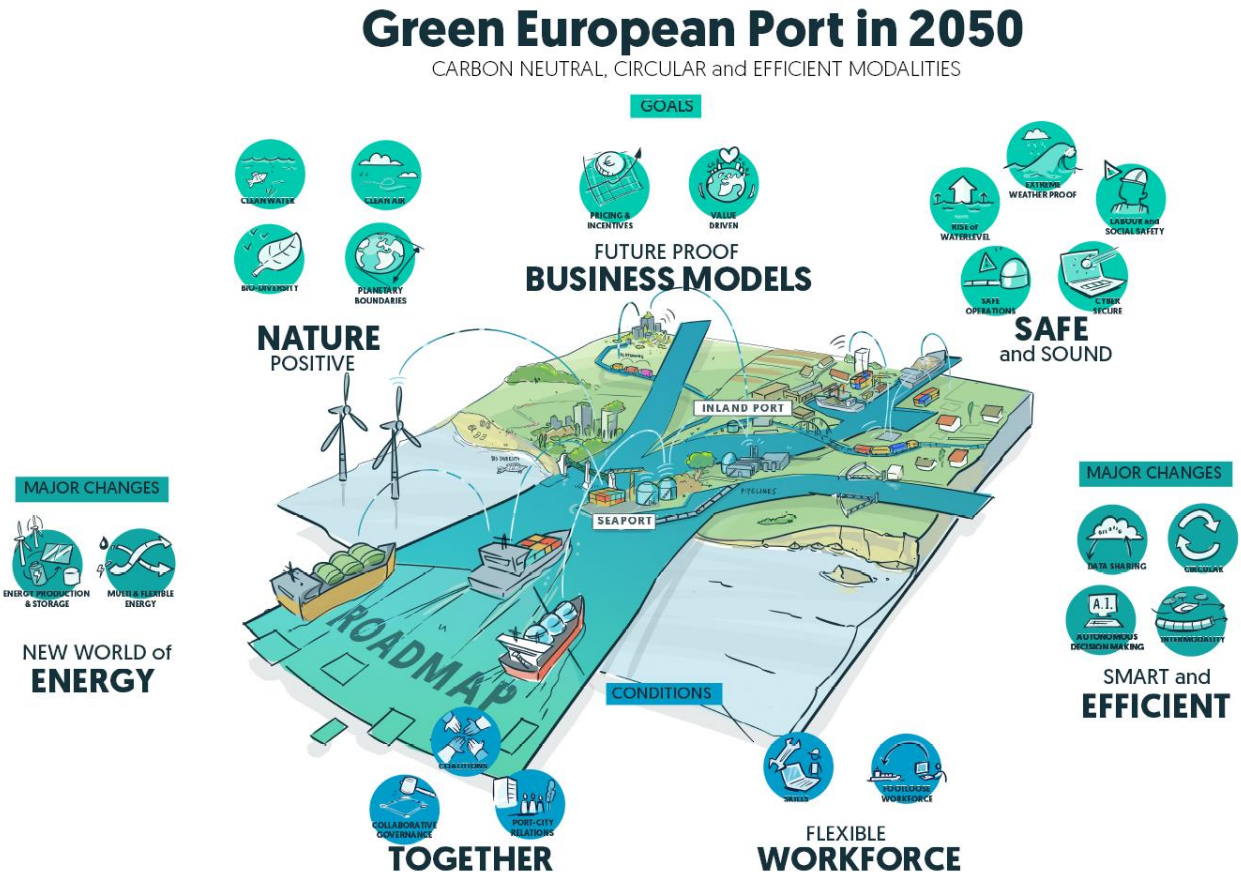
By 2050, the safe, efficient and competitive European ports will play a key role in enabling a net zero and nature positive world, while adapting to a new energy system and smart green modalities based on future-proof business models.

Goals describe what ports must achieve to be key accelerators for greening European transport to the fullest, while strengthening their position in the energy supply chains: operating net zero, within all planetary boundaries and becoming nature positive, with clean water, clean air and restored biodiversity as standard operating conditions; being safe and resilient against extreme weather, sea level rise and cyber threats; and adopting competitive, future-proof business models based on true pricing (2) that internalises environmental and social costs.

Major changes describe what needs to be transformed to reach those goals. In a new world of energy, fossil fuels will account for less than 5% of the energy mix by 2050. It will be replaced by wind, water, solar, biowaste and nuclear sources, with hydrogen, ammonia, methanol and batteries as dominant carriers. Ports will shift from passive energy consumers to active nodes in intelligent, multi-energy networks – simultaneously producing, storing and distributing energy and accelerating this change. In operations, full digital connectivity, AI-driven intermodality, terminal automation, blockchain-enabled data sharing and circular economy principles will redefine how ports and their hinterland connections function, making them smart and efficient.

Conditions describe what should be in place for the transition to succeed: collaborative governance structures that bring together ports, public authorities, industry and citizens; active port-city relationships that secure the social licence to operate; and a flexible, continuously upskilled workforce for whom life-long learning is an operational norm rather than an aspiration.

Figure 1: MAGPIE vision of a Green European Port in 2050



Taken together, the MAGPIE vision establishes that net zero, nature positive, safe, efficient and competitive are not competing objectives — they are mutually reinforcing requirements. No single technology or governance model will deliver them. The transition toward the future smart green port demands integration across energy and logistical systems, digital infrastructure, business models and human capital, and collaboration that extends well beyond the boundaries of any individual port.

MAGPIE's vision was developed to ensure that all European seaports and inland ports will be able to implement the 2050 vision directly or use it as inspiration for the development of their own port-specific vision. In collaboration with WP2, the vision is used for communication and dissemination of the MAGPIE project. Next to this, the vision serves as the strategic foundation for the MAGPIE roadmap (Task 9.3) and the handbook (Task 9.4), providing the shared direction against which all subsequent work package outputs will be assessed.

Introduction

European ports are at the heart of one of the defining challenges of our time: decarbonising transport and logistics while maintaining the competitiveness and resilience of a sector that handles over 74% of the EU's external trade (3). The MAGPIE project is established precisely to accelerate this transition. Funded under the EU Horizon 2020 programme (4) and running from October 2021 to December 2026, MAGPIE is an international collaboration coordinated by the Port of Rotterdam. The consortium brings together four major European ports (port of Rotterdam, HAROPA port, port of Sines and DeltaPort), nine research institutes and universities, 32 private companies and four other organisations, combining operational experience with scientific rigour at a scale that no single port or institution could achieve alone.

MAGPIE is structured around ten work packages spanning the full innovation chain: from energy supply and digital solutions to ten demonstrators across maritime, inland waterways, road and rail transport, to non-technological barriers and, ultimately, to the dissemination of results through a European Green Port Master Plan. The project's ambition is not merely to demonstrate isolated solutions, but to provide a replicable, integrated pathway for the greening of European ports.

Positioning of WP9 in the project

Work Package 9 (WP9), also known as the Master Plan for European green ports, is the strategic capstone of MAGPIE. While the other work packages generate the technical and operational innovations, WP9 is responsible for synthesising these into a coherent, long-term perspective for the sector: the European Green Port Master Plan. WP9 addresses four interconnected tasks: a baseline assessment of the current state of European ports (Task 9.1), the vision for the future smart green European port, as shown in this deliverable (Task 9.2), the development of a roadmap towards 2030, 2040 and 2050 (Task 9.3), and the elaboration of implementation guidance in a handbook for ports (Task 9.4). Together, these tasks answer the essential questions for ports: Where are we now? Where do we need to go? How do we get there?

This deliverable: D9.2

Deliverable 9.2 is the MAGPIE vision document for the Future Green European Port with an outlook to 2050 and answers the questions of 'where we need to go'. It contains a comprehensive and ambitious picture of what European ports should look like in 2050 if they are to be net zero, nature positive, safe, efficient and competitive.

A vision can provide clear guidance on 'what good looks like', encourage growth by aiming to reach higher, and help structure strategies and priorities towards a long-term goal. The MAGPIE vision is not an academic exercise but is developed to ensure that all European seaports and inland ports are able to implement the 2050 vision directly or use it as an inspiration for the development of their own port-specific vision. In collaboration with WP2, the vision is used for communication and dissemination of the MAGPIE project. It also serves directly as the structural framework for the roadmap (Task 9.3), the handbook (Task 9.4) and for the Master Plan as a whole, and it provides the direction of travel against which the MAGPIE demonstrators and other project outputs can be assessed.

The vision is grounded in the global and European policy context: the Paris Climate Agreement's 2050 net-zero ambition, the EU Port Strategy, the Water Framework Directive, the Nature Restoration Regulation and others, and the planetary boundaries

framework developed by the Stockholm Resilience Centre. Seven planetary boundaries have already been exceeded. The urgency is not theoretical.

Approach

The MAGPIE vision was developed through a structured co-creation process involving the Vision team, consisting of all four port partners and a broad group of knowledge and expert partners. The process unfolded in four steps. First, a brainstorm session with the Vision team identified the subjects that should constitute the 2050 vision, resulting in 22 topics organised into six thematic groups (see Figure 1). The deliverable 9.1 (Status Report on Sustainable and GHG-Neutral Initiatives within European Ports) provided input for defining these subjects. Second, individual partners led elaboration sessions on each topic, producing draft visions per topic. Third, the owners of topics within each of the six strategic themes (like Nature Positive) jointly developed theme-level vision statements through iterative online sessions. Fourth, all theme visions and individual topics were synthesised into a single, coherent MAGPIE vision statement, structured around three dimensions: the goals to be achieved, the major changes required and the conditions that must be in place.

Each of the 22 vision topics were assigned to a partner within WP9, ensuring accountability and active involvement across the consortium. The entire process was anchored in desk research - covering the relevant policy frameworks, scientific literature on planetary boundaries and green economy principles - and culminating in the MAGPIE vision visual (Figure 1) which served as a shared reference throughout the project and used for communication and dissemination activities in WP 2.

Next to the activities within the MAGPIE project, separate discussions were held with the other Horizon 2020 projects in the context of WP10 (PIONEERS, STARGATE, OLGA and TULIPS) to identify cooperation possibilities. The provided input supported the selection of topics relevant for the MAGPIE vision and the structure of the text. The discussions with PIONEERS (and MAGPIE) ports, taught us that many ports have a long-term ambition or vision that is not specifically developed for the port itself, but for the city, region, or otherwise. The use of these more generic visions for structuring port strategy is, therefore, more difficult. Best practices of port-specific visions, like the port of Rotterdam Port Vision, show that port-specific visions act as a true compass for ports, port authorities and their stakeholders.

The result is an overall vision (Chapter 2) in which ports are considered key accelerators for greening European transport to the fullest, while strengthening their position in the energy supply chains, and is structured around three dimensions: goals, major changes and conditions. These are each further elaborated in the chapters that follow: the goals European ports must achieve by 2050 (Chapter 3), the major changes in the energy system and logistical operations required to reach those goals (Chapter 4), and the conditions - governance, collaboration and workforce - without which the transition towards a smart green port cannot succeed (Chapter 5). Chapters 3-5 are developed to create further understanding and subject-specific suggestions for changes in a port, elaborating on the overall MAGPIE vision in Chapter 2.

1. Vision: Smart green ports in 2050

By 2050, the safe, efficient and competitive European ports will play a key role in enabling a net zero and nature positive world, while adapting to a new energy system and smart green modalities based on future-proof business models.

2050 marks the midpoint of this century. Although this is symbolic in itself, 2050 is also a landmark year for global ambitions like the Paris Climate Agreement. The goal of the EU-funded MAGPIE vision is to eliminate nearly all harmful emissions or pollution in European ports while remaining safe and competitive. In this way, ports will not only flatten the curve of climate change and respect the boundaries of our planet but also keep on providing safety and competitive added value for the port's users. European smart green ports will take the lead in building a sustainable, safe and competitive future together. In 2050 and beyond…

The European Commission launched the European Green Deal (5) in 2019, with the aim of a 90% reduction in the EU's greenhouse gas emissions from the transport sector by 2050. Smart green ports are even more ambitious: their objective is **net zero by 2050**. Ports are logistics hubs through which 90% of all transport in Europe passes (6). They will therefore play a major role in boosting the use of cleaner technologies, green energy carriers, and smart logistics concepts in maritime transport, port operations, and hinterland transport. That makes them a key accelerator for greening Europe. Port authorities have a leading role to play in this transformation in collaboration with local and regional authorities. To achieve this, they need to develop from landlords into actual port managers. The MAGPIE port vision provides a blueprint for achieving that net-zero goal.

Clearly, this move towards smart green ports will not be an isolated development. The emergence of new clean and circular markets will extend the port value chain and, in turn, strengthen the European ports as logistics hubs and as industrial and energy clusters. Ports will continue to operate in a context of broad societal, technological, geopolitical, economic, and climatic developments.

Nature positive

The focus of smart green ports goes beyond reducing greenhouse gas emissions. By 2050, Planet Earth will have to be in the safe operating zone[1]. This means that ports are part of the circular and green economy They must respect the planetary boundaries (1) that affect life on the planet: climate change, ocean acidification, chemical pollution, nitrogen and phosphorus loading, freshwater extraction, land conversion, biodiversity loss, air pollution, and ozone layer depletion. In this respect, the ports' ambitions go a step further than simple respect of the boundaries but aim to **become 'nature positive'**.

The sustainability goals for 2050 apply to every ship, every terminal, and every hinterland connection. Even so, different solutions will be required. There is no silver bullet. Combinations of measures will be developed that differ depending on the individual port.

[1] The Safe Operating Space (SOS) in the context of planetary boundaries defines the limits of human activity that allow for the maintenance of a stable and habitable Earth system similar to the Holocene era, beyond which the risk of abrupt and irreversible environmental change increases significantly

Safe and sound

Nature positivity depends vitally on adequate legislation and regulation, oversight, and incident response. And in 2050, as always: **safety comes first!** Against that background, ports will be safe and secure in all aspects. The hardware (assets, infrastructure, modalities, etc.) and the software (society, workers and digital ecosystem) will have a fully integrated safety regime and there will be no spills, unwanted emissions or accidents.

Ports will also be cybersecure and prepared for events such as extreme weather or structural changes such as sea and river level rise. Technical solutions to improve safety at all levels (like wearable tech, IoT technology, drones and hands-free communications) will be implemented in the port and the modalities. All the relevant safety conditions will be fully integrated in procedures, protocols, standards, etc. Human capital will not only be protected and safe but also skilled so that it has the capacity to comply with the safety regime and to deal successfully with the events referred to here.

Future-proof business models

Ports will remain places with specific geographical and economic benefits for business activities. Maintaining competitivity will continue to be essential. Changing values in society will lead to an increased wish for European industrial autonomy, resulting in a range of sourcing options that will include reshoring and nearshoring. On the other hand, those shifting values will affect the establishment of a circular economy based on the energy and raw materials transition and innovations like product passports.

The result will be the development of '**future-proof business models**' based not only on economic costing but also on factoring in the environmental and social costs for Planet Earth through 'true pricing' (2). The impact on the structure of the prices that consumers ultimately pay will incentivise the reduction of certain cost components. By adapting to these new values, companies in the port and the port authorities will turn this shift into a competitive edge on a worldwide scale and continue to contribute to local, regional and global prosperity.

Technological developments

Nevertheless, the context of port activities will have changed drastically by 2050. Technological developments like artificial intelligence, virtual reality, automation, data analytics and 3D printing will have a major impact on the deployment and working conditions of employees as well as on efficiency, competitiveness, safety, and security in ports and integrated transport. Technology will indeed make it possible to **optimise the use of different modes of transport**, significantly improving transport efficiency. For example, 'empty transport' in containerised or breakbulk cargo will be the exception in 2050, and we foresee a rise in market share for rail and inland waterway transport with respect to road transport.

Leading actors in innovations

As leading innovation actors, Europe's seaports and inland ports will play a pivotal role in the required technological developments. They will be home to the ongoing development of upgrades in infrastructure, new modes of transport such as hyperloops and drones, and the deployment of innovative transport concepts such as truck, and inland waterway transport platooning. Traffic congestion will be reduced drastically, with major fuel savings and cuts in emissions of greenhouse gas and other harmful substances as a result. However, the lion's share of these reductions will be achieved through the large-scale **switch to**

alternative, non-fossil energy carriers for transport, including last-mile transport. Those carriers range from electricity and hydrogen to e-ammonia, green methanol, bio-LNG and biodiesel.

Integration of systems

The need for new fuels implies changes for ports as well. The energy and raw materials transition will drive the integration of different systems – such as gas and electricity supplies – that have always been separate in the past and that will, in part, be produced and supplied locally. The large variety of applications, flexible conversion options and the flexible supply of new energy (like solar and wind), as well as new raw materials, will make the roles of producers and users more diffuse and all ports will become both producers and consumers of energy, with the role of ports and their port authorities expanding as a result.

Licence to operate

The licence to operate will be crucial for smart green ports in 2050. New technology and developments, such as the significant increase in the use of alternative energy (including nuclear in some ports), not only require different spatial requirements, but they also involve new perceived risks for port workers and local communities. **Good port-city relationships** will therefore be essential as a driver of social acceptance. A good relationship with stakeholders applies to transport routes to the European hinterland. Transparency will be required to address and alleviate concerns, and to generate buy-in. This will be done through an ongoing, open dialogue from ports with a wide range of relevant stakeholders, like terminal operator, NGO's, academic and research institutions.

Footloose workforce

Highly autonomous modalities, terminals and transport equipment will have an impact on the workforce in European ports, as will other forms of robotisation, automation and digitalisation. On balance, fewer employees will be needed for the direct operations in the port, which is a favourable development in the context of a declining labour force in Europe. Other types of jobs will become associated with the port.

In 2050, acquiring a **workforce with the right skills** will still be a challenge. In collaboration with educational institutions and knowledge institutes, life-long learning will be the guiding principle, with the central focus on a footloose workforce. Employees in this workforce will work at several locations in, around and outside of the port and receive direct and active support at work through technologies such as virtual reality and artificial intelligence. These initiatives will also contribute to greater functional flexibility with opportunities for remote working.

Net zero by 2050

All the developments described above are intended to reduce greenhouse gas emissions from transport by more than 90% by 2050 compared with 1990. There will be virtually no more new harmful emissions or pollution in ports and their surroundings. Existing pollution will have been cleaned up as much as possible. That is why European ports are aiming for net zero and nature positive by 2050. Any emissions will be offset or based on a specific reason (such as use in the circular economy). The result will be clean air, clean water, and clean land, as seen in the restoration of biodiversity levels in and around European ports.

Safe, secure, efficient, competitive, circular, without harmful emissions and pollution, a happy workplace and in sync with people, local authorities and nature in the locality while

contributing to economic value. With the support of the MAGPIE programme, European smart green ports will take the lead in building a sustainable, safe and competitive future together.

2. Further elaboration: Goals

The MAGPIE vision consists of 3 goals: net zero & nature positive, futureproof business models and safe and sound. These will work together towards becoming European smart green ports that will take the lead in building a sustainable, safe and competitive future, where nearly all harmful emissions or pollutions are eliminated. These goals ensure that ports will not only flatten the curve of climate change and respect the boundaries of our planet.

2.1 Net zero & Nature positive

In 2050, all the earth's planetary boundaries will be respected in a way that port activities will be in the safe operating space needed to maintain current environmental functions and life-supporting systems. Most planetary boundaries serve as direct input for the development of the port business and its business models. The ports' ambitions go a step further than respecting the boundaries: the aim is to be 'nature positive'. This means halting and reversing nature loss by 2030 on the basis of a 2020 baseline and achieving full recovery by 2050. For ports, this implies clean water and air, healthy land, and thriving biodiversity in and around ports alongside the industrial and nautical activities. Lost habitats will be restored, either at the port location itself, or in the immediate vicinity. These restored and created habitats will provide ecosystem services for people around the port and worldwide, such as carbon storage in oceans, trees and salt marshes, or freshwater storage for more frequent and more severe dry periods. Nature will have its own legal personality, with a representative involved in decision-making in the port on its behalf, either at the business level or in legislation. These ambitions will be developed in harmony with the ports' industries and other port users.



Planetary boundaries

Planetary boundaries interact with each other and apply to the planet. This means that the boundaries should not be addressed separately in port activities or business models, and that collaboration beyond the geographical scope of ports is essential. Ports will work together on the sources of possible harmful emissions or pollution to prevent them, and to tackle possible incidents, including when the port itself is the source, via source control. Responsibilities should be clearly demarcated in governance structures, and the continuous monitoring of sources, to safeguard a timely response, is therefore essential.

The nine planetary boundaries (1) for ports are:

1. Climate change: the emissions from the modalities and activities in the port should be zero for CO_2 and other relevant emissions. Ports, as providers of energy for many modalities and locations for industry, can supply the zero-emission energy needed and take the measures to ensure that there are no emissions from anywhere in the part of the supply chain they control by certification for example.
2. Ocean acidification: port-related activities will produce no carbon emissions so that the oceans will not absorb CO_2 and acidify. CO_2 is emitted to the atmosphere and port responsibilities do not stop at the port boundaries. Alliances with other ports,

areas and modalities are needed, especially in areas that extend beyond the scope of a port.

3. Introduction of novel entities: the toxic effects of new fuels on nature should be known and sufficient prevention measures should be taken.
4. Modification of biogeochemical flows: because fertilizers are hardly used in port systems, the impact from ports or related modalities on phosphorus loading is low. and not used in port systems. Depending on the type of fuel used, transport modalities emit nitrogen (e.g. ammonia as a fuel in marine shipping) which will be captured and used where needed or stored.
5. Freshwater change: drying up rivers due to changes in rain patterns, affects the connectivity of a port. The ports cannot steer this development but need to adapt. Next to this, using too much freshwater and source depletion will be impacted by the development of hydrogen and its derivatives as a fuel or feedstock. Freshwater is used for production, and water is released at user locations elsewhere disturbing the natural flow within the ecosystem.
6. Land systems change: ports aim to engage in business and expand, converting land for economic activities (roads, terminals, etc.). This impacts or removes wildlife habitats, removes carbon sinks and disrupts natural cycles. Ports should therefore strive to develop land in ways that counter those effects as much as possible, while maintaining economic activities and safety.
7. Biosphere integrity: economic activities may reduce the number and variety of species, and solutions should therefore be sought that promote co-existence. Where this is not possible, the balance between economic activity and loss of biodiversity should be reflected in decision-making.
8. Atmospheric Aerosol Loading: zero emissions of aerosols[2] is the goal for ports.
9. Stratospheric Ozone depletion: the legislation currently in place allows for the restoration of the ozone layer in forty years.

But the ports' ambitions go a step further than respecting the boundaries. The subjects (Figure 1Figure 1) to reach Nature positive are:



Clean air

To respect the planetary boundaries, harmful emissions will no longer be emitted in the port area, resulting in an increased license-to-operate of the port and improving the health of citizens and workers in the port and surrounding areas. The remaining emissions will be required for the circular economy or contribute to the health of citizens, like steam, and will play an important role in society.



Clean water

The changing freshwater cycle not only affects the port, but in 2050 ports will no longer be a source of water pollution and sediment contamination. Contamination from the past will be monitored, controlled and, if possible, eliminated. When pollutants come from upstream locations and ports will actively seek to eliminate those sources as well, for example by

[2] Microscopic matter and the gas suspending it together

setting up sediment management plans and lobbying for effective European and national regulation and law enforcement. Clean water is therefore a component of the planetary boundaries. Due to less CO_2 in the atmosphere the acidification of the oceans will reduce and this will improve biodiversity. Less chemical pollution of waters will allow biodiversity and animal fertility (including humans) to recover. Reducing excessive fertilisers in water bodies will lower nitrogen and phosphorus loading, which will bring the growth of algae under control and give underwater life the opportunity to thrive.

To ensure water is clean, it is necessary to stop emissions entering both salt and fresh water and tackle existing contaminants. Ports ensure clean water through river basin management. This means, clean waters in 2050 will require more collaboration from national and international river commissions in line with the (7)(WFD) and in regional or national water management bodies. Upstream-downstream impacts will be known This collaborative approach includes sediment management plans to clean up the historic contamination of sediments in river basins. It also requires instruments from organisations such as the European Commission. The EU Zero Pollution Action Plan provides direction for the reduction of pollution to levels that are no longer considered harmful to health and natural ecosystems, thereby directing EC instruments.

In addition, source control is important. Contaminants are best addressed at the source, because once in the water system, they are very difficult to clean up. The European Commission and member states have therefore focused on regulation to bridge this gap and better accommodate the ports with legislation based on the polluter pays principle with a focus on upstream sources and countries.



Biodiversity

As 2050 approaches, we have strong legislation safeguarding biodiversity: the Nature Restoration Regulation (8), the Soil Monitoring Law (9), and revised Ambient Air Quality directive (10). A larger EU-wide network is established of protected areas on land and at sea like Natura 2000 areas and marine protected areas. In addition, measures are introduced to enable the necessary transformative change to tackle the global biodiversity challenge through the development of a global strategy under the Convention on Biological Diversity (11)(CBD). This means ensuring a better implementation and tracking of progress, improvements in knowledge, financing and investment, and respecting nature in public and business decision-making.

As it affects the biodiversity in the water, measures will also be in place to balance the salt- and fresh water levels in ports and rivers in response to sea level rise, particularly in combination with lower river levels. Next to measure to protect nature against the introduction of invasive species by human activities.

2.2 Safe and sound

In 2050, the port will be safe and secure in all aspects. The hardware (assets, infrastructure, modalities, etc.) and the software (society, workers and digital ecosystem) will have a fully integrated safety regime. Spills, unwanted emissions or accidents will be a thing of the past. While preparations are in place to deal with events like cybercrime, extreme weather or structural changes such as sea level rise. Technical solutions to improve safety at all levels will be implemented in the port and for the modalities. All the relevant

safety conditions will be fully integrated in procedures, protocols, standards, etc. Human capital will not only be protected and safe but also well-educated to comply with the safety regime and deal successfully with disruptive events safely.



Labour and social safety

In 2050, ports will have a strong legislative framework that ensures the physical and digital protection and safety of workers in the port ecosystem, both for endogenous (for example, strikes) and exogenous events (like terrorist attacks, accidents and extreme weather). A safe environment for workers, with strong and resilient infrastructures and technologies meant to prevent any accidents, will be the standard.



Safe operations

In 2050, shipping and green ports (call, transfer and bunkering) will have a fully integrated safety regime to ensure safe operations and cyber security. There will be no spills, emissions or accidents. All the relevant safety conditions will be fully integrated in procedures, protocols and standards. The human capital will be in place and well educated to ensure safety and security on ships, in ports and other transport modes. Work for the port can be done at home using well integrated automation.



Extreme weatherproof

Extreme weather events will be more frequent in Europe in 2050. Ports will have adopted and implemented a 'anticipate, adapt and protect' policy for extreme weather. This will involve preventing heat stress by reducing local increases in temperature, bringing nature back to the port, and learning lessons from warmer regions such as natural air circulation and white-painted buildings.

Ports will 'anticipate' and prepare for disruptive events like storms, peak rainfall, and the increased risk of fires due to high temperatures and drought. Inland waterway levels will be extremely high or low more often and for longer periods. Ports will monitor weather events, communicate with the actors who need to be informed, enable them to act in a timely manner to reduce the effects of extreme weather and, if locked in, be self-sufficient to some degree.

An 'adapted' port calls for structural changes to modalities, infrastructure, port buildings, and processes in response to a new 'normal' with extreme weather, making them extreme weatherproof. Longer periods of extreme inland waterway levels requires the infrastructure of the rivers and channels in Europe to be in scope of this change to become extreme weatherproof as well.

These changes will mitigate the effects of extreme weather and safeguard business continuity by providing alternative options be it temporary or otherwise. But even with all the measures to anticipate and adapt listed here in place, extreme weather will still bring

risks. Protection will require measures to be taken on a case-by-case basis to keep these risks to an acceptable level.



Rise of the water level

In addition to situations with extreme weather, ports will also adapt to the sea level rise due to climate change. This is a slow but continuous process, therefore the infrastructure in the port will have been developed in good time by raising land, higher quay walls, etc.. This is done in the most cost-efficient way by combining technical solutions and procedures that are executed properly by all port stakeholders.

By 2050, ports will be resilient to sea level rise and be able to maintain operations or return to full operation very quickly after an extreme high-water event, protect ecosystems and remain attractive for future investments by companies.



Cyber secure

The use of artificial intelligence and machine learning technologies will be at the heart of cybersecurity, as will blockchain technology to protect data. By 2050, ports will have advanced processes and tools for managing cybersecurity information and risk management that will be supported by a broader European cybersecurity ecosystem. This will involve expert organisations, a cybersecurity certification scheme, the strengthening of market competitiveness, the promotion of post-quantum cryptography standardisation and adoption, and the promotion of collaboration and information sharing.

In addition, the development of Internet of Things (IoT) devices that detect anomalies or threats across networks and digital environments will have increased substantially, allowing real-time monitoring. Specifically, where access control is an issue, biometric IoT devices will be able to enforce secure, traceable physical access to sensitive areas. Of course, it will be important to secure IoT devices themselves and protect them from cyber-attacks.

The main challenge for a secure port is to have a highly qualified workforce, with the skills and ability to adapt to the technological changes, so that the port will be resilient and always cyber-secure. The basis for this will be a cybersecurity skills framework and competence assessment, in combination with education and professional training.

2.3 Future-proof business models

Ports are locations where companies remain competitive in their segments in 2050. This fundamental aspect will remain unchanged for ports as we look towards 2050. However, the future value will consist of economic considerations and will also encompass social and environmental aspects. 'True pricing' will be fundamental to the future-proof business models of the port in 2050.



Value driven

Ports create value for society and develop business models to do so in a sound way.

Business models can be transformed using various levers that affect both the creation and capture of value. The concept of planetary boundaries limits the creation of value by imposing restrictions on resources. Also the negative effects of the activities that create value will have an impact on the value creation. The planetary boundaries also affect the capture of value through customer preferences. In our MAGPIE vision, customers increasingly choose for sustainable products and are willing to pay a premium for them.

The adoption of a value-driven business approach will strengthen the position of ports as efficient logistics hubs and, if applicable, industrial clusters that operate in a climate-neutral and competitive manner. This involves creating synergies, exploring new markets, adopting new energy carriers, and embracing the principles of circular economy. The locational advantages of ports, such as robust transport networks and limited operational restrictions, will contribute to their success in this regard.

The trend to near-shoring and changes in global trade will affect transport structures. Synergies in and between industrial sectors will be created in port clusters and contribute to the extension of the port value chain far beyond traditional transport, logistics and related services. The trend from bulk commodities to small shipments with high value in containers will drive the establishment of new value-added services in and around port clusters strengthening their economic impact. The potential of 3D printing will be exploited and added to the value chain, making logistics more efficient.

Port clusters will be home to extensive automatization, where the use of artificial intelligence and robots will be standard to enhance efficiency and compensate for the demographic trend towards a smaller workforce, facilitating the successful specialisation of port economies and the focus on high-value sectors in global competition.



Pricing and incentives

The creation of value and the efficient utilisation of port resources are essential for future-proof port business models. In our vision for 2050, market design and functioning are based on true pricing. All the costs associated with the economic, social, and environmental value generated by ports will be included in the price and paid for by the customers, users of the port, and the port's business partners. Embracing true pricing will make business models sustainable.

True pricing will lead to changes in the behaviour of port actors. When port actors have to pay for the negative impacts they generate, such as carbon emissions, these and other factors will trigger the development of new business models. It is important to note that each company (or each cluster of companies) in a port has its own business model, making it difficult to provide specific details. In turn, the impact on ports and modalities may vary depending on the specific circumstances.

The government will have a role in pricing at all levels to encourage decision-making that will lead to sustainable solutions. Authorities will have the instruments needed to develop

and implement the right price incentives quickly and to accelerate the uptake of new resources and products that are in line with social and sustainability development goals.

The introduction of incentives will allow the market price to better reflect the true cost of goods and services including externalities like carbon emissions. In the long run, this can result in more informed decision-making and fewer harmful decisions without resorting to excessive regulation. Incentives can be seen as an intermediate step towards achieving a sustainable world.

While regulations can have an impact on business models, it is important to note that the long-term impact is uncertain, particularly when considering the year 2050. The regulations that are currently known are often short-term and they focus on carbon emissions and other related issues rather than all the goals of the MAGPIE vision. It is difficult to state specifically how regulations will direct the development of individual business models. However, it is worth exploring different possibilities and considering the potential impacts of future regulations on sustainable practices in port industries.

3. Further elaboration: Major changes

The Vision goals will be impacted by two major mostly technology-based changes, which are the energy and digital transition. Net zero & nature positive can only be reached when a new, and non-fossil, energy system is in place, and less energy is being used by being smart and efficient. Future-proof business models are needed as ports need to remain competitive, while their roles have been changed because of the energy and digital transition, a circular system and true pricing. The risks for the smart green port in 2050 will have changed drastically, compared to 2026. The need to be safe will be the same. Digitalisation is essential to limit the risks for a port, by monitoring, adapting, mitigating and communicating over these risks. But digitalisation is also a risk for cyber-attacks in itself. The new world of energy and circularity will eventually reduce the overall nature-based risks for a port like rising water levels, but will create new risks of its own, like the use of ammonia as bunker fuel, instead of only a feedstock for the chemical industry as it is now.

3.1 New world of energy

By 2050, the transport and logistics landscape will be defined by stringent emission standards and the widespread adoption of zero- and low-emission fuels, fostering a system where net zero, healthy environments, circularity, and operational efficiency coexist seamlessly. Ports will embrace this development given the importance of these elements for their future position as green, safe and competitive ports.



Energy production and storage

In 2050 there will be a net-zero world where fossil fuels will account for less than 5% of the energy mix. The primary energy sources will be wind, water and solar, supplemented by biowaste and nuclear.

The key energy carriers will be batteries, hydrogen and ammonia for land-based use and for short-sea shipping. Methanol, various diesel types and (bio-)LNG will be essential for long distances over sea, with SMRs for heavy users and to support land-based electricity stability.

Ports can play different roles in the energy value chain. With the new energy mix, these roles may change for ports. There are three elements to take into consideration:

1. Current port infrastructure and roles
2. Available area and safety buffer
3. Access to new electricity sources: land-based or offshore wind/solar parks

To increase the revenue per square metre in ports, most regular wind turbines will have been replaced by small-diameter, vertical-axis wind turbines, which produce less noise and are less harmful for birds.

By that time, large, far offshore solar/wind farms will meet an important part of our energy needs, not in the form of electricity but to store hydrogen in the most suitable way (e-fuel, solid hydrogen powders or hydrogen oils). It will be possible to transport those

carriers quickly and safely when packaged and they will have a high energy density. Since they will not require significant amounts of rare minerals, they will take over from batteries in many situations.

Despite the energy density, there will still be a significant energy loss (over 60%) when using hydrogen(carriers). This means that, when possible and practical, very large or energy intensive applications will run on either small modular reactors (SMRs) or nuclear fusion. If applications are small, but with high power and low volumes, they run on biowaste fuels. To prevent any adverse effects on nature, there will be strict regulation and tracing of biowaste sources and nuclear waste using low-energy blockchains.



Multi and flexible energy

Energy systems in 2050 consist of a collaboration of entities that generate, store, transform, distribute, and use energy. Renewable resources will be deployed at the port and offshore, covering the needs of the port as much as possible and providing a multitude of energy carriers - including electricity, hydrogen and ammonia - which can be produced onsite (or imported). Different sections of the port, whether terminals, cargo handling equipment, or refrigeration units, will act like different nodes connected to the energy and information network. They are part of a network of networks and will draw on and contributing to this energy web in accordance with their needs. Ships, trains and trucks in the port will connect seamlessly when docked or stationed, becoming temporary members of this interconnected system as well.

Most entities will have several roles. Electrolysers will transform renewable electricity into hydrogen, which will then be used by transport modalities in the form of hydrogen, methanol or ammonia. They will also be activated as users of electricity when there is excess renewable energy relative to demand and used as storage and converted back to electricity when needed. Battery-powered automated guided vehicles (AGVs) will be energy users, but it will be possible to plug them into the port local grid to provide electricity when generation is inadequate to meet demand. Buildings could be simultaneous consumers of energy, active stores of (thermal) energy or local producers of (solar) renewable electricity. And industries could be producers of heat, hydrogen, and renewable electricity, while simultaneously being able to activate certain industrial processes when the port or the grid has ample renewable resources available.

In 2050, this network of interconnected, multi-function, and cooperative entities will work as a dynamic, adaptative, quasi-living structure that can activate different components and functions to dynamically balance the supply and demand of energy. And in that way maximises the consumption of renewable generation and reduces waste. It will adapt and schedule logistics operations to fit forecasts of renewable generation, and store energy in times of abundance to feed demand when needed.

The physical network will be overseen by a layer of ‘intelligence’ and ‘real-time communications’, which can exchange signals and information with the different components in the network based on evolving demand. It will ensure energy is supplied when and where it is needed and predict future needs of port activities, like vessel schedules, and meteorological data. The entities in the network will connect via the different grids in the port transporting molecules for example the retrofitted pipelines that once transported fossil fuels now transport e-molecules like hydrogen, ammonia and synthetic fuels. New or adapted existing pipelines will also have been deployed to

accommodate new capacity for decarbonised fuels, electrons (for which a local and public grid may coexist) and heat (making use of the excess heat generated by different industrial activities as well as others such as data centres, compression and liquefaction facilities). This symbiotic entity will not be isolated: it will trade and share energy actively with the hinterland and the communities surrounding the port.

Modalities (especially vessels) will also be flexible regarding to the 'fuel' they use. For example, inland energy containers providing electricity could be battery- or hydrogen-based. Seagoing vessels could use both methanol and biodiesels. Very large working vessels may be fuelled by SMRs to be completely independent and occasionally supply the excess energy stored to ports. The role of batteries will change over time.

Batteries will still be important but shortages of critical raw materials (CRMs) will mean that low-density batteries (like sea-salt ones) become more important, as will the storage of electricity in hydrogen and other e-fuels. Road and rail will still require high-energy-density batteries, while ships and land-based applications will have switched to low-energy-density batteries.

Energy will still be transported by ship but it will have changed from oil products to renewable energy like hydrogen , ammonia, methanol, and biofuels (which can also be produced from waste sources).

3.2 Smart and efficient

To be more efficient, modalities related to ports will be not only sustainable but also smarter. This process will maintain the competitivity of the logistical system and reduce demand for energy. In a circular economy, less materials are needed as they will be used over and over again. Therefor a circular world will be more efficient.
And data sharing will be a basic condition to becoming more efficient and smart.



Intermodality[3]

By 2050, smart, fully digital systems will use artificial intelligence to manage transport in real time. These systems will automatically choose the best mix of transport methods-like road, rail, air, or sea -making the whole process smooth, efficient and autonomous. This will deliver lower costs, excellent arrival timing at the destination and less congestion.

Standardised open access systems, the physical internet and increased collaboration between operators will also contribute to the improvement of overall logistics. Hierarchical hub structures will bundle cargo flows and therefore reduce last miles. And those last miles will be emission-free – with drones, for example – reducing pollution in densely populated areas.

Overall, transport and logistics will be climate-neutral and drive global competition. Hyperloops will be used for high-density transport in heavily congested areas. Rail and waterborne modes will gain market share, contributing strongly to the achievement of the Green Deal objectives.

[3] Intermodality and multimodality are used interchangeable by the European Commission, see: https://transport.ec.europa.eu/transport-themes/logistics-and-multimodal-transport/multimodal-and-intermodal-freight-transport_en



Autonomous decision making

Cross-ocean shipping will be autonomous. Operations in ports will be executed by flexible local crews, or onboard crews, that perform maintenance during crossing. Inland ships will be controlled remotely by captains located on shore, allowing for a reduction in crew numbers on board. But some onboard crew will still be required, especially for loading and docking operations: the number of those operations will actually increase due to the use of energy container swaps.

Terminals and warehouses in ports will be fully automated, as will storage. Ports will offer a single smart window which uses algorithms to direct paperwork, to inform relevant authorities and detect risks to inspect. Blockchain will be used to ensure data validity and a quantum key distribution will be widely implemented for data security on each corridor.

Land transport will benefit from enhanced safety and efficiency due to autonomous truck and train convoys that require less human intervention and that can be organised in platoons. These 'follow the leader' convoys of trucks will be the standard. Autonomous trucks will be more popular due to increased safety and the shortage of human drivers.



Circular

In a more circular system, where products have a longer lifetime, the focus is on reuse and recycling, and models like X as a service (XaaS). New business models need to be implemented to ensure competitiveness of businesses and ports. The effects on ports include a potential decrease in the quantity of goods transported, as well as an increase in the price of goods due to the higher value placed on their longevity and sustainability. The overall need for transportation of goods will be reduced as goods are repurposed and recycled in more localised economies.

However, structures, infrastructure and modalities will be produced primarily in Europe to increase the levels of autonomy in resources and manufacturing. They will be made from repurposed structures and recycled materials, as well as raw materials from European mines. Ports will be a key element in the logistics of the circular economy and provide centres for collecting and transforming (repurpose, remanufacture, refurbish, repair, reuse) large equipment such as transport systems, including the adaptation of advances in 3D printing. Engineers will use circular design principles (Refuse, Rethink) to ensure that output maintains its highest value for the longest possible time. Digital product passports will detail their materials, origin, and future potential in terms of performance and allow recycling to return to the EU and ports in particular. Jobs in the circular era will include preparing artefacts for their continued or subsequent loops. At the end of a loop, these structures, products, parts, and materials will be separated and sent to dedicated recycling facilities to be fed into new production processes.



Data sharing

The logistics and port industry will undergo a transformative change with the emergence of enhanced data-sharing structures and infrastructure. Privacy concerns and the need for standardised data structures will guide this change. Data sharing will have to be digital and a basic condition for efficiency and circularity. The new data architecture will make intermodal and synchromodal transportation more efficient and create new roles for the workforce, adapting to a new landscape where autonomous operations in terminals and warehouses are the norm. Remote work will become more prominent, supported by a robust port and a logistical single-window system, linking autonomous elements and enhancing operational efficiency. Blockchain technology, or similar advances, will deliver data protection and trustworthiness, fostering a market where data is a valuable commodity.

4. Further elaboration: Conditions

Next to the major technical changes there are more non-technological conditions needed to reach the Vision goals. In WP 7 an extensive analysis of all non-tech barriers and non-tech solutions has been made, the dominant factor are people, evolving skills and the way they work together.

Becoming net zero & nature positive is a new and complex challenge. For this you need various expertise's, cooperations and coalitions at every level: government, port-city, workers etc. For future business models to be successful, the whole system needs to agree to changed value driven business models and the complete society embraces the concept of true pricing as the new standard. This can only be achieved via consensus in coalitions and governments. What is considered safe depends on the licence-to-operate of a port, which is meanly based on the citizens pro-actively being involved in advocating a healthy environment and how the workforce can safely operate.

4.1 Together

The port and its activities are elements in clusters and networks that extend beyond the port. In light of the challenges of the Vision goals at the national and European levels, and the energy and digital transition, the strengthening of collaboration in these clusters and networks will be essential.



Collaborative governance

In 2050, collaborative governance will be essential for the port organisation. It will fuel the process of establishing, steering, facilitating, operating, and monitoring cross-sectoral organisational arrangements to address public policy problems that cannot be easily addressed by a single organisation or the public sector alone. It will therefore be important to involve leadership and contributions from a wide range of relevant stakeholders. Ports and stakeholders will be in step with one another to achieve both public and private goals. Multiple stakeholders will participate in the creation, interpretation, and application of new actions, innovations, and policies. Public and private stakeholders will work together in collective forums such as coalitions on all kinds of port-related issues.



Coalitions

A coalition is a formal alliance of individuals or organisations that come together to work for a common goal. They design areas in line with different interests, including those of residents, governments, businesses, NGOs and knowledge partners. NGOs represent entities without a voice, like rivers. Coalitions support the long-term development of ports and their ecosystems and work with the principles of equity, sustainability, and robustness, supporting more coordination on common and shared goals, making roles and responsibilities explicit and ensuring the development of joint action plans.

Citizen organisations, associations and unions will be proactive and involved in advocating for their own health, work and life quality, and a healthy environment. The ports will involve citizens in the innovation process and have regular exchanges with people living close to the port. These initiatives will foster more acceptance of the ports and lead to the informed granting of a social licence to operate from citizens. New roles and spaces will be established that serve as the middle ground between inhabitants, institutes, and companies at that level, as neutral and independent connectors and convenors.



Port-city relations

In 2050 the port-city ecosystems will be mutually beneficial and co-create because of joint values incentivising a smart, sustainable and competitive port and port-city relationship, generally and at the systems level. Elements of these new port-city relations will include:

- involving citizens in the innovation process in different ways: hackathons, technology halls, encouraging students to develop their ideas, citizen science, etc.
- safeguarding access to the port and the waterfront with spaces where citizens can observe port operations, as well a public transport, cycleways and paths.
- ensuring that smart and green technologies are visible by organising school and university visits to the sites or school presentations from port employees.
- generating new jobs by using smart and green technologies
- collaborating with the universities and other stakeholders to deliver education and professional training in these domains.
- organising regular discussion sessions with people living close to the port regularly to ensure that there is continuous consultation about new and ongoing projects.
- interacting and debating about port activities with city, local stakeholders, companies, and citizens. This will be done at a central location like the Port Center Concept (12) or Portlantis (13) at the port of Rotterdam.

4.2 Flexible workforce

Different levels of autonomy will be introduced in the port by 2050. Terminals will have achieved the highest autonomy level, and they will almost all be fully automated, starting with containers and later also for processing wet and dry bulk. Monitoring and control will be remote, and a flexible repair and maintenance crew will be shared between terminals. Trucks will be a close second in automation and they will have started working with autonomous inter-terminal transport. By 2050, most driving will be autonomous, and this will include long-distance haulage. Loading and unloading cargo (not swapping energy containers) will still require humans.

Ships will be able to cross oceans remotely and autonomously but the presence of engines on over 90% of vessels means that onboard crews will still be needed. Crews will be deployed flexibly and often intervene during anchorage or on single voyages. Local crews will still be required to secure cargoes. The work-life balance will have improved and so will employee satisfaction.

Finally, in inland shipping, autopiloting will be the standard. The electrification of the fleet, regular berthing to swap power units, and more locks to manage the lower water levels

mean that full autonomy will be too expensive. Small crews will operate the locks, help with loading and unloading, and take care of maintaining the vessels.



Footloose workforce

As innovative technologies contribute to making the port and transport sector more autonomous and flexible, footloose working will be the standard by 2050. Employees will work at several locations because they are supported by a digital knowledge base. It will no longer be necessary to be familiar with individual locations, but employees will need specific skills that can be used at a range of locations.



Skills

Having enough employees is not enough: the workforce will also need to have the right skills. The new energy system will require specific skills. The labour market will be constantly changing due to the transitions and the associated technological developments. Educational institutions will have responded to changes in demand for labour. Companies keep their employees' skills up-to-date and provide development throughout life: life-long learning. The uncertainty of the transition underlines the importance of certain skills. In addition, to be more relevant in a port and maritime-related context, employees meet the following criteria: adaptability, adaptiveness, widely deployable, flexible, multidisciplinary, viable and generalist.

5. Conclusions

By 2050, the safe, efficient and competitive European ports will play a key role in enabling a net zero and nature positive world, while adapting to a new energy system and smart green modalities based on future-proof business models.

The MAGPIE vision establishes a clear, integrated picture of what European ports must become by 2050 to be key accelerators for greening European transport to the fullest, while strengthening their position in the energy supply chains. The chapters of this deliverable collectively make a coherent argument: net zero, nature positive, safe, efficient and competitive are not competing ambitions - they are mutually reinforcing requirements that must be pursued together, and that require actions across multiple dimensions simultaneously.



On goals (Chapter 3): European ports in 2050 must operate within all nine planetary boundaries, moving beyond compliance to regulations to become genuinely nature positive. This requires clean water and air, restored biodiversity, and the elimination of historical contamination - not as peripheral concerns but as core operating standards. Alongside environmental performance, ports must be safe across every dimension: prepared for extreme weather, water level rise, cyberthreats, and the physical and social safety of their workforce. Business models must evolve to incorporate true pricing that reflects environmental and social costs, making sustainability and safety a competitive advantage rather than a constraint.

On the new world of energy (Chapter 4): The energy transition is the a major structural change facing European ports. Fossil fuels will account for less than 5% of the energy mix by 2050. Primary energy will come from wind, water and solar, supplemented by biowaste and nuclear, with hydrogen, ammonia and batteries as the dominant carriers for port-related transport. Crucially, ports will no longer be passive energy consumers: they will be simultaneous producers, storers and distributors of energy, operating as nodes in an

interconnected, intelligent energy network. There is no silver bullet; the multi-energy, flexible system that emerges will require ports to make strategic choices based on their current infrastructure, available land and access to new energy sources.

On smart and efficient operations (Chapter 4): Digital connectivity, autonomy and data sharing will transform how ports and their associated transport modes function. Intermodality will be optimised in real time by AI-driven systems. Terminals will be fully automated. Blockchain will underpin data validity and cyber security. Circular economy principles will reduce the volume of goods in transit while increasing their value. The shift is not only technological: it also redefines the relationship between ports and their hinterlands, making transparency and data governance essential operational requirements.

On conditions (Chapter 5): None of the above is achievable without the right governance and human capital. Collaborative governance — involving ports, public authorities, industry, civil society and citizens — is a prerequisite for the social licence to operate that green ports will require. Coalitions and port-city relationships must be actively built and maintained. The workforce will need to be flexible, multi-skilled and continuously trained; footloose working, supported by digital tools, will be the norm. Life-long learning is not an aspiration but an operational necessity in a sector undergoing fundamental transformation.

Taken together, these chapters confirm that the path to the smart green European port of 2050 is both demanding and achievable. It requires integration - of energy systems, governance structures and workforce strategies -and it requires collaboration that extends well beyond the boundaries of any individual port. The MAGPIE vision provides the shared reference point from which the roadmap (Task 9.3) and implementation guidance (handbook, task 9.4) in subsequent WP9 tasks are developed.

Lessons learned and next steps

The Vision team learned that many ports don't have a long-term vision specifically developed for their port. They rely on the visions that are made by cities, regions or otherwise. In these, ports are a small part of an overall generic vision and therefore not easily usable for creating a port strategy. MAGPIE's vision was developed to ensure that all European seaports and inland ports will be able to implement a port specific vision. They can use the content directly or use it as inspiration for the development of their own port-specific vision.

Since the start of the project the world has greatly changed. Resilience became a very important element in the future of ports next to the defined goals in the MAGPIE vision (sustainable, smart and competitive). When ports are using the content of this vision for creating their own port-vision this element of resilience should be added.

The Vision answers the question of where the port needs to go to be net zero, nature positive, safe, efficient and competitive in 2050, but not how to get there. The MAGPIE roadmap (Task 9.3) shows which paths that different ports with different resources, characteristics and development levels can take to accomplish the Vision goals. The handbook (Task 9.4) shows the deployment of MAGPIE specific demonstrations, tools and solutions that contribute to the roadmap topics.

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