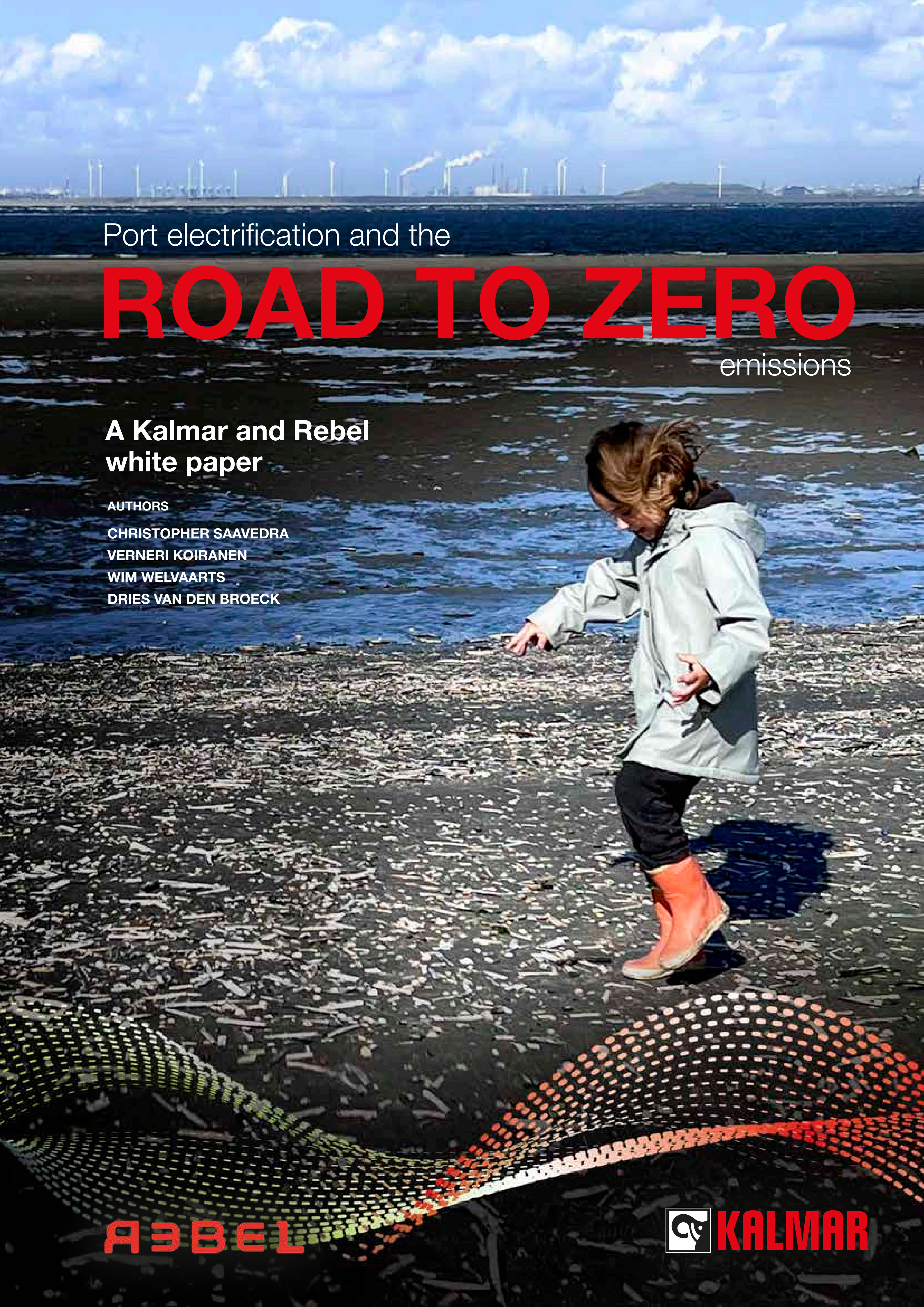

Port electrification and the

ROAD TO ZERO

emissions

A Kalmar and Rebel white paper

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Contents

EXECUTIVE SUMMARY

This white paper examines best practices and recommended approaches to develop decarbonisation roadmaps of container terminals operations. It considers both Scope 1 (direct) and 2 (indirect from generation of purchased electricity) emissions of the terminal operator's terminal equipment, refer the figure in Section 1.

It also touches upon additional ways to tackle decarbonisation of other processes in container terminals such as implementation of shore power and improving energy efficiency, though these are not the main elements of this paper.

This paper is a follow up to the earlier Kalmar and Rebel White Paper titled 'Designing future-proof container terminals' and uses the design philosophy laid out in the earlier paper to analyse multiple decarbonisation roadmap scenarios through a structured evaluation which leverages both technology and data to the maximum, including the use of simulations, modelling and detailed business case analysis.

1 Industry trends and investment drivers

Going green is not an option, it is a must do task that will require public and private cross-disciplinary and cross-national cooperation.

It is hard to stress the importance of reducing emissions enough. It is a challenge, which left unsolved, can lead to an environmental, humanitarian and economic crisis. Going green is not an option, it is a must do task that will require public and private cross-disciplinary and cross-national cooperation. Navigating the change to more eco-efficient operations comes with challenges for terminal operators as the switch to electric, or otherwise green equipment must happen with mitigating financial and operational impact. Global terminal operators have the same challenges while facing additional challenges, as regulations and standards can vary significantly between countries, and in some cases they might even shift quickly. The winds of change can be more easily weathered by proactively creating and implementing a roadmap with needed actions.

Today's container terminals operate in a competitive, highly pressured global business environment. Heavy consolidation between major shipping lines has led to a continuous increase in average ship capacity at terminals of all sizes. Simultaneously, terminal operators face high cost pressures while having to meet ever more demanding eco-efficiency targets. The drivers for increased eco-efficiency come from roughly three stakeholder levels, that can be broken down to **1) public opinion and regulation 2) customer demand and 3) internal and investor pressure.** All stakeholder levels demand eco-efficiency for slightly different reasons, however the impact to terminals is clear – less emissions.

1) The eco-efficiency targets are enforced through regulations while the **public opinion** is driving the change. Examples of public initiatives include:

- The US Senate recently passed the Inflation Reduction Act which includes $ 3 billion for electrified equipment at ports to reduce emissions.
- As part of the Green Deal, The European Commission adopted a set of proposals to make the EU's climate, energy, transport and taxation policies fit for reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels.
- In the 14th Five-Year Plan of the People's Republic of China, it is stated that pressure to decarbonize economy will be enormous after emissions peaking before 2030. This pressure will equally be felt in ports.
- In Australia, port operators are facing pressure to reduce emissions by local port authorities, with some ports targeting net zero as soon as 2030.

2) Large customers are putting pressure on their suppliers to meet their **emission reductions targets**. Examples of major climate pledges:

- Large cargo owners such as Amazon, Ikea and Unilever have signed up to a pledge to only move cargo on ships using zero-carbon fuel by 2040.
- Walmart has launched Project Gigaton, which aims to reduce emissions from the supply chain by 1 billion metric tons by 2030.

3) **Internal and investor pressure** has led to terminal operators signing up to climate pledges as well. Eco-efficiency is not a traditional financial metric and it can be hard to directly assign it any monetary value. However, it is considered in ESG analysis by investors and can be seen either as a risk or an opportunity, and therefore have a positive or negative impact on a company's value. Examples of climate actions taken by terminal operators:

- **APMT is targeting a 70 % emission reduction in Scope 1 & 2 emissions by 2030**, compared to the 2020 baseline, while targeting to be net-zero by 2040, in line with targets of parent company Maersk.

- **The CMA CGM Group has announced that it is creating a Special Fund for Energies**, to accelerate its energy transition and achieve net-zero carbon by 2050. The Special Fund is backed by a five-year $ 1.5 billion budget and comprises four pillars

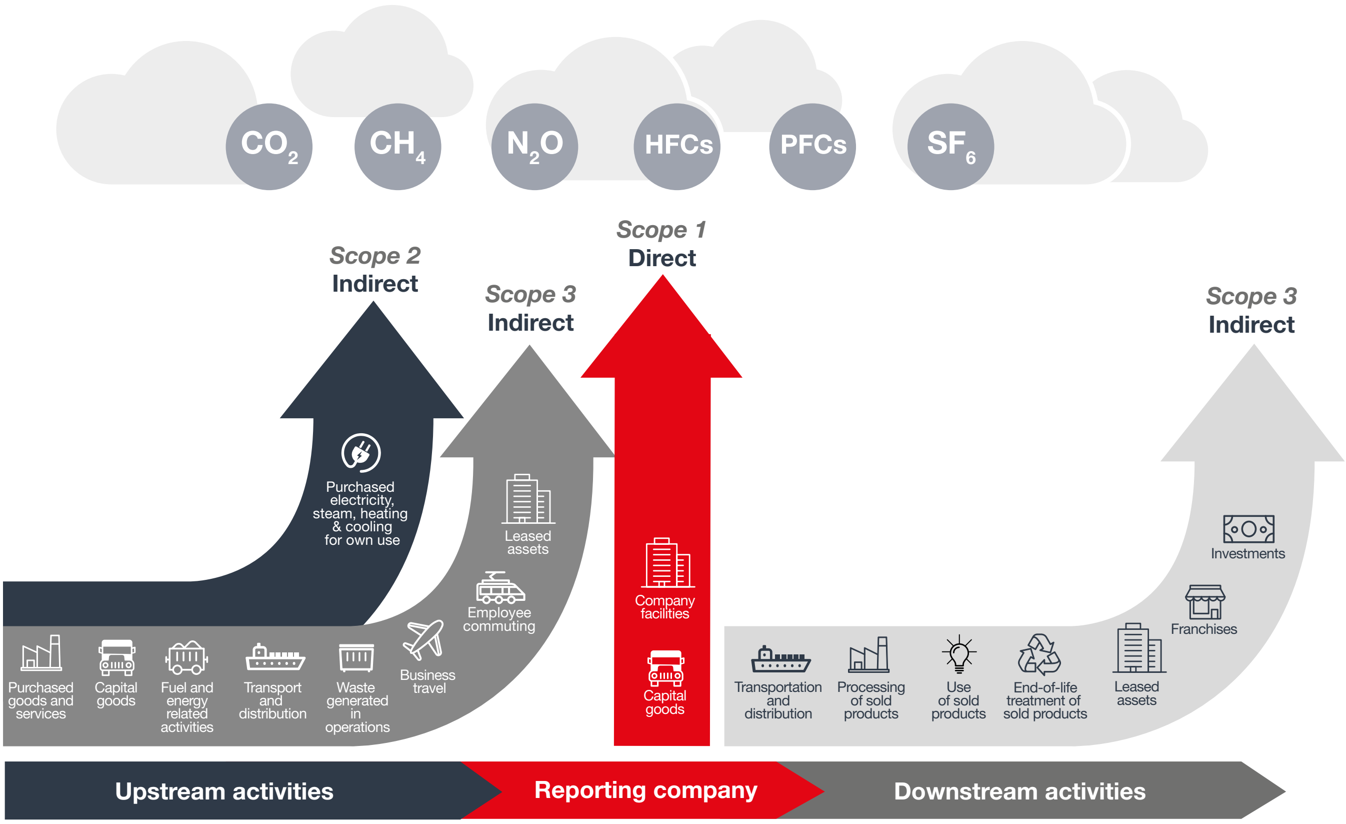
- **DPW has made a commitment of being net-zero by 2040**, with an intermediate target of 28 % carbon footprint reduction by 2030. Demonstrating efforts on the push, DPW has created a carbon footprint estimator for their customers.

- **PSA is targeting net zero by 2050** with intermediate targets of 50 % by 2030 and 75 % by 2040, scope 1 and 2 emission reduction.

- Many other port operators have recently laid out plans to become carbon neutral, with some terminal reporting carbon neutrality already.

Eco-efficiency is considered in ESG analysis by investors and can be seen either as a risk or an opportunity, and therefore have a positive or negative impact on a company's value.

To visualise these targets, we included a picture of different emission scopes according to the GHG Protocol.



Transforming Brownfield container terminal operations into carbon neutral operations is a highly challenging task that should balance cost of operation, service quality and effectiveness, and keep the terminal competitive for a wide range of potential future scenarios. The decision on the decarbonisation strategy of the terminal depends on many factors including the expected size of vessels, traffic forecasts, available plot size, labour market conditions, cost structure, available infrastructure and environmental impact. Furthermore, the terminal needs to consider how to differentiate from its competition to maintain and grow its market share.

PLANNING FOR DECARBONISATION

- **First step:** electrify operations, which also includes electricity regeneration
- **Second step:** sourcing of green electricity
- **Third step:** become more efficient, better planning – terminals have been doing this for a long time, probably some additional room for optimisation but limited.

Besides electrification of terminal equipment, the first step could also consider shore power supply which is the process of providing shore side electrical power to ships at berth while their main and auxiliary engines are turned off. The combined power requirement for the terminal equipment and shore power make up the majority of a terminal's electrical consumption. In a number of cases the local electricity grid feeding the terminal may need to be enhanced to power the terminal. It needs to be considered that if more reliance is being placed on one fuel source i.e. electricity the operations may become more vulnerable for power outages, terrorism and cyber crime. To mitigate these risks terminals could individually implement or expand existing backup power systems or potentially there is a role for Port Authorities to provide a communal backup power system to a collection of terminal operators.

To tackle scope two emissions a growing number of terminal operators consider renewable energy supply contracts and installation of solar and wind installations on their terminals.

Eco-efficiency is another important focus area for today's container terminals. Terminal operators are continuously taking additional steps to reduce emissions and energy consumption in their operations. Eco-efficient performance also translates into direct cost savings that improve the bottom line of the terminal, while promoting corporate responsibility and fulfilling stakeholder requirements. Particularly in areas in which changes in legislation are steering terminal operators heavily towards eco-efficient solutions, it is crucial to be able to demonstrate compliance with requirements already at the design stage.

AVOIDING THE COMMON DESIGN PITFALLS

Typically, when designing a terminal – and especially when considering electrification – operators have challenges in thinking through the full implementation plan for the design. When moving towards the implementation phase, it is easy to take shortcuts and make assumptions such as assuming the productivity figures of an ASC block based on data from another location, without taking into account local conditions and the terminal's own specific traffic profile.

Likewise, terminals often struggle with the required power capacity for terminal electrification. The quay, container stack and gate may all be optimised separately instead of as a unified system. A system is only as strong as its weakest link, and especially for the deep technical interdependencies involved in an automated terminal, the only practical way to gain a realistic view of the total system is to perform careful testing with simulations that utilise authentic scenarios and data.

Ultimately, operators face two main challenges when seeking to design successful terminals. Firstly, the required decisions are extremely complex and involve multiple interlinked variables, so they can only be handled with a structured approach and purpose-built tools. Secondly, each business case is extremely dependent on the individual conditions of the terminal. Generalised guidelines (e.g. how many cranes are needed for a container block of a given size) are of limited value, and designers must do the evaluation based on the specific situation and business goals of their own terminal.

Each business case is extremely dependent on the individual conditions of the terminal.

At the core of a successful terminal design project is a structured design approach that leverages technology and data for the best results. The tools and processes for making more informed design decisions already exist, and a small investment in the design stage can be orders of magnitude more economical than having to make changes later on in the process.

In this paper, we present a basic framework for this kind of structured design approach to decarbonise terminal operations, while providing an overview of some of the tools that are available for terminal operators seeking to minimise the impact of the unknown in a difficult one-time decision event. In essence, this process involves combining operational, technical, financial and environmental data with a clear market and business focus. If the decarbonisation roadmap can be shaped with a phased approach in which key decisions can be kept open until later on in the project, designers can reach more certainty about input parameters and thus make better and more informed decisions before locking onto the chosen solution.

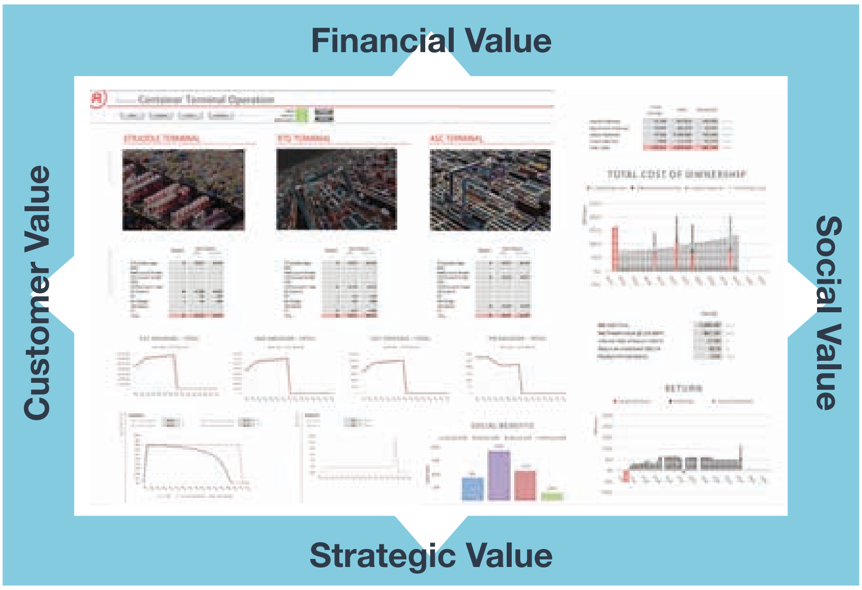
Finally, we want to emphasize the fact that there is not a single set of actions to decarbonise terminals. Depending on a number of variables, such as infrastructure or low-cost energy availability, decarbonisation can be achieved by gradual electrification of fleet, equipment retrofitting, biofuels or soon with synthetic fuels such as green hydrogen. In the transition period for brownfield terminals equipment fleet will likely include a mix of green and legacy handling equipment, a mixed fleet situation can help terminal operators to learn the ins and outs of new technologies and lower threshold for full scale decarbonisation.

2 Building business cases that link operations to total value

When introducing port electrification in an existing (brownfield) site, design and operating decisions need to be linked to sound project appraisal by framing the problem in a holistic manner. As mentioned in our previous White Paper *Designing future-proof container terminals* the financial assessment is more than just an instrument for quantifying the impact on terminal running costs and total cost, profit or return on investment. On the contrary, the development of a flexible business case fosters business solution thinking throughout the entire planning of decarbonisation steps. The business cases stimulate explicit thinking alongside multiple business dimensions by addressing issues and challenges from various angles such as customer needs, changes in technology and staffing requirements, impact on maintenance and civil infrastructure development. In addition, it provides an opportunity to simulate reduction of GHG emissions for multiple decarbonisation roadmaps within the flexible business case model.

It is clear that terminal electrification will impact total value. In addition to investment in conversion- and/or replacement of equipment, terminals may require enhanced grid connection and investment in installation of fast charging- and/or busbar systems amongst others. The terminal's energy cost will likely be affected due to new regulation (such as CO_2 taxation) and shift to electricity consumption. Also, terminal productivity is likely to be affected due to required recharging of equipment.

For this purpose, business cases are developed to consider the options from a 360-degree perspective on value creation. In this way, the choices and trade-offs in the operational design can be linked directly to customer value, financial value, strategic value and social value.



Social value are the cost and benefits for third parties such as employees, inhabitants, economic system, the government and the surrounding scarce natural resources. Decarbonisation options impact value are measured in terms of health benefits due to reduction in emissions, and could potentially include other gains such as safety, know how, taxes and economic efficiency. In addition, the societal and environmental benefits identified creates a basis to justify potential capital subsidies and/or other incentives to be provided to positively influence the business cases and support the implementation of port electrification.

Customer value encompasses the satisfaction of the users of the terminal, including vessel operators and cargo owners. The impact of changes in performance at the customer end, such as equipment availability, speed (turnaround time) and particularly the reliability of service should be valued. Accordingly, customer value is linked to financial value through potential gains (or losses) in market share, as well as through positive or negative impact on pricing levels.

Strategic value reflects the terminal's agility towards changes in the market and the broader operating environment. The business case thus evaluates options to expand, reduce or exit operations over time. Decarbonisation roadmaps that increase flexibility offer important benefits to terminals. The conditions of concession agreements will amplify the relevance of such strategic value drivers over the long-term operating horizon.

Financial value is primarily derived from the investment and operating cash flows. Alternative decarbonisation options are typically compared against their financial performance measured by the Internal Rate of Return, the Pay Back period or Net Present Value. Business cases must help in understanding how financial value can be improved through savings in operational expenditures and better planning of capital layouts.

The development of a robust flexible business case including GHG emissions is an iterative process. A first version will support initial design thinking by considering a broad range of decarbonisation options. Multidisciplinary teams challenge the assumptions and each business case version is tested and re-tested with sensitivity analysis. Accordingly, the business cases will focus the design process and ensure attention is given to the right parameters that enhance value. The business cases also help identify knowledge gaps and highlight the importance of data quality. An integrated and dynamic setup will stimulate the joint creation of alternatives and multiple scenarios instead of locking too fast into a single vision. As such, maximum flexibility and adaptability are embedded into the entire design process. The model will gradually develop into a full business and GHG emission simulator capturing all decarbonisation options considered for value enhancement.

The business cases will focus the design process and ensure attention is given to the right parameters that enhance environmental value.

The societal benefits consider the positive effect of reduction of emissions for each of the identified options. These benefits vary by emission type, location and over time. For example, street-level particulate matter emissions in urban areas are more harmful than in a remote port site. In addition, health cost increases as time progresses. The flexible business case allows making informed decisions regarding the various decarbonisation scenarios during each design stage. In addition, the results of the social business case support potential subsidy application and/or contractual negotiations with the Port Authority.

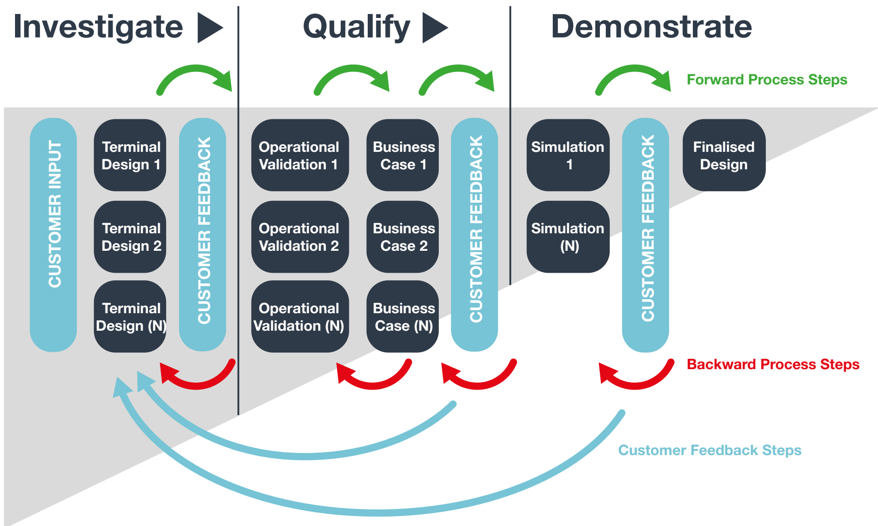
Finally, the business case provides detailed insights in Scope 1 and 2 GHG emissions which can be used for future GHG emissions reporting requirements.

3 Structuring the design process

Create a decision tree that will provide the ability to evaluate options and respond to changes in the environment by purposefully 'stretching' the design process at every phase.

In large-scale terminal decarbonisation projects, the standard way of working typically involves a limited depth of preliminary evaluation as well as an early focus on a single concept. As per the earlier White Paper a better approach is a structured phase-by-phase method that leverages technology and data to provide additional time for evaluation before committing to the final concept.

It should be noted that this step-by-step approach does not mean carrying out small-scale pilot projects, but acquiring more information and improving decisions while retaining the flexibility to adapt. An essential concept is to create a decision tree that will provide the ability to evaluate options and respond to changes in the environment, by purposefully "stretching" the design process at every stage. At each phase, designs and business cases are evaluated iteratively, retracing back to earlier steps as needed.



In practice, the design team will move between a high-level planning workflow and the tactical realities in the daily operations of the terminal. By taking in daily real-world experiences as inputs to the process, the overall decarbonisation roadmap can continuously improve from phase to phase, taking into account the operational realities of the terminal. This is essential since too often terminal design is carried out on a theoretical basis that forgets the actual circumstances on-site.

OVERALL PROJECT FLOW

A proven, successful approach to structuring the terminal design process flow is to divide it into three major phases:

First, the **Investigate** phase examines a wide range of potential design solutions while taking into account the terminal's business environment goals, preferred investment strategy, and physical site footprint. The implementation phase is considered on a general level, but no single terminal design concept is yet locked down at this point. Next, the **Qualify** phase includes more detailed operational validation and business case analysis on a variety of options. Finally, the **Demonstrate** phase ensures and validates that the selected design meets its objectives by utilising tools such as terminal simulations and 3D modelling. These project phases will be examined in more detail in subsequent sections of this paper.

TYPICAL DESIGN PROBLEMS AND CHALLENGES

Based on extensive real-world experience on terminal decarbonisation projects as well as the business and financing processes involved, some of the most common challenges that designers face include the following:

Business case comprehensiveness. Are your calculations detailed and realistic enough? Do they include equipment, IT and infrastructure costs, with realistic assumptions for each?

Risk and scenario comprehensiveness. Is your chosen design robust towards changes and alternative scenarios? What will happen if traffic patterns, container volumes or your business environment change suddenly?

Involving all required skills. Are you making optimum use of the available know-how all through the project, both within your organisation as well as with suppliers and external partners?

Later refinements or additional information. As new data and real-world experience comes in, it is easy to overlook feeding it back into the models to verify if the selected concept is still the optimal choice.

A proven, successful approach to structuring the terminal design process flow is to divide it into three major phases.

Comparing apples to apples. It is often difficult to compare different scenarios, as their cost elements may differ significantly. Careful structuring of the models is needed to ensure meaningful outputs.

Too little time available for a proper analysis. Project timeframes may exert significant pressure on designers to move forward with selecting a terminal concept. However, at the analysis stage, even a small additional investment in time and money for analysis will bring huge savings by avoiding costly changes later in the project.

Design feasibility. Can the proposed design actually be implemented at the site in the intended timeframe, when taking into consideration coexisting operations at the terminal, as well as the physical requirements of transporting and setting up equipment? Often, the end result is defined without thinking about all the intermediate steps of the actual implementation process, which can be costly and/or time consuming.

The typical end result of failing to address these challenges is that in order to meet time, skill set and budget limitations, there is a premature focus on one operational concept, without performing solid checks of sensitivities and sufficient evaluation of alternative scenarios.

In any terminal design project, it is crucial to remember that focusing on the planning phase will actually save money later on.

ESSENTIAL TOOLS

The key tool for managing the terminal design process is an integrated **Flexible Decision Tool**. This is software that utilises a wide range of available information to facilitate informed, optimised decision making and to create a set of realistic business cases on the basis of real-world data.

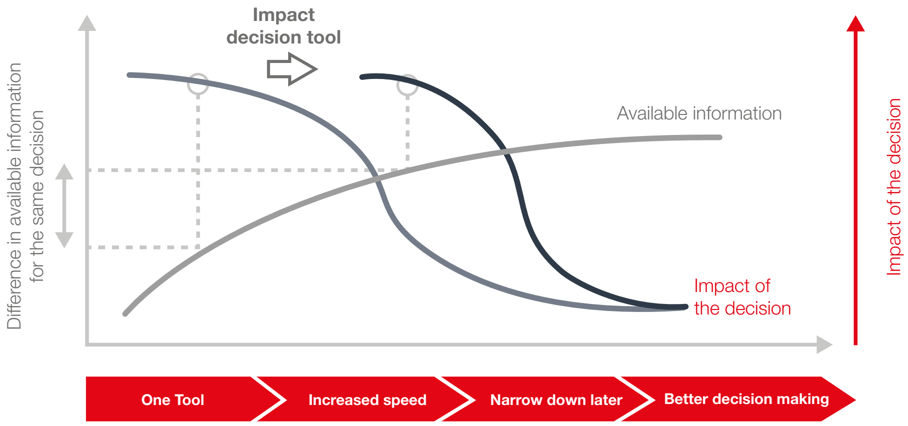
Inputs of the Flexible Decision Tool can include, among others:

- **Timing aspects:** concession duration and construction period
- **Financing assumptions:** inflation, taxes, debt funding
- **Terminal parameters:** area, volume characteristics, TEU ground slots, stacking height
- **Activity statistics:** horizontal transport, yard moves, gate, inspection, housekeeping
- **Equipment parameters:** maximum running hours per unit, moves per hour, spare parts cost, maintenance per hour, useful economic lifetime, emissions per hour
- **Investment costs:** infrastructure, equipment, IT
- **Social costs:** health cost per emission type
- **Other operational costs:** labour, energy and fuel, insurance
- Revenues per container type

The outputs for each scenario include, among others:

- Total Cost of Ownership, Internal Rate of Return, Net Present Value
- Cash flow statement
- Balance sheet
- Environmental impact

FLEXIBLE DECISION TOOL



PLAN WELL NOW, SAVE MONEY LATER

In any terminal design project, it is crucial to remember that focusing on the planning phase will actually save money later on. This is the reason for using the Flexible Decision Tool, as faster and more detailed evaluation of multiple scenarios enables options to be kept open longer, thus improving the quality of decision making as additional information becomes available.

Finally, a factor that is worth careful consideration is choosing the right design services partner with real-world experience in terminal integration. Every terminal is unique, even though superficially most container terminals follow one of a few well-established design schemes. For designers in today's terminal industry, the key question is how to do things better by taking advantage of the new technology that is available. The ultimate value will come from knowing how utilise the possibilities that are available and tailor them to the unique situation of the terminal. This capability can only be acquired by practical experience in integrating systems, solutions and equipment in the field.

4 Phase 1: Investigate

The goal of the Investigate phase is to map out various options for decarbonisation alternatives in order to meet the business objectives of the terminal while decreasing emissions. This phase examines the relative strengths of different layout options, terminal concepts and transportation systems (automated stacking cranes vs. rubber-tyred gantry cranes, straddle carriers vs. automated guided vehicles etc). Pathways to zero emissions can already be evaluated at this stage.

This phase examines the relative strengths of different layout options, terminal concepts and transportation systems.

Example alternatives that could be considered in this Phase include for instance replacement of diesel driven equipment with hybrid or fully electric driven equipment (step 1). Subsequent steps 2 and 3 could consider but are not limited to possible implementation of solar and wind power infrastructure at the terminal and efficiency measures.

This project phase also examines the terminal design process from the wider context of the terminal's investment goals and financing structure. In simplification, the various options can be divided into Low CAPEX / ”short-horizon” and High CAPEX / ”long-horizon” terminal concepts. A solution with lower capital expenses will offer a shorter timeframe in recouping the investment and will provide easier options for adjusting equipment fleet sizes due to changes in capacity demand or other factors.

Additionally, the Investigate phase needs to address the implementation plan when electrifying existing terminal operations due to required electric infrastructure. For operational (brownfield) projects, this is a highly relevant question that may cause great issues if not properly studied and even rule out some equipment due to charging strategy and changes to terminal infrastructure. A charging strategy can have a huge impact on the required peak power from the grid for the terminal. Choosing a wrong charging strategy can cause major operational disruptions if equipment is not able to get required charging speed due to infrastructure constraints.

5 Phase 2: Qualify

At this phase, the total value of each decarbonisation scenario begins to take shape, supported by terminal capacity calculations and fleet size estimations.

The Qualify project phase researches and numerically assesses alternative solutions in extensive detail. The full range of decarbonisation options is evaluated, and a comprehensive business case and GHG emission analysis (CAPEX, OPEX, ROI, GHG emission savings, etc.) is prepared for several potentially viable scenarios.

At this phase, the total value of each decarbonisation scenario begins to take shape, supported by terminal capacity calculations and fleet size estimations. Sensitivity analysis is an essential step that explores the effects of changes in various parameters such as various CO_2 emission cost scenarios, operating volumes, dwell times, TEU ratios or a wide range of other metrics. The end goal is to begin to shape a decarbonisation roadmap that will be robust towards changes while continuing to provide the business results required by the terminal.

Given the strong focus on maritime decarbonization in EU and globally, it is realistic to anticipate that terminal operations can be covered in the future by an emission trade system and in Europe to be included potentially in the EU ETS system. The European Union Emissions Trading System (EU ETS) has been the first large GHG emission scheme worldwide, where the principle of 'cap-and-trade' is adopted. The system focuses on a common EU methodology for the calculation of GHG emissions and covers currently the sectors of power and heat generation, energy-intensive industries and aviation within Europe. Since 2005 an emission reduction of 42.8% has been achieved within the EU in the considered sectors. Due to the high overall EU target of at least -55% emission reduction by 2030 compared to 1990 levels, emission reduction plans expand and anticipate to include buildings, road transport as well as the maritime sector. For buildings and road transport a separate EU emission trading system is considered, which in the latest proposal would also include "fuels for additional sectors." [1] The maritime transport sector is targeted to be included in a revised version of the presently existing EU ETS system. The monitoring of vessel emissions in European ports aims to achieve a cut-off of approximately 66% of the CO_2 vessel emissions produced locally.

Case study example –
decarbonisation scenarios for various operational concepts

To illustrate this project phase, we have expanded the original illustrative case study for evaluating the financial returns and environmental impact of terminal electrification for three different operational concepts at a balanced import/export terminal with a capacity of 2 million TEU:

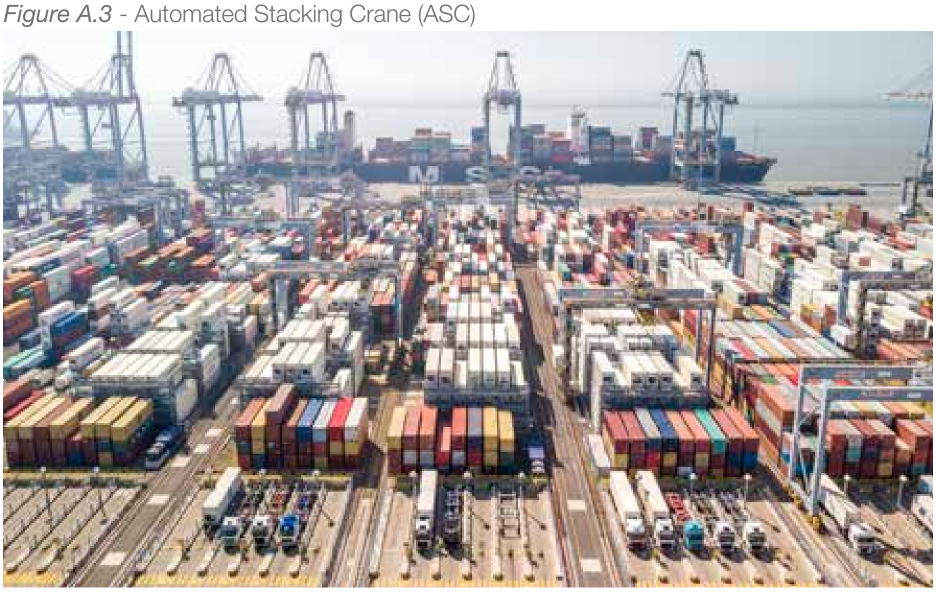
- Straddle Carrier Terminal
- RTG Terminal
- ASC Terminal

1. In December 2022 the European Parliament and European Council reached a provisional, political agreement on several 'Fit for 55' legislative proposals, including the extension of ETS to maritime shipping emissions (gradually between 2024 and 2026), and the establishment of a separate ETS for road transport, buildings and (new in the latest agreement) fuels for additional sectors by 2027 (Council of the EU, Press release, 18 December 2022, 'Fit for 55': Council and Parliament reach provisional deal on EU emissions trading system and the Social Climate Fund). At this point, it is not clear which sectors are covered, but it seems likely that non-road mobile machinery will be included. The new ETS system will organized at the level of fuel distributors (i.e. fuel distributors will be required to purchase emission rights for the fuel they sell). It is therefore easy to include non-road mobile machinery in the scope of the new ETS.

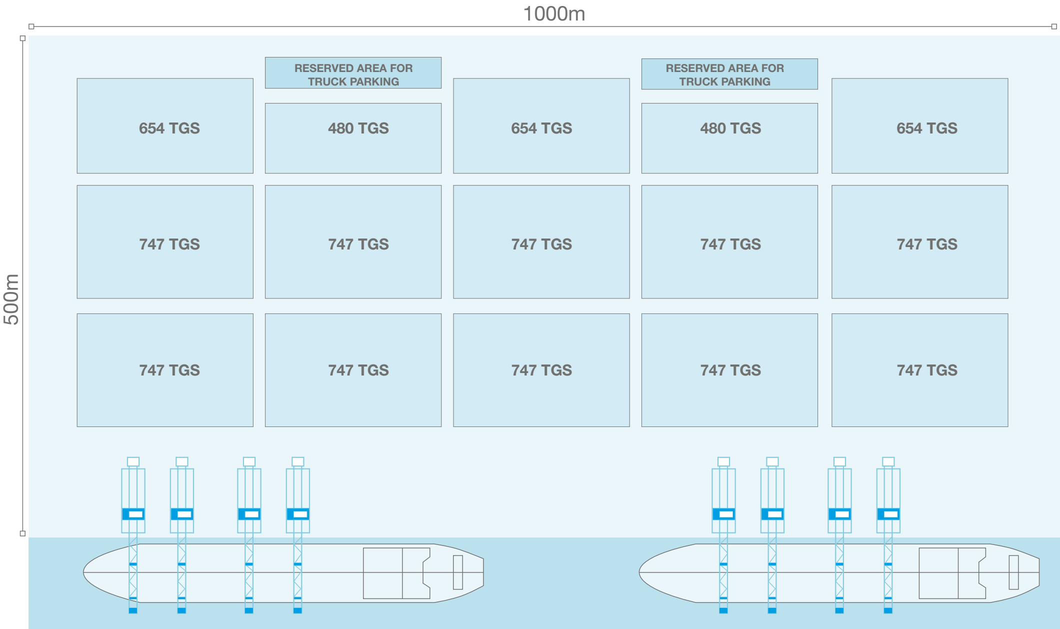
Figure A.1 - Straddle Carrier

Figure A.2 - Rubber-tyres Gantry Crane (RTG)

Figure A.3 - Automated Stacking Crane (ASC)



The theoretical terminal assumes a quay length of 1,000 m and a yard depth of 500 m. For the straddle carrier terminal, the number of TEU Ground Slots (TGS) has been maximized as per the below figure. Allowing sufficient manoeuvring space along the apron, in between the blocks and at the backside of the terminal, a total of 10,635 TGS are foreseen divided over 15 blocks.

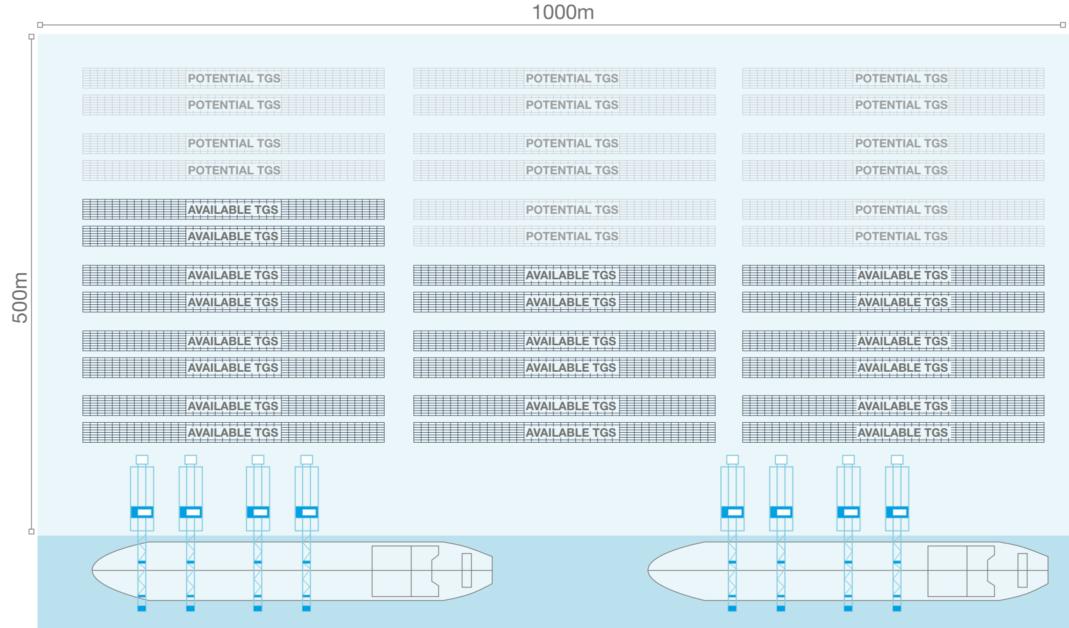


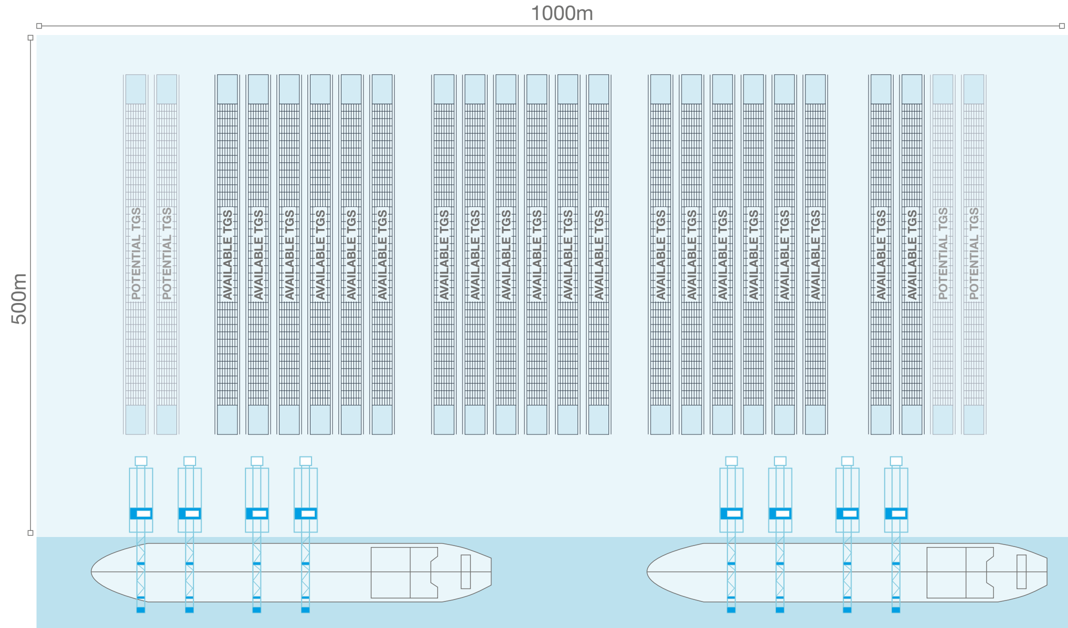
A dwell time of 4.3 days and a peak factor of 1.15 have been adopted, which results in a capacity of 2 million TEU.

Similarly, for the RTG and ASC terminal configurations, we have maximised the number of TGS (see figures below).

For the present case study, we assume that existing diesel driven equipment can continue operating till the end of its technical lifetime and will thereafter be replaced with electrical driven equipment. For instance, for the straddle carrier terminal case study, we have modelled replacement of the diesel strads with electric equivalents. Similarly, for the RTG terminal we assume that both RTGs and TTs are diesel driven and will be replaced with electrical equivalents. Finally for the ASC terminal we assume that the diesel shuttles providing horizontal transport between the apron and waterside interchange zone will be replaced with electric shuttles at the end of their technical lifetime. The following table summarises the main terminal characteristics for each concept.

	Straddle Carrier	RTG	ASC
Current equipment fleet characteristics	Diesel Strads Tier IV	Diesel RTGs Tier IV TT Tier IV	Diesel Shuttles, Tier IV Electric ASCs
Current diesel driven equipment fleet age (in % of total fleet)	**Strads** 25% - 2 years old 50% - 6 years old 25% - 9 years old	**RTG** 25% - 2 years old 50% - 6 years old 25% - 9 years old **TT** 25% - 1 years old 50% - 3 years old 25% - 5 years old	**Shuttles** 25% - 1 years old 50% - 3 years old 25% - 5 years old





The original 'Container Terminal Operation - Flexible Decision Tool' purposely prepared for the previous White Paper has been expanded to include emission calculations. It allows the user to model replacement of diesel driven equipment with hybrid or fully electric driven equipment and amend specific features of the site such as concession duration, characteristics of the volume to be processed, labour costs, etc. and provides financial results of each of the scenarios chosen. It should be noted that the outputs are for illustrative purposes only, and an actual production study would include a significantly larger number of both inputs and outputs. The purpose of the case study is to highlight how external factors in the wider business environment of the terminal can significantly influence the relative investment profitability of different terminal concepts, sometimes in ways that may be hard to predict intuitively.

The base case assumes a capped volume of 2 million TEU per annum and a concession duration of 40 years. The total electricity consumption is assumed to be produced from renewables and there is sufficient power available at the terminal site (i.e. no costs in the business case have been foreseen for grid upgrades outside of the terminal site). Labour costs are based on the European market. Other terminal operational specific assumptions are as follows:

Straddle Carrier Terminal

- The diesel fuelled straddle carriers are replaced with fast charge straddle carriers fully electric after the end of their technical life time
- The new electric straddle carriers have a reduced productivity due to recharging time
- The business case includes amongst others cost for erection of fast charge stations on the terminal, and one-off cost for refurbishment of workshop and provision of training to personnel

RTG Terminal

- The diesel fuelled RTGs will be replaced with fully electrified RTGs after the end of their technical life time
- Similarly, the diesel fuelled TTs will be replaced with fully electrified TTs after the end of their technical lifetime
- The new electric TTs have a reduced productivity due to recharging time
- The business case includes amongst others cost for erection of busbar systems, fast charge stations on the terminal, and one-off cost for refurbishment of workshop and provision of training to personnel

ASC Terminal

- The diesel fuelled shuttle carriers are replaced with fast charge shuttle carriers fully electric after the end of their technical life time
- The new electric shuttle carriers have a reduced productivity due to recharging time
- The business case includes amongst others cost for erection of fast charge stations on the terminal, and one-off cost for refurbishment of workshop and provision of training to personnel

The below table shows the total GHG emissions during the 40 years concession term for the various concepts. For comparison the 'business as usual' option for each operational concept has been included as well i.e. the existing diesel equipment will be replaced with new diesel driven equipment after the end of its lifetime.

Table 1 - Results case study – Total GHG emissions

GHG Emissions (tons)	CO_2	NO_x	SO_x	PM10
Straddle Terminal (Diesel)	566,515	842	88	32
Straddle Terminal (Electric)	68,680	102	11	4
RTG Terminal (Diesel)	440,950	655	69	25
RTG Terminal (Electric)	43,636	65	7	2
ASC Terminal (Diesel)	346,656	515	54	19
ASC Terminal (Electric)	18,158	27	3	1

The impact of the potential introduction of CO_2 emission cost is evaluated as well. With reference to the below footnote we have for this case study assumed a conservative bandwidth of 50 to 100 Euro/ton[2]. This additional financial cost has been applied from 2026 onwards to all diesel fuelled equipment.

The following tables indicate changes in the internal rate of return and payback period for the three operational concepts including the 'business as usual' option. In addition, the table includes 'adjusted' internal rate of returns and payback periods when applying the above-mentioned CO_2 cost.

Table 2 - Financial results case study

Financial Metrics	Internal Rate of Return (%)	Payback Period (years)	Adjusted Internal Rate of Return (50 Euro)	Adjusted Payback Period - years for 50 Euros	Adjusted Internal Rate of Return (100 Euro)	Adjusted Payback Period - years for 100 Euros
Straddle Terminal (Diesel)	28.76%	5.6	28.34%	5.7	27.91%	5.7
Straddle Terminal (Electric)	26.92%	5.8	26.73%	5.9	26.55%	5.9
RTG Terminal (Diesel)	26.02%	5.9	25.65%	6.0	25.29%	6.1
RTG Terminal (Electric)	24.97%	7.4	24.86%	7.4	24.75%	7.4
ASC Terminal (Diesel)	33.51%	5.5	33.29%	5.5	33.07%	5.5
ASC Terminal (Electric)	32.97%	5.5	32.94%	5.5	32.92%	5.5

Based on the foregoing table following high-level conclusions are drawn based on the case study:

Straddle Carrier terminal

- In the scenario with no CO_2 cost the internal rate of return of the 'business as usual' option is approx. 1.8 % better than the 'electric' option
- In the scenario whereby a CO_2 cost of 100 Euro/ton is applied the internal rate of return gap reduces to approx. 1.4 % i.e. an improvement of approx. 0.4 % overall

RTG terminal

- In the scenario with no CO_2 cost the internal rate of return of the 'business as usual' option is approx. 1.1 % better than the 'electric' option
- In the scenario whereby a CO_2 cost of 100 Euro/ton is applied the internal rate of return gap reduces to approx. 0.5 % i.e. an improvement of approx. 0.6 % overall

ASC terminal

- In the scenario with no CO_2 cost the internal rate of return of the 'business as usual' option is approx. 0.6 % better than the 'electric' option
- In the scenario whereby a CO_2 cost of 100 Euro/ton is applied the internal rate of return gap reduces to approx. 0.2 % i.e. an improvement of approx. 0.4 % overall.

2. In an impact assessment of the revision of the ETS conducted by the European Commission a carbon price of 70-80 euro/ton was forecasted for 2030 (in 2015 prices, which means that 30% must be added to obtain the current value in 2023 prices). In fact, this price level is already reached as of today. However, some industry observers point out that carbon prices will not stay at this high level because of expected excess supply in the near future. Furthermore, the provisional agreement of the European Parliament and the European Council on the revision of the ETS stipulates that if the price of allowances exceeds € 45 over a certain period of time, additional allowances will be released increasing the supply on the market. Given the above we have assumed a bandwidth of 50-100 euro/ton. It should be pointed out that these forecasts are characterized by a very high level of uncertainty. For instance, in the long-term scenarios made for the assessment of Dutch energy and climate policies carbon prices of up to 500 euro/ton in 2030 are assumed in some scenarios (Aalbers, R., G. Renes en G. Romijn. (2016) WLO-klimaatscenario's en de waardering van CO_2-uitstoot in MKBA's. Opgesteld op verzoek van de Begeleidingscommissie werkwijzer MKBA milieubeleid. CPN/PBL Achtergronddocument. 13 November).

6 Phase 3: Demonstrate

3D modelling of the preferred terminal design is a useful tool for visualising potential issues, and simulations can utilise real-world terminal data for maximum accuracy.

Finally, the Demonstrate phase includes careful validation that the selected design option meets its objectives. Terminal simulations are used to demonstrate the design and to verify its operation in different scenarios. An essential point to remember is that simulations are dynamic models that make it possible to validate scenarios that cannot be addressed with static spreadsheet-based models. 3D modelling of the preferred terminal design is a useful tool for visualising potential issues, and simulations can utilise real-world terminal data for maximum accuracy. Even at this stage, iterative process steps are taken back and forth before finalising the selected design. The simulation tool is critical when identifying the right amount of charging stations, the locations of those and the required fleet-size to reach the desired operational KPIs.

AVOIDING SCENARIO LOCK-IN

A typical design error is to validate for only one future scenario. Instead, the design sensitivity tests should again be run against a wide range of different scenarios and use cases. These may include, for example, the impact of:

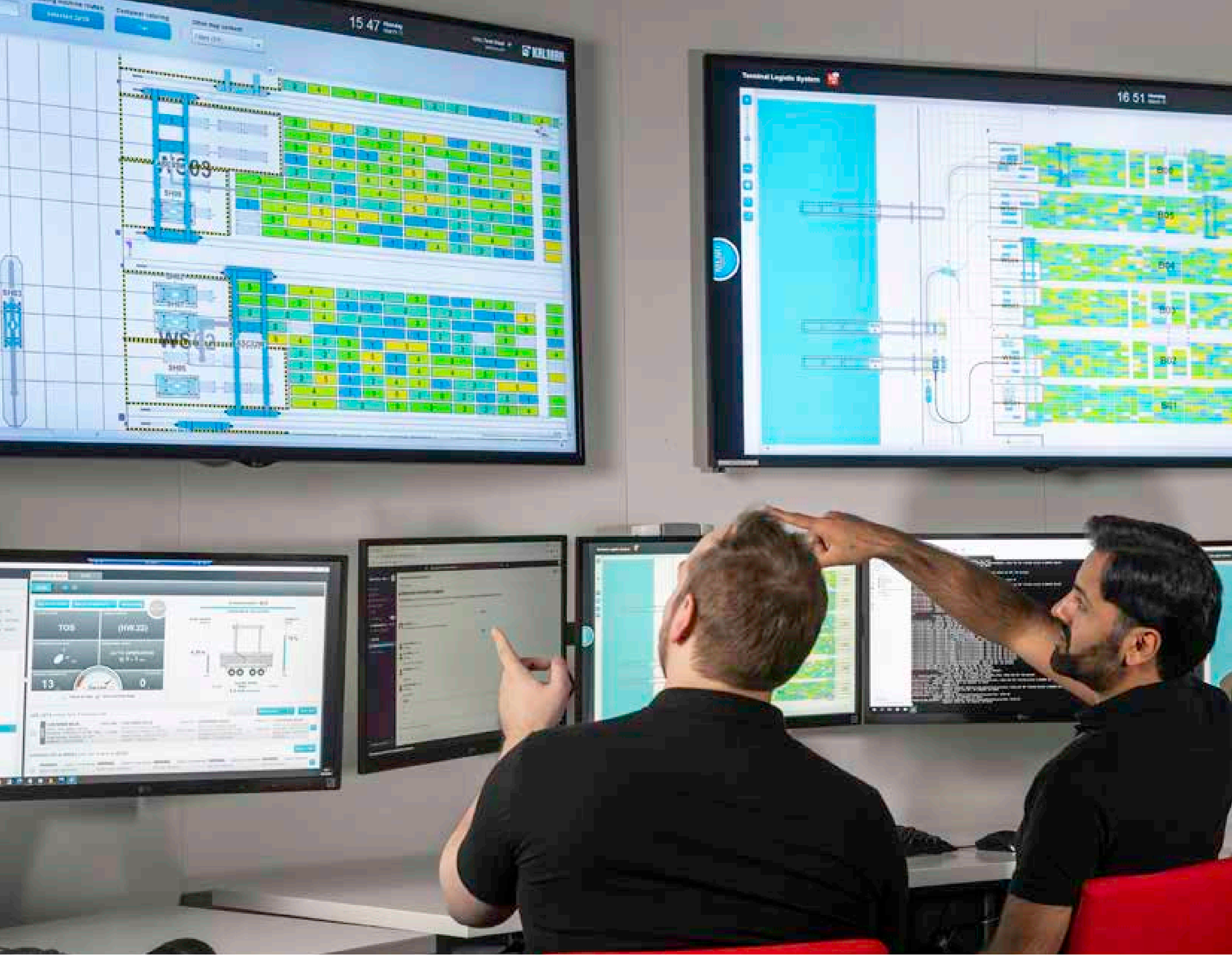
- Equipment and vessel speeds and delays
- Type of equipment and fleet sizes
- Location and amount of charging stations
- Variances to reveal bottlenecks
- Traffic arrival patterns
- Stacking height
- Unexpected changes and crisis situations
- TOS (Terminal Operating System) decision making
- Human decision-making during operation

To provide meaningful outputs, the simulations must be run with high-quality input data as well as accurate equipment and software modelling that corresponds to the actual operations of the terminal. 3D equipment models can reveal previously overlooked space issues as well as potential areas for congestion. Historical and current real-world data from terminal operations is the ideal input for simulations. Furthermore, the outcomes of the simulation should also be fed back into the static models created earlier in the project to review their potential impact on the business cases.

HOW TO GET THE MOST OUT OF SIMULATIONS AND EMULATIONS

Simply running terminal simulations or creating visually attractive 3D renderings of various terminal concepts is not enough. Based on the experience of the authors, to gain the maximum benefit from the design process and to reach the best possible outcome, the following points are crucial.

Create an involved team. Trusted partners can provide support in the design process, but responsibility for the future cannot be outsourced. The terminal organisation needs to create a common understanding of the processes that are being modelled, while also being aware of the inherent simplification that



is involved in any simulation. When done right, simulation is a great way to become familiar with the cause-and-effect relationships that affect terminal capacity and performance.

Utilize the simulation model built. Too often, terminals commission detailed simulations during the design phase and then bury the results in the drawer. Models can be kept up to date, calibrated to reality and reused after the go-live to validate production processes under changing conditions.

EMULATION

By using the emulation tools, you can start testing on early stages and without physical cranes or equipment the automation integration between different systems. This testing will be run on a virtual environment prior to go-live delivering the following benefits:
- Validate operational scenarios and processes
- Find bottlenecks
- Adjust / optimize parameters and layout
- Estimate terminal KPIs
- Train personnel to use the system

7 Conclusions

Decarbonising a container terminal – whether a Brownfield or Greenfield site – is an exacting task that calls for complex decision making based on limited information and changing external conditions. However, the process can be managed in a structured way to maximise the ability to utilise technology and data to keep decarbonisation options flexible as long as possible. The key elements of a well-planned and successfully executed decarbonisation roadmap process can be summarised as follows:

- **There is no one size fit all solution.** The local energy sources available, legislation and initiatives need to be taken into account.
- **Don't compromise on the design phase.** Time and money invested in the design phase will be paid back later in the project, at which point correcting early mistakes will cost significantly more.
- **Get really involved** – take responsibility for your future.
- Use the technology and data available to the fullest. Adopt and internalise their use in your organisation.
- **Plan for the widest range of futures you can imagine,** not just one scenario.
- **Trust the partners that have done it before.** Remember that your suppliers also want your project to become a successful, world-class reference.
- **Focus on the whole lifecycle of the system,** not just on the go-live date.
- **Simulation and Emulation tools are very powerful.** To get the most out of them you must have the right inputs and a proper calibration of the system.
- **The selected option must meet your operational, environmental and financial targets.**

ABOUT KALMAR

Kalmar, part of Cargotec, offers the widest range of cargo handling solutions and services to ports, terminals, distribution centres and to heavy industry. Kalmar is the industry forerunner in terminal automation and in energy efficient container handling, with one in four container movements around the globe being handled by a Kalmar solution. Through its extensive product portfolio, global service network and ability to enable a seamless integration of different terminal processes, Kalmar improves the efficiency of every move.

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ABOUT REBEL

Rebel is a worker-led, close cooperation of 20+ specialist ventures made up of a pool of economists, engineers, operational and finance experts and investors that put their focus on one thing: to bring true change for a better world and society. Rebels want to achieve tangible progress in societal issues globally, ranging from sustainability, ports and other transportation infrastructure, energy and urban regeneration, to healthcare and the social sector. Rebels work on a wide range of topics globally and is proud to have over 300 dedicated employees, each of them specialists in their field, and co-owners of the company.

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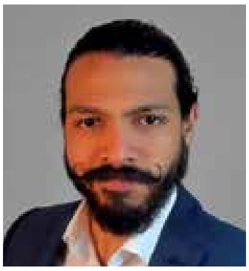

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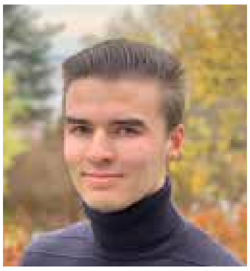
Christopher is the head of the Terminal Design Services team in Kalmar, part of Cargotec, a global leader in cargo handling solutions. He has over 12 years international experience in the planning, design, implementation and operations of ports and container terminals. He has worked at Cargotec close to 4 years, where his key projects have been the decarbonization and automation of brownfield & greenfield terminals. Before joining Kalmar, he held various positions in container terminals for APM Terminals and SSA Marine, participating in different automation projects, continuous improvement projects and other initiatives to improve customer satisfaction.



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Verneri is working as a Specialist in the Terminal Design Services team. His background is in Strategy where he managed multiple projects, from which many closely related to Kalmar's Climate Strategy, including Kalmar's automation division's internal Climate Roadmap. He holds a B.Sc. in Supply Chain Management and Finance from Turku School of Economics and is passionate about developing sustainable businesses that thrive in the green transition. Additionally, he has experience in start-up entrepreneurship.

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Wim is port expert at Rebel. He has over 22 years international experience in the planning, design and implementation of ports and harbours overall. He has been responsible for managing numerous multi-disciplinary port development projects around the world as a Maritime Consultant with RoyalHaskoningDHV and Program Manager Terminal Infrastructure with Terminal Investment Limited (TIL), the 6th largest private global container terminal operator. Since joining Rebel in late 2016, he has been involved in various operational and financial assessments of container terminal projects. Wim offers a unique blend of experience in the optimisation of terminal and operational design, with infrastructure and civil engineering, to address today's challenges in a broader social and sustainability transition process by linking finance, operations, engineering and environment.

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Dries is Director of Rebel Ports and Logistics and Financial Modelling Expert, who has worked at Rebel for over 15 years. In his first years at Rebel, Dries developed his profound financing skills in the project finance team of Rebel. Later his interest in ports and logistics grew, resulting in an internal transfer to the Ports and Logistics team, where his financial modelling and business case structuring skills are considered as an added value for the team. Dries has vast experience in structuring and developing financial models, with a special interest in decision tools. These tools enable decision makers to take informed courses of action by clearly displaying the impact of certain decisions over time. The core of this is in structuring the large amount of available data and visualizing the results to allow for useful conclusions that enable informed decision making.

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