Green Ports in 2050

Four desired economically competitive and climate-neutral futures for Europe’s ports



IN COOPERATION WITH PIONEERS

Co-funded by the European Union

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Envisioning green port futures to drive transformation

We live in a VUCA -Volatile, Uncertain, Complex, Ambiguous- and even BANI world -Brittle, Anxious, Non-linear, Incomprehensible. In times of crisis, people tend to turn in on themselves, losing sight of other points of view, perspectives and opportunities. The transition towards a climate-neutral port however demands farsightedness and an open mind. Since decisions on the green transition of ports may have ramifications for years to come, we need to link decisions today to possible outcomes in the future.

Strategic foresight is a way of making sense of the world and doing just this. **It is not about trying to predict the future, but about making it possible to imagine multiple, uncertain futures**, to accept uncertainty and ultimately to anticipate and adapt to these possible futures. We use foresight to...

...reperceive

The green transition for ports requires a fundamental reimagining of how ports operate and integrate with their ecosystems. Challenging current world views and creating a vision of what these possible, green futures may look like, is imperative to inspire action.

... align stakeholders

The climate-neutral futures in this report provide a shared vision and reference framework to help diverse stakeholders align their understanding of future challenges and opportunities. This is necessary to ultimately build consensus around strategic priorities.

... anticipate opportunities

We created the desired future scenarios to help ports see their role as drivers of change, not just as responders. It helps ports anticipate and prepare for opportunities and disruptions before they occur.

... make robust strategic decisions

Foresight and scenario planning help port authorities that operate in highly uncertain environments with long investment horizons, to make robust strategic decisions under uncertainty. Scenario planning tests these strategies against multiple possible futures rather than betting on a single forecast.

... envision protopian, climate-neutral futures

We need to avoid the paralysis that dystopian scenarios can create by showing that negative futures are not inevitable and prevent the dismissal that often accompanies utopian visions that seem too good to be true or impossible to achieve.

Therefore we tried to envision "protopian" future scenarios as pathways to better futures that are both environmentally beneficial and economically viable, making change feel both necessary and possible. This approach creates opportunities. It recognises that the future is not predetermined but can be actively shaped through strategic decisions made today. Protopian futures are ambitious enough to drive meaningful change, realistic enough to maintain credibility, and specific enough to guide concrete action. This makes them particularly valuable for complex, long-term transformations like the green transition of European ports, where sustained stakeholder commitment and gradual progress are essential for success.

We consider these scenarios a starting point for building broad coalitions and securing stakeholder commitment.

Foresight methodology used to envision the green port futures

There are several methodologies to practise foresight. Considering the large time horizon for the transition to climate-neutral ports in 2050 and the higher uncertainty this entails, we considered scenario planning to be the best methodology for this purpose.

We combined expert opinions to define the axes that are the starting point for the scenarios. **These axes were chosen because they are considered having the largest impact on the greening of ports and the highest uncertainty about how they will pan out in the future.** This high uncertainty makes it necessary to map out the extremes on these dimensions to be able to envision multiple possible scenarios.

We used desk research to build on the aforementioned opinions of sustainability experts and conducted a horizon scan to capture what is already happening today to develop the scenarios and make them more plausible. The results of this research can be found in the “Evidence report” as an annex to this document.

The scenarios were developed under the PIONEERS project, co-funded by the European Commission. Seeing as the PIONEERS project was scoped to the decarbonisation of the maritime and logistic activities of ports, we largely stayed within these boundaries for these future scenarios as well.



Two guiding questions shaped the exploration

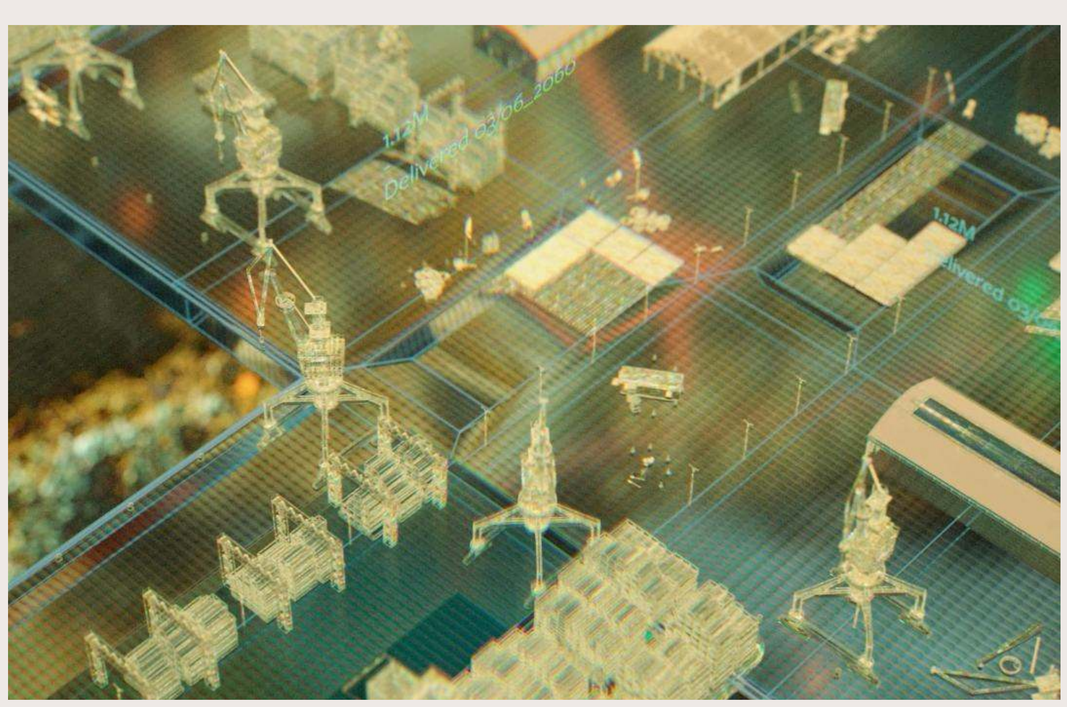
01 **Who drives change?** The public or the private sector?

02 **How fast does change happen?** Through radical innovation or gradual, incremental innovation?

The combination of these two guiding questions helped us create four climate-neutral futures for European ports. In these futures we explore what we can’t predict. Will the transition be driven by the public or by the private sector and will this happen fast or slow? By combining the most extreme answers to these questions, we end up with four futures. Knowing that the road to climate-neutrality won’t be as extreme. It will end up somewhere in between, combining the scenarios.

Using foresight to move from vision to action

Crossing these dimensions reveals four futures. Each future represents a possible world shaped by today's decisions. Behind them are 44 decision points and 100+ signals already visible in Europe and beyond, connecting foresight with real developments in technology, governance, and social change.



These scenarios are not forecasts, but explorations of possible climate-neutral futures, built from today's signals and tomorrow's potential. They invite reflection, dialogue, and bold action. Together, they show how the choices made today can steer ports toward a greener future.

However, in order for these scenarios to become useful, it is the step after the development of the scenarios that is most important. There are several ways to put these scenarios to good use.

The most obvious is as **a strategy and roadmap-building tool that allows you to backcast to what is necessary today and in the upcoming years and decades to be able to transition to a climate-neutral port.**

Alternatively, you can use them to make sense of what you see happening today and how this might evolve in the future. In other words, to stress-test the decisions being made today and adapt your strategy accordingly.

Backcasting

The most practical way to use this guide is through backcasting. Use the clarity of the 2050 endpoint in each scenario to build a strategy and roadmap.

How to get started:

01 Organise a workshop with a diverse group of people and send the scenarios as a pre-read to all participants.

02 Work with the entire group or -if you are pressed for time- split up the participants in four groups, one group per scenario. Hand out the scenario onepagers.

03 For each scenario, answer at least these questions:

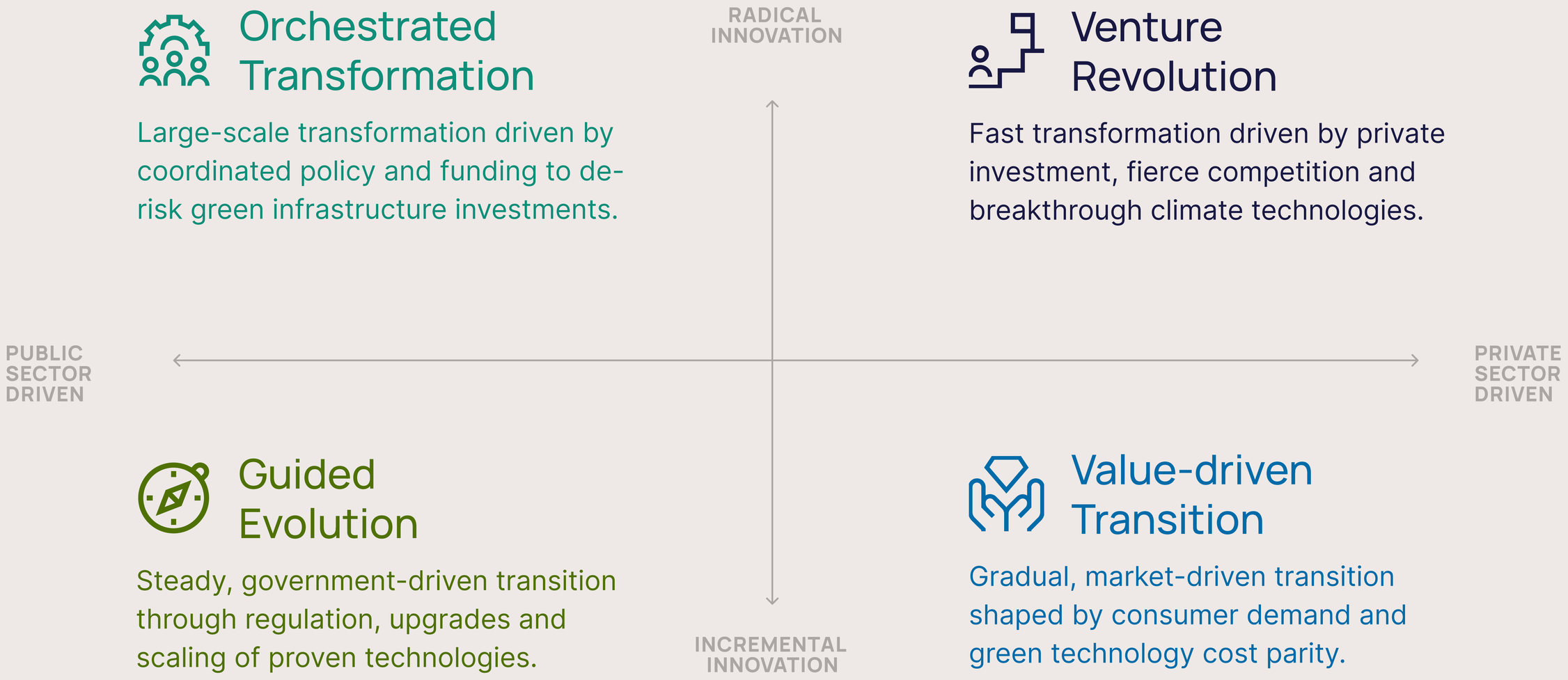
- Are we already moving towards this future and **is this what we want?**
- If this future would come true, **what does this mean** for our port and for the wider port ecosystem?
- **What is holding us back** or driving us forward to make this future happen?
- If we want this future to come true, **what should happen:** 3-5 milestones with regards to policy measures, changes in norms and beliefs, new practices and technologies etc?
- If we want this future to come true, **what should we be doing**: initiatives to reach those milestones in the next 5, 10 and 25 years?

04 Compare the answers for each scenario to identify which initiatives or investments are robust and high-performing, regardless of which futures materialise?

05 Prioritise actions, initiatives and projects according to your vision, strategy and climate ambitions.

06 Build a roadmap and review this roadmap regularly, as well as your vision and strategy.

Four climate-neutral futures at a glance



The four desired future scenarios work like a compass for navigating the long road toward climate-neutral ports by 2050. **The destination, climate-neutrality, is the same, but there are several major highways to get there.**

By exploring the four futures, the report encourages ports to recognise the signals emerging around them, strengthen the capabilities that matter in every scenario, and choose the path that aligns with their ambition and vision.

In what follows, we explore each future in depth: how this future world is shaped in terms of economy, environment and people, as well as how ports and port ecosystems would function and operate in this world. Important to note, is that when we talk about ports in the report we are not only talking about port authorities, but about the wider port ecosystem.

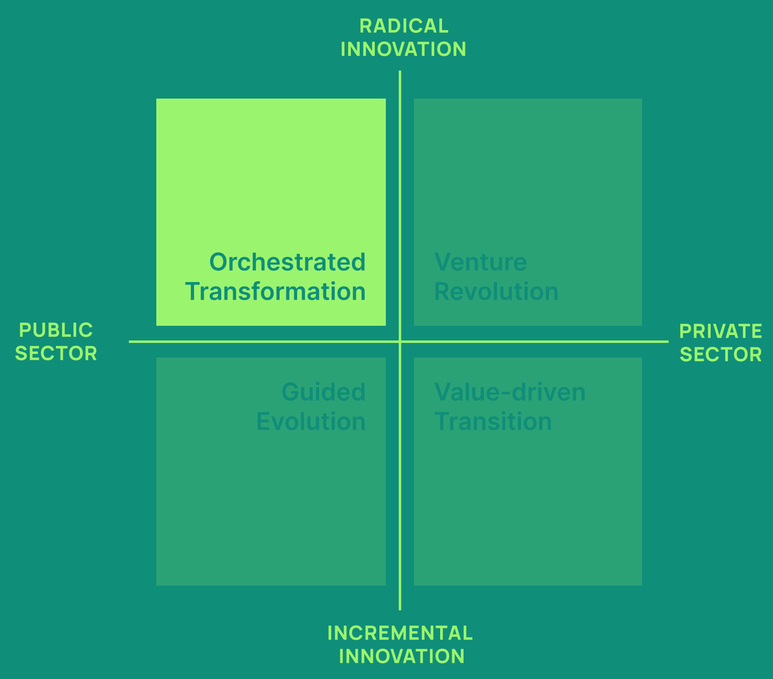
The horizontal axis shows who leads the way.

- Driven by the government or **public sector**, with coordinated planning, shared risk and long-term vision to serve the common good.
- Driven by the **private sector**, with consumer and market pressure and the pursuit of profit setting the pace.

The vertical axis shows how quickly and boldly the system changes.

- At the top you have **radical innovation**, defined by deep restructuring, major investments, developing new products, services, business models and breakthrough technology.
- At the bottom sits **incremental innovation**, shaped by optimisation, upgrades and scaling proven technology.

Orchestrated Transformation



In this scenario, governments lead climate action through coordinated state intervention to de-risk decarbonisation at scale. Innovation is radical, deploying breakthrough technologies through large-scale, state-led programs that align investment across sectors to deliver deep transformation.

PUBLIC SECTOR DRIVEN
RADICAL INNOVATION

In this "orchestrated transformation" scenario, **governments drive rapid decarbonisation with coordinated public investments**, aligning sectors and resources in the public interest. Driven by the need for **energy security** and **climate resilience**, ambitious large-scale state-led programs drive radical innovation and the deployment of breakthrough technologies. Ports become **strategic system integrators** and **clean energy hubs**, empowered by public funding and policy support to anchor the transformation to climate neutrality.



FUTURE WORLD

What if the next climate and geopolitical crises convince governments that only they can coordinate transformation towards a climate-neutral future at the scale and speed required?

This future of “orchestrated transformation” is born from a sequence of “enough” moments: the weeks on end that rivers ran too high, the summer the heat killed quietly and at scale, the winters the energy system buckled, and the years in which accumulating geopolitical crises disrupted supply chains.

Extreme climate shocks expose fragilities across the economical and energy systems. **Global geopolitical tensions** underline Europe’s dependence on imported fuels. Uncoordinated green tech pilot projects proliferate without ever tipping the system. By the early 2030s, it becomes painfully evident that without aligned investment and long-term direction, even the most promising solutions will arrive too late.

Governments start setting up **large-scale, state-led decarbonisation programs** that cut across sectors. They coordinate investment and align government, industries and R&D behind shared climate goals. Political leaders treat climate neutrality and resilience as strategic infrastructure, on par with energy security and economic competitiveness. They assume responsibility for building the foundations of a zero-carbon economy at scale. This moment marks a shift in how change is organised.

Strong bilateral and multilateral cooperation between European states and with key global partners creates momentum that no single actor could achieve alone. Shared standards, joint energy investments and coordinated trade rules begin to reshape markets far beyond Europe, triggering a wider global transformation rather than a regional one.

REAL WORLD EXAMPLE

One giant leap for mankind

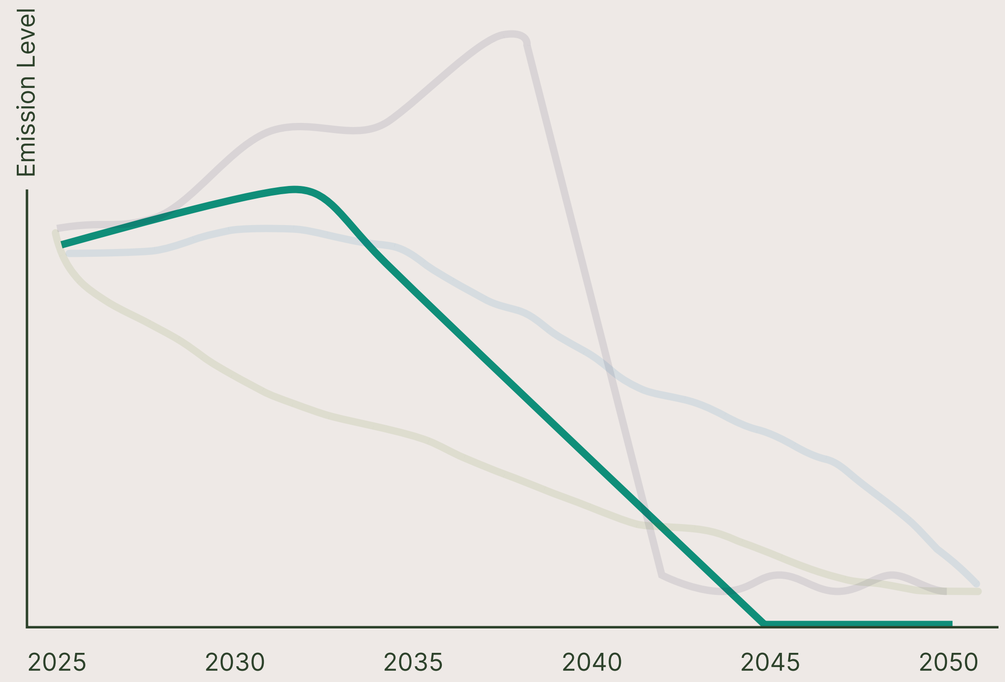
Think of the moment humanity set foot on the moon. What drove the Apollo Program was a total societal alignment. Governments, scientists, and industries working together, powered by a clear goal. This commitment meant government mandates instantly cleared regulatory roadblocks, vast public funds absorbed market risk, and the continent’s best engineers dedicated themselves to a common vision. In this future scenario that same focused ambition now defines Europe’s response to climate change.

Environment

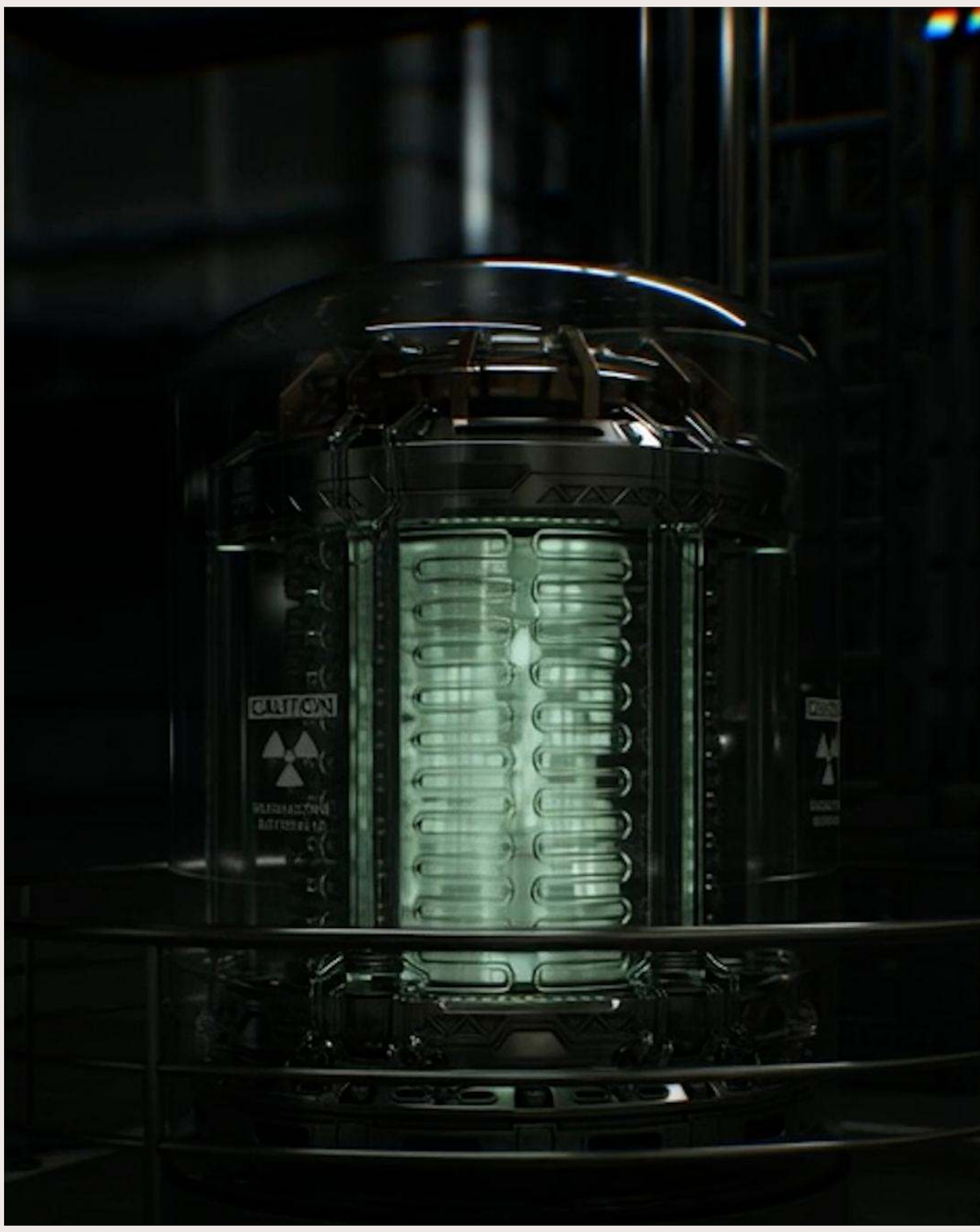
Energy security and climate action merge into a single agenda. Large-scale renewable generation, firm low-carbon power and resilient grids are rolled out as shared infrastructure. Decarbonisation becomes a collective project, guided by long-term masterplans instead of short-term market signals. National energy “digital twins” model the system, making it possible to simulate the effect of all conceivable climate extremes before they occur. Combining this with an exploration of consequences of policy choices before they are made, allows governments to move faster without flying blind.

Europe starts rebuilding its critical natural infrastructure: large, protected zones stitched together by green–blue corridors that let ecosystems breathe, migrate, and recover. Forests are linked to wetlands, rivers reconnected to floodplains, coastlines buffered by dunes and saltmarshes. Climate benefits come from restoring high-impact landscapes —especially peatlands and wetlands— where rewetting turns major carbon sources into long-term carbon stores, while also cooling landscapes and improving resilience to extremes.

Biodiversity rebounds because connected habitats reduce fragmentation and allow species to move as temperatures shift. Restoring free-flowing rivers and floodplains accelerates recovery across entire water catchments. Healthier soils, wetlands and floodplains store water in wet months, release it in dry months, filter pollution, and reduce both flood peaks and drought severity.



Delayed but decisive - steep drop / **Emissions** continue to rise in the early years, revealing the limits of fragmented efforts. This becomes the turning point where policymakers recognise that incremental change will not close the gap fast enough. Once coordinated measures take hold, emissions begin a steep decline reaching climate-neutrality before 2050.



Economy

Long-term economical certainty is created through public orchestration. Governments use public funding, guarantees and publicly governed open test sites to de-risk capital-intensive green transitions that markets alone cannot finance. Governments guarantee the first wave of infrastructure, and they reduce the risk for companies. This makes businesses more willing to invest alongside them.

Grants are strategically targeted as bridge finance to move technologies from pilot to scale. Once systems mature, stable regulation, aggregated demand and long-term offtake agreements replace grants as the primary economic driver. This phased approach creates predictable pipelines for manufacturers, energy producers and logistics operators, enabling industrial capacity to scale. This means market growth is slower to start, but far more sustainable, because it is anchored in infrastructure that delivers climate neutrality, energy security and long-term competitiveness simultaneously.



People

The new social contract is blunt: we have to move fast, but we will try to get everyone on board, and we will not let the costs fall on the already exposed.

Daily life changes fast enough to feel like a national mobilisation. At first it is deeply unpopular in the ways that only real change can be. Permits are streamlined but that means public works start everywhere at once: streets opened up, neighbourhoods re-plumbed for heat networks and power upgrades, car access re-routed, new rules landing with little patience for “later.”

Then gradually the tone shifts. The disruptions begin to pay off: energy bills stabilise as clean power scales, air quality improves, summers become more survivable in cooler buildings and greener streets. Public programs create visible work and pride. The remaining political tension is no longer about whether to rebuild, but about who steers the new operating system of society: how much is delegated to automated decision-making (ai), how transparent the models are and whether the benefits and the burdens are shared in ways people recognise as fair. People put their trust in public institutions and increasingly value inclusivity, long-term thinking and sustainability-focused innovation, with a greater openness to change.

Green Tech

In this future scenario, government underwrites fast, large-scale and coordinated builds. That is why technology in this world leans on high-capex, networked, and long-lead technologies that only the state can stitch together at scale.

The following technologies are possible in this scenario:

- ✓ Space-based solar power (SBSP)
- ✓ E-fuel bunkering networks (hard infrastructure)
- ✓ Large offshore solar and wind farms
- ✓ Green ammonia, e-methanol, and white hydrogen
- ✓ Autonomous zero-emission deep-sea vessels
- ✓ Islandable microgrids
- ✓ Onshore Power Supply (OPS)
- ✓ Battery Energy Storage System (BESS)
- ✓ Offshore electrolysis platforms
- ✓ Autonomous delivery vehicles
- ✓ E-trucks
- ✓ Digital twins
- ✓ Quantum computing
- ✓ Holographic telepresence
- ✓ Remote operations
- ✓ Marine Carbon Dioxide Removal (mCDR)
- ✓ CO2 to chemical conversion units
- ✓ Geoengineering pilots
- ✓ Small Modular Reactors (SMRs)

WILD CARD

Space-based solar power (SBSP)

As a strategic hedge against land scarcity and intermittency, governments explore space-based solar power (SBSP). Large solar arrays in orbit capture constant sunlight and beam energy back to earth via microwaves to receiving stations near coastal industrial zones. While not yet commercially proven, SBSP represents a long-term option for virtually unlimited clean energy. A strongly coordinated, public-led system seems to be the only way to internalise the very high capital requirement, cross-border governance and long regulatory lead times associated with SBSP.

Source / NASA Office of Technology, Policy, and Strategy. (2024). Space-based solar power: Lifecycle cost and greenhouse gas emissions assessment. National Aeronautics and Space Administration. https://www.nasa.gov/wp-content/uploads/2024/01/otps-sbsp-report-final-tagged-approved-1-8-24-tagged-v2.pdf?emrc=744da1



FUTURE PORT

Ports in this future emerge as strategic anchors within EU climate plans

Positioned as clean fuel hubs and energy gateways, they reinforce continental resilience and security. Governments empower ports with dedicated funding, streamlined permitting, and direct involvement in policy-making. Public investment drives grid upgrades, innovation and large-scale deployment of breakthrough technologies.

In turn, ports convene key actors—shipping lines, terminal operators, energy suppliers, and grid operators—under unified masterplans, embedding decarbonisation into every operation. As system integrators, ports lead the collective shift to climate neutrality, benefiting from stable funding and clear regulations that support long-term planning and circular supply chain transformation.

01 / Global trade & shipping

Coordinated fuel transition

Trade patterns fragment along decarbonization lines as Europe's coordinated carbon pricing and fuel standards create a two-tier shipping system: compliant vessels access priority berths, faster clearance and lower fees, while non-compliant ships face delays and surcharges. Major shipping alliances initially resist but gradually align as the coordinated demand from European ports creates economies of scale for clean fuel infrastructure that no fragmented market could sustain.

A defining shift occurs at sea. Supported by public funding and acceleration programs for emerging technology, a new generation of autonomous, zero-emission deep-sea vessels enters service. These ships combine clean fuels with AI-enabled navigation systems that continuously optimise routes, speed and energy use. Advanced optimisation supported by quantum computing for complex routing and energy modelling, reduces fuel consumption, avoids congestion and integrates vessels seamlessly into port microgrids. The result is fewer emissions, higher safety and radically lower operating costs.

Ports adapt by investing more in digital coordination, data services and system integration. While electrification dominates short-distance and stationary uses, long-distance shipping and some heavy processes still require energy-dense fuels. In this scenario, governments deliberately narrow the fuel landscape to avoid fragmentation.

Ports develop shared infrastructure for green ammonia and e-methanol, a zero-carbon fuel produced using clean electricity. In parallel, white hydrogen, a naturally occurring hydrogen extracted from geological formations is explored as a strategic complement. Unlike green hydrogen, it requires no electrolysis and can provide low-cost, low-carbon supply where geology allows, reducing pressure on electricity systems. Focused fuel infrastructure is planned at corridor level, with harmonised safety rules, smart sensors ensuring zero-leak operations and long-term offtake agreements. This coordinated approach lowers investment risk for both ships and terminals and prevents a proliferation of incompatible fuel systems across ports.

02 / Port Infrastructure

A resilient power system and a shift to circular materials

Electrification becomes the backbone of this future. Governments coordinate long-term investment in a diversified clean power mix designed to deliver both abundance and reliability. Large offshore solar and wind farms are rolled out at scale, complemented by Small Modular Reactors (SMRs), which are compact nuclear reactors that provide steady, low-carbon baseload power. Unlike traditional nuclear plants, SMRs are factory-built, faster to deploy, and can be located closer to industrial clusters, making them suitable for port environments where grid stability is critical.

Ports are reorganised around reliable, islandable microgrids: local electricity networks that can operate independently from the national grid if needed. These islandable microgrids integrate renewable generation, SMRs, battery storage and demand-response systems, ensuring that terminals, logistics hubs and adjacent industries retain power during grid disruptions. Electricity becomes cheap and is no longer constrained by national bottlenecks, allowing for a radical shift in electrifying all stationary operations connected to the port.

This resilient power system will be necessary to provide the much-needed energy that a large-scale and sustainable rebuild of critical infrastructure in ports and the larger port ecosystem requires. However, decarbonisation extends beyond energy into the materials that are used to build and maintain port infrastructure. Governments introduce harmonised circular construction rules, because the carbon footprint of ports is also locked into steel, concrete, aggregates, and maintenance works. These new rules prioritise radical reuse, repair, low-carbon alternatives and local sourcing by default.

Ports are developing into regional circular hubs where reuse and local recycling of construction materials are standard, supported by government policy mandating circular construction and short material supply chains. They host facilities that recover steel, concrete and critical materials from demolition, dredging and industrial by-products to avoid the emissions from hauling waste out and virgin material in. Ports also cap the supplier radius so projects rely on local supply chains to cut transport emissions and reduce exposure to global price shocks.

This reduces emissions while also strengthening resilience: fewer imported raw materials, shorter supply chains and lower exposure to geopolitical shocks.

03 / Logistics & Supply Chain

The great rebuild

Hinterland logistics becomes one of the most visible mobilisation fronts. Countries invest jointly in critical infrastructure and move fast. Diesel trucking collapses first under hard deadlines and policy that favours e-Trucks and induction charging infrastructure. New ultra-fast electrified rail systems are built. Inland shipping is modernised through mandated clean propulsion and standardised charging and battery container swap points along green shipping corridors. The first years are messy, construction is everywhere. Fortunately, rerouted traffic, labour shortages and temporary capacity dips end up being worth it: quieter nights, sharply lower air pollution near terminals and along freight routes, with a positive impact on public health.

Water management is upgraded in parallel because it's inseparable from resilience: runoff treatment, spill prevention, and "water-safe logistics zones" become standard, cutting contamination while also reducing flood risk and keeping operations stable during extreme weather.



04 / Labour & Community

Managing transition at scale

Automation and new energy systems reshape port work profoundly. Manual and repetitive tasks decline, but governments intervene early to prevent social disruption.

Companies organise large-scale retraining programs to prepare workers for roles in grid management, fuel handling, digital operations and system oversight. These initiatives are reinforced by state-funded retraining that aligns skills with the needs of the climate-neutral port ecosystem. Structured reskilling pathways ensure that an ageing workforce can combine updated knowledge and skills with their lifelong expertise, instead of exiting prematurely. Digital twins, virtual replicas of ports and energy systems, allow operators to test changes safely before implementation, improving safety and reducing downtime. AI supports decision-making rather than replacing human oversight.

The port ecosystems trust in this "orchestrated transformation" grows because the transformation is planned, visible and supported. Cleaner air, stable employment and energy security reinforce social acceptance.

Strengths, Weaknesses, Opportunities & Threats

Orchestrated Transformation is defined by strong public coordination and the capacity to drive deep, system-wide change at speed.

Its core **strength** lies in the ability to mobilise large, coordinated programmes that can deliver rapid decarbonisation across infrastructure, industry, and services. Public funding plays a critical enabling role: it reduces investment risk, accelerates deployment, and helps bring a wider range of actors along. Stable regulation, clear standards, and inclusive planning create certainty for businesses and strengthen public legitimacy—while unified, long-term planning also boosts resilience to climate shocks and geopolitical disruption.

At the same time, this model carries structural **weaknesses**. It depends on sustained high levels of public spending and long-term political commitment, which can be difficult to maintain. Centralised governance can introduce bureaucratic rigidity, slower decision-making, and the risk of locking into specific technologies too early. In the near term, large-scale infrastructure upgrades may also disrupt daily life and business operations, requiring careful sequencing and communication to preserve support.

The **opportunity** space is significant. EU-wide coordination—through shared standards and joint investment—can strengthen competitiveness while enabling rapid scaling of key technologies. The same approach can improve energy security, support more resilient supply chains, and catalyse new industries and jobs through state-backed innovation and industrial policy.

However, the scenario is not without **threats**. Changes in government can undermine continuity and weaken policy execution. Innovation may stagnate if market incentives are crowded out or regulation becomes overly prescriptive. Finally, as systems become more interconnected and digitally managed, cyber-physical security vulnerabilities increase, making resilience and security-by-design essential to safeguard the transition.

EARLY WARNING SIGNS

What to look out for

Europe's competitiveness deteriorates. Falling industrial output, investment flight, and widening gaps vs. the US/Asia in clean-tech and energy costs trigger calls for assertive state intervention to protect strategic sectors and keep Europe economically relevant.

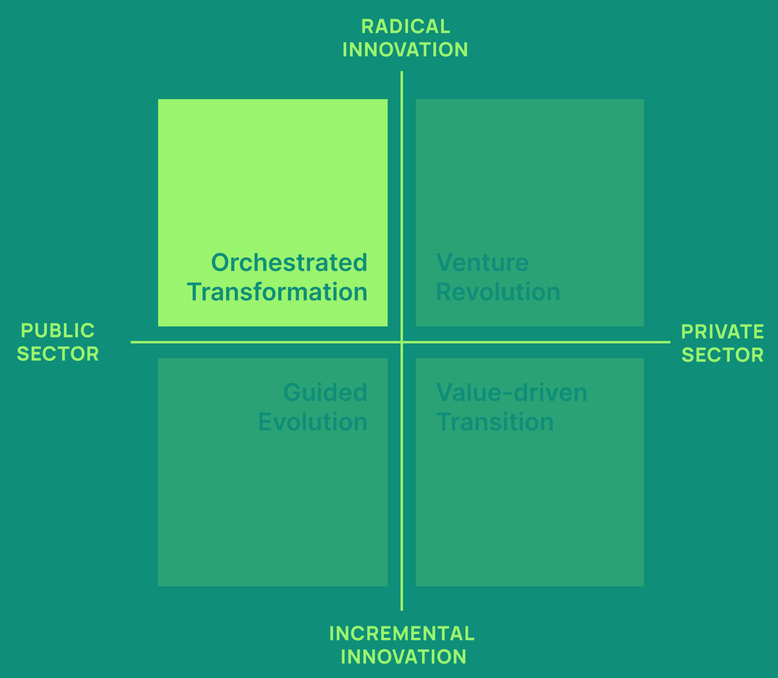
Rising public demand for decisive government action. Opinion polls and election platforms converge around calls for state-led climate infrastructure, signalling readiness for more centralised coordination.

String of climate-related large infrastructure failures. Repeated port shutdowns, grid outages, or transport disruptions reveal systemic fragility and prompt governments to intervene more directly.

Acceleration of EU-level joint financing mechanisms. A rapid expansion of shared investment tools (green bonds, cross-border funds, public procurement alliances) shows political alignment around large-scale intervention.

Early experimentation with state-backed clean-fuel corridors. Pilot programs linking ports, shipping lines, and energy producers under unified public mandates indicate movement toward coordinated industrial planning.

Orchestrated Transformation



PUBLIC SECTOR DRIVEN / **RADICAL** INNOVATION

FUTURE WORLD

Large-scale transformation driven by coordinated policy and funding to de-risk green infrastructure investments.

Climate shocks and energy/geopolitical crises expose fragility in infrastructure, supply chains, and energy systems. Fragmented actions fail to tip the system, so by the early 2030s governments shift to coordinated European intervention: shared standards, guarantees, and joint infrastructure to align industry and R&D behind climate neutrality and resilience as strategic priorities.

Economy / Governments de-risk capital-intensive transformations with public funding, guarantees, open test sites, and long-term offtake—grants bridge pilot-to-scale, then stable regulation and aggregated demand take over.

Environment / Emissions rise early, then fall steeply once coordination takes hold—reaching climate neutrality before 2050. Energy becomes shared strategic infrastructure (resilient grids, abundant low-carbon power) while nature-based restoration is scaled for resilience and carbon storage.

People / A fast “mobilisation” phase is disruptive, then pays off through more stable energy costs, cleaner air, and visible public programmes—political tension shifts to questions of governance, transparency, and fairness in how the new system is run.

FUTURE PORT

Ports in this future emerge as strategic anchors within EU climate plans

GLOBAL TRADE & SHIPPING

Trade splits into a two-tier system (compliant ships get priority access, non-compliant face delays/ surcharges) while governments narrow fuel fragmentation through coordinated green-fuel infrastructure.

PORT INFRASTRUCTURE

Ports become clean-energy gateways and system integrators, scaling electrification and resilient power systems under unified plans, and embedding circular materials rules into how assets are built and renewed.

LOGISTICS & SUPPLY CHAIN

A coordinated “great rebuild” reshapes hinterland flows: diesel declines under hard deadlines, clean road and corridor infrastructure scales fast, and resilience upgrades become core to keeping operations stable in extreme weather.

LABOUR & COMMUNITY

Automation and new energy systems reshape work, so governments and social partners fund large-scale retraining to keep workers included.

Trade Pattern Shift HIGH
Intensified global trade via coordinated corridors

Infrastructure Upgrade Intensity HIGH
Major system rebuilds

Automation Intensity HIGH
Coordinated automation

Workforce Stability HIGH
Planned, stable transformation

Ship. Fuel Trans. Intensity HIGH
Clean fuels scale fast via public coordination

Port Role in Energy Systems HIGH
Ports as energy hubs

Data as Access Requirement HIGH
Mandatory via regulation

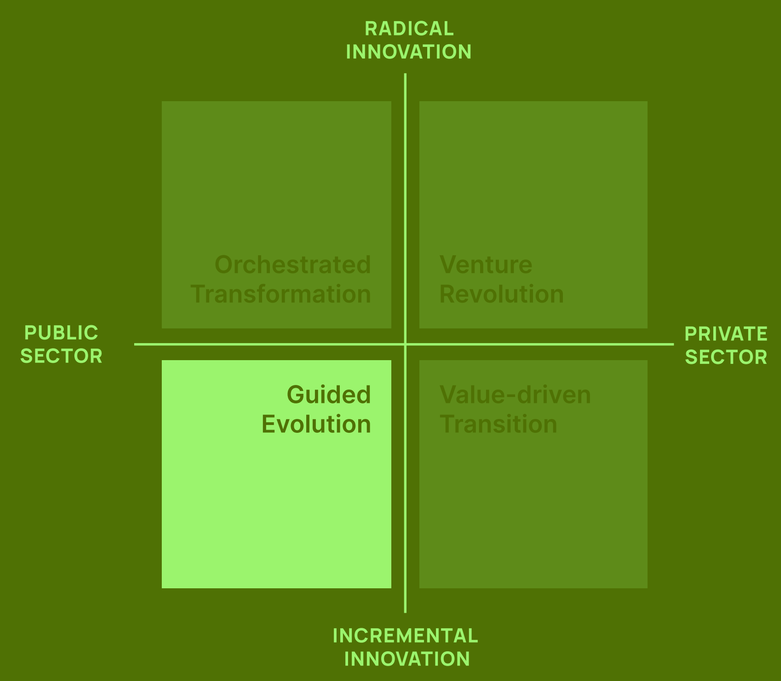
Skills Shift Intensity HIGH
Large-scale reskilling



EARLY WARNING SIGNS

- **Europe’s competitiveness deteriorates:** industrial decline and clean-tech/energy cost gaps trigger calls for assertive state intervention.
- **Rising public demand for decisive government action:** polls and election platforms converge on state-led climate infrastructure.
- **String of climate-related large infrastructure failures:** repeated port/grid/ transport disruptions prompt direct intervention.
- **Early experimentation with state-backed clean-fuel corridors:** pilot programmes linking ports, shipping, and energy under unified mandates.
- **Acceleration of EU-level joint financing mechanisms:** rapid expansion of shared investment tools (green bonds, cross-border funds).

Guided Evolution



In this scenario, the government takes leadership, meaning that public authorities drive change through policy frameworks, coordinated standards, and public investment in proven solutions. Innovation follows an incremental path, prioritising the scaling of reliable technologies over experimental breakthroughs, ensuring continuity of service and minimising disruption to existing systems.

PUBLIC SECTOR DRIVEN INCREMENTAL INNOVATION

In this "guided evolution" scenario, **governments drive cautious decarbonisation** through coordinated frameworks that prioritise proven technologies and operational continuity. Driven by **security threats** and an **ageing population** that strain public budgets, phased public investment scales reliable solutions while avoiding disruption. Ports become **dependable executors of EU-aligned standards**, advancing climate neutrality through steady, managed upgrades that balance progress with stability.



What if security pressures and stretched budgets force Europe to choose stability and proven upgrades over speed and revolutionary bets in climate transition?

This future of "guided evolution" does not arrive through one grand decision; it unfolds through a long sequence of coordinated steps. Europe moves into this future under the combined weight of rising **security threats** and an **ageing population**. Security concerns—physical threats to critical infrastructure, cyberattacks on essential services, and geopolitical instability that disrupts supply chains—push governments to prioritise continuity. An ageing population strains public budgets and creates pressure to maintain stable employment and public services without sudden upheaval. Together, these pressures lead governments to **prioritise business continuity**: keeping essential services running, protecting citizens, and reducing exposure to shocks.

Decision-makers adopt a **risk-averse mindset**. They extend the life of existing assets and scale technologies that have already demonstrated reliability. Investment focuses on "no-regret" pathways—measures that deliver predictable returns, maintain service continuity, and benefit from strong public oversight.

This moment marks a shift in how change is organised. Public authorities emphasise policy frameworks that promote the scaling of proven technology and solutions. The state focuses on protecting citizens, stabilising essential services, and reducing exposure to shocks through coordination and steady incremental innovation.

REAL WORLD EXAMPLE

Coordinated, gradual change

Think of the European Green Deal, a framework that coordinates climate action across an entire continent. It does not impose a radical redesign overnight. Instead, it sets shared targets, aligns member states around common standards, and supports the gradual scaling of proven solutions. In this future, that same logic defines Europe's approach to decarbonisation: cumulative, coordinated, and built on reliability rather than risk.

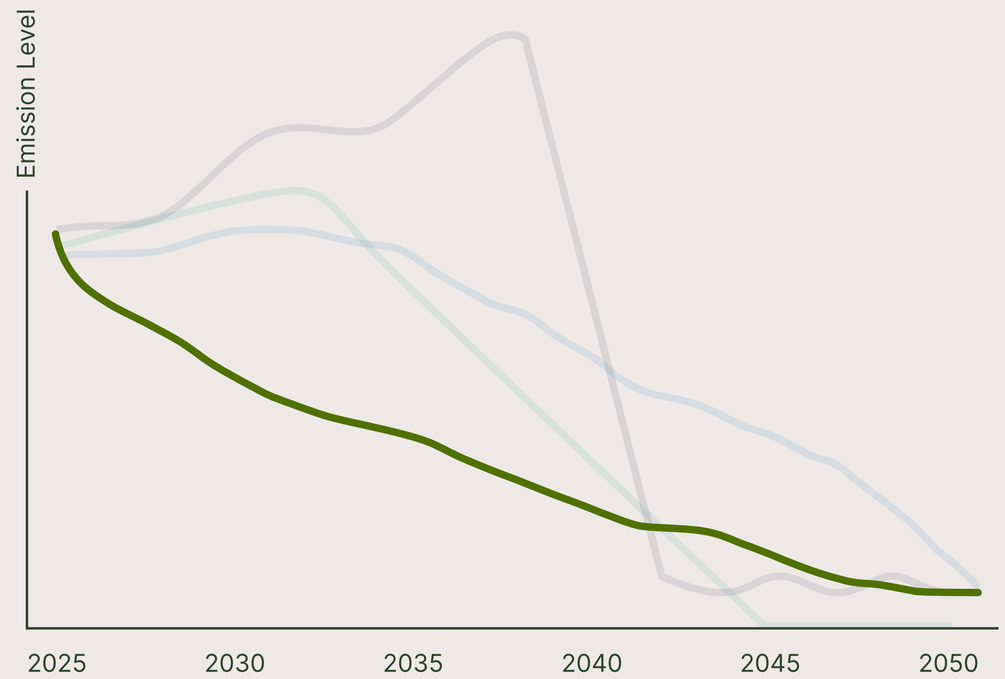
Environment

In this future, Europe chooses reliability over reinvention in its energy systems. Governments prioritise energy systems that are predictable, serviceable, and low-risk, extending the life of proven assets rather than commissioning entirely new technologies. Nations prolong existing nuclear infrastructure and invest in islandable microgrids—local electricity networks capable of operating independently from the national grid during disruptions—with dual-use functionality that can support both civilian services and emergency needs.

As proven technologies, hydropower, wind and solar farms continue to operate and scale where necessary to meet climate neutrality targets. The focus is on upgrading existing assets, replacing ageing turbines and panels with more efficient models on the same sites, improving grid connections to reduce curtailment, and enhancing forecasting systems to make renewable output more predictable. Scaling occurs at a controlled pace that avoids overextending public budgets or introducing untested systems that could fail or require expensive course corrections.

Soil is treated as a controlled resource. Excavated soil must be tested, classified, and reused only in approved applications such as cement, roads, or flood protection, with strict limits on contamination.

Water pollution trends downward through tighter discharge rules, better storm water capture, and gradual retrofit of industrial run-off controls. Storm water management improves through green infrastructure (permeable surfaces, retention ponds, and vegetated swales) that captures and filters rainwater before it carries pollutants into rivers and coastal waters.



Smooth and steady - reliable progress / **Emissions** follow a path of managed, gradual decline. Without steady intervention, structural inertia would have kept emissions stagnant. Instead, a consistent emphasis on efficiency gains, phased electrification, and systematic upgrades gradually reduces total output. The trajectory is reliable: while lacking the speed for early radical cuts, the accumulation of incremental progress ensures the 2050 net zero goal is met.



Economy

In this future, Europe operates with caution. Governments finance greening projects and favour scaling proven technologies. This approach reduces speculative investment and ensures transitions remain controlled and predictable, though it also limits the pace of deployment.

Global trade slows as security concerns and geopolitical mistrust reshape supply chains. Physical and cyber threats to critical infrastructure push nations to abandon volatile deep-sea routes in favour of "trusted corridors". Consequently, inland transport, short-sea shipping, and regional cross-border links become the backbone of a more selective, secure trading network.



People

After a decade of security scares and an ageing population, governments make stability the top priority. They set national standards, publish compliance lists, and tie rebates and lower tariffs to certified upgrades. Households are required to register major devices, allow basic metering for energy and air quality, and use approved contractors for replacements. Each year people tick off small, mandated improvements like swapping old heaters and vehicles for certified high-efficiency models and enrolling in verified green tariffs. Progress is checked by inspectors and shown on public dashboards. The message is simple. Follow the standard, keep your receipts, and fix what you have before buying something new.
Buying shifts because the rules change. Spare parts must be available for set periods, and retailers must accept returns for deposits and repairs.

People value policies that minimise risk, protect essential services and prioritise collective wellbeing. Public sentiment favours gradual improvement over disruptive change, with trust depending on the state’s ability to deliver tangible benefits without imposing sudden costs or upheaval.

Green Tech

This future values stability and reliability. Technologies in this world lean on dual-use incremental innovations, proven solutions, retrofits and tech-neutral add-ons that are easy to meter, maintain, and audit. Upgrades slot into what already works to raise uptime and keep costs predictable.

The following technologies are possible in this scenario:

- ✓ Shore power
- ✓ Dual-fuel ship configurations
- ✓ Batteries at key terminals
- ✓ Verified carbon capture systems for older ship engines
- ✓ Modular clean fuel equipment and ship-side kits
- ✓ Islandable microgrids
- ✓ Robotic underwater inspection and maintenance
- ✓ Electric and hybrid cargo-handling equipment
- ✓ Waste-heat recovery systems
- ✓ AI-assisted logistics planning
- ✓ Existing nuclear infrastructure
- ✓ Existing hydropower infrastructure

WILD CARD

Electrochemical ocean carbon removal integrated into port breakwaters

Modular electrochemical units embedded in port breakwaters draw CO_2 directly from seawater, regenerate alkalinity, and precipitate carbonate solids. The process increases seawater alkalinity, enhancing carbon storage capacity. Carbonate solids can be used as construction aggregates, reducing demand for mined materials.

This wild card appears as a temporary buffer closing the gap between climate targets and slower real-world progress under incremental transition. Governments use ocean carbon removal to balance committed climate neutrality targets against the cautious pace of phased decarbonisation, buying time while emissions from ships, ports and industry fall through steady upgrades.

The technology aligns with incremental logic through dual-use deployment. Port breakwaters already protect harbours. Embedding carbon removal units allows testing without new infrastructure or disruption, delivering coastal protection and climate benefits simultaneously. Governments fund pilots through existing budgets, limiting risk, and scale gradually once monitoring matures. Deployment is government-guided and precautionary: gradual, tightly regulated, with extensive ecosystem monitoring assessing impacts on water chemistry, biodiversity, and food chains before expansion.

Source / World Economic Forum (2024). Direct ocean carbon capture technology explained. https://www.weforum.org/stories/2024/10/direct-ocean-capture-carbon-removal-technology/



PORTS IN THIS FUTURE

Ports in this future operate as dependable executors of EU-aligned climate standards within an increasingly security-conscious Europe.

In this future scenario, ports operate as dependable executors of EU-aligned climate standards within an increasingly security-conscious Europe. They advance decarbonisation through steady, managed scaling and upgrades that prioritise operational continuity and risk minimisation.

Ports coordinate incremental improvements across shipping lines, terminal operators, energy suppliers, and hinterland transport providers, ensuring that each upgrade integrates smoothly with existing operations.

As reliable nodes in a cautiously evolving system, ports maintain trade flows and energy security while gradually reducing emissions, benefiting from stable regulations and long planning horizons that allow infrastructure investments to mature predictably over decades.

01 / Global trade & shipping

Cautious trade that leads to nearshoring

Security concerns and geopolitical uncertainty slow some deep-sea routes, while short-sea shipping and intra-European links gain importance. Governments steer trade toward trusted partners with aligned regulatory standards through customs policy, security screening, and bilateral agreements.
This transition is reinforced by the loss of major cross-border gas pipelines that previously supplied Europe. The disruption of these energy routes exposed the vulnerability of depending on infrastructure that crosses geopolitically unstable regions. As a result, nations prioritise regionally controlled maritime infrastructure over fixed transnational pipelines.

Regionalisation reduces average voyage lengths and lowers fuel consumption per shipment. On the other hand, it fragments markets, slowing the scale-up of clean fuel infrastructure as smaller trading zones struggle to justify large-scale bunkering investments across multiple fuel types.

Shipping companies modernise cautiously under persistent regulatory uncertainty, balancing emissions reduction with financial risk. Older vessels are retrofitted with hybrid propulsion systems that cut emissions during port operations. Carbon capture systems are installed to treat exhaust gases, reducing both emissions and compliance costs under tightening regulations. Ships without these upgrades face rising fees that create pressure to invest without forcing immediate fleet replacement. New vessels prioritise dual-fuel designs, allowing operators to switch between conventional and cleaner fuels as prices, bunkering infrastructure and regulations evolve.

Governments avoid committing early to a single green fuel, maintaining technology-neutral policies that drive gradual decline in fossil fuel intensity while allowing multiple alternatives to coexist. Conventional fuels persist longer than in other futures, but are increasingly constrained by tightening efficiency standards and emissions caps. Sustainable fuels such as biofuels, green methanol, and ammonia are introduced where supply chains are proven, but scale slowly as governments prioritise economic stability over rapid transition. This approach limits stranded assets and economic disruption, but also slows absolute emissions reductions. Governments accept this trade-off explicitly, relying longer on carbon capture as a temporary, imperfect compliance mechanism while fuel infrastructure, fleet renewal, and supply chains gradually align with long-term decarbonisation goals.

02 / Port Infrastructure

Incremental upgrades for resilience and reliability

Physical infrastructure is upgraded incrementally to maintain operational reliability under changing climate conditions. Quays and terminals are reinforced to withstand more frequent extreme weather. Energy supply systems are upgraded to support shore power and battery storage at berths, allowing vessels to connect to the grid while docked and reducing reliance on polluting auxiliary engines.

Ports install treatment systems that filter contaminated run-off before it reaches waterways. Industries adopt closed-loop cooling systems and improved waste handling that reduce the volume and toxicity of discharges.

Industrial facilities within port areas adopt waste-heat recovery systems that capture excess thermal energy from production processes and redirect it for heating or on-site operations. These systems lower energy demand and emissions without requiring new generation capacity, making them low-risk investments with immediate cost benefits that fit the cautious investment logic of this future.

Ports deploy digital systems to improve yard management, reduce equipment idle time, and coordinate multimodal flows more efficiently. Drones and robotic underwater inspection systems monitor port infrastructure (quay walls, piles, and navigation channels) extending asset lifetimes and reducing the risk of disruptive emergency repairs.

Governments progressively tighten requirements on embedded carbon in construction, pushing ports toward higher reuse of steel, concrete, and dredged materials. Circular construction practices expand, but mostly through optimisation of existing supply chains rather than radical redesign of procurement and logistics. Ports increasingly coordinate reuse and recycling flows where economically viable, acting as regional material hubs for recovered aggregates and structural components.

03 / Logistics & Supply Chain

No-regret efficiency across multimodal corridors

Hinterland transport decarbonises through steady, regulated upgrades. Rail capacity expands where bottlenecks are chronic, inland waterways receive phased efficiency gains through cleaner engines, shore power at terminals, and improved traffic management, and trucks electrify first on predictable, high-volume corridors where charging infrastructure delivers clear returns.

Multimodal connections are strengthened to reduce road freight congestion. Rail and barge routes are upgraded with improvements to capacity, electrification, and scheduling coordination. Inland waterways become more reliable through lock maintenance, regular dredging, and installation of charging or refuelling points for electric or hybrid barges at key terminals.

Goods handling and distribution are optimised through AI-assisted planning systems that coordinate vehicle arrivals, loading bay allocation, and cargo sequencing. These systems reduce congestion, minimise idle time, and improve fuel efficiency.

Digitalisation focuses on proven technologies: terminal operating systems tracking containers in real time, predictive maintenance systems identifying equipment issues before breakdowns, and data-sharing platforms improving coordination between ports, shipping lines, and hinterland operators.



04 / Labour & Community

Gradual reskilling and social stability

Employment in ports evolves gradually. Many roles shift from manual cargo handling toward inspection, maintenance, system monitoring, rostering, and customer service. Workers are retrained through mandatory programs co-funded by employers and the government, ensuring that those displaced by automation or changing operational needs can transition into new roles within the port ecosystem.

Training focuses on practical micro-credentials that workers can accumulate over time, stored in a national digital wallet that makes skills visible to employers. Older workers benefit from structured reskilling pathways that allow them to combine updated knowledge with lifelong expertise, avoiding premature exit from the labour market.

The relationship with the local community is shaped by visible improvements: cleaner air from reduced diesel emissions, quieter operations due to electric equipment, and stable employment that supports local economies. Trust in the port as a responsible employer and neighbour grows as these benefits become tangible.

Strengths, Weaknesses, Opportunities & Threats

Guided Evolution is characterised by steady, regulated progress that prioritises predictability, safety, and continuity.

Its main **strength** is that it builds on proven technologies and incremental upgrades, allowing decarbonisation to advance with limited disruption to daily operations and lower financial risk. Strong regulation and public oversight provide stability and help safeguard essential services, while a structured approach to upskilling supports social peace and reduces labour-market shocks. The result is a transition that feels manageable and broadly acceptable, even if it is less dramatic than more transformative pathways.

The **weaknesses** of this scenario stem from its pace and reliance on incrementalism. Decarbonisation progresses slowly, often depending on efficiency improvements and carbon capture to close the gap to net zero. Without bold renewal, infrastructure risks becoming outdated, and the overall system may struggle to keep up with the scale of change required. Fragmentation across EU member states can further weaken competitiveness, especially if standards, incentives, and investment priorities diverge. The scenario also tends to dampen experimentation, which can reduce innovation and slow the emergence of breakthrough solutions.

Guided Evolution nonetheless offers meaningful **opportunities**. It can strengthen regional trade and trusted supply chains, while supporting a local circular economy that reduces material dependence and improves resource efficiency. Optimising and digitalising existing systems can deliver significant efficiency gains, and incremental adaptation—combined with dual-use investments that serve both decarbonisation and resilience—can steadily improve the port's ability to cope with disruption over time.

The key **threats** relate to the scenario's narrow margin for delay. If efficiency gains stall, climate impacts accelerate, or carbon capture fails to deliver sufficient reductions, the pathway can fall short of targets with limited capacity to catch up quickly. Slow adaptation also leaves ports more exposed to extreme weather events, and prolonged stagnation may erode public support for the transition—especially if costs are visible while progress feels too gradual.

EARLY WARNING SIGNS

What to look out for

Brownfield priority / New mega-projects stall while retrofits surge. Major ports favour scaling proven technologies over commissioning entirely new infrastructure, signalling a preference for upgrading what already exists.

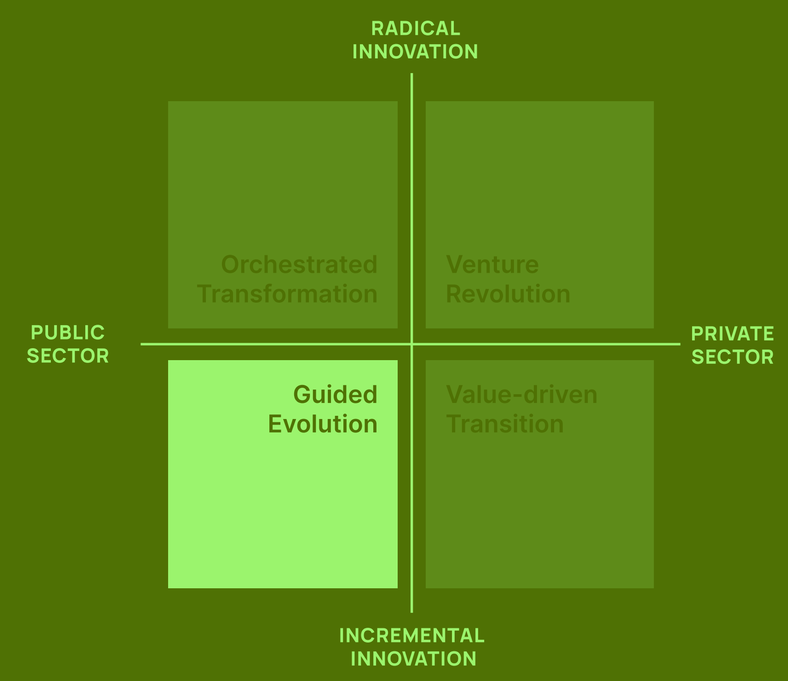
Resilience over ambition / Policy shifts to emphasise "critical infrastructure protection and resilience," revising climate, defence, and supply chain budgets that reflect dual-use funding priorities: investments are justified not only by climate benefits but also by their contribution to security and continuity. Climate action receives less dedicated funding as a standalone priority but still benefits from broader resilience spending.

Regional trade dominates / Short-sea and intra-European shipping grow faster than deep-sea trade, signalling a move toward trusted, local supply chains and reduced reliance on distant, less secure trade routes.

Proven tech mandate / Subsidies and regulations increasingly favour low-risk, standardised solutions. Experimental pilots stall or fail to secure funding, indicating that policymakers are unwilling to bet on unproven technologies.

Guided Evolution

PUBLIC SECTOR DRIVEN / INCREMENTAL INNOVATION



FUTURE WORLD

Steady, government-driven transition through regulation, upgrades and scaling of proven technologies.

Rising security threats and an ageing population push governments toward risk aversion and continuity. Europe scales reliable technologies and extends existing assets through “no-regret” upgrades with predictable returns and strong public oversight.

Economy / Public financing and standards steer investment toward proven tech and controlled deployment. Trade slows and becomes more regional/selective as security concerns reshape supply chains and trusted corridors.

Environment / Emissions gradually decline—efficiency gains, phased electrification, and systematic upgrades help reach net zero by 2050. Energy systems prioritise reliability (prolonged nuclear, controlled scaling of wind/solar, and islandable microgrids). Water pollution trends downward through tighter discharge rules and stormwater retrofits.

People / Households complete mandated annual efficiency improvements, tracked by inspections and public dashboards. Rules push “repair before replace” with required spare parts and deposit/repair take-backs.

FUTURE PORT

Ports in this future operate as dependable executors of EU-aligned climate standards within an increasingly security-conscious Europe.

GLOBAL TRADE & SHIPPING

Trade shifts toward regional routes as security checks slow long-haul flows; shipping decarbonises gradually through retrofits and dual-fuel ships, guided by predictable government rules (no sudden bans).

PORT INFRASTRUCTURE

Ports strengthen and optimise what already exists: resilience upgrades, more shore power, better water controls, and practical digital tools to run terminals more reliably and extend asset life.

LOGISTICS & SUPPLY CHAIN

Emissions fall through phased upgrades: more rail where capacity is tight, cleaner inland shipping, and electric trucks first on high-volume corridors, using planning tools to cut congestion and idle time.

LABOUR & COMMUNITY

Jobs shift slowly and remain stable: more monitoring and maintenance, less manual handling, supported by employer-funded retraining that helps workers.

Trade Pattern Shift MID
Regional + selective trade (security-driven)

Ship. Fuel Trans. Intensity MID
Cautious shift (retrofits + dual-fuel)

Infrastructure Upgrade Intensity LOW
Incremental retrofits

Port Role in Energy Systems LOW
Energy supports operations

Automation Level LOW
Assistive tech only

Data as Access Requirement LOW
Data for security + efficiency (not full gatekeeping)

Workforce Stability HIGH
Stable roles, gradual change

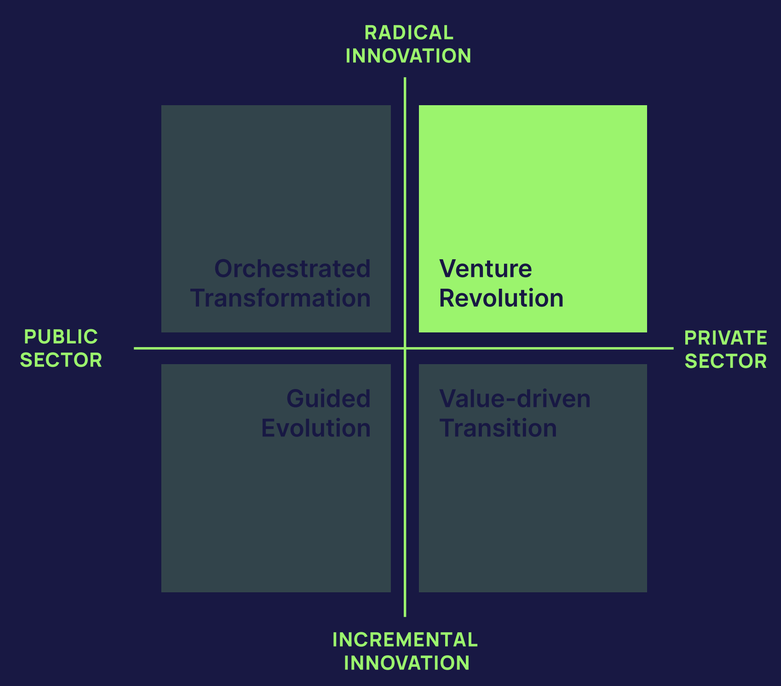
Skills Shift Intensity LOW
Gradual upskilling



EARLY WARNING SIGNS

- **Brownfield priority:** retrofits surge while new mega-projects stall.
- **Resilience over ambition:** policy frames climate action as critical infrastructure protection and continuity.
- **Regional trade dominates:** short-sea and intra-European shipping outpaces deep-sea flows.
- **Proven tech mandate:** subsidies/regulation favour standardised, low-risk solutions; experimental pilots stall.

Venture Revolution



In this scenario, the private sector leads the transformation, with governments playing a limited coordinating role. Innovation is radical, involving breakthrough technologies that create entirely new markets and disrupt existing industries rather than refining established systems.

PRIVATE SECTOR DRIVEN
RADICAL INNOVATION

In this "venture revolution" scenario, **private companies drive rapid decarbonisation** through fierce competition and radical innovation, filling gaps left by slow government coordination. Driven by **commercial opportunity**, **nuclear fusion** (a process that mimics how the sun produces energy by fusing light atoms together, releasing enormous amounts of clean power), and **AI breakthroughs**, venture capital and corporate consortia deploy transformative technologies rapidly. Ports become **competitive innovation arenas, shaped by private capital and deal-driven ecosystems** where first movers consolidate advantage while others struggle to access the capital needed to compete.



FUTURE WORLD

What if private capital flows into ports faster than governments can plan, turning climate tech into a winner-takes-all race?

This future of "venture revolution" is born from a sequence of limited government coordination: the seasons when **climate shocks** accelerated faster than policy could respond, the years when **public institutions moved too slowly** to coordinate solutions, and the moment when private actors realised they could not wait for direction that would never arrive in time.

The late 2020s bring a series of **heatwaves**, **prolonged droughts**, **floods**, and **storms**. Governments struggle to keep pace with accelerating climate shifts. Public institutions cannot provide the coordination or solutions that companies need to protect their operations and supply chains. By the early 2030s, it becomes clear that private actors must fill the gaps themselves or risk losing assets, market position, and competitive advantage.

Companies start driving change through market mechanisms. They coordinate through private consortia, deploy capital into experimental business models, and push ahead with whatever solution works fastest and scales quickest. Investors finance despite the risk of technical failure and market rejection, in exchange for the chance to dominate emerging energy markets. Their motivation is straightforward: **turn climate uncertainty into profit**, **capture the highest Return on investment**, and **secure competitive first-mover advantage**. Firms treat climate technology as a strategic asset, on par with data infrastructure and supply chain control.
They assume responsibility for building the systems that governments cannot deliver at speed.

This moment marks a shift in how change is organised. Innovation accelerates through venture funding, corporate alliances, and rapid experimentation. Companies set the tempo for the wider system, pushing new technologies into global supply chains and creating market-driven momentum that no single government could achieve alone.

REAL WORLD EXAMPLE

Breakthrough Innovation

Think of Waymo deploying driverless taxis across American cities. What drove this breakthrough was pure private ambition—no government master plan, no coordinated industry standard, just one company racing ahead with venture capital and radical technology. Waymo didn't wait for regulators to define the rules; it created working prototypes, tested them at speed, and forced policy to catch up. In this future scenario, that same competitive, experiment-first energy now defines Europe's response to climate change.

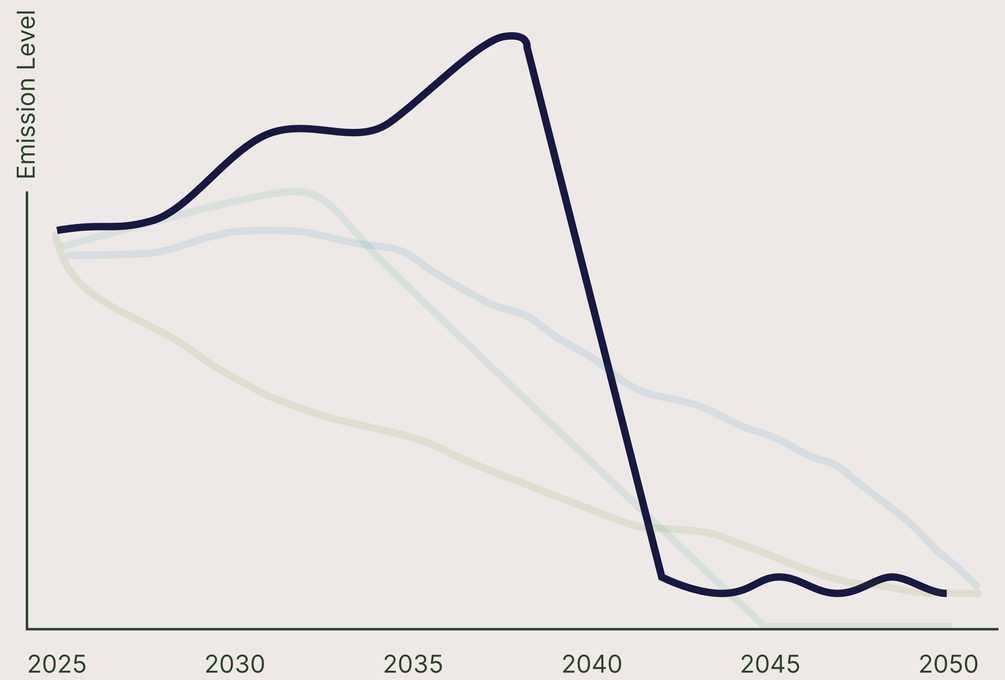
Environment

Energy systems transform through high-risk private ventures. Companies chase first-mover advantages in frontier solutions including wave-energy converters (devices extracting power from ocean wave motion), and ultra-compact portable power units (mobile energy systems for applications without grid access). These technologies mature because investors accept the risk of technical failure and market rejection in exchange for the chance to dominate emerging energy markets. The rush to commercialise creates an experimental energy landscape where multiple competing systems develop simultaneously, with market performance determining which technologies survive and scale.

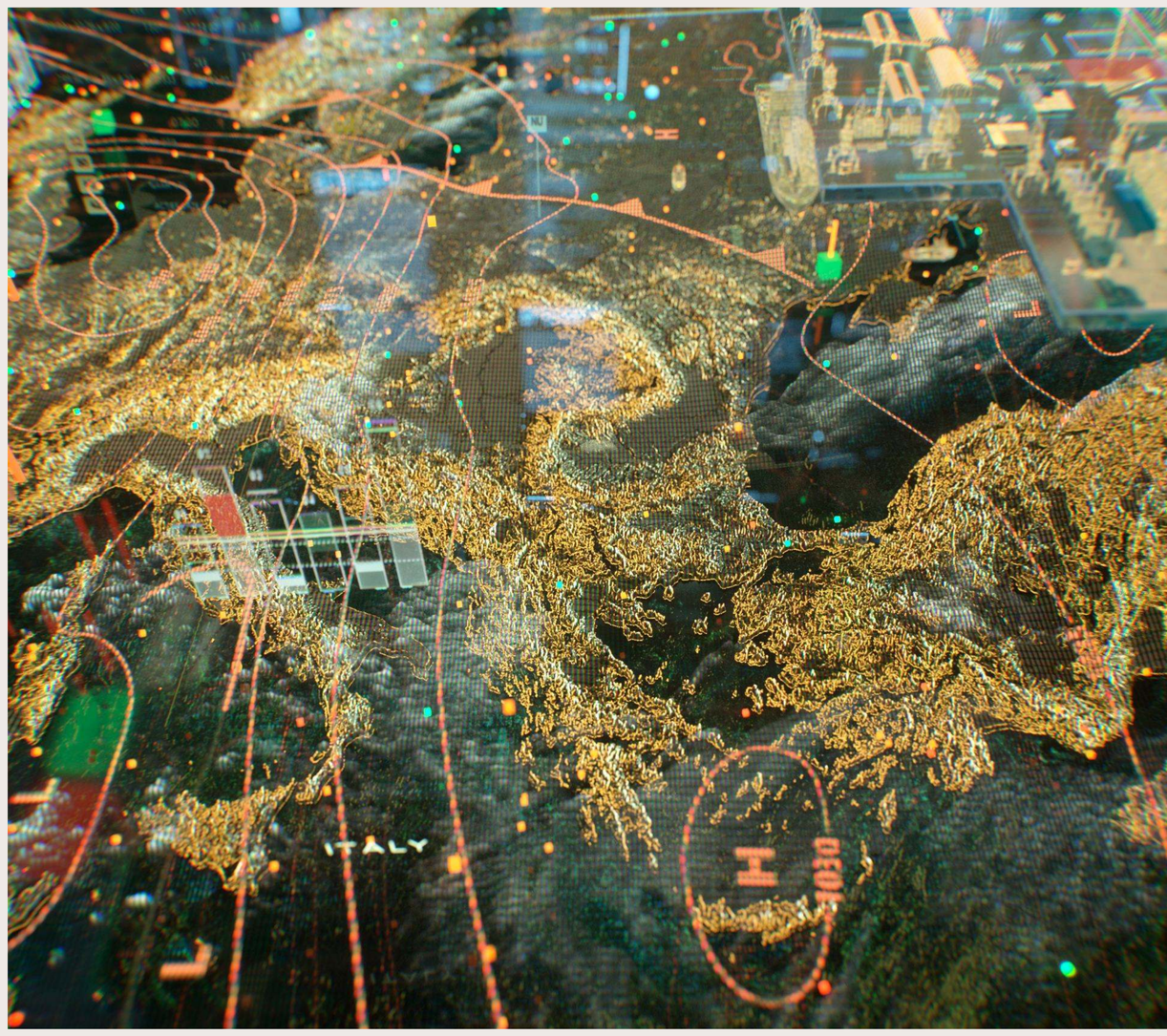
Nuclear fusion begins serving data centres for AI development because they need electricity, reliability, and cost certainty in large quantities. Once nuclear fusion provides firm clean power at scale, compute becomes cheaper and more abundant, accelerating AI capabilities across logistics, optimisation, and automation. This more powerful AI drives faster innovation—designing better materials, optimising complex networks, and tightening operations in real time. The flywheel is self-reinforcing: abundant clean power enables more AI, and more AI enables faster deployment of clean power and automated infrastructure throughout the economy.

Clean fuels scale when nuclear fusion-powered electricity becomes abundant and cheap, making synthetic fuel production economically viable, while simultaneously volatile fossil fuel prices make alternatives competitive. E-methanol and ammonia—synthetic fuels made by creating green hydrogen via electrolysis (splitting water using electricity) and combining it with captured CO_2 (for e-methanol) or nitrogen (for e-ammonia)—become standard across industries because they can store and transport energy where direct electrification is impractical. Electricity powers all systems that can be electrified. Carbon capture (systems removing CO_2 from exhaust or atmosphere) operates only when it generates profit or feeds industrial buyers. Circular material flows grow into revenue-generating markets, transforming worn components and recovered feedstocks into commercial products.

Environmental benefits are uneven. Frontrunner regions see rapid air-quality gains as diesel disappears from daily operations. Water stress intensifies in energy- and manufacturing-heavy regions, especially around data centres, hydrogen production, and electronics manufacturing. Cheap nuclear fusion power enables desalination in some areas, but pressure concentrates where production scales fastest.



Late breakthrough cliff / **Emissions** follow a volatile and non-linear path. They rise initially as governments lack coordination to implement effective carbon controls. The turning point arrives when nuclear fusion power proves commercially viable, triggering a self-reinforcing cycle: cheap, abundant energy accelerates AI capabilities, which drives faster innovation and deployment of clean technologies across all systems. Emissions then drop sharply and non-linearly, with the decline steepening as nuclear fusion matures for maritime applications. Progress levels off once dominant technologies secure market share, though adoption remains uneven based on access to capital.



Economy

Economic gravity shifts decisively toward private investment in this future. Venture funds, corporate consortia, and high-capital innovators drive development at a pace public budgets cannot match. Markets reward speed and first movers, creating fierce competition across global supply chains that intensifies as companies chase profit opportunities wherever they appear.

Collaboration becomes opportunistic. Lightweight research consortia, innovation hubs, maker-spaces, and temporary labs replace long-term partnerships coordinated by governments or industry associations. These arrangements form quickly around specific technical challenges, dissolve when solutions emerge, and reform around new opportunities, creating a fluid innovation ecosystem driven by immediate commercial needs.

Trade intensifies and supply networks reshape continuously as companies deploy new technologies to optimise performance. This creates room for frontrunners to move faster while slower players fall behind, unable to match the capital investment or technical capabilities required to compete. The result is an economy where market position can shift rapidly, with high rewards for success but significant risks for those who cannot keep pace with technological change or access sufficient capital to experiment and scale new solutions.



People

The social contract is written by performance. If a service meets its promise, it earns your trust and your money. If it slips, you switch. Most households run on bundles for power, mobility, housing and deliveries with clear uptime targets and automatic credits when those targets are missed.

People allow platforms to read home devices, travel habits and spending in exchange for lower prices and faster response. You can opt out, but it is slower and more expensive, so most people accept constant measurement as the price of a smooth life. Personal dashboards show reliability scores for everything from air quality at home to the punctuality of your street’s courier route. People compare these scores the way they once compared phone plans.

Social protection is lean in this environment. Instead of broad safety nets, access to services depends more on individual income and financial wealth. People value status and quality of life. They are open to constant change, accepting rapid shifts in work patterns and skill requirements as the price of participation in a fast-moving economy.

Green Tech

This future is market-led and speed obsessed. Capital flows to technologies that deliver a quick payback. Technologies in this world lean on financeable solutions that scale fast and that perform where needed.

The following technologies are possible in this scenario:

- ✓ Wave-energy converters
- ✓ Ultra-compact portable power units
- ✓ Sodium-ion batteries
- ✓ E-fuel micro-hubs
- ✓ Methanol fuel systems
- ✓ Ammonia fuel systems
- ✓ Hydrogen engines
- ✓ Carbon capture systems
- ✓ AI copilots
- ✓ Fleet robotics
- ✓ Autonomous vessels
- ✓ Hyperloop systems
- ✓ Near-space cargo systems
- ✓ Autonomous inland transport
- ✓ Yard robots
- ✓ Underwater drones
- ✓ Autonomous E-Trucks
- ✓ Drone-based logistics
- ✓ Nuclear Fusion
- ✓ Space-based solar power (SBSP)

WILD CARD

Nuclear Fusion in Autonomous Vessels

This technology combines next-generation autonomous vessels with nuclear fusion reactors that provide continuous, zero-emission energy for propulsion, onboard AI systems, and advanced logistics operations. The vessels integrate fully with real-time navigation and fleet-management platforms, enabling long-duration, high-efficiency operations without refuelling.

This wild card appears in this future because high-stakes markets reward radical innovation with potentially transformative returns. Private consortia deploy and scale nuclear fusion-powered autonomous vessels as rapidly as possible to secure first-mover advantages in verified zero-emission, long-range logistics before regulatory frameworks and infrastructure standards mature, allowing them to define technical specifications and capture market share in next-generation maritime transport.

Source / Van Rheenen et al. (2024), Nuclear fusion as unlimited power source for ships, TU Delft / IMDC 2024 file:///Users/madecoworker/Downloads/vanRheenen_NuclearFusionas_Final%20(2).pdf



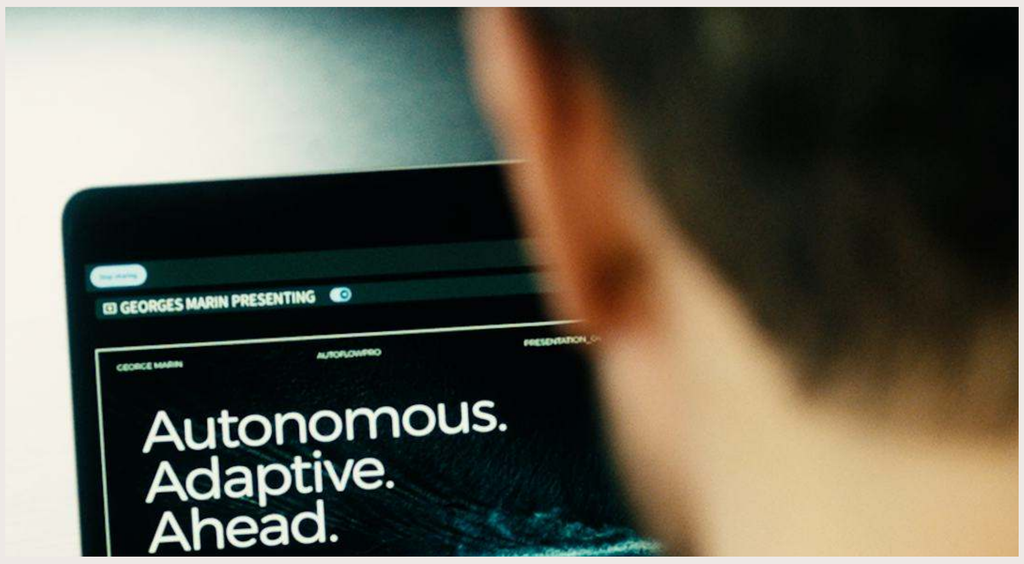
PORTS IN THIS FUTURE

Ports in this future evolve into deal-driven ecosystems where venture funds and corporate consortia race to capture first-mover advantages.

As nuclear fusion power proves viable in data centers, it makes compute dramatically cheaper and more abundant, accelerating AI capabilities across logistics, optimization, and automation. This more powerful AI then enables faster deployment of clean technologies throughout port systems, creating a self-reinforcing cycle of innovation.

Ports evolve into deal-driven ecosystems where venture funds and corporate consortia race to capture first-mover advantages. As nuclear fusion technology matures for maritime applications, the traditional logic of port bunkering weakens—vessels with onboard nuclear fusion systems operate for months without refuelling.

Ports that attract innovation capital and successfully deploy breakthrough technologies consolidate their position, while those lacking investment or technical capabilities fall behind in a system where abundant clean energy and advanced AI optimisation become the primary competitive differentiators.



01 / Global trade & shipping

Autonomy, nuclear fusion power, and performance-driven trade

Trade intensifies as private companies chase profit opportunities across global supply chains. Supply networks reshape continuously through new technologies, creating advantages for frontrunners. Shipping becomes a competitive arena where first movers in breakthrough energy systems and autonomous operations capture premium customers.

Nowhere is the disruption more visible than at sea. Advanced AI systems drive rapid improvements in route optimisation, fleet coordination, and autonomous navigation, giving early adopters decisive operational advantages.

The more radical shift follows as nuclear fusion technology matures for maritime applications. A share of deep-sea vessels can operate for months without bunkering because onboard nuclear fusion-based power changes the logistics equation: fewer fuel stops, less route constraint, and far more autonomy in where ships can go and how long they can stay at sea.

Shipping remains mixed: some fleets run on e-methanol and green ammonia—synthetic fuels made from clean electricity—because they are scalable, tradable, and fit many engine pathways. Others adopt onboard nuclear fusion systems to eliminate bunkering dependence almost entirely. The net effect on ports is profound: traditional bunkering centrality weakens, and ports compete more on speed, maintenance capabilities for advanced propulsion systems, compliance processing, digital coordination, and specialized services than on fuel supply depth.

02 / Port Infrastructure

Deal-driven innovation zones and frontier systems

Ports operate as innovation incubators driven by private capital, commercial risk-taking, and speed-to-market incentives. Innovation zones open inside terminals, hosting private research clusters where logistics tech, automation, and clean fuel systems are prototyped at commercial speed.

Private consortia lease space to test frontier energy systems. Breakthrough battery-storage pilots using sodium-ion batteries (which rely on more abundant materials than lithium-based alternatives) and e-fuel micro-hubs (small-scale facilities producing synthetic fuels from clean electricity on-site) appear as investors chase high returns. Electricity powers all plug-in systems across port operations. Carbon capture systems operate selectively when they generate profit or feed local industrial buyers.

Ports integrate into experimental urban infrastructure by hosting pilots for hyperloops (ultra-high-speed tube-based transport systems) and near-space cargo systems (high-altitude or suborbital delivery platforms), serving customers that are willing to pay premiums for maximum speed. Industrial clusters located within port zones test technologies under real operational conditions before wider commercial deployment.

03 / Logistics & Supply Chain

Fully automated, high-speed logistics ecosystems

Customs-in-motion systems (digital shipment data and risk checks are processed while cargo is already en route, so most loads arrive effectively pre-cleared), autonomous E-Trucks, and robot- and drone-based logistics keep goods moving continuously without traditional processing delays. AI agents orchestrate these flows end-to-end—predicting congestion before it forms, rerouting assets in seconds, and allocating robots and berth slots dynamically to maintain throughput.

Autonomous logistics platforms operate within ports, where autonomous inland transport, yard robots, and underwater drones work in controlled environments to maintain constant high-speed flows. AI-driven optimisation continuously coordinates these systems, balancing energy availability, slot capacity, and real-time risk signals across the port and its hinterland.

Autonomous yard movers (self-driving towing vehicles in terminals that automatically move trailers or containers between quays, stacks, and gates) guide containers onto conveyor tracks (dedicated automated transport lines, like an industrial 'metro' for containers and pallets) that feed directly into industrial clusters or high-speed rail connections.



04 / Labour & Community

Tech-heavy workforces and unequal outcomes

Workforces become highly specialised and tech-heavy. New professions emerge around hydrogen handling, fleet robotics, remote vessel assistance, performance analytics, and maintenance crews. Companies run their own training schools and hire from coding bootcamps as often as from maritime colleges, creating alternative pathways into technical work.

People without strong digital skills face harder entry paths. Private companies create paid upskilling programmes to widen their talent pool, though access remains competitive and exclusive. Stable contracts exist but typically cap at around 25 hours per week. Most workers combine several short assignments each month, matched to their certifications through digital platforms coordinating labour across multiple employers.

Routine work steadily decreases as automation advances through AI copilots, yard robots, autonomous vehicles, and drone systems. Ports become attractive to those comfortable with fast cycles and fluid roles, while offering fewer positions for those seeking steadier employment.

Strengths, Weaknesses, Opportunities & Threats

Venture Revolution is defined by speed, competition, and a strong belief that markets can outpace public coordination.

Its main **strengths** come from a market-driven, experimental mindset that accelerates the deployment of breakthrough technologies. Venture capital and corporate consortia invest aggressively, allowing solutions to scale quickly where there is a clear commercial case. Ports operating in this environment can move fast. Automation and digitalisation are major enablers, improving operational performance and reducing costs through data-driven optimisation.

These advantages come with structural **weaknesses**. Progress becomes uneven: actors with access to capital, talent, and technology advance quickly, while others fall behind. Fragmented standards and proprietary platforms can limit interoperability and create lock-in, making system-wide coordination harder. The labour market also becomes more flexible and precarious, increasing social insecurity through gig-based work and weaker collective safeguards. Over time, the ecosystem risks concentrating power in the hands of a few dominant players who control platforms, data, and investment flows.

The **opportunity** space is significant, especially for first movers. Aggressive innovation can create new markets, business models, and revenue streams—turning decarbonisation into a competitive edge. Ports that scale early may strengthen Europe's position globally, particularly if they become testbeds for advanced optimisation using AI and, potentially, quantum-enabled computing. The scenario can unlock rapid productivity gains and help build clusters of specialised expertise around frontier technologies.

However, Venture Revolution also carries clear **threats**. Market concentration can lead to monopolistic behaviour by large tech and logistics players, which may stifle competition and undermine long-term innovation. Smaller ports and businesses may be unable to keep up, widening regional and sectoral divides. Governments may struggle to regulate at the pace of change, increasing exposure to cyber and security risks in highly digitised systems. Social fragmentation and backlash may grow if the transition is seen as benefitting only a few. Finally, a lack of coordination can leave the system vulnerable to price spikes and supply chain disruptions, with fewer buffers to absorb shocks.

EARLY WARNING SIGNS

What to look out for

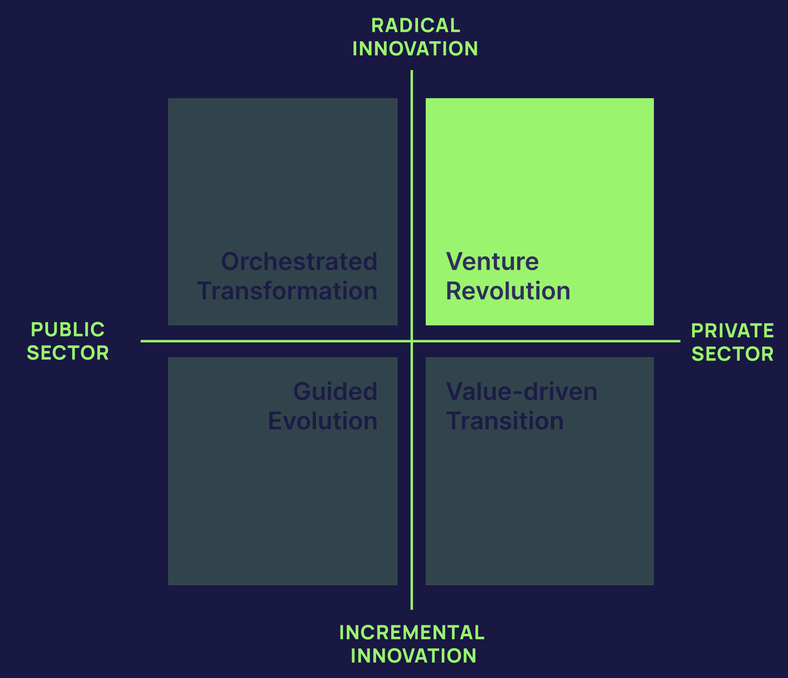
Sandbox Surge / Private consortia push for regulatory sandboxes or special zones in ports to test autonomous vessels and novel fuels, signaling an experiment-first environment.

Private Capital Takes Over / Public funding declines as venture capital and sovereign wealth directly finance port transformation and new builds, bypassing slow compliance processes.

Standards Fragment / Industry-wide interoperability collapses. Shipping lines launch proprietary platforms and fueling systems, marking a winner-takes-all race for technology dominance.

Tech Giants Move In / Non-maritime tech firms acquire stakes in ports and energy grids to control supply chain speed and reliability, turning logistics into a high-margin tech battlefield.

Venture Revolution



PRIVATE SECTOR DRIVEN / **RADICAL** INNOVATION

FUTURE WORLD

Fast transformation driven by private investment, fierce competition and breakthrough climate technologies.

A sequence of accelerating climate shocks exposes major coordination gaps. Governments move too slowly to provide solutions, so private actors step in to protect assets and capture opportunities—treating climate tech as a strategic advantage. Innovation accelerates through venture funding, corporate alliances, rapid experimentation, and whatever scales fastest. Emissions rise at first under fragmented action, then fall sharply and non-linearly once profitable breakthroughs take hold—reaching net zero by 2050, but with severe inequality between capital-rich frontrunners and those left behind.

Economy / Economic gravity shifts to venture funds and corporate consortia; collaboration becomes opportunistic (temporary hubs and labs), and market position can change quickly—high reward, high risk.

Environment / The turning point comes when nuclear fusion power becomes commercially viable, making energy cheap and abundant, boosting compute, and accelerating AI-enabled optimisation and materials/logistics innovation. Clean fuels (e-methanol/ green ammonia) scale when cheap clean electricity makes them viable; electrification expands wherever feasible; carbon capture deploys selectively where profitable.

People / Life runs on performance-based service bundles: if reliability drops, people switch. Most people trade data for cheaper, faster service and track everything via reliability dashboards. Social protection is lean. Access to services depends more on individual financial wealth.

FUTURE PORT

Ports in this future evolve into deal-driven ecosystems where venture funds and corporate consortia race to capture first-mover advantages.

GLOBAL TRADE & SHIPPING

Trade stays highly global and constantly re-routes; shipping lines choose ports that are fastest, most digitised, and easiest to clear, so “speed and coordination” become the main competitive edge.

PORT INFRASTRUCTURE

Ports become investment magnets: private consortia build test zones and scale what works quickly; ports that attract capital modernise fast, ports that don’t fall behind.

LOGISTICS & SUPPLY CHAIN

Operations become end-to-end automated: more clearance happens before arrival, and robotics / autonomous vehicles reduce waiting and keep cargo moving continuously, where operators can pay for it.

LABOUR & COMMUNITY

Work shifts to specialised tech roles and short, project-based contracts; opportunities concentrate with those who have in-demand digital skills, while routine jobs shrink.

Trade Pattern Shift HIGH
Global trade with constant re-routing

Infrastructure Upgrade Intensity HIGH
Rapid transformation

Automation Level HIGH
Aggressive automation

Workforce Stability LOW
Volatile, gig-based work

Ship. Fuel Trans. Intensity HIGH
Rapid, private-led adoption (winner takes most)

Port Role in Energy Systems HIGH
Ports as commercial energy platforms

Data as Access Requirement HIGH
Proprietary platforms set access rules

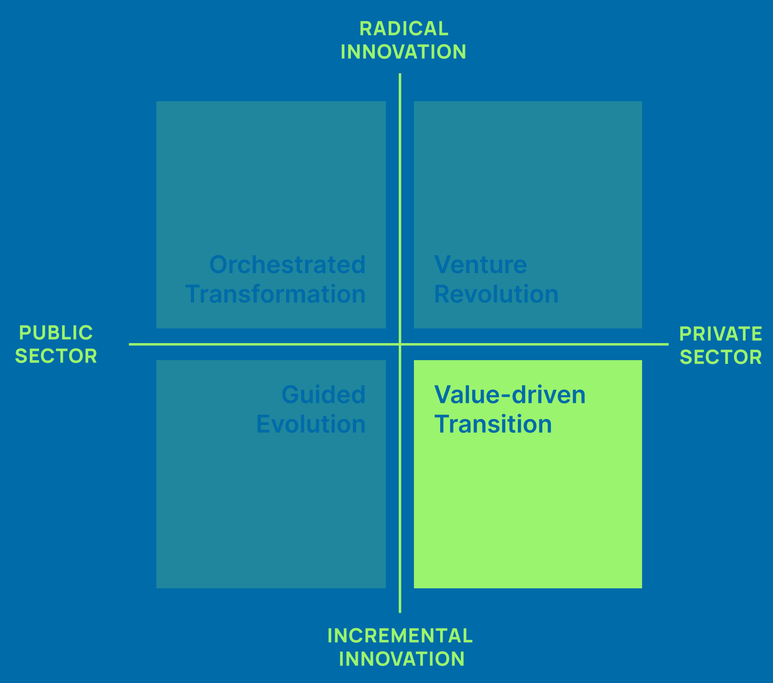
Skills Shift Intensity HIGH
Rapid skills disruption



EARLY WARNING SIGNS

- **Sandbox surge:** private consortia push for regulatory sandboxes/special zones to test autonomy and novel fuels in ports.
- **Tech giants move in:** non-maritime tech firms acquire stakes in ports and energy grids to control supply chain speed and reliability.
- **Private capital takes over:** venture capital and sovereign wealth directly finance port transformation/new builds as public funding declines.
- **Standards fragment:** proprietary platforms and fueling systems replace interoperability; winner-takes-all dynamics accelerate.

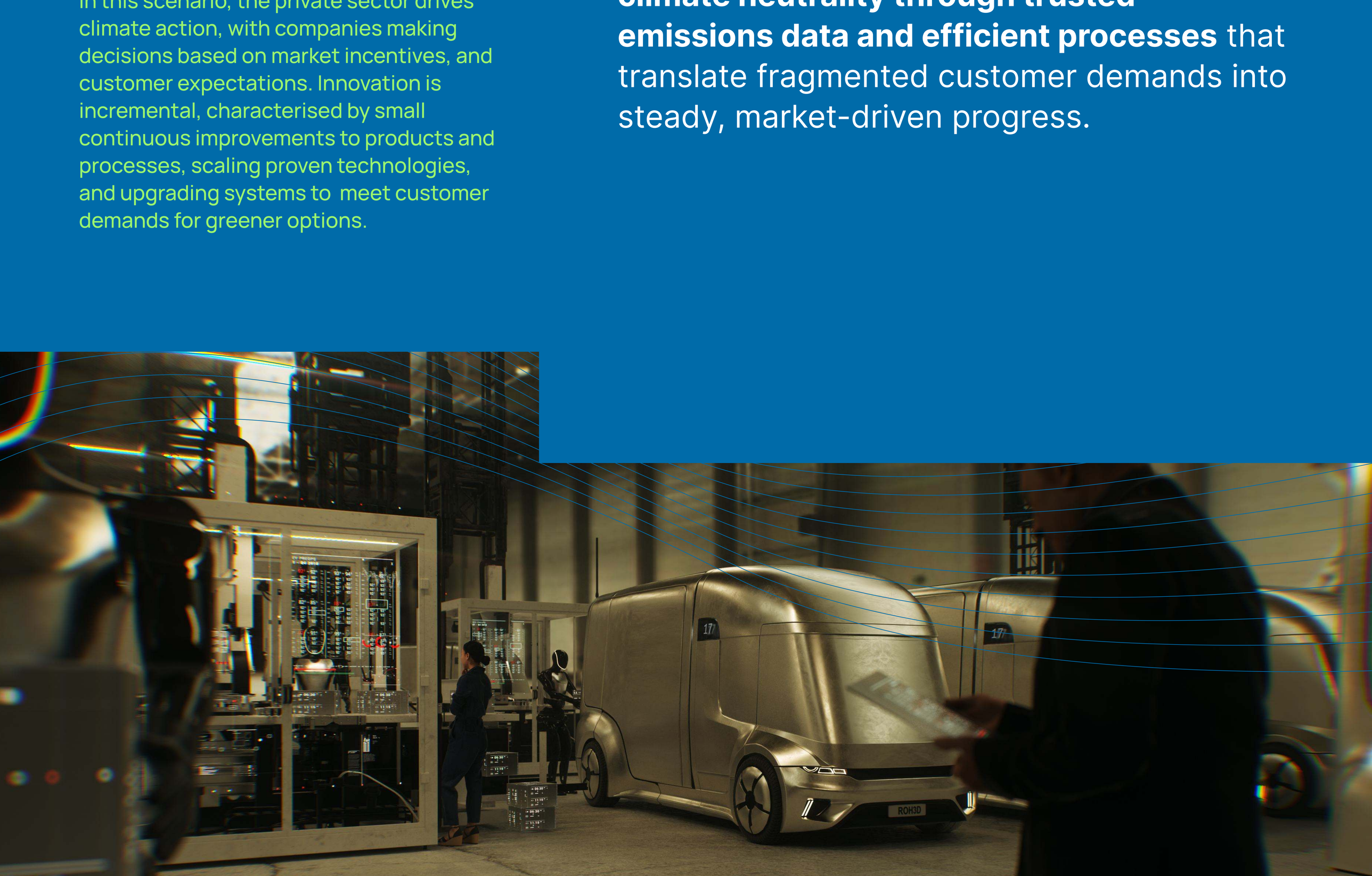
Value-driven transition



In this scenario, the private sector drives climate action, with companies making decisions based on market incentives, and customer expectations. Innovation is incremental, characterised by small continuous improvements to products and processes, scaling proven technologies, and upgrading systems to meet customer demands for greener options.

PRIVATE SECTOR DRIVEN
INCREMENTAL INNOVATION

In this "value-driven transition" scenario, **private companies drive incremental innovations** that deliver commercial returns while protecting market access. Driven by **customer pressure** and **green technology cost parity** to decarbonise. Ports become **compliance and verification hubs, enabling climate neutrality through trusted emissions data and efficient processes** that translate fragmented customer demands into steady, market-driven progress.



FUTURE WORLD

What if green tech cost parity, consumer and market pressures become stronger than government regulation in driving decarbonisation?

This future of “value-driven transition” is born from governments under strain from **rising public debt**, **inflation**, and **recurring climate shocks** that disrupt supply chains and damage critical assets. While states respond slowly, people shift their spending toward cleaner, local, and more sustainable products. Companies adapt to protect their reputation and maintain access to key markets, investing in low-emission practices that meet consumer expectations without waiting for new regulations.

Market pressure becomes the primary steering force, nudging firms toward incremental sustainability as they seek customer trust, and secure positions in the EU market. **Green technology cost parity**, green loans and eco-tax advantages steer companies toward cleaner solutions, reinforcing a steady, market-driven transition.

REAL WORLD EXAMPLE

Value-Based Change

Think of the solar panel industry's transition. What drove rooftop solar from niche to mainstream was not government revolution but consumer demand for sustainable energy combined with steadily falling costs that reached parity with grid electricity. Households and businesses adopted solar because it made financial sense while meeting their values. That same logic of enlightened self-interest now defines the private sector’s approach to decarbonisation.

Environment

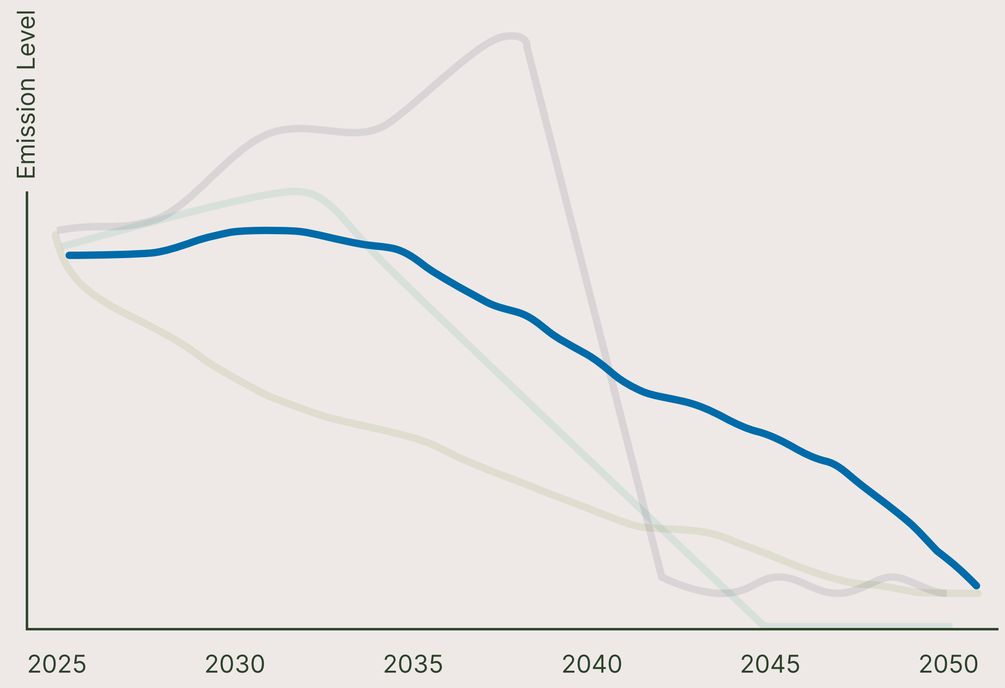
The transition towards climate-neutrality in this future advances only where emissions reduction aligns with market access, cost control, and reputational value.

The energy system develops through a mix of community-owned cooperatives, private solar and wind farms, and imported offshore wind power. Renewable reliability remains uneven across regions and seasons, so private actors deploy hybrid systems combining renewables with non-renewable sources where necessary to maintain grid stability.

Green technologies are adopted only when the economics are clear: the solution lowers costs or risks enough, and the payback period is short enough for investors to approve the spend. For the same reason, infrastructure budgets go to efficiency upgrades and optimisation, not to radical overhauls. Private capital therefore concentrates on the places where the financial return is strongest, which speeds up emissions reductions in those areas but leaves slower progress in sectors where the return is weaker or the payback is longer.

Cleaner fuel options gain market share as transparent emissions data shapes customer demand. Carbon capture deploys only where financially viable, primarily as contracted services for heavy industrial facilities with large concentrated emission sources such as cement plants, chemical factories, or waste incinerators located near port areas. These facilities invest in carbon capture to protect market access, to reduce their emissions and meet supply chain requirements from downstream buyers who demand verifiable low-carbon materials.

Water and soil health benefit from the rise of port-based circular hubs; as virgin material prices rise, the commercial value of recovering "waste" incentivises stricter control over industrial run-off and chemical leaks. This reduces contamination because industrial by-products are increasingly treated as valuable feedstocks rather than waste to be discharged.



Slow and steady / **Emissions** stagnate initially as global trade slows and local circular economies produce only modest reductions, falling short of climate targets. Over time, companies deploy incremental innovations to avoid exclusion from preferred supply chains and satisfy buyers. Emissions then decline steadily, though unevenly: sectors with immediate commercial returns reduce faster, while harder-to-abate areas lag behind.



Economy

Financing leans on eco-tax advantages and green loan programmes offering preferential rates to firms demonstrating year-over-year emission reductions. To avoid large upfront spending, money shifts toward service-based models, allowing operators to pay through operating expenses instead of prohibitive capital investments. For example, instead of a terminal operator buying a fleet of expensive electric cranes or hydrogen trucks, they "subscribe" to them by paying a monthly fee to a tech provider who owns and maintains the equipment, which turns a massive upfront cost into a predictable utility bill.

Trade and supply chains shift as global demand slows and consumers favour more local production. Circular economy models strengthen because digital product passports provide standardised electronic records of a product’s materials, origin, environmental footprint, and repair history, allowing buyers to verify sustainability claims and select cleaner products based on reliable data. At the same time, resource scarcity, rising virgin material prices, and tariff disputes increase the cost advantage of regional sourcing.

Retailers therefore source more from EU and nearby suppliers. Logistics patterns change accordingly: long-haul imports decline, regional distribution routes grow, and border flows become smoother even if total volumes drop, because routes are shorter and compliance is handled earlier. Vendors pre-file product passport data electronically so checks are completed while goods are still in transit. Mandatory supply-chain reporting makes transport emissions visible and comparable, which increases commercial pressure to choose low-emission options. Public funds reinforce this shift by supporting common data and reporting requirements for digital product passports and supply-chain emissions reporting, plus transparent scoring systems and small rebates that guide purchasing toward cleaner choices, without relying on massive subsidies.



People

In this future, people care about whether things are genuinely better for the planet, and they expect measured results. Claims about being “green” are checked by clear rules and audits. Companies that cheat are fined.
Every product has a simple “passport” you can scan with your phone to see where it was made, what it’s made of, how much energy it uses, and how to return or recycle it. Deliveries arrive at small neighbourhood hubs by cargo bike or quiet electric van.

Most buildings have been upgraded because renters now expect both comfort and lower emissions. Energy performance is visible and easy to compare, so tenants choose homes with better insulation, quiet ventilation, and lower energy use. Landlords improve buildings not out of goodwill, but because demand and regulation make poor performance harder to rent.
People often join local co-ops to share tools and own a slice of community solar and batteries.

The social contract is simple and widely accepted: caring for the planet is a shared responsibility, and companies are expected to prove their impact. People reward firms that show real, measured improvements and turn away from those that cannot.

Green Tech

This future advances because proof of emission cuts earns preference. Consumers choose providers that can show verified cuts in emissions. So, technologies in this world lean on incremental innovations, retrofits that are simple to verify and compare. Millions of small, audited upgrades add up because consumers reward measured emission cuts.

The following technologies are possible in this scenario:

- ✓ Renewable energy cooperatives
- ✓ Private wind and solar farms
- ✓ Hybrid energy systems (renewables plus fossil fuels)
- ✓ Shore power installations
- ✓ Waste-heat recovery systems
- ✓ Carbon capture systems for industrial facilities
- ✓ Digital product passports
- ✓ Container-stacking automation
- ✓ Yard planning optimisation systems
- ✓ Route planning and optimisation software
- ✓ Digital emissions scoring platforms
- ✓ Electric trucks (E-trucks)
- ✓ Agile on-site bunkering systems
- ✓ Modular fuel infrastructure for cleaner fuel options
- ✓ Independent emissions verification systems

WILD CARD

CO_2 used as a commodity instead of as a waste product

This technology consists of on-port conversion facilities that transform captured CO_2 into high-value carbon materials such as graphene and carbon black through plasma, electrocatalytic, or thermochemical pathways. These materials supply local markets for composites, coatings, and elastomer production, creating commercial products from what would otherwise be waste emissions.

This wild card appears in this future because firms in a private-led, incremental setting pursue option-like investments that monetise carbon streams without requiring system redesign. The technology becomes viable when unit economics approach cost parity with incumbent materials produced from virgin feedstocks, allowing companies to generate revenue from captured CO_2 while meeting customer demand for lower-emission material inputs. The conversion happens at port locations because industrial emission sources and potential manufacturing customers are co-located nearby, minimising transport costs and enabling short-distance CO_2 collection integrated into existing logistics flows.

Source / Ramirez-Corredores, M.M. Sustainable production of CO2-derived materials. npj Mater. Sustain. 2, 35 (2024). https://doi.org/10.1038/s44296-024-00041-9



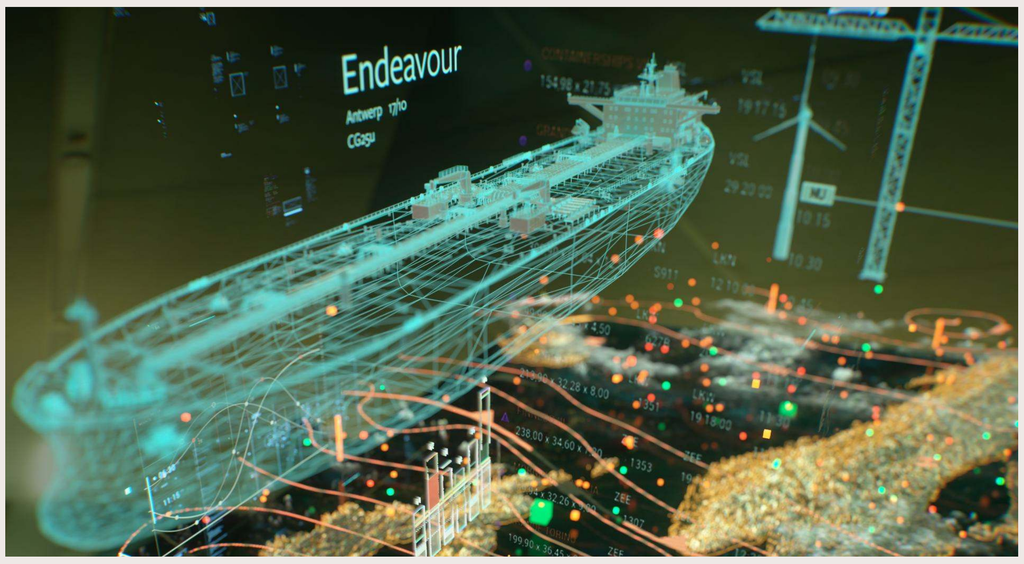
PORTS IN THIS FUTURE

Ports in this future operate as compliance and transparency hubs within market-driven supply chains where sustainability outcomes are shaped by the purchasing requirements of cargo owners, retailers, and industrial buyers.

In this value-driven transition future, ports operate as compliance and transparency hubs within market-driven supply chains where sustainability outcomes are shaped by the purchasing requirements of cargo owners, retailers, and industrial buyers.

Ports advance decarbonisation through incremental, commercially viable upgrades that prioritise predictable returns and operational continuity over radical transformation.

Market mechanisms—mandatory supply-chain reporting, digital product passports, and verified emissions data—translate buyer requirements into commercial pressure for low-emission operations, guiding change without forcing its pace.



01 / Global trade & shipping

Market-filtered trade and retrofit-led decarbonisation

Global trade volumes slow in this future as consumer preferences shift toward local and regional products. Long-haul imports decline while regional shipping trips grow, reshaping maritime networks toward shorter, more frequent routes. This shift reduces the total volume of goods moving through ports while increasing the frequency of smaller shipments concentrated on intra-European and near-shore routes.

Mandatory supply-chain reporting links transport emissions directly to market access, creating commercial pressure for low-emission shipping. Major retailers and cargo owners refuse to contract vessels with high verified emissions, applying standards that go beyond regulatory minimums. Shipping companies respond by upgrading existing fleets, prioritising measures that protect asset value and operational continuity. Therefore, vessels are retrofitted with efficiency improvements—such as advanced hull coatings, optimised propellers, and engine tuning—that lower fuel consumption and emissions at manageable cost, and with minimal downtime.

New vessel orders prioritise dual-fuel engines capable of operating on conventional fuels and cleaner alternatives such as e-methanol and ammonia, allowing operators to meet evolving customer requirements as fuel availability develops. Where fuel switching is not immediately feasible, ship-based carbon capture systems are installed as a compliance solution.

Vendors pre-file digital product passport data electronically before goods arrive, enabling compliance checks to be completed while cargo is still in transit. This parallel verification process avoids delays at arrival, allowing border flows to remain smooth despite increased documentation and reporting requirements.

02 / Port Infrastructure

Modular upgrades and verification-led access

Ports enforce shared reporting requirements, manage digital product passport verification, and ensure that every service provider meets buyer expectations for cleaner, low-emission operations. Their competitive strength lies in providing stable rules, verified emissions data, and reliable access to EU markets.

Incremental upgrades dominate infrastructure development. Ports integrate modular kits, plug-in systems, and certified low-carbon services without major overhauls, keeping transitions predictable and financially manageable. Energy infrastructure evolves flexibly: selective shore-power installations are added where economic payback is clear based on vessel call frequency and electricity pricing.

Modular fuel infrastructure allows ports to offer cleaner maritime fuel options including e-methanol and ammonia as demand grows, without requiring complete rebuilding of bunkering systems. Carbon capture systems deploy only where financially viable, primarily as contracted services for heavy industrial facilities with large concentrated emission sources located in port areas. Local carbon-valorisation networks enable short-distance CO_2 collection linked to nearby factories or small-scale hydrogen applications.

Ports evolve into regional material hubs, shifting their economic function from pure long-haul transit toward the management of local circular flows. They dedicate land and infrastructure to repair, recycling, and remanufacturing activities, supporting a circular economy model that strengthens due to virgin material prices rising as global trade slows under fiscal strain and tariff disputes—making regional material recovery the more stable and cost-effective choice . This is further enabled by digital product passports, which provide the transparency needed to verify material recovery opportunities.

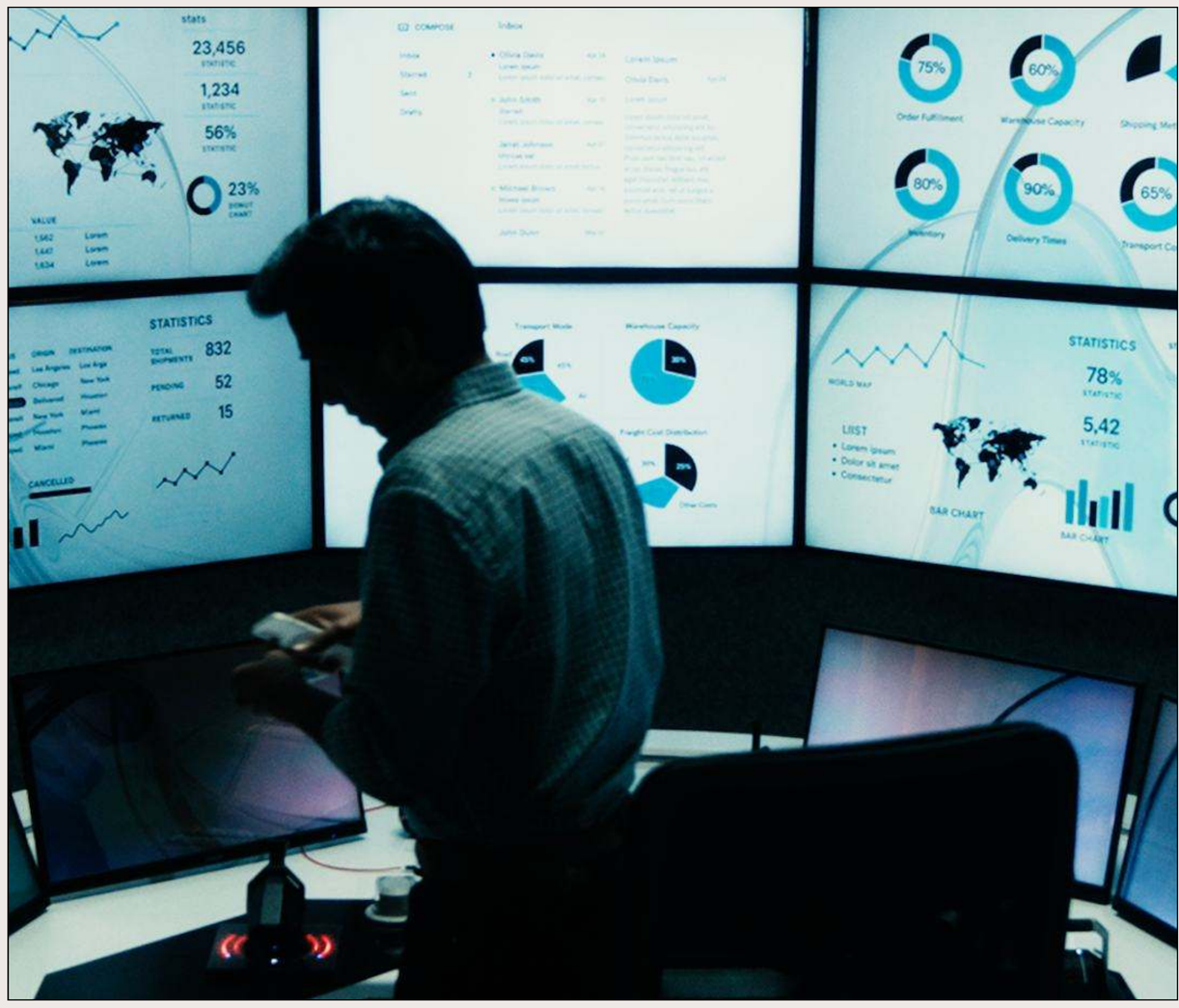
03 / Logistics & Supply Chain

Efficiency, electrification, and emissions-scored flows

Logistics networks lean more heavily on rail, barge, and electric trucks, supported by efficient route planning that keeps movement clean, predictable, and tightly managed. Smarter routing systems, rail booking platforms, truck appointment systems, and upgraded yard equipment reduce unnecessary energy use across daily operations.

Container-stacking automation and advanced yard planning optimisation tighten efficiency at the core of port operations, using the resulting cost savings to fund electrification and retrofit upgrades where financial returns are clear. Route planning and optimisation software improves flow through better coordination of multimodal connections. Digital emissions scoring platforms enable shippers to compare transport options based on verified carbon intensity, creating market pressure for cleaner logistics choices.

Digital product passports become gatekeeping mechanisms: port access increasingly requires verified emissions data, with missing or unverified documentation blocking entry or triggering higher fees. This transitions logistics coordination from purely operational concerns to include mandatory sustainability verification at every handoff point.



04 / Labour & Community

Upskilling for circular operations

People expect fair labour practices as much as greener operations. Employers fund training, so current workers can move into new tasks. Short, accessible training courses make it easier for port workers to upskill into new roles around digital systems, emissions verification and clean fuel operations. Workers transition from purely physical cargo handling toward roles that blend operations, data management, quality control, and safety oversight for increasingly automated and digitally integrated systems.

Ports create employment in circular economy activities as they dedicate space to repair, recycling, and remanufacturing. These roles support the shift from linear trade flows to regional material hubs, providing work in product refurbishment, component recovery, and local manufacturing that replaces some long-haul import activity.

Strengths, Weaknesses, Opportunities & Threats

Value-driven Transition is shaped by green tech cost parity, consumer expectations, and proof-based sustainability.

Its core **strength** is that decarbonisation progresses through commercially viable steps: market incentives and customer demand reward lower-emission choices, making change easier to adopt and finance. The scenario also reinforces a circular economy logic—supporting regional supply chains, more local production, and improved material reuse. Because progress is largely incremental, it tends to minimise disruption to operations and reduces financial risk compared to large, centrally planned transformations.

The main **weaknesses** relate to pace and coherence. With many actors developing their own certifications, standards, and verification protocols, fragmentation can increase administrative burden and create confusion about what “good” looks like. Progress is often uneven: activities with clear commercial returns move first, while hard-to-abate sectors lag behind. Without significant public investment, the system can struggle to deliver the large-scale infrastructure shifts needed for deeper, faster emissions reductions.

The **opportunity** space is substantial, especially in transparency and new business models. Digital product passports, emissions scoring, and data-driven logistics can improve traceability, unlock market access, and strengthen trust. Regional supply chains can shorten routes, reduce exposure to global volatility, and expand circular economy activities. The scenario also enables innovation in financing and value capture—such as service-based models that lower upfront costs, and carbon-to-commodities platforms that turn emissions reduction into new revenue streams.

Key **threats** centre on credibility, investment capacity, and momentum. If verification systems are inconsistent or poorly enforced, greenwashing risks rise, undermining trust and potentially damaging market access. Public infrastructure projects may stagnate if investment declines, creating bottlenecks that markets alone cannot solve. Momentum is also vulnerable to economic downturns: if consumer pressure weakens or costs rise, decarbonisation may slow. Ultimately, the biggest risk is that incremental progress is not fast enough—leaving emissions reductions short of what is required to meet 2050 targets.

EARLY WARNING SIGNS

What to look out for

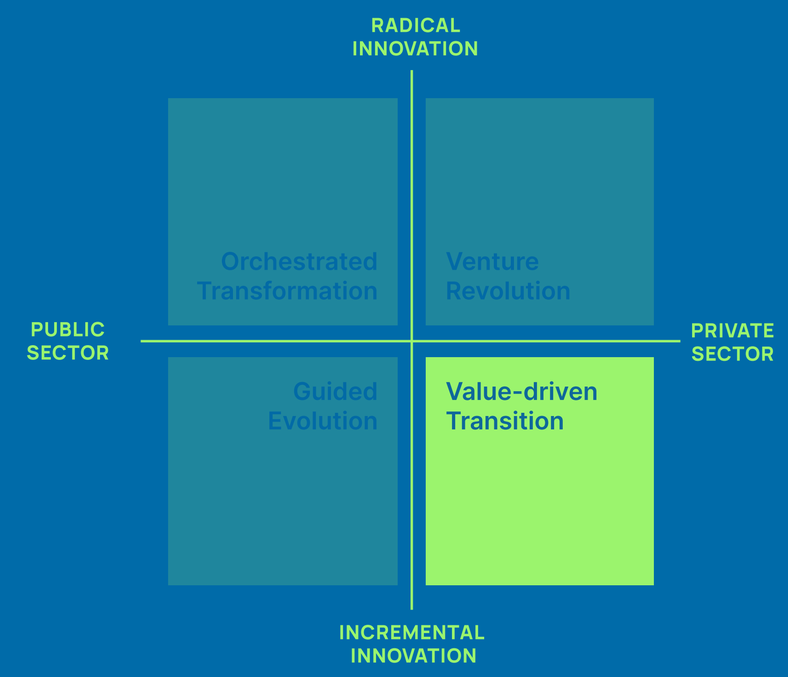
Green Tech Cost Parity / Clean technologies reach price equivalence with conventional alternatives in key sectors, removing financial barriers to adoption and triggering accelerated market uptake driven by customer preference.

Retailer Green Wall / Major retailers or consumer goods coalitions refuse cargo transported on high-emission ships, setting standards stricter than regulatory requirements and forcing shipping companies to upgrade or lose access to profitable routes.

Digital Product Passports Gatekeeping / Port access requires verified emissions data through digital product passport systems, with missing or unverified documentation blocking entry or triggering significantly higher fees that make non-compliance commercially unviable.

Reverse Logistics Expansion / Ports dedicate substantial land and infrastructure to repair, recycling, and remanufacturing activities, signalling a fundamental shift from linear trade flows toward circular material hubs serving regional production networks.

Public Projects Stall / State-funded port expansions or major infrastructure projects face delays or cancellation due to fiscal constraints, forcing greater reliance on private capital and modular upgrades that can be financed through operating budgets.



Value-driven transition

PRIVATE SECTOR / INCREMENTAL INNOVATION

FUTURE WORLD

Gradual, market-driven transition shaped by consumer demand and green technology cost parity.

Public budgets are constrained by rising public debt, inflation, and recurring climate shocks. Governments set direction but lack capacity for large-scale mandates. As clean technologies reach cost parity, market access, reputation, and risk management become the main drivers of action.

Economy / Demand shifts toward regional, circular supply chains. Green loans, eco-tax advantages, and service-based financing steer investment toward low-risk upgrades with clear returns.

Environment / Emissions decline where reductions align with cost savings or market access. Renewable energy expands through private and cooperative models, backed by hybrid systems to ensure reliability.

People / Consumers expect proven environmental impact: products have scannable passports and green claims are audited. Upgraded low-emission buildings become the baseline, while co-ops, repair culture, and clean last-mile hubs are the norm.

FUTURE PORT

Ports in this future operate as compliance and transparency hubs within market-driven supply chains where sustainability outcomes are shaped by the purchasing requirements of cargo owners, retailers, and industrial buyers.

GLOBAL TRADE & SHIPPING

Trade becomes more regional as demand shifts to local products; big buyers exclude high-emission shipping, so operators focus on efficiency upgrades and cleaner fuel options to keep market access.

PORT INFRASTRUCTURE

Ports act as compliance and transparency hubs, investing in modular upgrades (only where demand and payback are clear) and expanding circular activities like repair, recycling, and remanufacturing.

LOGISTICS & SUPPLY CHAIN

Logistics optimises for cost and emissions: more rail/barge/e-trucks on predictable corridors, more optimisation and automation, and verified emissions data becomes a condition for smooth port access.

LABOUR & COMMUNITY

Jobs shift toward oversight, data, verification, and circular-material handling; employers retrain to retain staff, and ports support local jobs through circular services.

Trade Pattern Shift MID
Regionalising demand, selective global trade

Ship. Fuel Trans. Intensity LOW
Upgrades where payback exists (market access-driven)

Infrastructure Upgrade Intensity MID
Incremental retrofits

Port Role in Energy Systems MID
Energy as a strategic asset (selective build-out)

Automation Level MID
Selective automation for efficiency

Data as Access Requirement HIGH
Verified emissions data gates access/value chains

Workforce Stability MID
Stable core, gradual upskilling

Skills Shift Intensity MID
Skills shift toward data/ verification/circular roles



EARLY WARNING SIGNS

- **Green tech cost parity:** clean options consistently match or undercut fossil-based alternatives.
- **Reverse logistics expansion:** ports dedicate land to repair, recycling, and remanufacturing.
- **Retailer green walls:** major buyers exclude high-emission transport from their supply chains.
- **Public projects stall:** major state-led port expansions are delayed, favouring private, modular upgrades instead.
- **Digital product passport gatekeeping:** unverified cargo faces delays or higher port fees.

01 / Orchestrated Transformation

Strategic anchors within EU climate plans

02 / Guided Evolution

Dependable executors of EU-aligned climate standards.

03 / Venture Revolution

Deal-driven ecosystems where venture funds and corporate consortia race to capture first-mover advantages.

04 / Value-driven Transition

Compliance and transparency hubs within market-driven supply chains where sustainability outcomes are shaped by buyers.

GLOBAL TRADE & SHIPPING

01 / Orchestrated Transformation	02 / Guided Evolution	03 / Venture Revolution	04 / Value-driven Transition
Trade Pattern Shift HIGH Intensified global trade via coordinated corridors	**Trade Pattern Shift** MID Regional + selective trade (security-driven)	**Trade Pattern Shift** HIGH Global trade with constant re-routing	**Trade Pattern Shift** MID Regionalising demand, selective global trade
Ship. Fuel Trans. Intensity HIGH Clean fuels scale fast via public coordination	**Ship. Fuel Trans. Intensity** MID Cautious shift (retrofits + dual-fuel)	**Ship. Fuel Trans. Intensity** HIGH Rapid, private-led adoption (winner takes most)	**Ship. Fuel Trans. Intensity** LOW Upgrades where payback exists (market access-driven)

PORT INFRASTRUCTURE

Infrastructure Upgrade Intensity HIGH Major system rebuilds	**Infrastructure Upgrade Intensity** LOW Incremental retrofits	**Infrastructure Upgrade Intensity** HIGH Rapid transformation	**Infrastructure Upgrade Intensity** MID Incremental retrofits
Port Role in Energy Systems HIGH Ports as energy hubs	**Port Role in Energy Systems** LOW Energy supports operations	**Port Role in Energy Systems** HIGH Ports as commercial energy platforms	**Port Role in Energy Systems** MID Energy as a strategic asset (selective build-out)

LOGISTICS & SUPPLY CHAIN

Automation Intensity HIGH Coordinated automation	**Automation Level** LOW Assistive tech only	**Automation Level** HIGH Aggressive automation	**Automation Level** MID Selective automation for efficiency
Data as Access Requirement HIGH Mandatory via regulation	**Data as Access Requirement** LOW Data for security + efficiency (not full gatekeeping)	**Data as Access Requirement** HIGH Proprietary platforms set access rules	**Data as Access Requirement** HIGH Verified emissions data gates access/value chains

LABOUR & COMMUNITY

Workforce Stability HIGH Planned, stable transformation	**Workforce Stability** HIGH Stable roles, gradual change	**Workforce Stability** LOW Volatile, gig-based work	**Workforce Stability** MID Stable core, gradual upskilling
Skills Shift Intensity HIGH Large-scale reskilling	**Skills Shift Intensity** LOW Gradual upskilling	**Skills Shift Intensity** HIGH Rapid skills disruption	**Skills Shift Intensity** MID Skills shift toward data/verification/circular roles

Key Takeaways

This report explores four scenarios for how European ports could achieve climate neutrality by 2050. This transition will require ports to navigate uncertainty, anticipate disruptions, and adapt to a rapidly evolving context.

The scenarios demonstrate that while the path to climate neutrality may differ, the pressures of climate shocks, geopolitical instability, energy system instability and skills shortages are universal. These must be proactively managed. **Ports can take on this role as pivotal enablers of Europe's climate-neutral ambitions.** The next decade is critical in this journey. Early, strategic investments in future-proof capabilities unlock flexibility and reduce the risk of stranded assets.

European ports stand at a historic crossroads. The path to climate neutrality is uncertain, complex, and fraught with challenges, but it is also rich with opportunity. The choices made today will determine whether ports lead the transition or risk being left behind by faster, more adaptive competitors.

01

Invest in future-proof capabilities

Ports should prioritise investments in digital infrastructure, data management, modular energy systems, and workforce upskilling. These capabilities are valuable in every scenario, enabling ports to adapt quickly, verify emissions, and maintain operational resilience regardless of how the future unfolds.

02

Build robust and flexible strategies

Develop strategies that can withstand shocks and adapt to changing conditions. Use scenario planning and backcasting to identify actions that are effective across multiple futures. Regularly stress-test plans against new developments, and avoid overcommitting to single technologies or rigid pathways.

03

Strengthen collaboration and ecosystem alignment

Foster strong partnerships across public authorities, private sector actors, knowledge institutions and local communities. Alignment on standards, data sharing and joint investments reduces fragmentation and accelerates progress. Building coalitions enhances the ability to respond to emerging challenges and opportunities.

04

Anticipate regulatory, technology and market trends

Stay ahead of evolving regulations, funding, market and technology trends, such as AFIR, ETS, green tech cost parity and consumer expectations. Proactively engage with policymakers and industry groups to shape rules and access funding. Monitor early warning signals to adjust strategies before disruptions occur.

05

Embed agility and resilience

Design infrastructure, operations, and business models for agility and resilience. Modular upgrades, flexible financing, and contingency planning help ports respond to supply chain shocks, energy volatility, and climate impacts. Cultivate a culture of experimentation, continuous learning and rapid adaptation.

The future is in your hands

Achieving net zero is possible in each of these scenarios -it was the starting point for the development of the scenarios- but none guarantees success.

The report does not specify who will finance the transition or assess the full feasibility of each pathway. Also, technology optimism is present, but real-world deployment may lag. In other words, not much has to go wrong to miss net zero targets. Especially incremental pathways are vulnerable to delays, underperforming technologies, or economic downturns. The ability to scale solutions rapidly and maintain momentum is essential. This requires leadership alignment and stakeholder coordination to avoid stranded assets or system fragmentation.

The most future-ready ports will strengthen capabilities that perform well in all scenarios, while building coalitions and preparing for multiple futures simultaneously. **Ultimately, the question is not which scenario will materialize, but how ports can act now to succeed in any future, ensuring robust, credible, and adaptive progress toward climate neutrality.**

The window for shaping the transition is open, but it will not remain so indefinitely. The future is in your hands. Seize it.

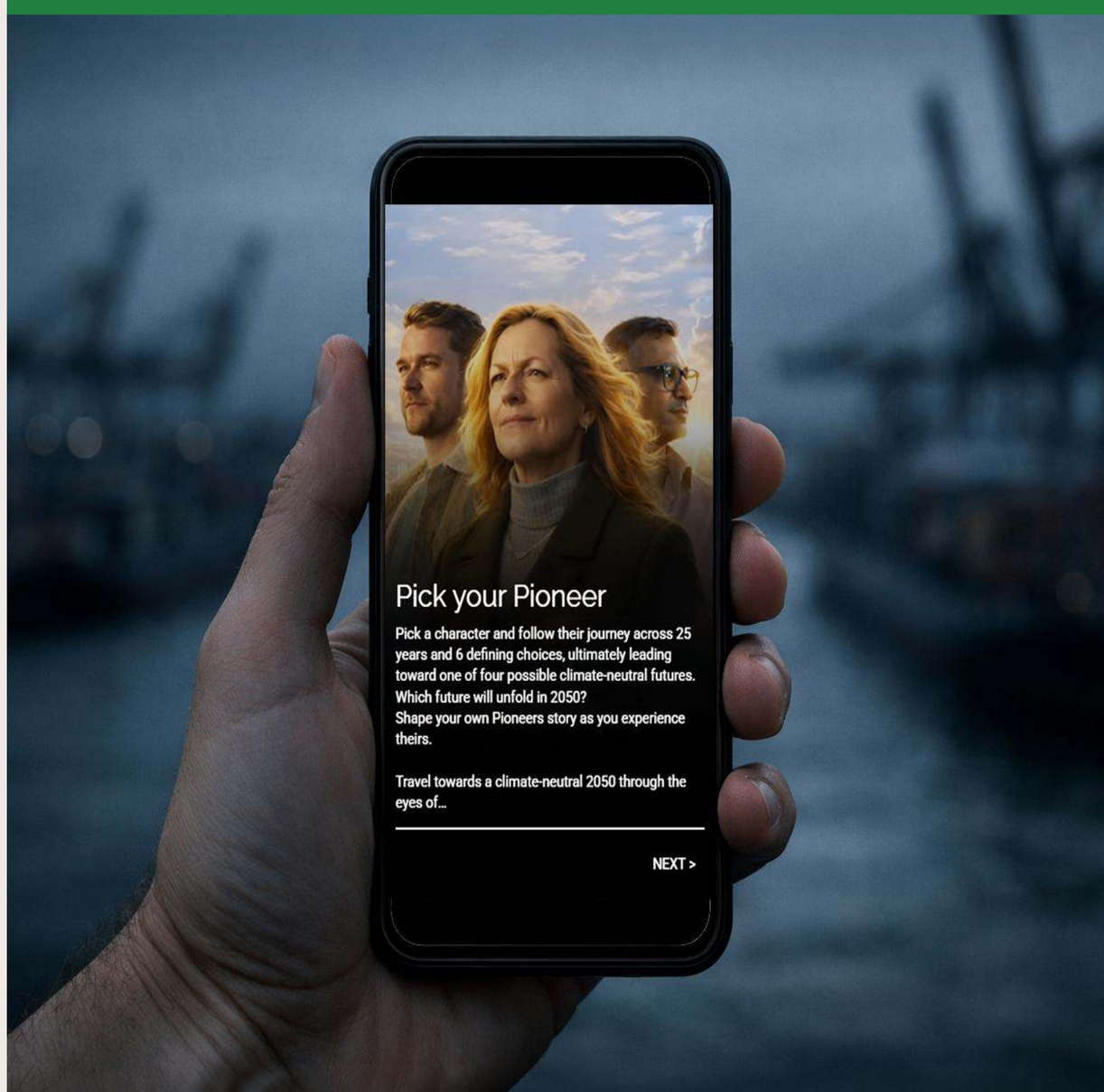
“The future is in your hands” An interactive film

When it comes down to “wicked” problems like climate-neutrality, it’s easy to believe that you are powerless. Shaping the future doesn’t happen with one big bang, though. The transition towards a climate-neutral port consists of a series of events and a string of choices, made by a broad spectrum of stakeholders. If you are reading this, you are one of these stakeholders. Every decision you make drives the port’s future towards climate-neutrality or perhaps… missed opportunities.

Submerge in the “future is in your hands” film. Experience the interactive stories of three fictional pioneers, shaping European ports’ path to climate neutrality. Choose a character, cast off in 2026 and see where your intuition and choices lead them by 2050.

Check out the film on pioneers-ports.eu

Tip: use this film as an introduction or energizer to your keynotes or backcasting workshops -explained in the introduction of this report.

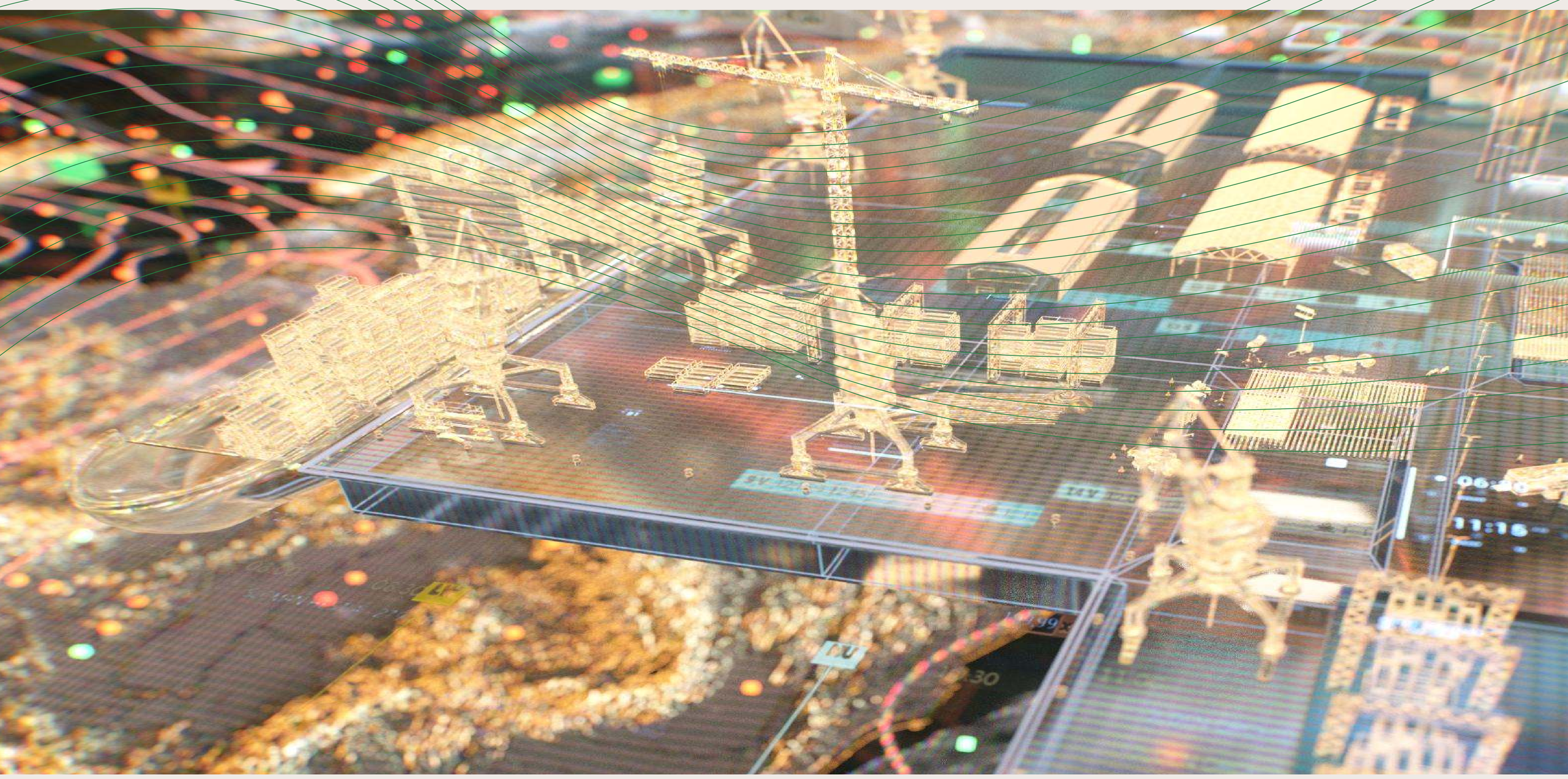




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Evidence Report



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Introduction

This evidence report brings together the signals, trends, and data points that underpin the four future scenarios. It acts as the factual backbone of the work: a structured overview of the developments shaping ports through the lenses of society, technology, economy, environment, and policy. It does not predict the future; instead, it shows what is already changing today, based on public, reputable sources.

01

Regulation is becoming the strongest and most certain driver.

EU rules such as AFIR, FuelEU Maritime, and the ETS extension to maritime are legally binding and already entering implementation. These will reshape port investment priorities, energy systems, and competitive positioning by 2030 and beyond.

03

Decarbonisation technologies are maturing, but unevenly.

Shore power, electric yard equipment, high-power truck charging, and digital optimisation are operational today. Meanwhile, hydrogen, ammonia and carbon-capture infrastructure remain early-stage and uncertain, creating real planning risk for ports.

05

Labour and social pressures are tightening.

Ageing demographics, climate-related risks, and rising expectations for clean operations (especially in dense urban regions) are increasing pressure on ports to automate, reskill, and reduce local impacts.

02

Economic incentives are shifting toward “clean-call” competitiveness.

Tariff models, funding schemes, and corridor partnerships increasingly reward low-emission ships, OPS use, and zero-emission logistics. Ports that cannot provide compliant infrastructure risk losing traffic.

04

Environmental performance is becoming a licence-to-operate issue.

Air quality, noise, circular construction requirements, and climate-resilience constraints are now reshaping how ports can expand or operate, especially those close to cities.

These signals show that structural change is already underway, even if timelines and technologies remain uncertain. The scenarios take these verified trends and explore their possible interactions toward 2050.

The Decision Points in this report translate a large and fragmented research base into a clear structure for building and comparing future port scenarios.

It is derived from 100+ research signals*, each documented with a source link, a short description, and a clear implication for ports. Rather than treating these signals individually, they were consolidated to identify the recurring choices that materially shape how ports decarbonise, invest, and operate over time.

Each Decision Point represents a strategic choice that ports and related actors repeatedly face (for example, how power is provided at berth, how fuels are introduced, how carbon costs are made visible, or how data is governed). The focus is deliberately on decisions, not on individual technologies, to avoid locking scenarios into specific solutions too early.

To build the framework, signals were clustered by the type of decision they implied. Signals were also filtered for significance and relevance, retaining only choices that consistently appeared across sources and had clear operational, financial, or system-wide consequences for ports. This resulted in nine shared themes, each containing alternative Decision Points that express different ways the same choice could be resolved.

Each Decision Point option is assigned to a future according to who carries responsibility and risk, how investment is mobilised, how disruptive the change is to existing systems, and how mature or proven the underlying solutions are. Together, these factors determine whether a choice aligns with a public-led or private-led future, and whether it supports incremental adaptation or radical transformation.

The Decision Points serve three purposes. First, they provide a common backbone for all futures, ensuring internal coherence. Second, they make differences between futures explicit and comparable, showing which choices diverge and why. Third, they act as a bridge between research and technology detail: specific technologies are added later, only where they logically follow from the decision context of each future.

This approach ensures that the scenarios are not collections of trends, but structured, decision-driven futures grounded in evidence and usable for strategic thinking under uncertainty.

* All sources, signal descriptions, and port-specific implications are documented in this Evidence Report.

	Future 01 Orchestrated Transformation	Future 02 Guided Evolution	Future 03 Venture Revolution	Future 04 Value-driven Transition
01 / ONSHORE POWER SUPPLY (OPS) Plug in or pay. OPS shifts from optional to expected.	1.A Fixed OPS 2.A Port/terminal capex 3.A Islandable microgrid		1.B Mobile/BESS bridge 3.B Mobile BESS on call	2.B As-a-Service/PPP
02 / ELECTRIFICATION Beyond OPS - Electrify things that move in ports: tugs, trucks, yard kit.	1.A Fixed charging stations 2.A Port/terminal capex 3.A BESS / microgrid at hubs		1.A Mobile/modular first 2.A Charger-as-a-Service 3.A Mobile backup on call	
03 / EMISSIONS TRADING SYSTEM (ETS) Make the carbon cost visible. Nudge clean choices on all calls.	1.A Transparent and real-time emissions view	1.B Federated APIs (decentralised apps)		
04 / CARBON CAPTURE, UTILISATION AND STORAGE (CCUS) Handle captured CO_2 like cargo: buffer, meter, ship or pipe.	1.A Pipeline + large terminal 2.A Open-access, multi-user		2.B Mobile/modular first 3.A Charger-as-a-Service 3.B Mobile backup on call	1.B Ship-based first (modular)
05 / CARBON NEUTRAL FUELS (CNF) Uptake is likelier when demand matches supply.	1.A Permanent berth & systems (fixed area) 2.A Focus bets via aggregated demand 3.A Produce locally + min. stock		1.B Modular start (truck/ tanker/barge) 2.B Offer mixture of options 3.B Import via corridors + multi-fuel fallback	
06 / EFFICIENCY & DATA Ports as active enablers, not just transit points.	1.A Single Source of Truth (via PCS)	2.A Zero-emission at berth required	1.B Federated APIs (decentralised apps)	2.B Minimal change efficiency add-ons
07 / SUSTAINABLE TRANSPORT Defaults & power chargers shape inland mobility.	1.A Invest in new infrastructure	1.B Reinforce current infrastructure 2.A Rely on national MCS network 3.A Guidance only through (synchromodality) 3.B Default sustainable mode	2.B Gate hubs / In-port MCS	
08 / MATERIAL FOOTPRINT Build-phase carbon falls when tenders cap concrete & allow reuse.	1.A Radical reuse & local by default	1.B Performance spec with a carbon cap		
09 / SOCIAL IMPACT Skills, health and neighbour trust drive permits, uptime & funding.	1.A Port-led reskilling pact	2.A Adapt people & shifts 3.A Incentives-by-default 3.B City–port clean & quiet compact	2.B Automate ops by design	1.B Vendor/platform training marketplace

01 / Social

Social trends shape how ports interact with workers, cities and communities. Demographic shifts, skills availability and public expectations influence how ports organise labour, design services and engage stakeholders. Social acceptance is becoming increasingly important, especially where port activity intersects with urban life.

EU ageing & dependency (2024)

STATUS **IN PROGRESS**

INSIGHTS The EU population is ageing rapidly. As of 1 January 2024, over one-fifth of EU residents (21.6 percent) were aged 65 or older, and the median age reached 44.7 years. Between 2014 and 2024, the median age increased in almost every member state, reflecting longer life expectancy and declining birth rates. The share of very old people (80+) is growing fastest, and the old-age dependency ratio continues to rise, placing pressure on labour markets and social systems.

FOR PORTS Ageing and dependency tighten the labour pool for ports, increasing pressure to automate, invest in continuous upskilling, and redesign shifts for safety and retention.

SOURCE https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Population_structure_and_ageing

Skills shortages expected as digitalisation/decarbonisation advance (2024)

STATUS **IN PROGRESS**

INSIGHTS Digitalisation and decarbonisation are accelerating EU-wide, creating structural skills shortages. Demand grows for technical, digital, and green-transition roles, while ageing workforces and slow training systems widen the gap.

FOR PORTS Ports must invest in targeted upskilling for OPS, ZE equipment, and data roles, and work with unions on just-transition plans to secure critical talent.

SOURCE https://www.europarl.europa.eu/RegData/etudes/STUD/2024/747266/IPOL_STU%282024%29747266_EN.pdf?

Practical guidance for social dialogue, skills & protection

STATUS /

INSIGHTS EU guidance outlines how automation and digitalisation will reshape transport jobs, calling for proactive social dialogue, skills development, and worker protection. It highlights the need for training, reskilling, health and safety measures, and frameworks that help workers adapt while ensuring fair transitions.

FOR PORTS Supports creation of structured training, reskilling, and safety requirements in port tenders and PPPs, ensuring automation upgrades protect workers and strengthen long-term workforce resilience.

SOURCE https://transport.ec.europa.eu/transport-themes/social-issues-equality-and-attractiveness-transport-sector/social-issues/automation-transport/recommendation-means-address-impact-automation-and-digitalisation-transport-workforce_en?

Citizen support for climate action: 81% support EU climate-neutral 2050; strong backing for renewables/ efficiency (2025)

STATUS /

INSIGHTS The 2025 European Commission climate survey shows strong and consistent public backing for climate action. Eight in ten Europeans support making the EU climate-neutral by 2050, and a large majority favour investments in renewables, energy efficiency, cleaner transport, and sustainable infrastructure. Citizens increasingly expect companies and public institutions to take visible, credible steps toward emissions reduction.

FOR PORTS High citizen support gives ports a strong social mandate to implement green measures such as OPS requirements, green dues, cleaner logistics corridors, and efficiency upgrades — as long as benefits are clearly communicated and visible to local communities.

SOURCE https://climate.ec.europa.eu/citizens-stakeholders/citizen-support-climate-action_en?

Notable scepticism in parts of the EU tied to energy-cost trade-offs (2024)

STATUS /

INSIGHTS A 2024 EBRD study reports that skepticism toward green policies is growing in several EU countries, largely because households feel the impact of higher energy and living costs. Support for climate measures remains widespread, but willingness drops sharply when policies are perceived to raise bills or reduce purchasing power. Concerns are strongest among lower-income groups and regions facing economic strain.

FOR PORTS Expect pushback if measures raise visible costs; pair rules with clear benefits/ offsets.

SOURCE https://www.reuters.com/world/europe/green-scepticism-greater-eu-than-neighbours-ebrd-finds-2024-03-05/?

~1 in 5 workers faced extreme heat; climate risks rising (2025)

STATUS (OSH PULSE 2025 'OCCUPATIONAL SAFETY AND HEALTH IN THE ERA OF CLIMATE AND DIGITAL CHANGE')

INSIGHTS Extreme heat exposure is rising across Europe, with around one in five workers already facing dangerous temperatures. EU-OSHA warns that climate change is driving more frequent and intense heatwaves, increasing risks of heat stress, reduced productivity, and workplace accidents. Sectors with outdoor or heavy physical work are most affected, and employers are urged to adopt stronger prevention, monitoring, and adaptation measures.

FOR PORTS Shift patterns/shade/cooling; automate high-heat tasks; consider night ops windows.

SOURCE https://osha.europa.eu/en/highlights/heat-work-preventing-illness-and-protecting-workers?

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SOURCE https://osha.europa.eu/en/highlights/heat-work-preventing-illness-and-protecting-workers?

EU population growth driven by migration; rising pressure in urban and coastal regions (2024)

STATUS /

INSIGHTS Port–city pressure on land, housing, and jobs is increasing as population growth is concentrated in urban and coastal regions, creating stronger expectations for cleaner and quieter operations.

FOR PORTS Higher population density around ports heightens demands for cleaner, quieter, and more space-efficient operations.

SOURCE https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Population_statistics_at_regional_level

More people living in cities and dense urban areas (2024)

STATUS /

INSIGHTS Europe’s population continues concentrating in cities and functional urban areas, where growth is strongest. Larger cities attract most newcomers, increasing density and intensifying pressure on housing, services, and local environments.

FOR PORTS More neighbours near terminals means higher expectations for clean air, low noise, and transparent community dashboards.

SOURCE https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Urban-rural_Europe_-_demographic_developments_in_cities

Gas sector “Just Transition” deal collapses; EU retraining pact fails to materialise (2024)

STATUS /

INSIGHTS Talks on an EU-level “Just Transition” agreement for gas-sector workers broke down in 2024. Unions and employers failed to reach consensus on funding and reskilling obligations, leaving no coordinated EU retraining pathway as the sector declines.

FOR PORTS Ports cannot rely on sector-wide reskilling pipelines and should build their own training and just-transition requirements into tenders and workforce plans.

SOURCE https://www.ft.com/content/98e2007a-c0a3-4756-8079-ab5a49b4ccaf?

Calls to strengthen the legal framework for Just Transition in regions.

STATUS /

INSIGHTS The study reviews the uneven progress of the Just Transition across EU regions and argues that current legal tools are not strong enough to guarantee fair, predictable support for workers and communities affected by decarbonisation. It recommends clearer legal obligations, longer-term funding, and stronger coordination between EU, national and regional actors.

FOR PORTS Opportunity to align port workforce plans with EU Just Transition mechanisms and tap into regional funds for upskilling and reskilling.

SOURCE https://www.europarl.europa.eu/RegData/etudes/STUD/2025/759354/CASP_STU%282025%29759354_EN.pdf?

02 / Technology

Technological development continues to redefine port operations. Digital tools, automation, energy systems and new transport technologies create opportunities for efficiency, safety and emission reduction. Ports that invest in scalable, interoperable technologies strengthen their resilience and competitiveness.

Oslo installs 1.6 MW shore power for container vessels (2024)

STATUS **OPERATIONAL**

INSIGHTS Oslo's container terminal (Yilport) now offers 1.6 MW shore power, enabling container ships to plug in at berth instead of using auxiliary engines. The system reduces local air pollution, noise, and CO_2, and is part of the port's wider rollout of OPS across terminals.

FOR PORTS Demonstrates a working OPS setup for container ships; provides a replicable technical and governance model for other ports to adopt.

SOURCE https://www.oslohavn.no/en/menu/klima-og-miljo-i-oslo-by-og-havn/land--og-ladestrom/

Stockholm launches OPS plus microgrid pilot for port resilience (2024)

STATUS **PROGRAMME ANNOUNCED**

INSIGHTS Stockholm is developing an OPS system supported by a local microgrid, combining solar, batteries and smart controls to stabilise power supply during peak demand. The project strengthens energy resilience and ensures continuous shore-power availability for vessels.

FOR PORTS Blueprint for resilience add-ons that protect OPS uptime during peaks.

SOURCE https://www.portsofstockholm.com/about-us/news/2024/innovation-with-sustainable-microgrid-technology-will-strengthen-ports-of-stockholm/

Tallinn–Helsinki Twin-Port VI expands OPS at Muuga and Vuosaari (2024)

STATUS **FUNDED**

INSIGHTS The Twin-Port VI programme upgrades ferry and cargo operations between Tallinn and Helsinki with new OPS installations at Muuga and Vuosaari. The project improves energy efficiency, reduces emissions from RoPax and cargo vessels, and strengthens coordinated green transport links across the Gulf of Finland.

FOR PORTS Cross-border template; co-financed; supports Baltic green corridor.

SOURCE https://www.ts.ee/en/ongoing-eu-projects/

Hamburg to require OPS use for cruise and select vessels by 2027

STATUS **PROGRAMME ANNOUNCED**

INSIGHTS Hamburg plans to mandate shore-power use for cruise ships and other major segments from 2027. The mandate supports the city's air-quality goals and anticipates full compliance with EU FuelEU Maritime requirements before 2030.

FOR PORTS Signals OPS-usage norm-setting ahead of 2030 FuelEU mandate.

SOURCE https://www.cruisenews.io/hamburg-mandates-shore-power-for-cruise-ships-by-2027/

Rotterdam tests mobile battery-powered OPS units (2024 pilot)

STATUS **PILOT**

INSIGHTS Rotterdam trialled mobile, containerised battery units to deliver shore power to sea-going vessels without fixed infrastructure. The system provides flexible OPS where grid connections or quay retrofits are not yet available.

FOR PORTS Demonstrates OPS-lite for mixed traffic; reduces capex and grid peaks.

SOURCE https://www.portseurope.com/successful-pilot-with-moveable-shore-power-for-sea-going-vessels-in-rotterdam-port/

Cavotec unveils modular mobile shore power system (PowerAlign)

STATUS **PROGRAMME ANNOUNCED**

INSIGHTS Cavotec introduced PowerAlign, a modular and mobile OPS system designed for container terminals. It delivers shore power without fixed quay infrastructure, using plug-and-play units that can be deployed, scaled, or relocated as needed.

FOR PORTS Gives S/M ports flexible compliance path; SPaaS-style contracting.

SOURCE https://www.mynewsdesk.com/cavotec/pressreleases/cavotec-launches-poweralign-a-new-shore-power-solution-designed-for-container-terminals-3392436

World’s first pure battery bunker tanker enters service (Japan)

STATUS **IN PROGRESS**

INSIGHTS Japan has deployed the world’s first fully battery-powered bunker tanker, equipped with large Corvus battery systems enabling zero-emission operations during fuel supply runs. The vessel demonstrates that high-energy, all-electric service craft can operate reliably in commercial settings.

FOR PORTS Proves zero-emission bunkering is viable. EU ports can require ZE service craft in-port and plan shore-charging at bunker berths.

SOURCE https://www.offshore-energy.biz/worlds-1st-zero-emission-tanker-showcases-corvus-batteries/

POAB opens public e-truck charging hub; MCS-ready high-power bays

STATUS /

INSIGHTS Port of Antwerp-Bruges has launched a public high-power charging hub for electric trucks, including bays designed for future Megawatt Charging System (MCS) use.

FOR PORTS Template for gate-area ZE-drayage charging; signals MCS corridor build-out.

SOURCE https://milence.com/press-release/milence-deploys-its-first-megawatt-charging-system-solution-at-the-port-of-antwerp-bruges/

Volta 1, Europe’s first fully-electric tug, goes into service.

STATUS /

INSIGHTS Port of Antwerp-Bruges has deployed Volta 1, Europe’s first fully electric tugboat, demonstrating that heavy-duty harbour towing can be powered entirely by batteries with validated ranges and charging routines.

FOR PORTS Harbour craft electrification now operational; replicable duty cycles and charging ops.

SOURCE https://alternative-fuels-observatory.ec.europa.eu/general-information/news/port-antwerp-bruges-launches-europes-first-battery-electric-tugboat-volta

Sweden’s first electric reachstacker delivered and in use.

STATUS /

INSIGHTS Sweden has deployed its first fully electric reachstacker, confirming that high-power terminal equipment can operate on battery systems with practical duty cycles and reliable performance.

FOR PORTS Heavy yard kit electrification viable; plan charging and power peaks at terminals.

SOURCE https://vertikal.net/en/news/story/40154/swedens-first-electric-reachstacker

Small modular reactors for marine-based nuclear power plants

STATUS CONCEPT DEVELOPMENT (IAEA OVERVIEW, 2023)

INSIGHTS IAEA outlines emerging designs for marine-based small modular reactors that could supply stable, high-density power for offshore or coastal infrastructure. Concepts focus on enhanced safety systems, modular deployment, and long operational lifetimes.

FOR PORTS Potential future option for zero-carbon baseload near energy-intensive ports, but long-term, regulated, and high-scrutiny pathway.

SOURCE https://aris.iaea.org/Publications/2023%20IAEA%20Marine%20Based%20SMR%20Booklet.pdf

Continuous emission monitoring systems (CEMS) for real-time air-quality tracking

STATUS OPERATIONAL (COMMERCIAL SOLUTIONS)

INSIGHTS Advanced continuous emission monitoring systems measure pollutants such as NOx, SO_2, CO_2, VOCs, and particulates in real time. These systems support accurate, automated reporting and help operators meet tightening environmental and safety standards.

FOR PORTS Provides reliable emissions data for terminals and tenants, supports compliance with EU monitoring rules, and strengthens port–city transparency dashboards.

SOURCE https://www.gasmet.com/products/category/emission-monitoring-systems/continuous-emission-monitoring-system/

Freight forwarders adopt emissions-prediction software

STATUS IN PROGRESS (INDUSTRY UPTAKE)

INSIGHTS Freight forwarders are increasingly using emissions-prediction and tracking software to calculate, monitor, and report carbon emissions across multimodal supply chains. These tools automate emissions calculations, integrate with logistics systems, offer transparency and compliance features, and apply predictive analytics to optimise low-emission routes.

FOR PORTS Ports can plug into forwarder emissions-data flows, align with low-emission routing tools, and position terminals as preferred nodes for verified low-carbon voyages.

SOURCE https://www.smartfreightcentre.org/en/

Japan launches joint study on large-scale ship-based CCS value chain.

STATUS MOU SIGNED - IN PROGRESS

INSIGHTS Four major Japanese companies are conducting a joint feasibility study on a large-scale CCS value chain using ships to transport captured CO_2. The study explores long-distance shipping, storage options, and the infrastructure needed for a full maritime CCS system.

FOR PORTS Ports may need to prepare for CO_2 import/export terminals, storage handling, and CCS-ready berths as maritime carbon transport chains scale.

SOURCE https://www.offshore-energy.biz/four-japanese-majors-team-up-on-ccs-value-chain-study-utilizing-ship-transportation/

Onboard carbon capture gaining traction in shipping (Maersk ZCS)

STATUS **IN PROGRESS**

INSIGHTS Recent analyses highlight growing industry interest in onboard carbon capture and storage systems. Early pilots explore the technical and economic feasibility of capturing CO_2 directly on vessels, with case studies assessing energy use, storage requirements, and operational impacts.

FOR PORTS Ports may need to plan CO_2 reception points, temporary storage, and safe transfer systems if OCCS scales.

SOURCE https://www.zerocarbonshipping.com/publications/the-role-of-onboard-carbon-capture-in-maritime-decarbonization

CO_2 capture and offloading infrastructure at ports (PortEconomics)

STATUS **IN PROGRESS**

INSIGHTS CCU and CCS are increasingly recognised as tools to help reach climate goals. Studies highlight that ports could play a crucial role by hosting CO_2 offloading, temporary storage, and transfer infrastructure. Evidence shows that equipping around 20 major ports with CO_2 offloading capability could deliver climate benefits comparable to deploying 25 Mtoe of low-carbon fuels each year.

FOR PORTS Ports may need to plan CCS hubs, storage areas, and offloading systems to support maritime and industrial decarbonisation.

SOURCE https://porteconomicsmanagement.org/pemp/contents/part3/green-supply-chain-management-ports/carbon-capture-utilisation-and-storage/

Carbonated building materials as CO_2 removal technology

STATUS **IN PROGRESS**

INSIGHTS Carbonated building materials use captured CO_2 in the production of cement, steel, glass, and other construction inputs. According to the IEA, these sectors account for a significant share of global industrial emissions, and carbon mineralisation offers a pathway to lock CO_2 into durable materials while reducing embodied emissions.

FOR PORTS Future port-area construction and retrofits could use carbonated materials to cut embodied emissions and support local CO_2 utilisation markets.

SOURCE https://www.carbonfuture.earth/cdr-technology/carbonated-building-materials

Autonomous subsea shuttles move liquefied CO_2 from offshore capture to injection wells.

STATUS /

INSIGHTS Concept proposes autonomous subsea shuttles that transport liquefied CO_2 from offshore capture sites to subsea injection wells. These vehicles attach to flowlines on the seabed to load or offload CO_2, providing a flexible alternative to fixed pipelines for offshore carbon storage.

FOR PORTS If offshore CO_2 storage expands fast and pipeline lead-times or permits stall, SSTs could unlock marginal fields and add redundancy to CO_2 export chains—especially for S/M ports seeking CCUS roles without large pipelines.

SOURCE https://jpt.spe.org/subsea-shuttle-concept-brings-co2-subsea-reservoirs

First commercial-scale e-methanol plant opens (Denmark)

STATUS **OPERATIONAL**

INSIGHTS Denmark has opened the world's first commercial-scale e-methanol plant, producing green methanol from renewable electricity and biogenic CO_2. The facility is backed by European Energy with offtake agreements from major buyers including Maersk and Mitsui, marking the shift from pilots to industrial production.

FOR PORTS EU supply signal for green methanol bunkering; port demand pull from early adopters (European Energy; Mitsui; Maersk).

SOURCE https://www.reuters.com/sustainability/climate-energy/worlds-first-commercial-scale-e-methanol-plant-opens-denmark-2025-05-13/

X-Press Feeders completes first bio-methanol bunkering in Singapore (with SIMOPS)

STATUS **OPERATIONAL**

INSIGHTS Singapore conducted its first simultaneous operations (SIMOPS) bio-methanol bunkering for an X-Press Feeders vessel, marking a major step in scaling alternative-fuel bunkering. The operation involved ship-to-ship transfer while cargo activities continued safely, demonstrating that methanol bunkering can meet commercial efficiency and safety requirements.

FOR PORTS Proves SIMOPS efficiency; signals EU corridor readiness for methanol feeders.

SOURCE https://safety4sea.com/singapore-achieves-one-methanol-fuel-milestone-after-the-other/

First ship-to-ship ammonia bunkering demonstrated in Rotterdam

STATUS **PILOT**

INSIGHTS Rotterdam completed a controlled ship-to-ship transfer of liquid ammonia as fuel, testing handling procedures, safety systems, and multi-agency coordination. The pilot validated emergency response protocols, gas detection setups, and crew training requirements for toxic fuel operations.

FOR PORTS Sets template for NH_3 SOPs and emergency drills; de-risks CNF rollout.

SOURCE https://ammoniaenergy.org/wp-content/uploads/2025/06/AEA-LEAD-Vessels-Executive-Summary-June-2025.pdf

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World's first large methanol deep-sea vessel bunkers in Antwerp

STATUS **OPERATIONAL**

INSIGHTS A deep-sea vessel completed a large-scale methanol bunkering operation in Antwerp under controlled SIMOPS conditions. The operation tested safety zones, fuel handling procedures, and multi-actor coordination for methanol as a marine fuel.

FOR PORTS Demonstrates SIMOPS readiness for methanol at scale; template for SOPs.

SOURCE https://ammoniaenergy.org/wp-content/uploads/2025/06/AEA-LEAD-Vessels-Executive-Summary-June-2025.pdf

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ZEMBA buyer alliance accelerates demand for zero-emission shipping

STATUS **OPERATIONAL**

INSIGHTS ZEMBA brings together major cargo owners to commit long-term offtake for zero-emission fuels and shipping services. The alliance uses pooled purchasing to de-risk supply, support early green corridors, and stimulate scalable fuel production.

FOR PORTS Buyers alliance to bundle clean-energy shipping; helps anchor early ZE corridors.

SOURCE https://www.shipzemba.org/

ZEMBA awards first zero-emission shipping tender (2024)

STATUS **OPERATIONAL TENDER AWARDED**

INSIGHTS ZEMBA's first aggregated tender awarded to Hapag-Lloyd covers a biomethane-based zero-emission service for 2025–26, avoiding an estimated 82k tCO_2e. A second tender is planned, shifting focus toward e-fuel services and scalable long-term contracts.

FOR PORTS Demand aggregation enables CNF lanes; prepare methanol/ammonia SOPs + tariffs.

SOURCE https://www.hapag-lloyd.com/en/company/about-us/newsletter/2024/05/hapag-lloyd-wins-zemba-tender-for-zero-emission-shipping-service.html

EMSA review: Potential use of nuclear power for shipping

STATUS /

INSIGHTS The European Maritime Safety Agency (EMSA) explores the technical and regulatory feasibility of using nuclear power for shipping, assessing safety, licensing, and strategic implications. The report outlines conditions under which nuclear propulsion or energy supply might be viable for future maritime transport.

FOR PORTS Ports should consider future requirements for nuclear-equipped vessels or supply infrastructure, including safety regulations, docking protocols, and potential public acceptance challenges.

SOURCE https://www.emsa.europa.eu/publications/item/5366-potential-use-of-nuclear-power-for-shipping.html

Only 4 percent of hydrogen projects reach final investment decision

STATUS /

INSIGHTS Europe's hydrogen sector is slowing, with only a small fraction of announced projects securing final investment decisions. High production costs, uncertain offtake, and regulatory delays are stalling scale-up despite strong policy ambition.

FOR PORTS Hydrogen-based fuels may scale slower than expected, so ports should hedge with flexible fuel strategies and avoid overcommitting infrastructure until supply signals strengthen.

SOURCE https://strategicenergy.eu/hydrogen-projects/#

EMSA enables FuelEU Monitoring Plans in THETIS-MRV

STATUS /

INSIGHTS EMSA has activated new THETIS-MRV functionalities allowing companies to prepare and submit FuelEU Maritime Monitoring Plans, detailing how vessels will track energy use, emissions, and compliance data under the FuelEU regulation.

FOR PORTS Ports must prepare for increased data flows linked to OPS and zero-emission technologies; alignment with THETIS standards supports smoother reporting for port-based services and future export of monitoring data.

SOURCE https://www.emsa.europa.eu/reducing-emissions/news-activities/item/5306-fueleu-maritime-monitoring-plans-in-thetis-mrv.html

Flexible book-and-claim system for low-GHG marine fuels (GMF, 2024)

STATUS **CONCEPT RECOMMENDED / EARLY PILOTS UNDERWAY**

INSIGHTS The Global Maritime Forum outlines how a book-and-claim chain of custody system can accelerate early adoption of low-GHG marine fuels. It allows shipowners, cargo owners, or charterers to claim the use of low-carbon fuels without needing the physical molecule at the bunkering port, using certified accounting and verification.

FOR PORTS Enables low-GHG fuel uptake before physical supply scales; ports must prepare for certification, auditing, and integration with digital fuel-tracking systems.

SOURCE https://globalmaritimeforum.org/insight/a-book-and-claim-chain-of-custody-system-for-the-early-transition-to-zero/

Windship Technology secures funding for wind propulsion and onboard carbon capture system

STATUS **IN PROGRESS**

INSIGHTS Windship Technology received Clean Maritime funding to advance a combined wind-assisted propulsion system and onboard carbon capture unit. The project integrates large rigid sails with carbon capture to significantly reduce fuel use and emissions on commercial vessels.

FOR PORTS Demonstrates a route to zero emission shipping for bulkers & tankers. It will use wind propulsion to dramatically reduce annual fuel consumption, which when coupled with a carbon capture system, provides a route to zero emissions for ships fitted with conventional diesel engines.

SOURCE https://windshiptechnology.com/clean-maritime-funding-secured-by-windship-technology/#:~:text=Windship%20Technology%20has%20been%20awarded,our%20partners%20carbon%20capture%20technology.%E2%80%9D

Optimised ship arrivals cut 4–14 percent CO_2 in multi-year Rotterdam trials

STATUS **COMPLETED PILOT (2018-2022)**

INSIGHTS The IMO–GIA, TNO and Port of Rotterdam conducted multi-year trials showing that Just-in-Time (JIT) arrival planning can reduce voyage CO_2 emissions by 4–14 percent by cutting unnecessary waiting and optimising speed during approach.

FOR PORTS Low-capex pathway to immediate CO_2 cuts through digital slotting and real-time arrival/berth planning via PCS, PortXchange or Wärtsilä tools.

SOURCE https://www.imo.org/en/mediacentre/pages/whatsnew-1718.aspx

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Port of Rotterdam tests geofenced vessel-movement tracking to cut CO_2 and improve traffic flow

STATUS **PILOT / IN PROGRESS**

INSIGHTS The Port of Rotterdam is trialling geofenced tracking of vessel movements to map idle time, anchorage behaviour and fuel use more precisely. The system creates automatic alerts and rules based on location, helping operators reduce unnecessary manoeuvring and improve flow efficiency.

FOR PORTS Replicable low-cost measure: use geo-rules to monitor idle and anchorage time, track fuel KPIs, and set operational nudges.

SOURCE https://www.mdpi.com/2305-6290/9/3/122

Orca AI platform delivers CO_2 emissions reductions in real-world shipping operations

STATUS **OPERATIONAL (COMMERCIAL USE)**

INSIGHTS Orca AI offers an AI-based navigation platform that helps ships optimise routes, speeds, and operational decisions to lower fuel consumption and CO_2 emissions. Users report measurable emissions reductions after adopting the system, demonstrating digital tools' role in decarbonising maritime transport.

FOR PORTS Ports should recognise digital navigation and fleet-optimisation platforms as part of the decarbonisation toolkit; potential to integrate with port slotting, traffic flow management and environmental reporting systems.

SOURCE https://oceannews.com/news/science-technology/orca-ai-platform-drives-significant-reduction-in-co2-emissions/

Global surge in green shipping corridors pairs climate goals with shared digital data systems

STATUS **PROGRAMME ANNOUNCED**

INSIGHTS Since COP26, more than sixty green corridor partnerships have launched, combining decarbonisation commitments with shared digital infrastructure. These initiatives promote aligned standards, data-sharing, and coordinated operational practices across ports, carriers, and corridors.

FOR PORTS Use corridor MOUs to standardise data flows (EMSWe-aligned, PCS APIs) and tie JIT/slotting to green incentives.

SOURCE https://www.linkedin.com/pulse/how-digital-green-corridors-revolutionising-global-maritime-simha-q6exe/

Rotterdam and Singapore deepen green and digital shipping corridor.

STATUS **OPERATIONAL (WORKING GROUPS ACTIVE)**

INSIGHTS Singapore's Maritime and Port Authority and the Port of Rotterdam have expanded their green and digital corridor partnership. Joint working groups now coordinate on methanol, ammonia, and methane bunkering standards, as well as digitalisation projects that align data, procedures, and operational safety across both ports.

FOR PORTS Template: corridor MoU + data rails (EMSWe-aligned) + fuel SOPs you can copy into local bylaws.

SOURCE https://www.portofrotterdam.com/en/news-and-press-releases/rotterdam-and-singapore-strengthen-collaboration-green-and-digital-shipping?

AI route optimisation model ("Ship Kernels") doubles voyage efficiency potential

STATUS **IN PROGRESS (INDUSTRY TRIALS)**

INSIGHTS A new AI model predicts ship performance with far higher accuracy by learning vessel behaviour across weather, loading and route patterns. It enables more precise speed–power curves and fuel-use forecasts, improving planning for operators and logistics partners.

FOR PORTS Ports can use these predictions to improve berth planning, cut idle time, and better align JIT arrivals with weather, congestion and berth availability.

SOURCE https://toqua.ai/whitepapers/how-ship-kernels-can-double-route-optimization-fuel-savings

Alfa Laval offers modular clean-tech systems for ship decarbonisation

STATUS **OPERATIONAL PORTFOLIO**

INSIGHTS Alfa Laval provides scrubbers, fuel-treatment systems, heat-recovery units, methanol-ready equipment, and energy-efficiency technologies already deployed across global fleets.

FOR PORTS Ports can reference these mature technologies when designing fuel-agnostic bunkering rules, OPS integration, and energy-efficiency incentives.

SOURCE https://www.alfalaval.com/industries/marine-transportation/marine/

Autonomous yard machines improve port efficiency and reduce land use

STATUS **CASE-STUDIED AND OPERATIONAL IN PILOTS**

INSIGHTS GIHub highlights autonomous cranes, vehicles and yard equipment that increase productivity, reduce collisions, and optimise space requirements through automated flow control.

FOR PORTS Ports can pilot autonomous yard assets to cut turnaround times, boost safety, and reduce footprint constraints at dense terminals.

SOURCE https://www.gihub.org/infrastructure-technology-use-cases/case-studies/autonomous-machines-for-efficient-ports/#:~:text=Automation%20can%20improve%20efficiency%20by%20increasing%20the,also%20require%20less%20space%20than%20traditional%20ports.

Swiss CST develops mobile high-power charging system for heavy transport

STATUS **IN PROGRESS (DEVELOPMENT PHASE)**

INSIGHTS The CST project in Switzerland is building a mobile, containerised high-power charging solution for electric heavy-duty trucks. The system enables flexible deployment along corridors or at logistics hubs without requiring major grid upgrades.

FOR PORTS Ports can deploy mobile chargers to electrify drayage quickly, bridge grid constraints, and test demand before investing in permanent MCS infrastructure.

SOURCE https://www.cst.ch/en/the-project/

Milence deploys first Megawatt Charging System and plans corridor expansion

STATUS **OPERATIONAL**

INSIGHTS Milence has activated its first Megawatt Charging System for heavy-duty electric trucks, demonstrating high-power charging in real operations while preparing a wider European MCS corridor.

FOR PORTS Plan gate-adjacent MCS with booking/slotting and sync charging with PCS time windows to support ZE drayage.

SOURCE https://milence.com/press-release/milence-demonstrates-the-first-megawatt-charging-system-at-the-hub-in-landvetter-sweden-together-with-volvo-trucks/

Germany launches national heavy-duty e-truck charging network

STATUS **PROGRAMME ANNOUNCED**

INSIGHTS Germany is rolling out a large-scale public charging network for electric heavy-duty trucks, with MCS-ready sites positioned along major freight corridors.

FOR PORTS Enables zero-emission drayage to and from ports and supports AFIR-aligned adoption of ZE heavy vehicles.

SOURCE https://www.reuters.com/sustainability/germany-launches-electric-truck-charging-network-decarbonize-transport-2024-07-03/

Germany launches tender for nationwide fast-charging hubs for trucks

STATUS **PROGRAMME ANNOUNCED**

INSIGHTS Germany has opened a national tender to build high-power charging hubs for electric heavy-duty trucks along major logistics corridors. The programme supports large-scale deployment of fast-charging to accelerate ZE freight.

FOR PORTS Enables ZE drayage connectivity between ports and inland hubs; supports planning of MCS-ready port access roads.

SOURCE https://www.now-gmbh.de/en/news/pressreleases/tender-launched-for-fast-charging-infrastructure-for-trucks/

Critical-minerals squeeze hits batteries, e-trucks and yard equipment

STATUS /

INSIGHTS EU analyses highlight tightening supply of critical raw materials such as lithium, nickel, cobalt and rare earths. Rising demand from EVs, grid storage and industrial electrification is outpacing secure supply, increasing costs and extending lead times for battery-dependent technologies.

FOR PORTS Slower MCS and ZE-drayage adoption; delays in electrifying yard gear; higher capex and need for battery-agnostic procurement strategies.

SOURCE https://www.consilium.europa.eu/en/infographics/critical-raw-materials/

Rising cyber-attack risk increases vulnerability of port navigation and traffic systems

STATUS /

INSIGHTS NATO's recent assessment highlights growing exposure of maritime and port infrastructure to cyber-attacks targeting navigation systems, vessel traffic services and digital logistics platforms. Compromised systems could disrupt routing, create collision risks and interrupt cargo flows.

FOR PORTS Ports need stronger cyber-resilience, real-time monitoring of navigation data, and contingency procedures for traffic management if digital systems fail.

SOURCE https://gettransport.com/en/blog/nato-report-warns-about-maritime-vulnerabilities

AI taking over

STATUS /

INSIGHTS Analyses show AI automating a growing share of cognitive, administrative and operational tasks. Roles in customer service, planning, finance and routine decision processes are increasingly supported or replaced by AI systems, reshaping workforce structures and skills demand.

FOR PORTS Ports need to prepare for AI-driven changes in planning, documentation and customer interfaces, and invest in retraining for data, automation and oversight roles.

SOURCE https://www.nexford.edu/insights/how-will-ai-affect-jobs#:~:text=Artificial%20intelligence%20(AI)%20could%20replace,Customer%20service%20representative

Modular DAC (Direct Air Capture)

STATUS PILOT-TO-EARLY DEPLOYMENT; MODULAR DAC CONCEPTS MATURING

INSIGHTS Containerized or modular DAC units capable of removing CO_2 directly from air, often designed for co-location with renewable or industrial waste-heat sources.

FOR PORTS Ports can host DAC clusters next to ammonia/e-methanol plants, using waste heat/cold from terminals. Potential new revenue via carbon credits and green-fuel integration.

SOURCE https://www.geoengineeringmonitor.org/geo-map-dac-feb-2024

Electrochemical Ocean Carbon Removal in Port Breakwaters

STATUS EARLY EXPLORATION / PILOT STAGE

INSIGHTS Electrochemical ocean carbon removal uses engineered systems embedded in coastal infrastructure—like port breakwaters—to pull CO_2 directly from seawater. This approach enhances the natural carbon uptake of the ocean without relying on land-based capture and can produce useful by-products while aiding coastal protection. Current efforts focus on early prototypes and small-scale pilots, demonstrating potential but not yet proven at commercial scale. The technology is seen as a low-impact carbon removal option that can be integrated into existing maritime structures.

FOR PORTS For ports, integrating electrochemical carbon removal into breakwaters offers a way to use existing infrastructure for active carbon removal while continuing to protect against waves and erosion. It aligns with broader coastal resilience investments and could position ports as early adopters of ocean-based climate solutions. Adoption would start with pilots and feasibility studies linked to port breakwater upgrades.

SOURCE https://www.weforum.org/stories/2024/10/direct-ocean-capture-carbon-removal-technology/

Space Bubbles (space-based solar shield concept)

STATUS SPECULATIVE R&D; ACADEMIC CONCEPT

INSIGHTS A proposed raft of transparent silicon bubbles deployed at a Lagrange point to deflect a small portion of solar radiation. Intended as a reversible emergency geoengineering intervention.

FOR PORTS Minimal direct operational impact initially, but ports could be involved in launch logistics, special materials handling, or satellite support assembly flows if such programs ever materialize.

SOURCE https://senseable.mit.edu/space-bubbles/

Space-Based Solar Power (SBSP)

STATUS **SPECULATIVE R&D**

INSIGHTS Space-Based Solar Power is technically feasible in theory: large solar arrays in orbit could collect energy continuously and beam it to Earth. However, the concept remains early-stage and highly experimental.

FOR PORTS If SBSP scales, ports could play an enabling role in industrial logistics, heavy project cargo, offshore launch supply chains, and specialised materials handling.

SOURCE https://www.nasa.gov/wp-content/uploads/2024/01/otps-sbsp-report-final-tagged-approved-1-8-24-tagged-v2.pdf?emrc=744da1

White Hydrogen

STATUS **EARLY EXPLORATION**

INSIGHTS White (natural) hydrogen forms underground through geological processes and, if extractable at scale, could offer very low production costs and near-zero operational emissions compared to green hydrogen. Recent discoveries in France and early exploration in Spain suggest significant potential, but commercial viability depends on successful extraction, environmental safeguards, and regulatory changes. It remains an emerging, uncertain resource, not yet a deployable solution.

FOR PORTS ports in regions close to potential reserves could later play a role in hydrogen logistics, storage, export, and industrial clustering if production materialises.

SOURCE https://shorturl.at/w9w7v

Nuclear Fusion in Ships

STATUS **LONG-TERM RESEARCH / HIGHLY EXPERIMENTAL**

INSIGHTS Nuclear fusion could theoretically provide near-limitless, carbon-free power for ships, using deuterium–tritium reactions instead of fossil fuels. Compared to nuclear fission, fusion avoids meltdown risks and long-lived radioactive waste. However, current fusion reactors are too large, too powerful, and far too expensive for commercial shipping, and require complex cooling, shielding, and maintenance systems. The technology is not expected to be commercially viable for ships before the end of the century.

FOR PORTS For ports, fusion-powered vessels remain a very distant possibility. If ever realised, they would drastically reduce fuel bunkering needs and emissions, but would require new safety regimes, emergency protocols, and port-side electrical integration. For now, fusion is best treated as a speculative long-term signal, not a deployable solution.

SOURCE Van Rheenen et al. (2024), Nuclear fusion as unlimited power source for ships, TU Delft / IMDC 2024

Quantum Computing for Global Logistics Optimization

STATUS **EARLY EXPLORATION**

INSIGHTS Quantum computing is a new form of computing designed to solve extremely complex optimisation problems that are difficult or slow for today's computers. In logistics, this includes tasks such as route planning, scheduling, and managing large, interconnected supply chains. By processing many possible solutions at once, quantum systems could significantly improve efficiency compared to traditional models. Most real-world applications today rely on hybrid systems, where quantum tools support classical software rather than replace it. The technology shows strong potential but is not yet widely deployable at scale.

FOR PORTS For ports, quantum computing could eventually improve planning and coordination across terminals, vessels, hinterland transport, and energy use. Potential benefits include reduced congestion, better use of infrastructure, faster decision-making under uncertainty, and lower emissions through more efficient operations. In the near term, ports may engage through pilots or partnerships focused on optimisation and digital twin simulations rather than operational deployment.

SOURCE https://quantumzeitgeist.com/quantum-computing-for-global-logistics-optimization/

Quantum-Accelerated Optimization for Logistics

STATUS **EMERGING RESEARCH**

INSIGHTS This paper explores how quantum computing can speed up optimisation tasks that are central to logistics (such as routing, allocation, and scheduling) by solving very complex mathematical problems much faster than classical computers. It shows that quantum-inspired algorithms can reduce computation time significantly for large-scale optimisation, helping systems find better solutions under tight constraints. While fully universal quantum machines are not yet widely available, the research demonstrates that hybrid methods combining quantum techniques with classical computing can already outperform traditional approaches on benchmark problems. The focus is on optimisation performance, scalability, and where quantum advantage could realistically appear first.

FOR PORTS For ports, early use cases could involve digital twin scenarios and simulation tools, where quantum-assisted optimisation helps identify better plans under uncertainty, even before full quantum hardware is widely accessible.

SOURCE https://arxiv.org/html/2402.17520v1

Quantum-Accelerated Optimization for Logistics

STATUS **EMERGING RESEARCH**

INSIGHTS This paper explores how quantum computing can speed up optimisation tasks that are central to logistics (such as routing, allocation, and scheduling) by solving very complex mathematical problems much faster than classical computers. It shows that quantum-inspired algorithms can reduce computation time significantly for large-scale optimisation, helping systems find better solutions under tight constraints. While fully universal quantum machines are not yet widely available, the research demonstrates that hybrid methods combining quantum techniques with classical computing can already outperform traditional approaches on benchmark problems. The focus is on optimisation performance, scalability, and where quantum advantage could realistically appear first.

FOR PORTS For ports, early use cases could involve digital twin scenarios and simulation tools, where quantum-assisted optimisation helps identify better plans under uncertainty, even before full quantum hardware is widely accessible.

SOURCE https://arxiv.org/html/2402.17520v1

Carbon-to-commodities platforms producing advanced carbon materials

STATUS **EMERGING / RESEARCH & EARLY DEVELOPMENT**

INSIGHTS Converting captured CO_2 into valuable products and long-life materials is a growing field of research that could provide both carbon utilisation and economic value. The reviewed work shows that numerous chemical pathways exist to turn CO_2 into inorganic and organic materials using renewable or carbon-neutral energy sources. While many routes have been tested at small scale, few have reached commercial deployment and significant technical and energy efficiency challenges remain. A circular approach — where CO_2 is captured, used to make materials, and waste is minimised — is key to sustainability and potential negative emissions if renewable energy is used.

FOR PORTS For ports, carbon-to-commodities platforms could offer a way to use locally captured CO_2 streams to produce higher-value materials (e.g., carbonates, polymers or other carbon products) instead of storing or releasing them. Embedding such processes near or within port industrial clusters could turn emissions into commercial feedstocks, strengthen circular economy linkages, and create new revenue streams. Early activity would likely focus on pilot projects and partnerships with industry given limited commercial scale today.

SOURCE Ramirez-Corredores, M.M. Sustainable production of CO2-derived materials. npj Mater. Sustain. 2, 35 (2024). https://doi.org/10.1038/s44296-024-00041-9

Hydropower in the European Union

STATUS **ESTABLISHED TECHNOLOGY WITH ONGOING STRATEGIC IMPORTANCE**

INSIGHTS The 2025 status report focuses on hydropower and pumped-storage hydropower, outlining their current development, markets, and value chains across the EU. It highlights that hydropower remains the largest provider of renewable electricity storage and provides grid flexibility amid rising wind and photovoltaic volatility.

FOR PORTS As hydropower and pumped storage provide long-duration energy storage and grid balancing, this enhances the reliability of clean electricity supplies that ports depend on for electrification of terminals, shore power, and charging infrastructure. Increased storage capacity can reduce reliance on fossil backup during peak loads, supporting port decarbonisation and operational stability. Ports located near hydropower resources or integrated with hinterland energy networks may also play roles in energy logistics, facilitating the movement of power, equipment, and services tied to renewable-driven supply chains.

SOURCE QUARANTA, E., GEORGAKAKI, A., LETOUT, S., MOUNTRAKI, A., INCE, E. et al., Clean Energy Technology Observatory: Hydropower and pumped storage hydropower in the European Union - 2025 - Status report on technology development, trends, value chains and markets, Publications Office of the European Union, Luxembourg, 2025, https://data.europa.eu/doi/10.2760/3389272, JRC143929. https://publications.jrc.ec.europa.eu/repository/handle/JRC143929#:~:text=In%202022%2C%20the%20European%20Commission,the%20top%2010%20world%20companies.

03 / Economy

Economic trends influence trade flows, investment cycles and operational priorities at ports. Market conditions, infrastructure funding and cost structures guide decisions on development and modernisation. Ports operate as economic hubs whose performance depends on broader financial and commercial dynamics.

EU grants €3.2m for Zeebrugge cruise OPS

STATUS **FUNDED**

INSIGHTS The EU is providing €3.2 million to support the installation of onshore power supply at Zeebrugge's new cruise terminal. The funding covers design and construction of OPS infrastructure to reduce emissions from berthed cruise vessels and improve air quality.

FOR PORTS Confirms co-funding path S/M ports can emulate for cruise terminals.

SOURCE https://www.seatrade-cruise.com/ports-destinations/zeebrugge-to-install-new-cruise-terminal-and-shore-power

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Copenhagen Malmö Port: Environmental discounts & price model incl. electricity

STATUS **OPERATIONAL**

INSIGHTS Copenhagen Malmö Port has introduced a revised tariff model that rewards cleaner vessels through environmental discounts and includes electricity pricing to support the shift toward shore power. The scheme incentivises operators to reduce emissions during port calls by linking fees to environmental performance.

FOR PORTS Tariff lever that can nudge OPS use and low-emission calls.

SOURCE https://www.mynewsdesk.com/copenhagen-malmo-port-cmp/news/cmp-introduces-environmental-discounts-491134

Oslo sets zero-emission surcharge and transparent OPS pricing

STATUS **OPERATIONAL**

INSIGHTS Shows how ports can use pricing to accelerate OPS uptake, recover infrastructure costs, and create a clear, predictable fee structure.

FOR PORTS Tariff lever to nudge OPS use and fund assets; replicable transparency.

SOURCE https://www.oslohavn.no/globalassets/oslo-havn/dokumenter/oslo-havn-publikasjoner-2025/prices-and-commercial-terms-2025.pdf

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Reykjavik updates 2025 port tariff with green incentives and transparent OPS fees

STATUS **OPERATIONAL (2025 TARIFF IN FORCE)**

INSIGHTS Revised tariff introduces clearer OPS pricing, environmental discounts, and structured fee categories that support low-emission vessel calls.

FOR PORTS Shows how small or medium ports can use tariff design to steer OPS uptake, create predictable cost signals, and fund energy-transition assets.

SOURCE https://cdn.prod.website-files.com/664c5c4e2aed028ecda3e892/684abc4231c3a6b1dd0079de_Business%20Conditions%202025.pdf

Gothenburg & North Sea Port offer discounts for cleaner fuels

STATUS **OPERATIONAL**

INSIGHTS Both ports apply environmental discounts that reduce port fees for vessels using cleaner fuels and lower-emission technologies, creating a cost signal that favours greener calls.

FOR PORTS Tariff lever to reward OPS/CNF use on targeted routes.

SOURCE https://www.reuters.com/sustainability/germany-launches-electric-truck-charging-network-decarbonize-transport-2024-07-03/

EU funds €422m for new port energy and clean-fuel infrastructure

STATUS **FUNDED**

INSIGHTS The EU's Alternative Fuels Infrastructure Facility (AFIF) is financing 39 new projects across Europe, including shore-power installations, megawatt charging, and alternative-fuel bunkering infrastructure. The grants support deployment of zero-emission mobility and port decarbonisation assets.

FOR PORTS Funding pool for OPS/MCS and CNF bunkering at EU ports.

SOURCE https://cinea.ec.europa.eu/news-events/news/alternative-fuels-eu422-million-eu-funding-boost-zero-emission-mobility-2025-02-06_en

Antwerp-Bruges introduces updated environmental port tariffs

STATUS **POLICY IN FORCE**

INSIGHTS New tariff structure links port dues to vessel emissions and energy-use reporting, encouraging cleaner calls and better operational data.

FOR PORTS Nudges timely emissions/energy data; enables port-call optimisation.

SOURCE https://www.portofantwerpbruges.com/en/news/tariff-adjustments-2024

Green Award-certified barges receive automatic 10–15% port dues discount

STATUS **POLICY-IN-FORCE**

INSIGHTS Barges holding Green Award Gold or Platinum certification automatically qualify for reduced port dues, rewarding cleaner inland vessel operations.

FOR PORTS Low-admin lever to boost inland shipping uptake and reduce gate-area truck emissions.

SOURCE https://www.portofantwerpbruges.com/en/news/automatic-discount-green-award-inland-vessels

Oslo introduces zero-emission surcharge with OPS exemptions

STATUS /

INSIGHTS Oslo adds a per-gross-tonne surcharge for vessels that do not operate emission-free. Ships connecting to OPS or operating zero-emission receive exemptions, creating a direct financial incentive to switch.

FOR PORTS Model for using tariff signals to push OPS uptake and zero-emission calls, while ring-fencing revenue to fund future infrastructure.

SOURCE https://www.offshore-energy.biz/oslo-to-waive-quay-fees-for-ships-operating-emission-free-while-linked-to-shore-power/

Gothenburg offers dues discount for ships bunkering ≥30 percent fossil-free fuel in-port

STATUS **POLICY IN FORCE**

INSIGHTS Vessels that bunker at least thirty percent certified fossil-free fuel during their call receive a ten percent discount on port dues. Eligibility is verified through auditable sustainability documentation.

FOR PORTS Uses tariff incentives to anchor clean-fuel bunkering locally and increase CNF uptake, while creating a documentation model others can replicate.

SOURCE https://www.portofgothenburg.com/globalassets/dokument/port-tariff-2024.pdf

Copenhagen Malmö Port introduces ESI-linked environmental discounts

STATUS **OPERATIONAL**

INSIGHTS CMP applies the Environmental Ship Index (ESI) to offer tiered dues discounts across vessel categories. The scheme rewards lower-emission ships using a standardised, externally verified scoring method.

FOR PORTS Provides a turnkey KPI and discount structure via ESI that ports can adopt with minimal setup, enabling consistent, low-admin environmental incentives.

SOURCE https://www.mynewsdesk.com/copenhagen-malmo-port-cmp/news/cmp-introduces-environmental-discounts-491134

EU e-commerce surges toward USD 900 bn; last-mile volumes continue to rise

STATUS **MARKET GROWTH TREND (2024)**

INSIGHTS European e-commerce demand is expanding, pushing up parcel flows and intensifying last-mile logistics activity. The shift increases pressure on urban hubs, fulfilment networks and port-adjacent distribution centres.

FOR PORTS Rising gate and yard pressure requires earlier visibility of truck flows. Ports can use the trend to justify JIT/slotting upgrades and enable zero-emission drayage infrastructure.

SOURCE https://assets.ctfassets.net/xhb8a7jtuvut/7aceOBVM4WkC5kshcNvULg/e20c7fb8b8e3f64382d31ca4ce27150a/_2024__Europe_E-Commerce_Logistics_Market_Report.pdf

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Falling investments in fossil fuel supply

STATUS /

INSIGHTS IEA data shows declining upstream fossil-fuel investment compared to historical levels. Capital is shifting toward renewables, efficiency and electrification, increasing uncertainty for long-term oil and gas supply and raising exposure to price swings.

FOR PORTS Ports handling fossil energy may face volume volatility and must prepare for declining throughput, asset repurposing and earlier transition to alternative fuels.

SOURCE https://www.iea.org/reports/world-energy-investment-2025/executive-summary

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New investments dual use (funding that goes defence benefits other sectors)

STATUS /

INSIGHTS EU is increasing funding for dual-use innovation, directing defence R&D toward technologies that also support civilian sectors such as cybersecurity, AI, robotics and advanced materials. This strengthens strategic autonomy and accelerates cross-sector spillovers.

FOR PORTS Ports can access technologies originally developed for defence, such as advanced surveillance, resilient communication systems and automation tools that improve safety and security.

SOURCE https://sciencebusiness.net/news/r-d-funding/dual-use/explained-eu-dual-use-and-defence-funding-changes

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Resilience bonds & parametric insurance

STATUS **SCALING IN CLIMATE-RISK FINANCE; INCREASINGLY USED BY CITIES AND INFRASTRUCTURE OPERATORS**

INSIGHTS Financial instruments where payouts trigger automatically when predefined thresholds (storm surge, windspeed, heat index) are exceeded. Enable rapid recovery and reduce long-term financing costs for climate adaptation.

FOR PORTS Provides new funding channels for quay elevation, flood barriers, microgrids, reef breakwater fields, and other protective works. Can lower the cost of capital for sustainable terminals.

SOURCE https://www.cpicfinance.com/blueprints/resilience-bond-for-risk-reduction/

04 / Environment

Environmental factors increasingly determine how ports plan, operate and expand. Climate impacts, resource use and local environmental quality create pressures to adapt infrastructure and processes. Environmental performance is becoming central to long-term port sustainability and licence to operate.

Local recovery and recycling of concrete (upcycled sand pilot)

STATUS **PILOT**

INSIGHTS The pilot processes demolished concrete into high-quality secondary materials. Using advanced crushing and separation, the project produces “upcycled sand” suitable for structural concrete, reducing demand for virgin aggregates and cutting transport emissions.

FOR PORTS Ports can replace up to 40 percent of conventional sand with locally recovered material, lowering material emissions and reducing truck flows linked to aggregate supply.

SOURCE https://pioneers-ports.eu/portfolio-item/local-resource-recovery-for-green-circular-concrete/

2024 Ramboll GPP guide shows practical CO_2-per-m^3 limits for low-carbon concrete

STATUS **GUIDELINE**

INSIGHTS The guide translates Green Public Procurement criteria into workable carbon benchmarks for concrete mixes. It provides example specifications, verification methods and procurement templates that demonstrate how embodied-carbon limits can be applied reliably in real projects.

FOR PORTS Confirms that enforceable carbon thresholds for quay and terminal concrete are feasible today, enabling ports to set $kgCO_2e/m^3$ limits in upcoming procurements.

SOURCE https://ecostandard.org/wp-content/uploads/2024/10/Driving-GPP-in-construction-Ramboll-November-2024.pdf

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Belgium launches Concrete Circularity Center to scale recycled concrete use

STATUS **IN DEVELOPMENT**

INSIGHTS The Concrete Circularity Center brings together research institutes and industry to develop high-quality recycled aggregates, new crushing technologies, and design guidelines. It aims to industrialise closed-loop concrete reuse and improve the performance and traceability of recycled concrete.

FOR PORTS Enables ports to specify higher recycled-content concrete in quay walls, pavements and buildings; supports compliance with circular-procurement targets and reduces demand for virgin aggregates.

SOURCE https://www.buildwise.be/nl/onderzoek-innovatie/onderzoeksprojecten/concrete-circularity-center/

EU targets 30 percent circular material use rate by 2030

STATUS **POLICY TARGET**

INSIGHTS The European Environment Agency tracks the share of secondary materials in the EU economy, with the EU aiming to lift the circular-material-use rate from around 12–13 percent today to 30 percent by 2030. This drives demand for recycled aggregates, metals, plastics, and construction materials.

FOR PORTS Ports can align procurement with EU circular-material targets, prioritise high-recycled-content concrete and steel in infrastructure projects, and strengthen local recycling loops to meet future compliance expectations.

SOURCE https://www.eea.europa.eu/en/analysis/indicators/circular-material-use-rate-in-europe#:~:text=The%20European%20Union%20aims%20to,material%20use%20rate%20by%202030.

PIONEERS launches new circular concrete demo

STATUS **PILOT**

INSIGHTS The PIONEERS programme is testing circular construction solutions that replace virgin sand with locally recovered materials sourced from demolition waste, reducing extraction impacts and transport needs.

FOR PORTS Ports can integrate circular aggregates into quay works and buildings, cutting embodied emissions and strengthening local material loops.

SOURCE https://pioneers-ports.eu/portfolio-item/local-resource-recovery-for-green-circular-concrete/

Using wastewater sludge as a low-carbon input for steel production

STATUS **RESEARCH & EARLY INDUSTRIAL TRIALS**

INSIGHTS European research projects are exploring how dried wastewater sludge can replace part of the coal used in steel furnaces. The material has high biogenic content and can lower fossil CO_2 emissions while reducing waste sent to landfill or incineration.

FOR PORTS Ports hosting steel, cement or waste-to-resource industries can integrate sludge-to-material loops, reduce local waste volumes, and position themselves as hubs for circular feedstock supply.

SOURCE https://projects.research-and-innovation.ec.europa.eu/en/horizon-magazine/sewer-furnace-how-wastewater-sludge-greening-steel-production?pk_source=newsletter&pk_medium=email&pk_campaign=20112025&pk_content=environment-agriculture-energy

96% of EU urban residents exposed to PM2.5 above WHO guideline.

STATUS **EU AIR-QUALITY ASSESSMENT (2024)**

INSIGHTS The EEA reports that almost all urban residents in the EU are exposed to PM2.5 concentrations exceeding the WHO guideline. The main contributors include road transport, residential heating, agriculture, and shipping-related emissions in dense port–city areas.

FOR PORTS Strengthens the case for OPS mandates, ZE first-mile trucking, and stricter berth-emission clauses due to city-side health pressure.

SOURCE https://www.eea.europa.eu/en/analysis/publications/europes-air-quality-status-2024

Air pollution in France causes >€16 bn/yr in costs and over 40k premature deaths (2025)

STATUS **NATIONAL HEALTH-ECONOMY ASSESSMENT (2025)**

INSIGHTS A new analysis quantifies the combined healthcare, productivity, and economic burden of PM2.5 and NO_2 exposure in France, with strong evidence linking urban mortality to chronic pollutant levels.

FOR PORTS Ports face rising expectations to cut local emissions through OPS adoption, ZE yard equipment, and differentiated tariff incentives tied to air-quality outcomes.

SOURCE https://www.lemonde.fr/en/environment/article/2025/01/30/air-pollution-s-economic-and-health-costs-in-france_6737584_114.html

One in five Europeans exposed to harmful transport noise

STATUS **EU ENVIRONMENTAL ASSESSMENT (2024)**

INSIGHTS The EEA finds that over 20% of Europeans experience transport noise above health-based limits, mainly from road corridors, rail lines, and port-adjacent logistics areas. Long-term exposure is linked to cardiovascular impacts, sleep disturbance, and reduced wellbeing.

FOR PORTS Expect stricter night-time noise rules; incentivise quiet operations, ZE equipment, and berth scheduling to reduce community impacts.

SOURCE https://www.eea.europa.eu/en/newsroom/news/europeans-exposed-to-harmful-noise-pollution-levels

Port noise identified as a measurable health and nuisance impact

STATUS **EU PROJECT RESULTS PUBLISHED**

INSIGHTS The PENTA project documents how port-related noise contributes to sleep disturbance, stress, and reduced neighbourhood wellbeing. It provides methods to measure, map, and classify noise sources from terminal equipment, vessel calls, and logistics flows.

FOR PORTS Build noise KPIs into concessions; deploy acoustic barriers and zero-emission handling equipment.

SOURCE https://projects.centralbaltic.eu/images/files/result_pdf/PENTA_result4_noise.pdf

Insetting emerges as a stronger alternative to offsetting for corporate climate action

STATUS **THOUGHT LEADERSHIP / INDUSTRY INSIGHT**

INSIGHTS The article explains how insetting keeps emissions reductions within a company's own value chain rather than buying external offsets. It highlights benefits such as higher transparency, stronger stakeholder trust, and direct decarbonisation impact.

FOR PORTS Ports can use insetting to decarbonise their own logistics chains, invest in local low-carbon projects, and offer tenants value-chain aligned climate programmes that outperform traditional offset schemes.

SOURCE https://www.climeco.com/insights-library/insetting-accelerates-climate-action-from-within-why-does-that-matter/

Danube shipping disrupted by heatwave and low water levels

STATUS /

INSIGHTS A severe heatwave in Hungary has pushed Danube water levels to seasonal lows, forcing cargo vessels to reduce their loading capacity. Operators report that ships carry significantly less cargo to avoid grounding, slowing transport and increasing costs along a key European inland corridor.

FOR PORTS Inland-waterway dependent ports face reduced throughput, unreliable schedules, and higher freight volatility. Expect mode shifts, congested transhipment points, and increased need for resilience planning when river levels drop.

SOURCE https://www.reuters.com/business/environment/low-water-levels-danube-disrupt-shipping-heatwave-hits-hungary-2025-07-04/

Inland navigation weakened by recurring low-water events

STATUS **IN PROGRESS (2024 CCNR ASSESSMENT)**

INSIGHTS The latest CCNR annual report highlights frequent low-water episodes on major European rivers, reducing navigability and forcing barges to sail under-loaded or suspend operations. Climate-driven variability is increasing both the duration and severity of disruptions, impacting transport costs and schedule reliability across inland corridors.

FOR PORTS Barge reliability falls; ports need mode-switch playbooks (rail, short-sea), temporary storage, price escalators.

SOURCE https://inland-navigation-market.org/wp-content/uploads/2024/10/CCNR_annual_report_EN_2024_WEB.pdf

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Storm Babet caused severe storm surges and flooding across DK, DE and UK

STATUS /

INSIGHTS Storm Babet produced extreme rainfall, coastal flooding and high storm surges across Denmark, Germany and the United Kingdom. Authorities issued widespread alerts for coastal towns where overtopping, infrastructure damage and local transport disruption occurred.

FOR PORTS Ports need reinforced flood-risk mapping, storm-surge protection planning, and continuity procedures for extreme-weather closures.

SOURCE https://en.wikipedia.org/wiki/Storm_Babet

EU/JRC projections indicate rising coastal flood risk across Europe

STATUS **IN PROGRESS (MULTI-YEAR DATASETS)**

INSIGHTS EU and JRC modelling shows that coastal flood probabilities and expected annual damages rise throughout the century due to sea-level rise and more intense storm surges. Copernicus and ECFAS now provide operational flood-extent mapping that supports real-time assessment and early response.

FOR PORTS Ports need updated inundation maps, stronger adaptation plans, and integration of Copernicus flood data into emergency and continuity planning.

SOURCE https://ec.europa.eu/jrc/en/european-coastal-flood-risk

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Tuas Port built 5 meters above mean sea level for climate resilience

STATUS **OPERATIONAL**

INSIGHTS Singapore’s Tuas Port has been constructed on elevated ground five meters above mean sea level to protect operations from long-term sea-level rise and climate-driven flooding. The elevation is part of a national strategy to future-proof critical maritime infrastructure.

FOR PORTS Example of climate-ready port design; raises the bar for elevation standards, flood-proof construction, and long-term adaptation planning.

SOURCE https://www.mpa.gov.sg/docs/mpa/downloads/decarbonisation-blueprint.pdf

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Wildfire smoke and heat stress disrupt Mediterranean terminals

STATUS /

INSIGHTS CAMS monitoring shows that intense wildfire seasons around the Mediterranean generate prolonged smoke episodes and hazardous heat conditions. These events reduce visibility, degrade air quality and constrain safe outdoor work, affecting port operations during peak summer months.

FOR PORTS Poor AQ and visibility restrict work–rest cycles, crane operations and vessel handling; ports need heat protocols, air-quality thresholds and plans for ferry or feeder disruption.

SOURCE https://atmosphere.copernicus.eu/year-intense-global-wildfire-activity-2023

Europe records its warmest summer on record

STATUS /

INSIGHTS Copernicus Climate Change Service confirms that Europe experienced its warmest summer on record, with persistent heat anomalies across land and sea. Elevated temperatures intensified heat stress on workers, reduced operational windows, and contributed to marine heatwaves in adjacent basins.

FOR PORTS Higher operational heat exposure requires revised work–rest plans, cooling measures, and equipment derating rules; ports also need contingency planning for heat-related delays.

SOURCE https://climate.copernicus.eu

Renewables volatility: Dunkelflaute and offshore wind cable failures

STATUS /

INSIGHTS Periods of low renewable output during winter “Dunkelflaute” events coincide with rising reports of offshore wind cable failures. These incidents expose vulnerabilities in grid-connected renewable supply, with outages and reduced generation affecting regional electricity stability.

FOR PORTS Grid constraints or outages can curtail OPS, stall ZE-drayage charging, and impact port microgrids; ports need redundancy, storage and contingency power plans.

SOURCE https://www.rechargenews.com/wind/offshore-wind-industry-faces-thousands-of-cable-failures/2-1-1631483

05 / Political

Political and regulatory frameworks shape the rules and incentives under which ports operate. Legislation, public policy and international agreements influence investment plans, operational requirements and long-term strategy. Ports must align with evolving political priorities to remain compliant and competitive.

AFIR mandates onshore power supply (OPS) at TEN-T ports by 2030

STATUS **POLICY IN FORCE**

INSIGHTS The Alternative Fuels Infrastructure Regulation (AFIR) requires TEN-T core and comprehensive ports to provide OPS for container, passenger, and certain Ro-Ro vessels by 2030. The regulation sets minimum power availability, technical standards, and monitoring obligations.

FOR PORTS Creates a binding OPS deployment requirement and locks in long-term planning; enables funding applications and aligns port investment timelines with EU compliance.

SOURCE https://transport.ec.europa.eu/transport-modes/maritime/decarbonising-maritime-transport-fueleu-maritime_en

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Valencia authorised to tender €14.5m electrical substation (ST1)

STATUS **FUNDED**

INSIGHTS Spain's central government has formally authorised the Port of Valencia to issue a public tender for a €14.5 million high-voltage substation (ST1). The project enables OPS and broader grid modernisation, ensuring capacity for future electrification needs.

FOR PORTS Shows central-government alignment; replicable tendering language.

SOURCE https://www.valenciaport.com/en/the-port-of-valencia-receives-authorisation-from-the-government-to-put-out-to-tender-the-construction-of-an-electrical-substation-for-14-5-million/

EU ETS extended to maritime (phase-in 40% in 2024 → 70% in 2025 → 100% in 2026)

STATUS **POLICY IN FORCE**

INSIGHTS The EU Emissions Trading System now applies to maritime transport, requiring ships calling at EU ports to purchase allowances for their CO_2 emissions. Coverage ramps up from 40% in 2024 to full 100% liability by 2026, increasing the operational cost of fossil-fuelled voyages and at-berth emissions.

FOR PORTS Raises the cost of at-berth emissions and strengthens the financial case for OPS and zero-emission calls.

SOURCE https://climate.ec.europa.eu/eu-action/transport-decarbonisation/reducing-emissions-shipping-sector/faq-maritime-transport-eu-emissions-trading-system-ets_en

Low-GHG fuel supply unlikely to meet shipping demand by 2030 (DNV)

STATUS	ANALYTICAL REPORT
INSIGHTS	DNV analysis indicates that projected global production of low-GHG fuels will fall far short of expected maritime demand by 2030. Supply bottlenecks across e-methanol, ammonia, and advanced biofuels constrain early decarbonisation.
FOR PORTS	Ports should prepare for uneven fuel uptake across corridors, prioritise flexible bunkering infrastructure, and avoid over-committing to single-fuel pathways.
SOURCE	https://www.worldports.org/low-ghg-fuel-production-unlikely-to-meet-shippings-needs-by-2030-dnv-report-finds/

AFIR for OPS

STATUS	IMPLEMENTATION PHASE
INSIGHTS	AFIR is the new Alternative Fuels Infrastructure Regulation. An EU law (entered into force 1 Jan 2025) that forces EEA ports and member states to deploy infrastructure for alternative fuels, including mandatory Onshore Power Supply (OPS) for container and passenger ships >5,000 GT.
FOR PORTS	Must install sufficient OPS by 2030 for the ships covered (container & passenger), even if traffic volumes are modest. Investment burden is significant: infrastructure, grid reinforcement, space allocation. Risk of non-compliance → penalties, loss of attractiveness for shipping lines. Opportunity: early movers can position themselves as green-compliant ports and attract OPS-reliant vessels.
SOURCE	https://www.lr.org/en/services/statutory-compliance/fueleu-regulation/alternative-fuels-infrastructure-regulation/

Fitfor55 (ETS)

STATUS	IMPLEMENTATION & COMPLIANCE PHASE
INSIGHTS	A set of EU proposals to revise existing laws to meet its climate targets, including a 55% reduction in net greenhouse gas emissions by 2030 compared to 1990 levels. The EU Emissions Trading System (ETS) is a core part of this effort, with its reform including expansion to include new sectors like maritime transport, road transport, and buildings, along with other measures to lower emissions caps and phase out free allowances.
FOR PORTS	Higher costs for ship calls (ETS charges passed through), influencing routing choices. Pressure on ports to support decarbonisation: OPS readiness, low-carbon bunkering, efficiency measures. Competitive risk for smaller ports if they cannot accommodate ETS-driven operational shifts. Opportunity for ports that position themselves as low-carbon, efficient, and compliant hubs.
SOURCE	https://www.consilium.europa.eu/en/policies/fit-for-55/#:~:text=The%20Fit%20for%2055%20package%20aimed%20to%20reform%20the%20EU,free%20allowances%20for%20some%20sectors

Trade war with increasing tariffs on imports from China

STATUS /

INSIGHTS Escalating tariff measures between major economies continue to reshape global trade flows. Higher import duties on Chinese goods trigger rerouting, tariff avoidance and substitution toward third-country manufacturing. Studies show measurable shifts in declared origins and changing logistics patterns.

FOR PORTS Ports may see diverted cargo, re-routing via intermediary hubs, and increased customs complexity; potential volume volatility on Asia–Europe lanes.

SOURCE https://cepr.org/voxeu/columns/tariff-avoidance-and-import-measurement-lessons-first-us-china-trade-war

Conflict puts more pressure on supply of fossil fuels and cheap materials

STATUS /

INSIGHTS Geopolitical instability continues to disrupt access to fossil fuels and low-cost raw materials. Supply chain uncertainty raises energy costs, tightens global material markets and increases exposure to price shocks across industrial sectors.

FOR PORTS Ports must plan for volatile fuel prices, shifting bulk-material flows and potential increases in strategic stockpiling and storage demand.

SOURCE https://insights.taylorandfrancis.com/sustainability/energy-security/

Resilience becomes the leading strategy for EU, forcing energy shift towards local production and closed material loops

STATUS /

INSIGHTS EU climate and industrial policies emphasise resilience through domestic energy generation, reduced dependence on external suppliers and circular material systems. Strategic frameworks highlight local value creation, recycling and reduced exposure to global supply disruptions.

FOR PORTS Ports may shift from import-heavy models to hosting circular industries, local energy production and reverse-logistics flows that support closed material loops.

SOURCE https://environment.ec.europa.eu/strategy/circular-economy_en

Growing inequality and protest

STATUS /

INSIGHTS Research shows widening income gaps and rising economic insecurity in several EU countries. Higher inequality feeds public dissatisfaction, amplifying protest movements and increasing sensitivity to price shocks, infrastructure decisions and environmental impacts.

FOR PORTS Ports may face more scrutiny on local impacts, higher expectations for community benefits, and potential disruption if protest activity targets transport or logistics nodes.

SOURCE https://hiva.kuleuven.be/en/news/publications/docs/gillissen-goubin-reidsma-2024-economic-inequality.pdf

Red Sea and Suez insecurity becomes semi-permanent (Cape routing)

STATUS /

INSIGHTS Persistent attacks and instability in the Red Sea continue to push carriers toward detours around the Cape of Good Hope. The rerouting adds transit time, increases fuel use and causes schedule bunching. Analysts note that the disruption is shaping capacity, freight pricing and reliability across multiple global routes.

FOR PORTS Longer voyages increase ETS-priced emissions costs; expect fluctuating arrival patterns, bunching at terminals, and the need to update port green-dues calculators with real-time voyage emissions.

SOURCE https://www.reuters.com/world/maersk-says-red-sea-disruption-could-cut-asia-europe-capacity-20-2024-01-15/

Implementing defence financing and spending under the Economic Governance Framework

STATUS **IN PROGRESS**

INSIGHTS The Commission's ReArm Europe plan uses temporary fiscal flexibility (National Escape Clause) and a new SAFE loan instrument to ramp up defence spending. In practice, only 16 Member States activated the NEC, so the extra defence spending falls to ~€293–337bn instead of €650bn, and the SAFE legal basis is being challenged by Parliament, making the whole package less certain and clearly temporary, with future debt/fiscal consolidation pressures.

FOR PORTS This framework creates a strong financial and fiscal incentive for Member States and regions to steer cohesion/RRF money into defence-oriented or dual-use transport/logistics infrastructure (where ports can fit), rather than purely green/sustainable port projects, especially under tight budgets and temporary defence-friendly flexibility.

SOURCE https://www.europarl.europa.eu/RegData/etudes/IDAN/2025/764381/ECTI_IDA%282025%29764381_EN.pdf?utm_source=chatgpt.com

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Geoengineering treaties (SAI, space shields)

STATUS **EMERGING GOVERNANCE CONCEPTS / EARLY DIPLOMATIC EXPLORATION**

INSIGHTS International proposals for "climate peacekeeping" mechanisms to coordinate emergency geoengineering (e.g., Stratospheric Aerosol Injection, orbital sunshades). Focus on multilateral oversight, rapid-response governance, and cross-border monitoring to prevent unilateral deployment.

FOR PORTS Ports may be required to develop emergency operations protocols for geoengineering logistics (specialized shipments, surveillance assets, safe handling zones). Potential new role as coordination hubs for climate-response alliances.

SOURCE https://www.cigionline.org/static/documents/documents/CIGI%20Paper%20no.111%20WEB.pdf

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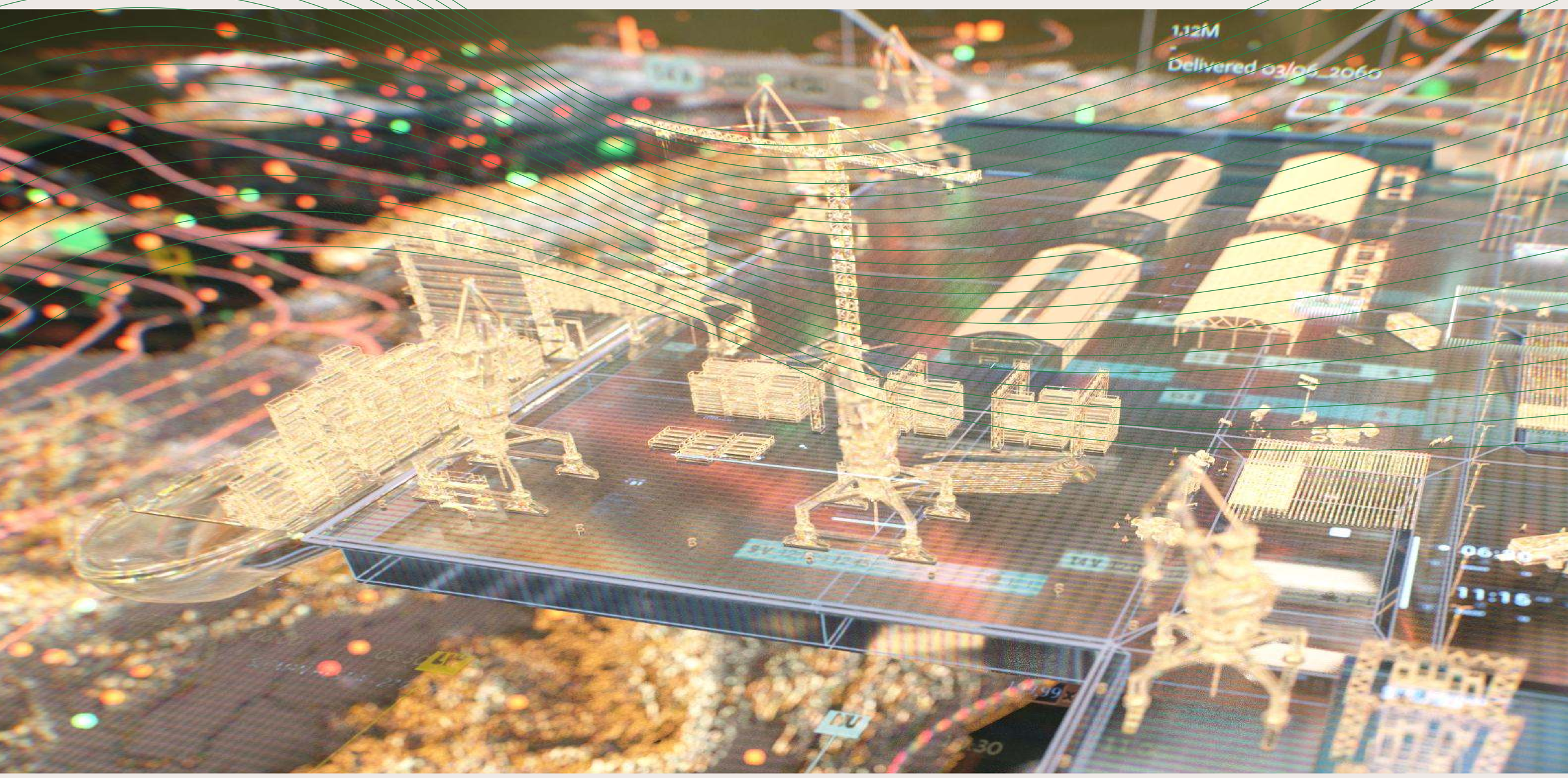
REPowerEU (Phase-out of Russian Energy Imports)

STATUS **ONGOING EU POLICY IMPLEMENTATION (2026)**

INSIGHTS The European Union's REPowerEU strategy and Roadmap commit to phasing out imports of Russian energy — including gas, oil, and, in time, related nuclear materials — as part of its energy security and clean-energy transition goals. A historic political agreement was reached in late 2025 to end Russian gas imports and prepare for the phase-out of Russian oil, and in early 2026 the EU adopted a regulation making the phase-out of pipeline and liquefied natural gas imports legally binding. This gradual but permanent ban aims to reduce energy reliance on Russia, diversify energy supplies, strengthen EU energy sovereignty, and minimise financing of external aggression. The policy works alongside broader REPowerEU measures to increase renewable energy deployment and accelerate energy diversification.

FOR PORTS The shift away from Russian gas and oil alters fuel sourcing patterns for port operations and the broader logistics system, driving demand for alternative energy carriers (such as LNG from non-Russian suppliers, hydrogen, and renewables). As energy markets diversify, ports may need to adapt infrastructure, storage, and bunkering services to support new supply routes and fuels. Increased volatility or transitions in energy supply can also affect port costs, scheduling, and integration with hinterland transport networks.

SOURCE https://energy.ec.europa.eu/strategy/repowereu-phase-out-russian-energy-imports_en



IN COOPERATION WITH PIONEERS

Co-funded by the European Union