

# Greening the Supply Chain

## **THE TIME TO ACT IS NOW**

Leveraging Technology to Drive Emissions Reduction  
and Efficiency in the Push Toward Net Zero



## Executive Summary

The maritime industry is rapidly shifting towards net-zero emissions, with container terminals playing a crucial role in this transformation. As regulatory pressures increase and customer demand for sustainable practices grows, ports are tasked with reducing greenhouse gas (GHG) emissions while maintaining operational efficiency. Although investments in electrification and renewable energy are key long-term solutions, AI-driven optimization offers an immediate and cost-effective approach to cutting emissions and enhancing terminal productivity.

This white paper examines the essential role of AI-based technologies in decarbonization efforts. By optimizing container movements and forecasting operational needs, AI-driven systems can lower emissions while improving throughput and reducing operational costs. Through case studies, we explore how container terminals can leverage AI to meet sustainability goals, enhance financial performance, and establish leadership in an increasingly competitive, eco-conscious marketplace. The future of terminal operations lies in integrating technology with sustainability, and the time for action is now.

## Market Context:

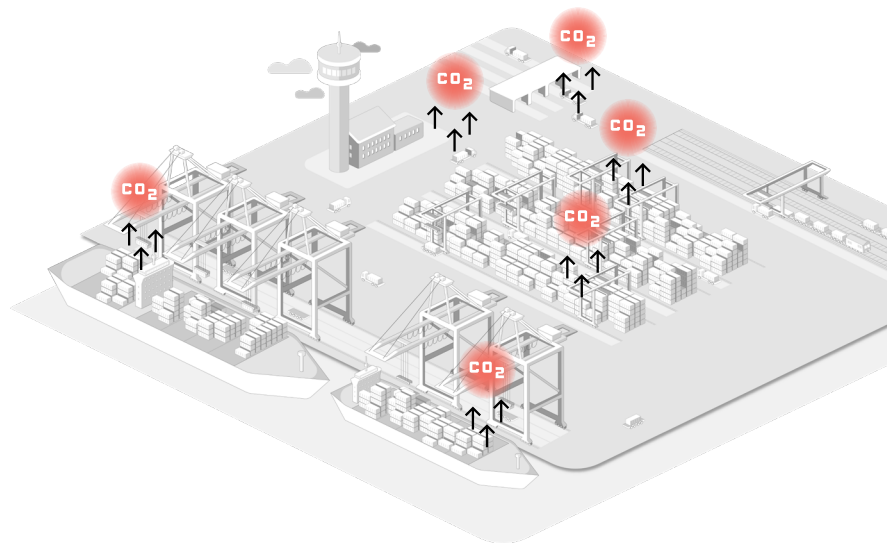
# Decarbonization in the Maritime Industry

The global maritime industry is experiencing a profound shift, driven by the urgent need to reduce GHG emissions and transition towards more sustainable practices. Container terminals, central to global trade, are critical players in this shift. Historically reliant on fossil fuels, terminal operations have significantly contributed to air pollution and CO<sub>2</sub> emissions. Currently, maritime shipping accounts for nearly 3% of global carbon emissions, and without meaningful action, this could rise by 50% by 2050<sup>1</sup>.

The demand for decarbonization has been amplified by stricter regulatory frameworks. Initiatives like the European Union's Fit for 55 package, which seeks to cut GHG emissions by at least 55% by 2030 compared to 1990 levels<sup>2</sup>, have set stringent emission reduction targets for the industry. The International Maritime Organization (IMO) is also pushing for ambitious action, aiming for net-zero greenhouse gas emissions by, or around, 2050, with targets set for cutting emissions by 20%-30% by 2030 and 70%-80% by 2040, against 2008 levels<sup>3</sup>. These regulatory pressures are forcing ports and terminals to rethink their operations and align with evolving environmental standards.

Beyond regulations, customers are increasingly prioritizing sustainability. Environmental, social, and governance (ESG) factors are becoming core to corporate strategies, with logistics companies and shippers seeking greener operations. Ports that offer sustainable options—such as shore power for vessels, electrified cargo handling equipment, and reduced waiting times—are better positioned to attract environmentally conscious customers and investors.

Emerging technologies are key in driving these efforts. Digitalization, artificial intelligence (AI), and automation are improving operational efficiency while helping terminals cut emissions. For instance, the IMO estimates that Just-in-Time (JIT) vessel arrival systems can reduce CO<sub>2</sub> emissions by up to 14% by minimizing waiting times and improving port call coordination<sup>4</sup>.



<sup>1</sup>["How much does the shipping industry contribute to global CO<sub>2</sub> emissions?" by Sinay](#)

<sup>2</sup>["Fit for 55" by the European Council](#)

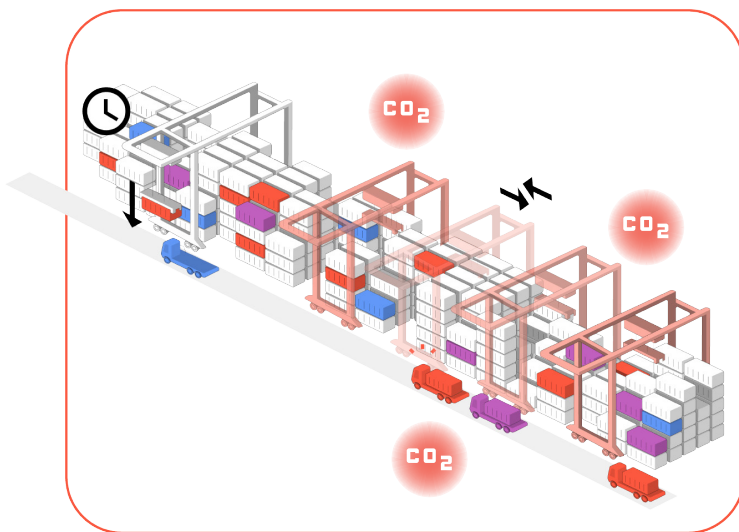
<sup>3</sup>["Climate impact of shipping" by the European Federation for Transport and Environment](#)

<sup>4</sup>["Lowering containership emissions through Just In Time arrivals" by the International Maritime Organization](#)

While decarbonization will require substantial investments in renewable energy infrastructure, grid enhancements, and electrification, AI and optimization technologies offer an immediate solution to reduce emissions. Terminals that adopt these technologies can make measurable progress toward sustainability while planning for long-term infrastructure upgrades.

## The Challenge: Achieving Net Zero Emissions in Container Terminals

Container terminals are facing a critical challenge: reducing greenhouse gas (GHG) emissions to achieve net-zero operations in the coming decades. While the goals — complying with international regulations, meeting customer expectations, and minimizing environmental impact — are clear, the path to realizing these goals is complex and filled with obstacles.



### Operational Inefficiencies and Environmental Costs

As container terminals upgrade equipment to reduce emissions and increase efficiency, they are forced to seek quick operational wins while these long-term improvements are underway. One major hurdle to decarbonization is the ongoing operational inefficiency, often exacerbated by outdated processes and reliance on fossil fuel-powered equipment. Suboptimal container

stacking results in frequent rehandling, driving up fuel consumption and emissions. Unproductive moves, such as unnecessary container rehandling, and trucks idling, further increase the carbon footprint and reduce overall efficiency.

Compounding this issue is the unpredictability of vessel schedules, with delays and frequent changes forcing reactive adjustments that detract from both sustainability and profitability. In this context, terminals must prioritize short-term improvements — such as AI-driven optimization — to streamline operations and reduce emissions while larger infrastructure and equipment upgrades are being pursued.

## Technological and Infrastructure Barriers

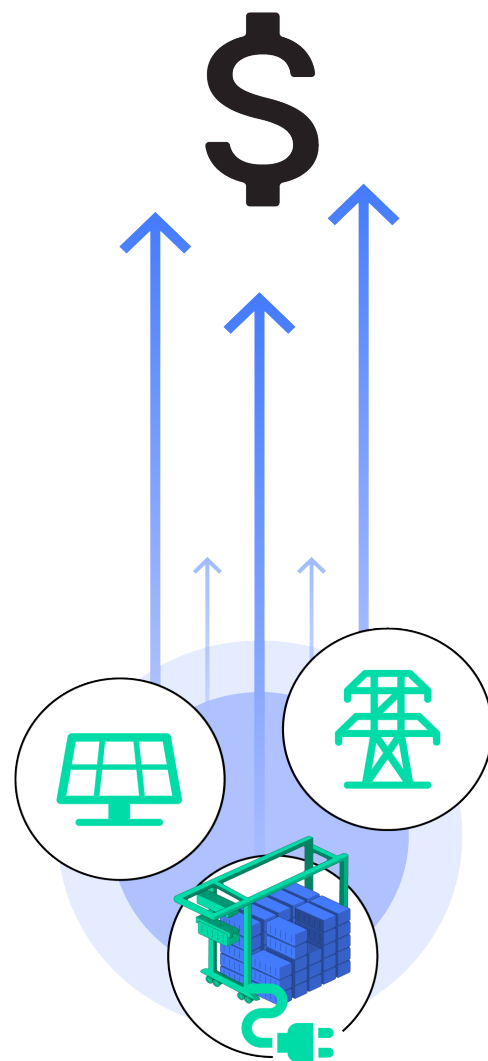
While electrification and cleaner energy sources present promising solutions for reducing emissions, they also come with substantial infrastructure and technological hurdles. Transitioning from fossil fuel-powered equipment to electric alternatives requires large investments in new equipment, enhanced grids, and charging infrastructure. Terminals in regions with aging infrastructure may struggle to accommodate these increased power demands.

Renewable energy sources, such as wind and solar, are essential for decarbonization but can be inconsistent and costly to implement. Moreover, terminals need energy storage solutions to maintain a reliable power supply. Adopting low and zero-emission fuels like hydrogen or methanol also presents challenges, including high costs, limited availability, and the lack of storage and bunkering infrastructure.

## Financial Constraints and Regulatory Pressures

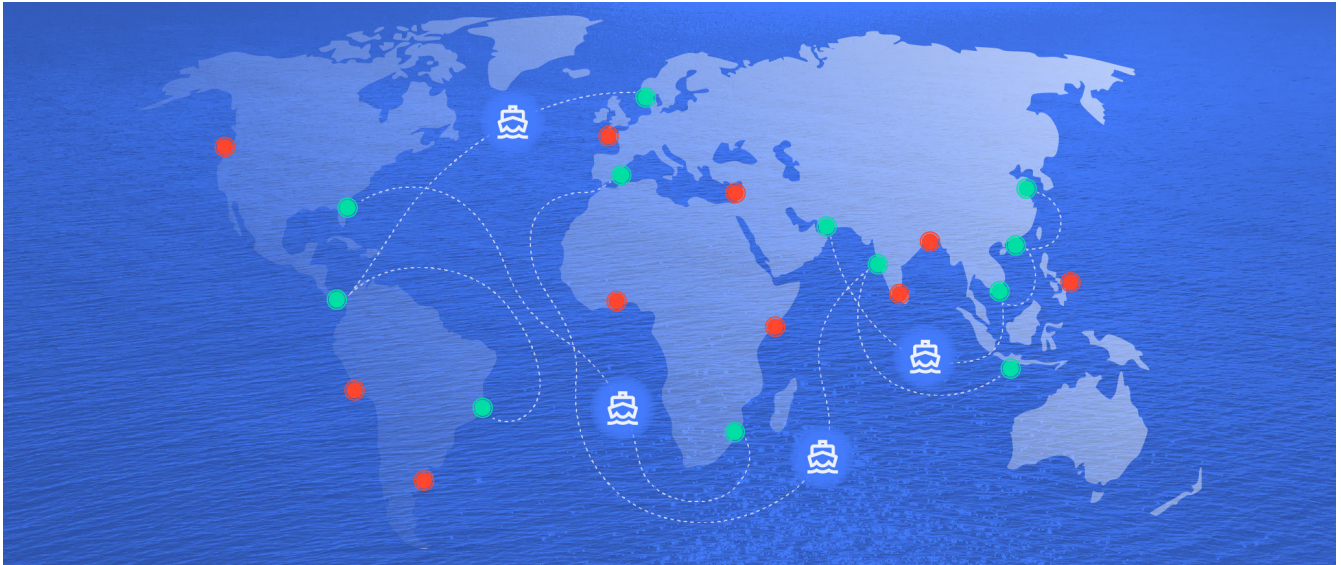
Reaching net zero by 2050 will require significant financial investments. The costs associated with electrifying equipment, upgrading energy grids, and deploying renewable energy solutions are substantial, often straining budgets, especially for smaller terminals. Even though the long-term environmental and financial benefits are clear, upfront costs remain prohibitive. Additionally, securing funding for these projects is challenging, as investors may be wary due to the extended payback periods typical of green infrastructure investments.

At the same time, regulatory bodies, such as the International Maritime Organization (IMO) and the European Union, are imposing increasingly stringent emissions reduction targets, pressuring ports and terminals to act swiftly. Failure to comply could result in fines, reputational damage, and a loss of business as more environmentally conscious customers and stakeholders prioritize sustainability.



Green Infrastructure Investments

## The Urgency to Act



The urgency to address these challenges is mounting and agility is key. As the maritime industry moves towards decarbonization, terminals cannot afford to fall behind. Shipping lines and customers are increasingly choosing ports that align with their sustainability goals, while local communities demand cleaner operations to reduce pollution and improve public health.

**Decarbonizing terminals is not only an environmental priority but also a business imperative. Terminals that fail to adopt responsive, sustainable practices risk losing their competitive edge as logistics companies favor greener ports.**

For the immediate future, however, widespread electrification of terminal transport will likely be concentrated in developed markets, where extensive infrastructure investments are being made to build and support electric vehicles. Developing markets may face delays in adopting electrification due to the complexity and cost of upgrading power grids and constructing charging stations. Many manufacturers anticipate that it will take ten years for electric power to become the default for new container handling equipment<sup>5</sup>.

The strategic decisions made today will determine whether terminals can maintain both operational and financial viability as the industry moves toward net-zero emissions by 2050. AI-driven optimization has become an essential tool for achieving the agility needed enabling terminals to make faster, smarter adjustments. Embracing AI optimization is critical for overcoming technological and financial barriers, ensuring that terminals can meet sustainability goals while remaining competitive in a rapidly evolving industry.

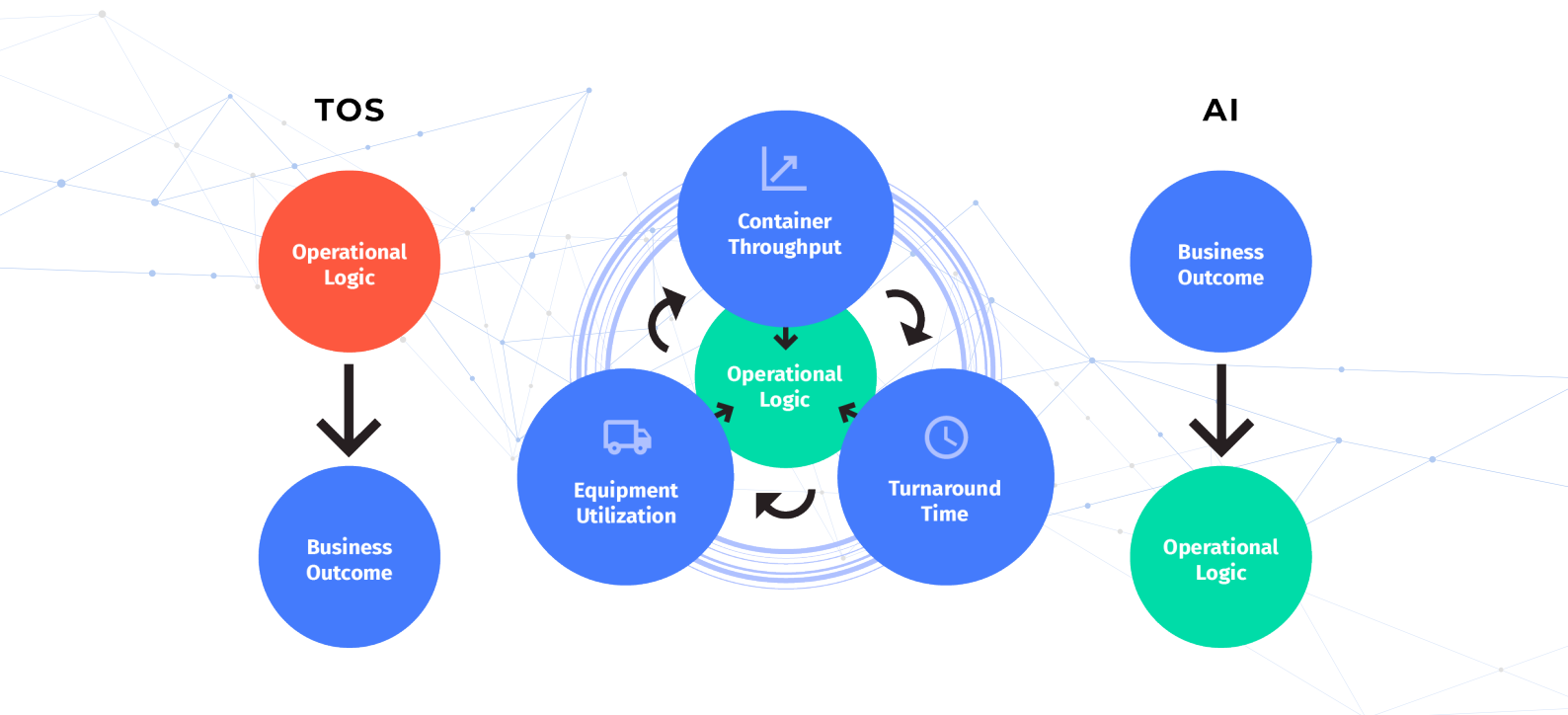
<sup>5</sup>["Reducing air emissions in a container terminal" by Kalmar](#)

# AI-Driven Solutions: The Key to Efficient and Sustainable Terminal Operations

Achieving net-zero emissions in container terminals requires more than incremental improvements in energy usage and equipment. While electrification and renewable energy are essential long-term solutions, integrating AI-driven optimization systems offers an immediate and impactful way to reduce greenhouse gas (GHG) emissions while enhancing operational efficiency. Leveraging AI, terminals can address key challenges such as unproductive moves, inefficiencies, and unpredictable operations, all while progressing toward sustainability goals.

## AI Intent-Driven Optimization: A Paradigm Shift for Terminal Operations

Traditional terminal operating systems (TOS) are often limited by rigid workflows that react to predefined scenarios, making it difficult to adapt to real-time conditions at the terminal. These limitations are evident when faced with fluctuating vessel schedules, unpredictable truck arrivals, uncertain rail reliability and barge congestion. AI-based systems, however, introduce a more flexible approach, operating based on intent-driven logic. These systems continuously analyze real-time data — such as vessel schedules, yard conditions, truck, rail, and barge movements — and generate operational strategies that align with business objectives.



AI-driven systems enable terminals to dynamically reprioritize tasks. For instance, if a vessel is delayed, the AI system can automatically adjust operations, minimizing unproductive container rehandles and reducing crane idle time. This real-time adaptability reduces fuel consumption and emissions while maintaining operational flow and efficiency.

## Harnessing Data for Predictive and Proactive Operations

One of AI's greatest strengths lies in its ability to predict and anticipate operational needs. By analyzing historical data and real-time inputs, AI-driven systems can forecast vessel arrivals, anticipate container handling demands, and identify potential bottlenecks before they occur. This predictive power is particularly useful in mitigating the effects of unpredictable vessel schedules, where delays often disrupt operations.

For example, AI-powered Just-in-Time (JIT) arrival systems can coordinate vessel speeds and arrival times with terminal availability, minimizing idle time and reducing fuel consumption both at sea and in port. The International Maritime Organization (IMO) estimates that the global implementation of JIT systems could reduce CO2 emissions in the shipping sector by 6% to 14%<sup>6</sup>, underscoring the critical role smart technology plays in driving emissions reductions.



**Furthermore, by predicting container movements and optimizing energy usage to enhance yard planning, AI systems enable terminals to reduce unnecessary steps, minimize fuel use, and enhance overall productivity. This focus on continuous improvement, aligns closely with the Lean goals of enhancing operational efficiency, reducing waste, and delivering customer value with fewer resources.**

## AI as a Bridge to Electrification and Renewable Energy

Beyond its immediate operational benefits, AI also serves as a bridge to long-term decarbonization strategies like electrification. Transitioning to electric equipment and renewable energy sources will take time and significant financial investment, but AI can maximize resource efficiency during this transition period.

<sup>6</sup>["Lowering container shipping emissions through Just In Time arrivals" by the International Maritime Organization](#)



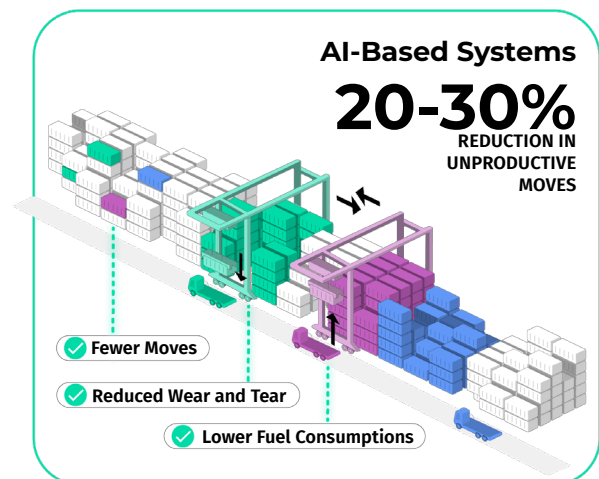
For instance, AI-driven battery management systems can optimize charging schedules for electric equipment, ensuring machinery is charged during off-peak hours to avoid operational disruptions. AI can also track energy usage patterns, recommending ways to lower peak power demand and alleviate pressure on the grid as terminals transition to electrified operations.

As renewable energy sources, such as solar and wind, become more integrated into terminal operations, AI will be crucial in managing energy flow and storage. By optimizing grid management and energy distribution, AI systems can ensure reliable power availability, even when renewable energy sources fluctuate. This reliability is key in environments where continuous access to power is essential for efficient terminal operations.

**Strategic Value:  
Sustainability Meets Profitability**

The strategic value of AI-driven optimization extends beyond emissions reduction; it directly impacts profitability. By minimizing unproductive moves, optimizing energy consumption, and improving overall operational efficiency, terminals can handle more containers and reduce turnaround times—driving revenue growth. Terminals that adopt AI-based systems have reported up to a 20-30% reduction in unproductive moves<sup>7</sup>, leading to faster truck turnaround times and increased productivity.

These efficiency gains also come with substantial cost savings. Fewer moves translate to lower fuel consumption and



reduced wear and tear on equipment, which in turn cuts maintenance costs. Over time, the savings from enhanced efficiency and reduced emissions can offset the initial costs of AI implementation, providing a clear financial incentive for terminal operators.

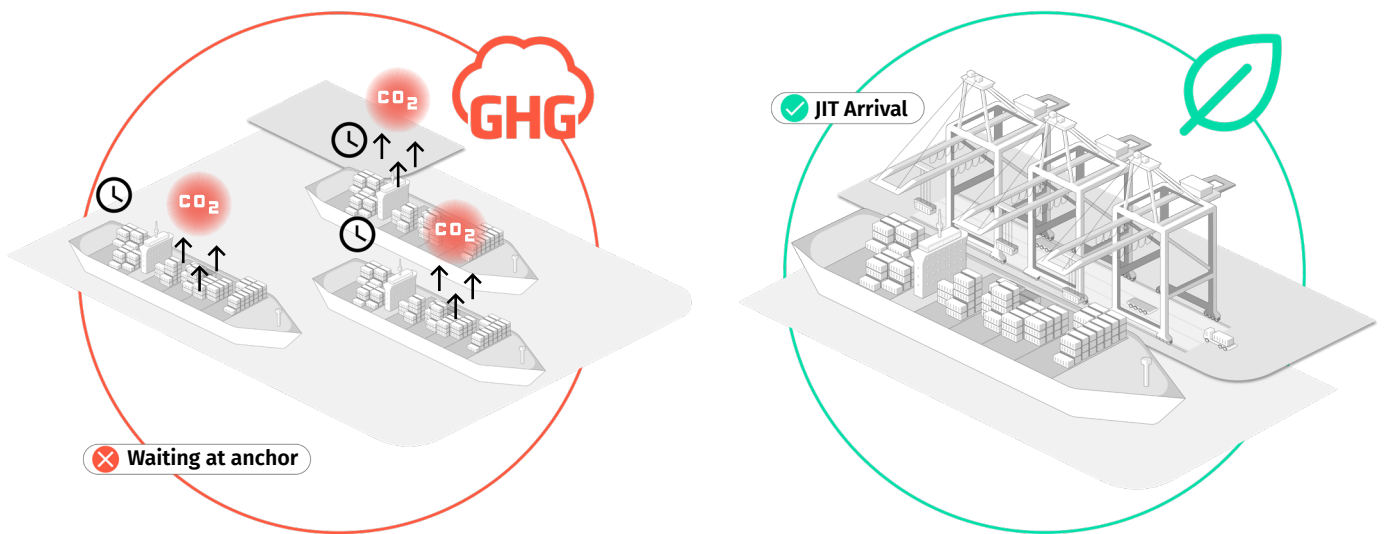
**In an industry with fluctuating margins and intense competition, the ability to improve both environmental sustainability and profitability is a powerful differentiator. Terminals that embrace AI-driven solutions will not only meet evolving regulatory and customer demands but will also gain a competitive edge in the rapidly evolving maritime sector.**

<sup>7</sup> [Enhancing Yard Operations with Smart Strategies, PTI Journal, CTAC 2024 Edition](#)

## Case Studies: Real-World Successes in AI-Driven Optimization

AI-driven optimization technologies are revolutionizing container terminal operations by improving efficiency, reducing emissions, and enhancing overall productivity. The following case studies highlight how smart solutions have achieved measurable gains in emissions reduction and operational performance.

### Optimizing Port Call Schedules to Reduce Vessel Emissions



Terminals can face significant challenges due to unpredictable vessel arrivals, resulting in long anchorage times and higher emissions from idling vessels. By implementing smart technology to optimize port call schedules and introduce Just-in-Time (JIT) arrivals, terminals are able to reduce unnecessary waiting periods for vessels. These systems facilitate better coordination between vessels and terminal availability, allowing ships to adjust their speed and arrival times accordingly.

A Just-in-Time (JIT) arrival system seeks to synchronize vessel speed during inbound voyages with berth availability, aiming to minimize waiting times. By adjusting the speed of vessels, JIT systems reduce fuel consumption and emissions during transit, while also limiting the time ships spend idling in anchorage zones. This dual impact leads to significant reductions in overall emissions, as less time is spent burning fuel both at sea and while waiting to dock at ports. AI can further refine JIT systems by leveraging real-time data and predictive analytics as well as dynamically adjusting operations, ensuring smoother coordination and improved sustainability.

Drewry analyzed the potential of Just-in-Time (JIT) ship arrival systems to reduce GHG emissions by cutting idle times in port anchorage zones. In one case, Drewry evaluated a port where vessels waiting for over a week accounted for nearly 70% of waiting time. By capping inbound voyage speeds to 10 knots, waiting time could be reduced by 31%, equivalent to 23,000 tons of CO<sub>2</sub>. A more conservative speed reduction to 12 knots would yield a 16% cut, or 11,800 tons of CO<sub>2</sub> emissions<sup>8</sup>.

This type of optimization not only improves operational efficiency but also contributes to a terminal's long-term sustainability targets.

### Enhancing Yard Operations for Greater Efficiency

In another case, a semi-automated container terminal that handled around 3,500 truck transactions daily faced considerable challenges with gate throughput due to unpredictable vessel arrivals. Only 30% of vessels arrived as scheduled, often resulting in export containers being positioned prematurely, only for the associated vessel to be delayed by days. This caused containers to be misplaced, obstructing other operations and complicating logistics for containers scheduled to depart by rail or road.

Additionally, the terminal's strategy of stacking containers up to five levels high, while maximizing capacity, created inefficiencies as containers had to be frequently repositioned to access specific units. This increased fuel consumption and lowered operational efficiency.

To address these issues, the terminal deployed an AI-driven optimization system integrated with its Terminal Operating System (TOS). The AI solution focused on optimizing container movements, using idle crane time for housekeeping tasks to improve operational flow. By predicting truck arrivals and analyzing operational patterns, the system minimized unnecessary rehandles, leading to faster truck servicing and a 40% reduction in rehandles. This reduction in unproductive moves not only



lowered operational costs but also reduced the terminal's carbon footprint. By streamlining operations, minimizing fuel consumption, and enhancing productivity, the AI system helped the terminal meet sustainability goals while increasing throughput and revenue by enabling quicker vessel unloading<sup>9</sup>.

<sup>8</sup> "JIT ship arrivals key in reducing GHG emissions at ports" by Heavy Lift & Project Forwarding International  
<sup>9</sup> Case Study: Leveraging AI based Housekeeping to improve Landside Operations by Avlino

## Implications for the Future of Terminal Operations and the Path Forward

The maritime industry stands at a crucial point in its decarbonization journey, with container terminals playing a vital role in shaping this future. As environmental regulations tighten and customer demands shift toward greener practices, the need for innovative terminal management has never been more urgent. Achieving net zero emissions by 2050 is no longer just an aspiration—it's a mandate requiring immediate and strategic action.

Looking ahead, the future success of the maritime industry will depend on how well it embraces innovation and adapts to evolving environmental standards. The road to decarbonization will offer terminals fresh opportunities for collaboration with technology providers, government agencies, and industry stakeholders. Terminals that invest in AI-driven optimization, electrification, and renewable energy sources will be at the forefront of creating smarter, greener, and more resilient operations.

**The opportunity is clear: taking action today allows terminal operators to secure their place as leaders in sustainable logistics, ensuring long-term viability in an evolving industry.**

Now is the time to act. As the maritime sector progresses toward decarbonization, the decisions made today will determine whether terminals can thrive in the future. AI-driven solutions provide the tools and insights necessary to navigate this transformation, helping you build operations that are not only efficient but also environmentally responsible.

**Take the Next Step:**

Contact Avlino today to explore how AI-driven optimization solutions can accelerate your journey toward net-zero emissions and operational excellence. Let's work together to create a more sustainable future for the maritime industry.

