NOVEMBER 2025

Load Profile Scenario Explorer

Explainer

ZEPA Zero Emission Port Alliance

Introducing the Load Profile Scenario Explorer

The Load Profile Scenario Explorer is a configurable explorer to help port stakeholders assess BE-CHE loads, grid feasibility, and electrification strategies.

Find out more and access the explorer here

OPEN EXPLORER

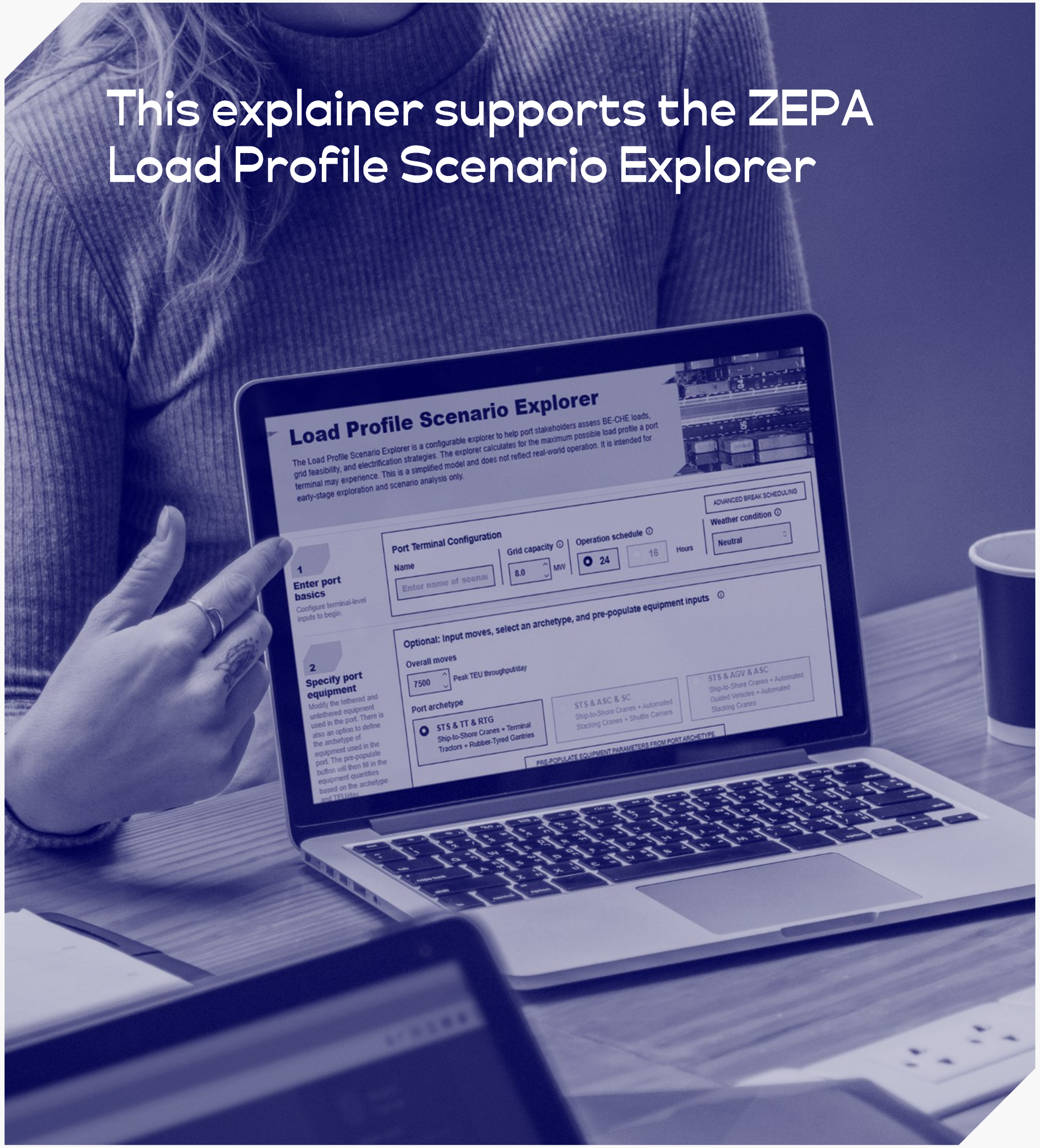
Specify port equipment
Modify the tethered and untethered equipment used in the port.

Explore results
Understanding how the different load profiles relate to each other.

Configure charging strategies
For untethered equipment such as terminal tractors and straddle carriers.

Table of contents

This explainer supports the ZEPA Load Profile Scenario Explorer



About this document

This user explainer supports the **ZEPA Load Profile Scenario Explorer**, an instrument for generating indicative estimates of future electric loads at container terminals. Stakeholders can use these outputs to anticipate peak power loads and begin exploring infrastructure planning with terminal operators, port authorities, and distribution system operators. The explainer outlines key concepts and assumptions, supported by a shared glossary. It explains how to use the Explorer, what it does and does not do, and how to interpret outputs. Example scenarios for three terminal archetypes are included, along with guidance on user inputs. The appendix provides a summary of key assumptions used in the model.

About ZEPA

The Zero Emissions Port Alliance (**ZEPA**) was formed expressly to **accelerate port decarbonisation**. Container terminals are our focus because the electrification of container-handling equipment is one of the most immediately addressable source of port emission. ZEPA aims to **accelerate take-up of battery-electric container handling equipment** (BE-CHE) among terminal operators by making BE-CHE **affordable and accessible by 2030**.

The Secretariat is hosted by **Systemiq** and is responsible for managing ZEPA's day-to-day operations and coordinating member activities, including research and analysis, project management, and industry engagement.

SYSTEMIQ

1. **Context & objective of the Load Profile Explorer**
2. Common language and key concepts in the electrification of port segments
3. How to use Explorer and example outputs
4. Recommended next steps and follow-ups
5. Appendix: Key assumptions and model set-up

The Load Profile Explorer aims to improve decision-making on fleet electrification at container terminals

Objective and use cases

Overall, the Explorer proposes **a shared language and common understanding of key concepts** to support alignment on this topic between stakeholders. Its key use case is to improve decision-making for fleet electrification by developing an Explorer that can estimate:

1. The **grid connection capacity** needed to use BE-CHE in a container terminal / how many BE-CHE to install given the grid connection capacity
2. How **BE-CHE loads compare to other (future) electric loads** in the terminal (e.g., shore power)
3. The **impact** of different **charging strategies** on the peak load
4. The **impact** of **battery energy storage systems (BESS)** on the peak load

Users

The Load Profile Explorer is intended for internal use to align on what drives peak demand or to create a shared support with external stakeholders. It provides **indicative estimates only**. Final assessments and decisions must be based on detailed energy systems modelling by the users, grid operators, RES developers, and other stakeholders

Terminal operators' strategy team, engineers and local terminal leadership, as a discussion starter internally, and with grid operators & port authorities

Port Authorities as a discussion starter with terminal operators, renewable energy developers and grid operators

OEMs in conversations with their customers

The Explorer allows users to generate general insights, it does not replace detailed terminal-specific engineering studies

What the Explorer does…

- Estimate a **terminal's primary electric load**, including container handling equipment and other electrified loads using a bottom-up approach
- Provide an **indicative view of the total and peak electrified load profile**, capturing both the magnitude and timing of power use
- Use **representative average and peak loads** for each type of equipment or system
- Apply "**worst day of the year"** (load-wise) assumptions on peak loads
- Capture intra-day variability in **15-minute intervals**
- Incorporate **stakeholder-validated generic inputs** and allows users to **adjust selected parameters**

What the Explorer does not...

- Provide final estimates of required **grid connection or electrical infrastructure capacity**
- **Replace detailed engineering studies** required for electrical infrastructure planning or permitting
- Use **actual load profile time series** from specific terminal equipment or systems
- Account for **seasonal or operational variations** in equipment use or load profiles across the full year
- Perform **minute-by-minute or high-frequency dynamic load** simulations
- Serve as a **digital twin or operational monitoring tool** for real-time terminal power management
- Offer **site-specific design-level accuracy** for each terminal

6 key concepts are important to take into account when discussing and exploring load profile scenarios

1. Levels of grid capacity constraints

- Capacity bottlenecks can occur at different levels, including at internal **terminal substations**, **upstream distribution or transmission** on TSO/ DSO level or **contracted capacity level** of grid operators
- Electrification assessments should therefore consider the **context of the full grid** (terminal, port, and national system)

2. Relevant time intervals to describe load profile

- Grid operators typically work with **15-minute averages** to understand broader load patterns and allocate grid capacity
- **Minute-by-minute modelling** reveals **short load spikes that are not visible in these averages**
- Use of 15-minute averages to reflect peak grid capacity means terminals must ensure that their own infrastructure can withstand short-term spikes, even if these are not critical at the TSO/DSO grid level

3. Coincidence factors to capture phased use

- Peak load calculations without a coincidence factor assume all equipment operates at full power simultaneously
- **Statistically and in practice, equipment use is phased** (i.e., not all cranes hoist at the exact same time), meaning true peaks are lower than the theoretical maximum

4. Different charging strategies for untethered equipment

- Different charging strategies (vehicle rotation, depot charging, opportunity charging, battery swapping) produce **very different peak loads**
- Choosing the right combination of strategies (in combination with battery energy storage) is essential for both **infrastructure design and cost optimisation**

5. Highest peak during the 'system peak day'

- The '**system peak day'** is when **the terminal operates at full capacity**[1]
- Within this day, the Explorer identifies **the peak 15-minute average interval**
- **This peak is indicative for critical infrastructure sizing**, while the average profile informs other topics (e.g., energy contracting, how to balance the grid throughout the year)

6. Battery energy storage systems (BESS) that absorb fluctuations

- BESS can be part of a grid-level and terminal-level resilience strategy
- BESS can absorb **short-term fluctuations**, **smooth peaks**, and **optimise energy use**
- By **shaving the peak on the 'system peak day'**, **BESS helps defer or avoid grid upgrades**

Deep-dives on next pages

Note: **[1]** To ensure robust system design, behind-the-meter solar generation is excluded from assumptions on the 'system peak day'. This reflects a worst-case scenario approach, ensuring the system can meet demand even during low-solar conditions (e.g. overcast days).

1. As economies and the power system electrify, electric load profiles and grid capacity requirements will increase at different levels

Increase at container terminal level

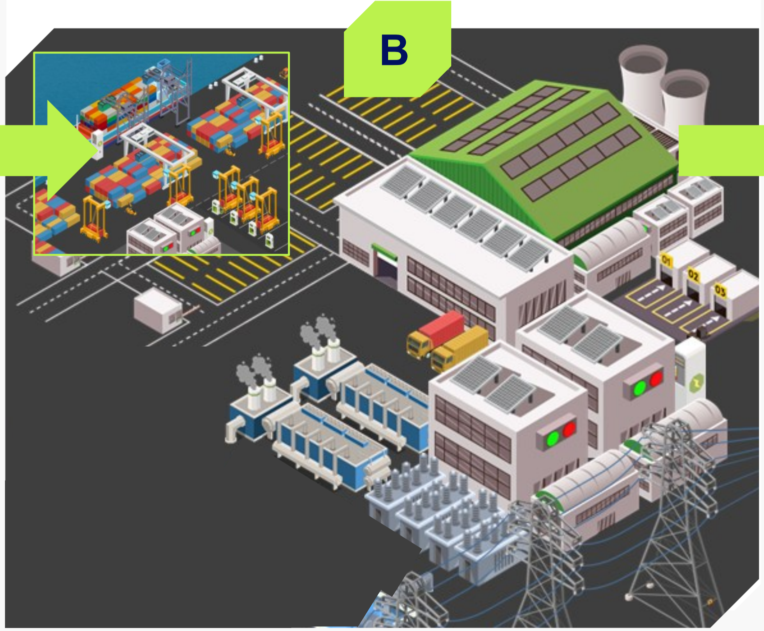
Increased uptake of BE-CHE and wider terminal electrification (reefers, shore power)

- Increase in terminal peak power load
- Increase in required internal electrical grid capacity
- Increase in required external electrical grid capacity (contracted with DSO)

Increase at port level

Increased electrification of port tenants' businesses (e.g., through electrified industry, terminals, power-to-X installations)

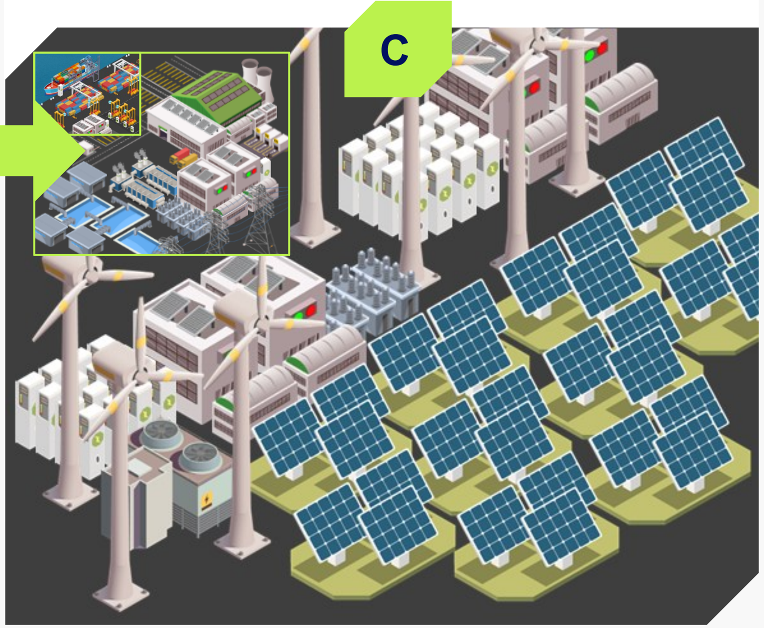
- Increase in port peak power load
- Increase in overall required electrical grid capacity



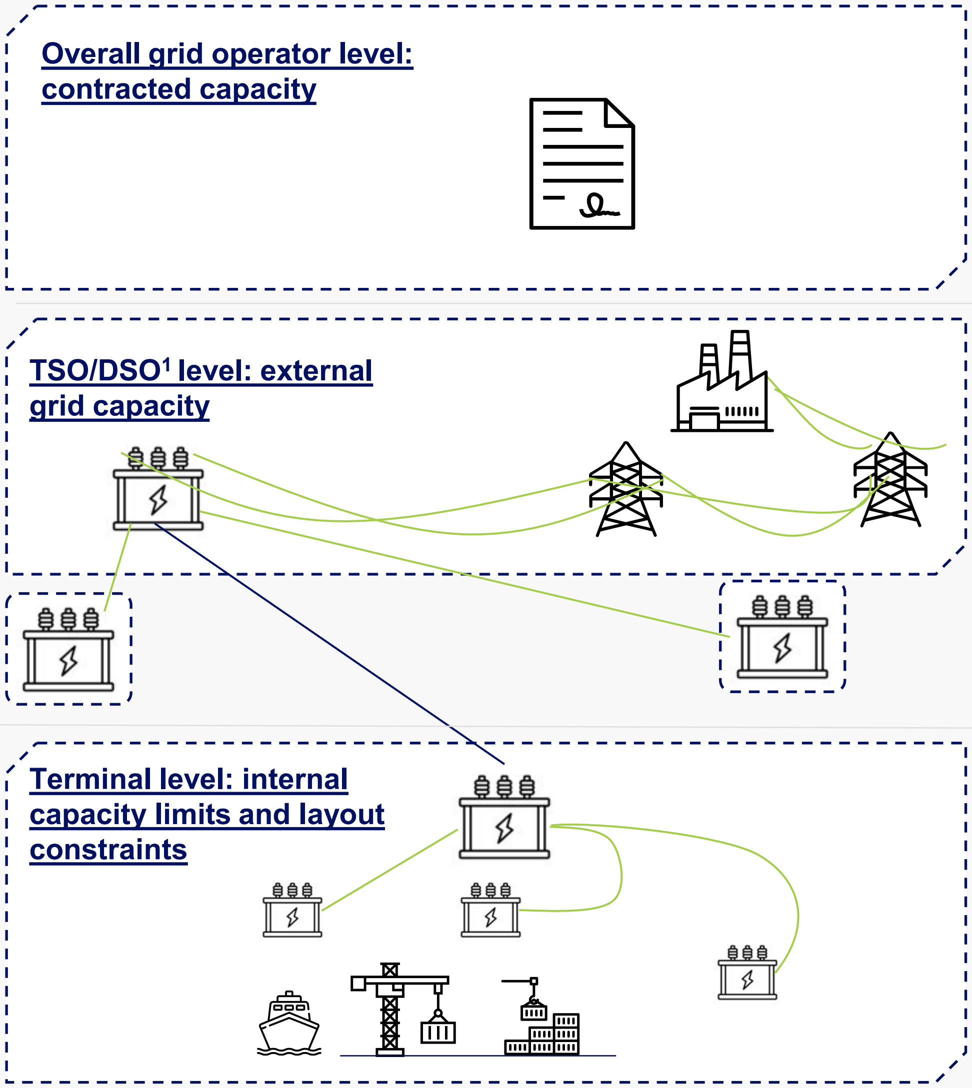
Increase at power system level

Increased electrification + variable renewable electricity generation (solar, wind)

- Increase in demand power load
- Increase in peak, variability and geographical spread of supply power load
- Increase in required electrical grid capacity



1. Container terminal electrification must be viewed across all levels: contracted capacity, external grid capacity and internal capacity limits



Overall grid operator level: contracted capacity

- **Contracted capacity limits.** Terminals are allocated a fixed connection capacity. It is critical to understand not just expected demand but the contracted ceiling with grid operators. This capacity limit is often determined on a 15-minute time interval. Shorter time interval peaks are usually not a contractual problem but can be a physical problem for the electrical infrastructure within a terminal.

TSO/DSO level: external grid capacity

- **External grid capacity.** Future demand growth at the terminal may exceed currently contracted limits, creating potential bottlenecks in upstream transmission and distribution infrastructure owned by third parties (e.g., TSOs or DSOs). In some geographies, this risk is particularly acute in distribution networks, where available capacity is influenced by concurrent load increases from other industrial users in the area.
- **Short peaks are not as important for upstream load profiles.** Coordination with port authorities and TSOs/DSOs is often required when 'long' surges occur. Minute/ sub-second peaks are often balanced out with other loads.

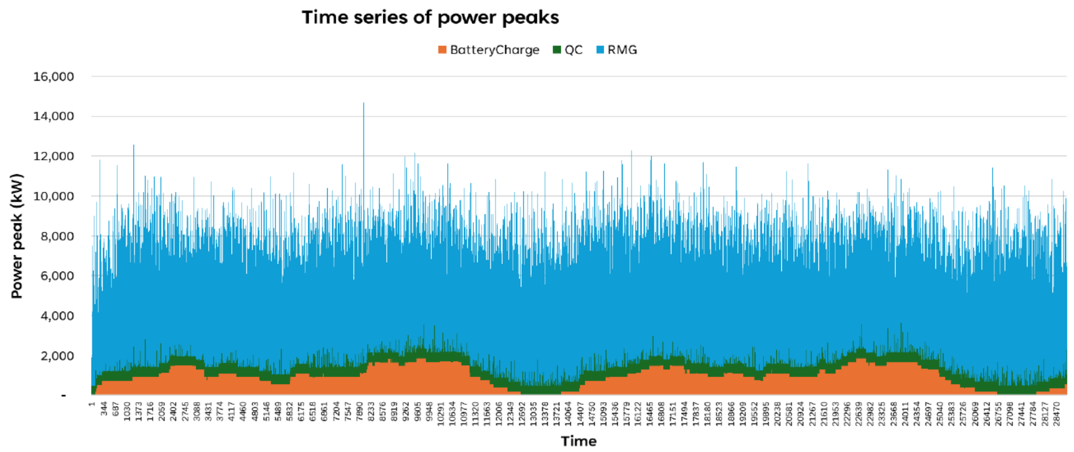
Terminal level: internal capacity limits and layout constraints

- **Peak load modelling.** Peak demand, not average use, drives infrastructure requirements. This Explorer focuses on the grid connection between the terminal and the distribution network within the port.
- **Internal capacity limits.** Many terminals were not originally built with substations sized for full electrification. Substation limits can become binding quickly, as minute-by-minute peaks will also need to be met.
- **Electrical layout constraints.** Yard electrification often requires additional transformers and dedicated cable routing.

Note: **[1]** In some geographies the TSO and DSO can be integrated.
Source: ZEPA Member inputs; Portwise and Witteveen & Bos expert input

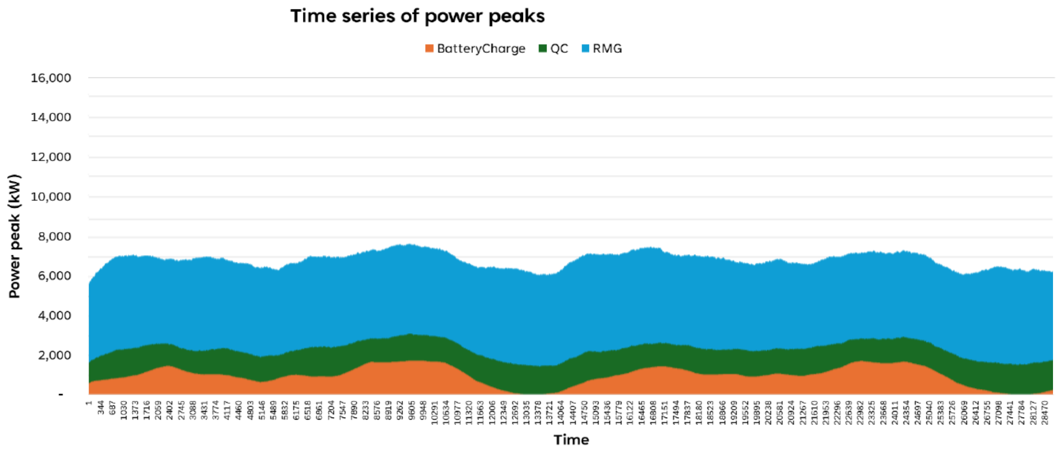
2. Second-by-second modelling shows short minute spikes missed in 15-minute averages; these are usually not a contractual problem but can be a physical problem for the electrical infrastructure

1 second power peaks over time



- Second-by-second modelling shows **high power peaks for very short durations**
- These short peaks **can be a physical problem for the electrical infrastructure within a terminal if equipment's physical capacity limits are exceeded**
- However, for most planning needs **these short peaks are not a problem** as the contracted grid capacity limit is often determined on a 15-minute time interval

15-minute power peaks over time



- A 15-minute load profile **smooths short-term fluctuations, showing broader trends useful for strategy and planning**.
- Though brief peaks disappear, it still highlights high and low activity periods and aligns with the 15-minute averages grid operators use to manage capacity.

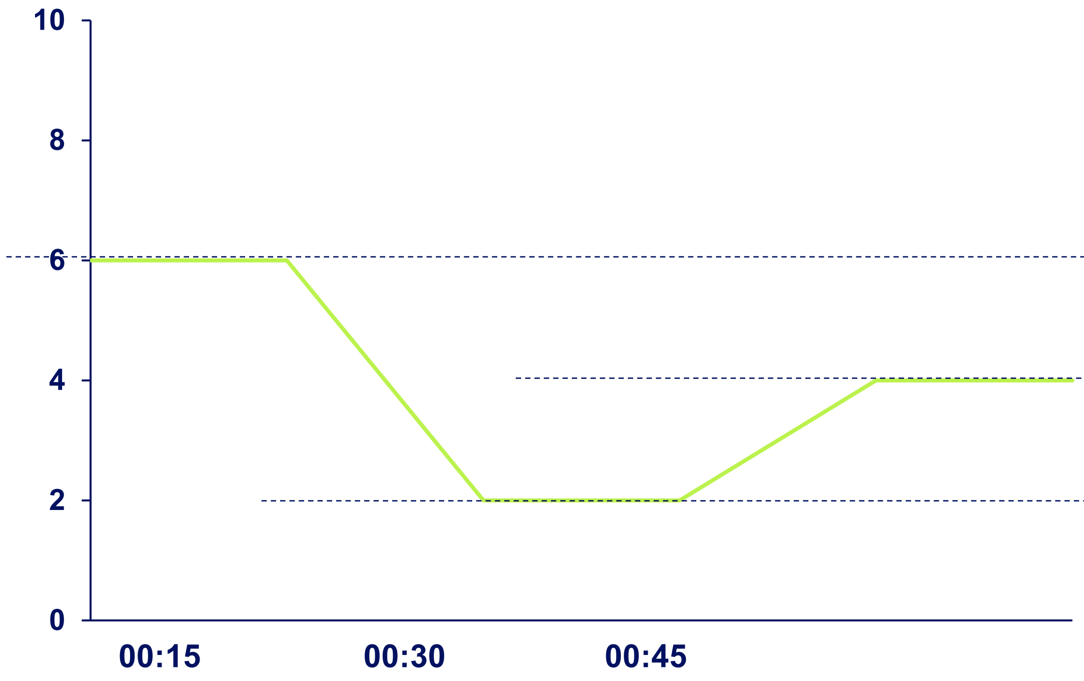
APPLIED IN LOAD PROFILE EXPLORER

Source: Portwise data

2. The explorer models the peak load for 15-minute intervals

The explorer plots the average in electrical load for 15-minute intervals

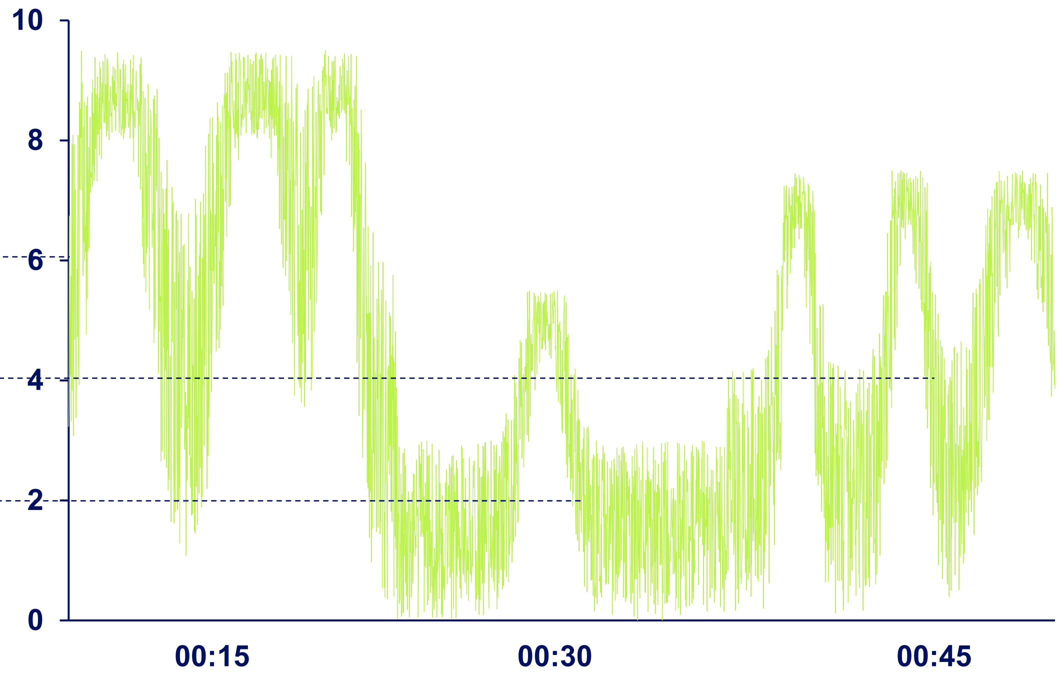
Terminal electrical load, MW



Whilst in reality, actual load fluctuations happen on a (sub)second basis

Terminal electrical load, MW

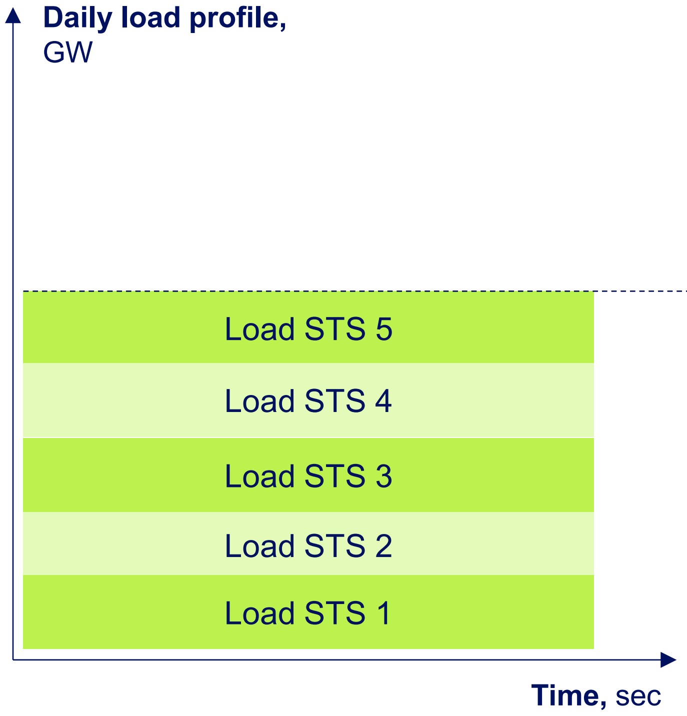
Illustrative



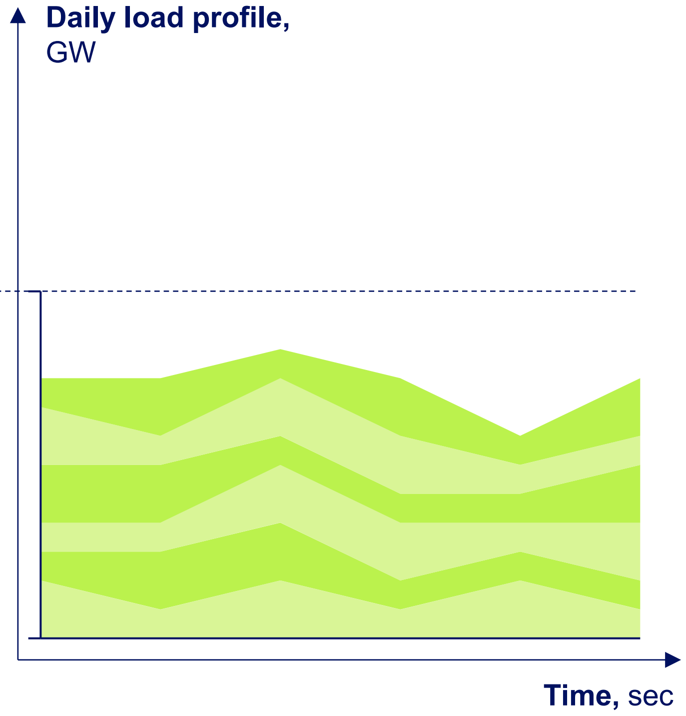
3. A coincidence factor is applied to more accurately reflect the actual 15-minute peak load, accounting for non-simultaneous equipment use

Without a coincidence factor, total peak load is overestimated as it assumes all equipment operates at full capacity simultaneously, which rarely occurs in practice

Total peak load, simple stacking



Total peak load, reality



The coincidence factor is therefore used to determine a more realistic peak load

Modelling approach

$$f_{Coincidence} = \frac{\sum_{i=1}^{n} Indiviual\ peak\ loads}{\sum_{i=1}^{n} Max\ (Aggregated\ loads)}$$

For example, if 10 CHE each have a peak load of 1 MW, the total peak load will not be 10 MW (10 x 1) but the coincidence factor x 10 MW

ZEPA Zero Emission Port Alliance

4. Different (combinations of) charging strategies can be considered in the Explorer, each with different impacts on the peak load

Charging strategy	Definition and charging logic	Impact on load peak
Vehicle Rotation	Operators **begin charging their BE-CHE when the battery reaches a low level** during their shift and **rotate to a charged BE-CHE vehicle** to continue their shift. This means there are always a few vehicles charging during operational shifts.	**Low** as vehicles are charged throughout the day. For 16-hrs operations: no charging assumed during non-shift hours.
Depot Charging	All BE-CHE units **charge simultaneously** at a central location during scheduled breaks and overnight (for 16-hour operations all vehicles charge once during the non-shift hours).	**Extremely high** for 24-hour operations as all vehicles charge at once. For 16-hour shifts, charging loads could be distributed more evenly, allowing vehicles to charge over an 8-hour window at reduced power levels, assuming load optimization strategies are applied.
Depot Charging with staggered breaks	Breaks are **split into three groups** to stagger the peak load.	**Lower** than 'regular' depot due to staggered breaks.
Opportunity Charging	BE-CHE charge **quickly and frequently throughout** operations during idle periods. These are the random periods of inactivity during which BE-CHE does not have any jobs whilst being in operation. Break time does not fall under idle time.	**Can sometimes lead to (random) small peaks** as vehicles charge infrequently throughout the day. For 16-hrs operations: no charging assumed during non-shift hours.
Battery Swapping	BE-CHE units **swap batteries** when the battery reaches a low state of charge during shifts. This means there are always a few batteries charging during operational shifts.	**Low** as batteries are charged throughout the day. For 16-hrs operations: no charging assumed during non-shift hours.

Note: **[1]** The random periods of inactivity during which Battery-Electric Container Handling Equipment (BE-CHE) does not have any jobs whilst being in operation. Break time does not fall under idle time.

Interested to learn more?

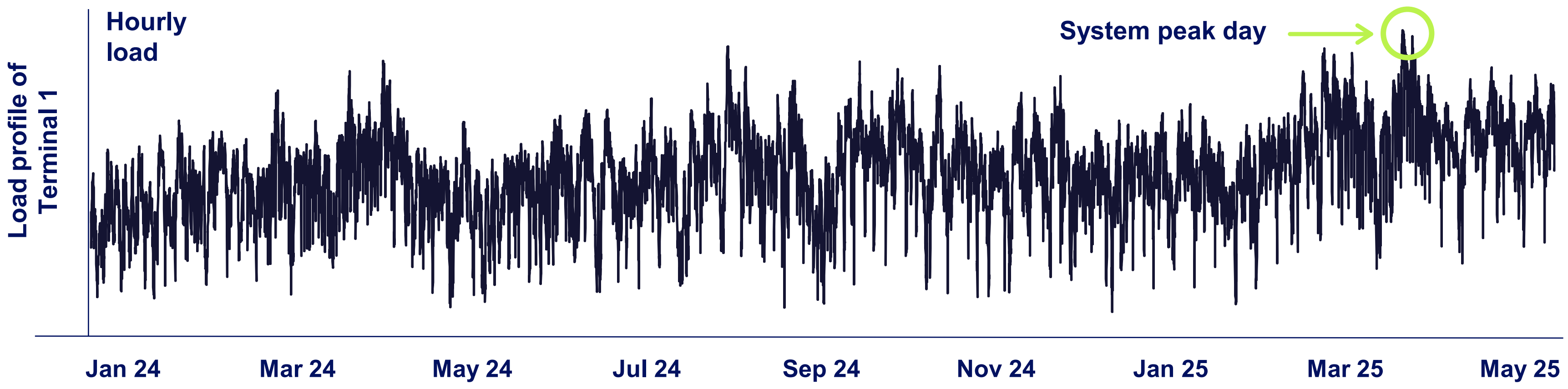
Read more detailed information in ZEPA's Voluntary Standards

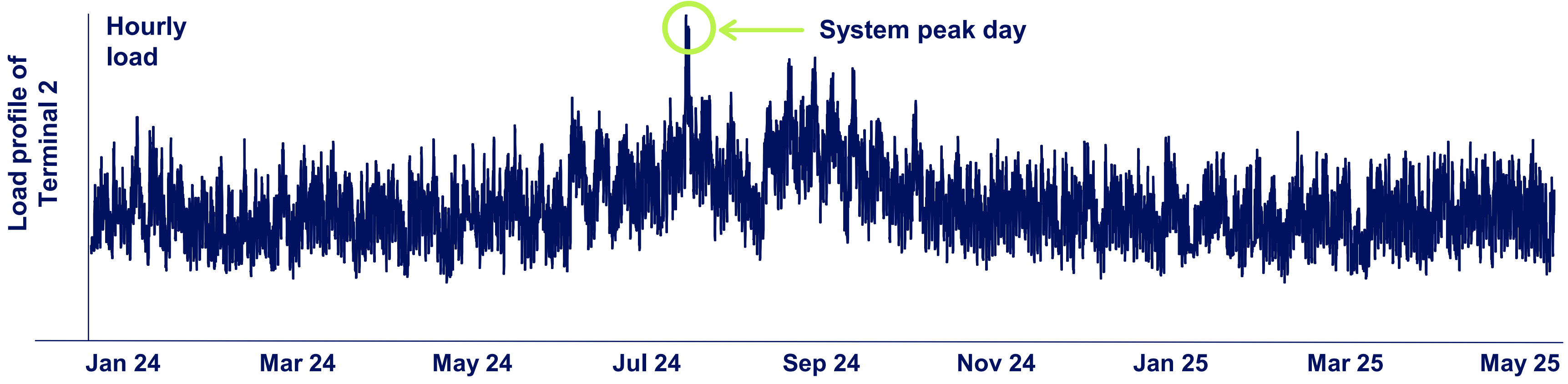
DOWNLOAD

5. Peak loads vary by operational patterns; the "system peak day" of the year serves as a key reference for sizing critical infrastructure

- Available data from conventional ports show **significant variation in load profiles over the year**, driven mainly by operational schedules and seasonal factors (e.g., reefer demand).
- **Infrastructure must be scaled to meet peak loads**. Therefore, this Explorer focuses on the "**system peak day**" of the year, assuming full terminal operation.
- Within this day, it identifies the peak interval, which informs critical infrastructure sizing.
- The **average profile**, in turn, supports analyses such as energy contracting and grid balancing throughout the year.

Illustrative timeline of the 'system peak day' of 2 different load profiles1 of conventional ports (ie including STS's and reefer plugs)





Note: **[1]** Load profile data based on anonymized member input.

EXAMPLE LOAD PROFILE 1A

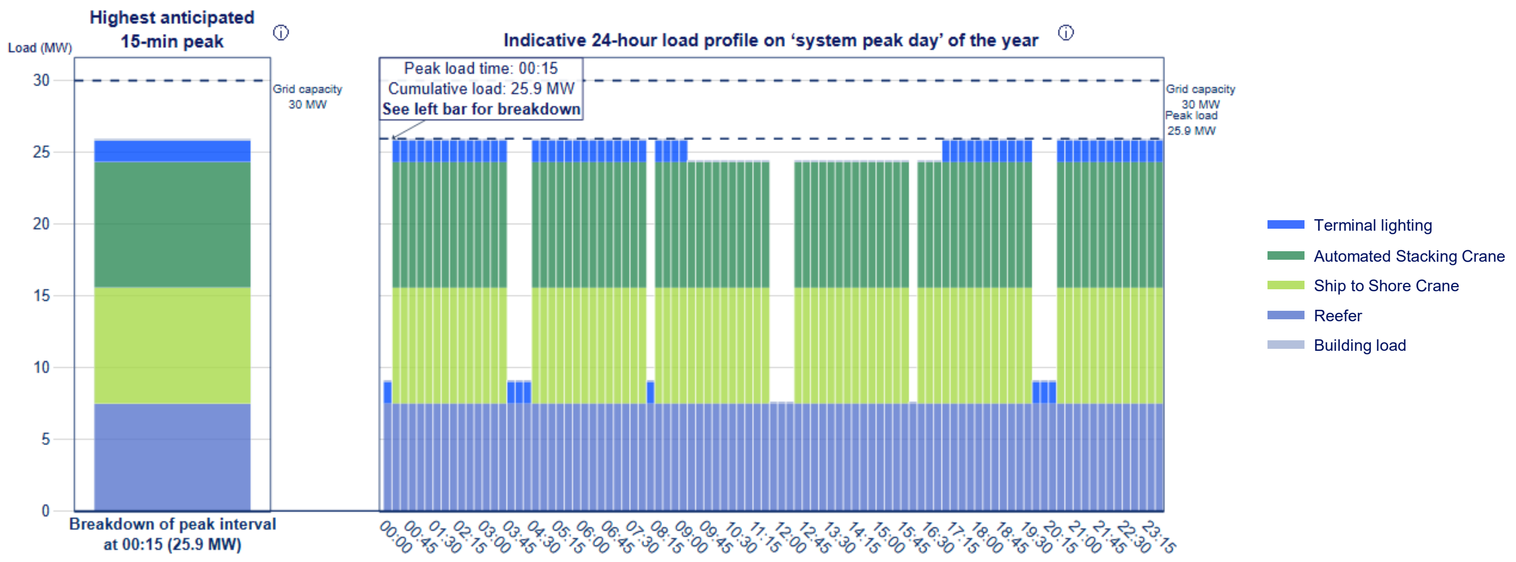
Ship-to-shore cranes, automated stacking cranes and reefers drive peak load in unelectrified terminals

Inputs

Terminal with no electrified equipment

Grid capacity	**30 MW**
Ship-to-shore cranes	**53**
Rubber tired gantry	0
Automated stacking crane	**79**
Terminal tractors	0
Straddle carriers	142 (0% electrified)
Automated guided vehicle	0
Reach stackers	21 (0% electrified)
Shore power	0
Reefer containers	**2500**
Terminal lighting	**1.5 MW**
Buildings	**5 x 0.027 MW**
BESS	No

Outputs



Insights

- In an unelectrified port, **ship-to-shore cranes account for ~30%, ACS for ~34% and reefers to ~30%**
- **4 MW spare grid** capacity available
- Ship-to-shore cranes and automated stacking cranes operate **throughout the day** (on average), with periodic breaks
- Terminal lighting only contributes to the load profile **during nighttime**

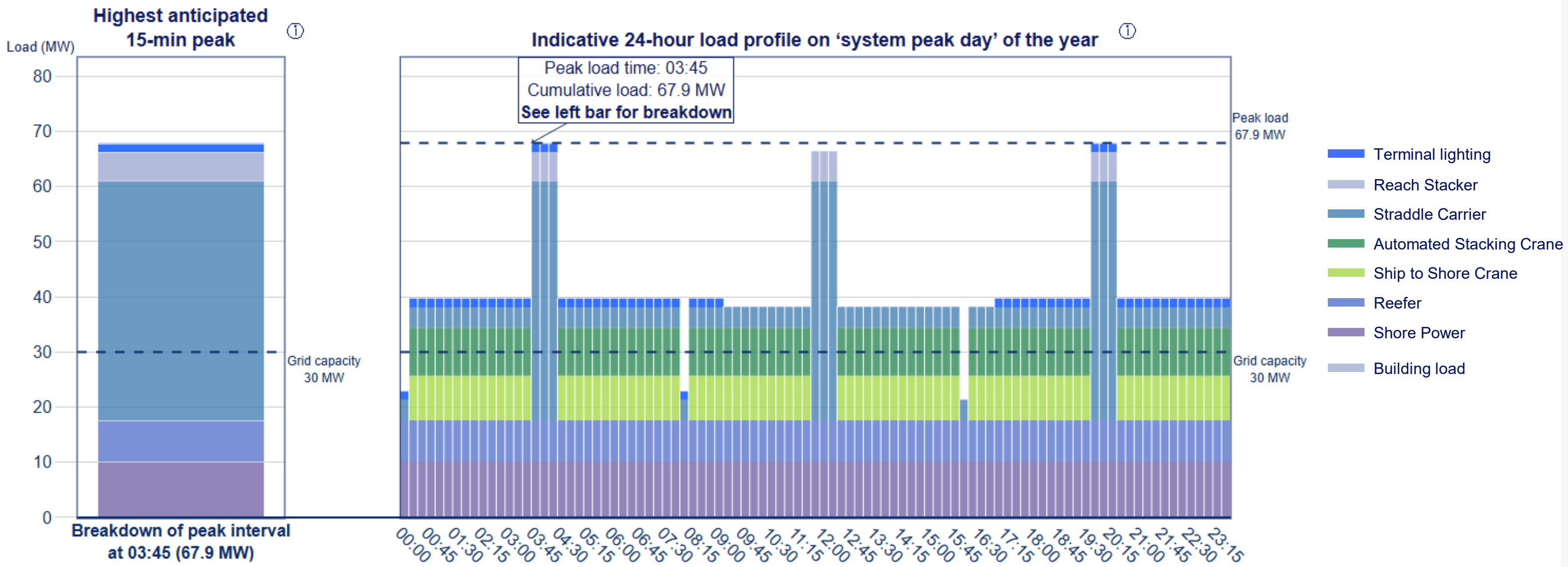
Reefers are a major driver of peak demand in electrified terminals

Inputs

Terminal with electric straddle carriers, reach stackers and shore power

Grid capacity	30 MW
Ship-to-shore cranes	53
Rubber tired gantry	0
Automated stacking crane	79
Terminal tractors	0
Straddle carriers	**142 (50% depot; 50% vehicle rotation)**
Automated guided vehicle	0
Reach stackers	**21 (100% depot)**
Shore power	**10**
Reefer containers	2500
Terminal lighting	1.5 MW
Buildings	5 x 0.027 MW
BESS	No

Outputs



Insights

- Overall, there is a **shortage of >35 MW** grid capacity when straddle carriers, reach stackers and shore power are added to the electrification mix
- **For straddle carriers**, a blended charging strategy is assumed: 50% depot charging, 50% vehicle-rotation charging. This leads to:
  - **A steady baseline load** from vehicle rotation across the day
  - **Sharp load spikes** from depot charging during breaks

ZEPA
Zero Emission Port Alliance

EXAMPLE LOAD PROFILE 1C

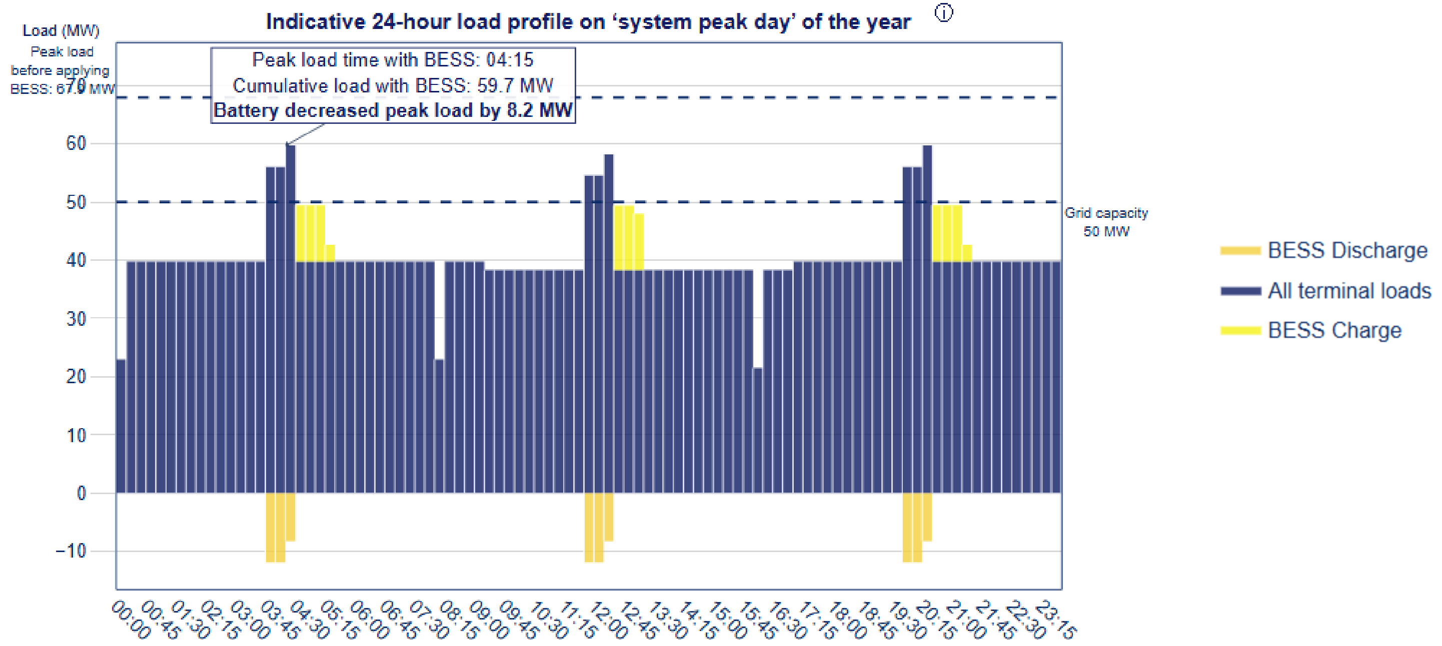
Battery storage reduces peak load and flattens daily load profile

Inputs

Terminal with electric straddle carriers, reach stackers and shore power and upgraded to 50MW

Grid capacity	50 MW
Ship to shore cranes	40
Rubber tired gantry	0
Automated stacking crane	79
Terminal tractors	0
Straddle carriers	240 (50% depot; 45% vehicle rotation, 5% opportunity charging)
Automated guided vehicle	0
Reach stackers	21 (100% depot)
Shore power	10
Reefer containers	2500
Terminal lighting	1.5 MW
Buildings	5 x 0.027 MW
BESS	**Yes**

Outputs



Insights

- The battery **reduces the maximum peak load by ~8.2 MW**, bringing it down from ~68 MW to ~60 MW and thereby keeping the load closer to the 60MW grid capacity limit
- **By discharging during high demand and charging during low demand periods,**, the BESS actively reshapes the terminal's load profile to smooth out fluctuations across the 24-hour cycle
- This **enables better alignment of the cumulative load profile with the available 50 MW grid capacity**, although additional grid capacity will still be required in this case study - as otherwise the battery system would incur significant costs.

ZEPA Zero Emission Port Alliance

How you can move forward with the Load Profile Scenario Explorer

A Initiate discussions with stakeholders

Use the Explorer to build a clearer understanding of **key electrification concepts** to facilitate proper exchange between port stakeholders.

- Apply it in **internal discussions** (strategy, engineering, operations) to align on what drives peak demand.
- Use it in **external conversations** (with port authorities, grid operators, OEMs) to establish a shared starting point before initiating detailed, terminal-specific analysis.

B Collect more granular data

Use the Explorer as a first step to assess the **importance of load profile data collection.** Subsequently, one can:

- Identify what **existing load profile data you already have**, and where you need higher-resolution insights (minute, 15-minute, hourly).
- Explore **how demand varies** by week, month, season, or weather (e.g., cooler weekends vs hot summer peaks).
- **Build a baseline** that can support deeper modelling and investment planning per terminal.

C Research the load profile optimisation strategies that fit a specific terminal

The Explorer highlights how different approaches can reduce peak load and improve cost efficiency, yet it only scratches the surface of what is possible. Examples of load optimisation strategies include:

Charging strategy optimisation – E.g., shift charging to periods of lower cost or higher renewable availability – such as overnight charging for depot.

Reefer optimisation – Reefers could provide flexibility by using short-term temperature buffers to shift load away from peak hours without compromising cargo. For frozen goods, experts highlight that reefers could be for example turned off for up to 9 hours with only a 1°C rise. The main challenge here is logistical, as temperature control is usually managed remotely by shipping lines, not terminals.[1]

BESS optimisation – Apply battery energy storage not only to cap maximum peak demand, but also to optimise overall energy costs.

Crane-to-vehicle charging – When a crane lowers a container, its hoist motor could generate electricity (regenerative braking). Instead of wasting this energy, studies[2] show that this could be captured and routed to partly charge reefers or BE-CHE, yet more research is needed on this topic.

Notes: [1] Some academic research also focuses on this topic. Examples of publications include Pei, R., Xie, J., Zhang, H., Sun, K., Wu, Z., & Zhou, S. (2021). **Robust multi-layer energy management and control methodologies for reefer container park in port terminal** and Tang, G., Zhao, Z., Schulte, F., & Iris, Ç. (2025). **Smart charging with demand response and energy peak shaving for reefer containers with Internet-of-Things**. ; **[2]** Some academic research also focuses on this topic. Examples of publications include Zhao, N., Schofield, N., Niu, W., Suntharalingam, P., & Zhang, Y. (2014, August). **Hybrid power-train for port crane energy recovery,** Kusakana, K. (2021), **Optimal energy management of a retrofitted Rubber Tyred Gantry Crane with energy recovery capabilities** and Aranaga Decori, P. A. (2020). **Implementation of energy recovery and storage systems in cranes in the Port of Gävle**.

1 Context & objective of the Load Profile Explorer

2 Common language and key concepts in the electrification of port segments

3 How to use Explorer and example outputs

4 Recommended next steps and follow-ups

5 Appendix: Key assumptions and model set-up

Operational schedules: 24h/16h operations at terminal

Parameter		Operational Schedule		Notes
		24h operations	16h operations	
Total operational time (h)		21	14	
Total break time (h)		2.25 (3x45 min)	1.5 (2x45 min)	
Total shift change time (h)		0.75 (3x15 min)	0.5 (2x15 min)	
Shift schedule	Shift 1	00:00-08:00	-	
	Shift 2	08:00-16:00	08:00-16:00	
	Shift 3	16:00-00:00	16:00-00.00	
Break schedule	Break 1	03:45-04:30	-	For staggered break charging: break 1A starts at 03:00, break 1B at 03:45 and break 1C at 04:30
	Break 2	11:45-12:30	11:45-12:30	For staggered break charging: break 2A starts at 11:00, break 2B at 11:45 and break 2C at 12.30
	Break 3	19:45-20:30	19:45-20:30	For staggered break charging: break 3A starts at 19:00, break 3B at 19:45 and break 3C at 20.30

Note: Schedules will be fixed in the excel-version of the Explorer, but may be adjustable in the Explorer

Pre-filled values for #vehicles in operation

Users can fill in the number of vehicles operational at the terminal themselves, or they can choose to **auto-fill estimated values for the number of vehicles based on the terminal archetype, container throughput and share transshipment.** This estimate is based on:

Archetype	Shipment type	Ratio of vehicles per STS
1. STS & TT & RTG	Import/export	**1 STS : 4 TT : 4.8 RTG**
	Transshipment	**1 STS : 4 TT : 2.4 RTG**
2. STS & ASC & SC	Import/export	**1 STS : 1.6 ASC[1] : 2.7 SC**
	Transshipment	**1 STS : 0.8 ASC[1] : 2.7 SC**
2. STS & AGV & ASC	Import/export	**1 STS : 4 AGV : 1.6 ASC[1]**
	Transshipment	**1 STS : 4 AGV : 0.8 ASC[1]**

The ratio of vehicles per STS depends on the #moves per hour a vehicle can perform and the moves required for a transshipment or import/export container move. For example, if an STS can perform 24 moves per hour and a RTG 10, the terminal needs 2.4 RTGs for every STS. For transshipment there is only 1 RTG needed per STS move, but for import/export there are 2 needed (1 RTG move to get container into stack, 1 RTG move to go to onward transport), so the ratio of vehicles is 1 STS : 4 TT : 4.8 RTG.

Assumptions on moves per hour for vehicles

Vehicle	Moves per hour
STS	24
TT	6
SC	9
RTG	10
ASC (module)	30
AGV	6
RS	12

Note: These are averages based on assumed moves per hours which varies heavily between terminals

Notes: 1. ASCs are counted in modules, not per single crane. Source: Stakeholder input.

Key inputs for tethered loads

Parameter	Equipment								Notes
	STS single[1]	STS double[2]	RTG	ASC	Shore Power	Reefer	Building	Lighting	
Average load single item (kW)	150	600	100	100	2000	4	-	-	Note: ratio of average load to peak load used to determine coincidence factor.
Peak load single item (kW)	1000	2500	350	400	2500	12	27	User input	
Load factor (%)	80%	80%	95%	95%	95%	95%	95%	95%	
Utilization factor (%) or moment	During operations only						During shifts	During dark hours (17.00-09.00)	
Coincidence factor	See coincidence factor slide						-	-	

Load for STS, RTG, ASC, Shore power, Reefer is calculated by: #equipment * Peak load single item * load factor * coincidence factor

Load for building is calculated by: #equipment * peak load single item * load factor * utilization factor / time

Notes: 1. Single-trolley STS. 2. Double-trolley STS. Not used in model currently, but may be incorporated.
Sources: stakeholder input, PNNL Total Load Profile Workbook, Zero-Emission Planning and Grid Assessment for Port of Los Angeles,

Key inputs and logic for untethered vehicles – Terminal Tractor

Parameter	TT + Charging Strategy					Notes
	Depot Charging	Vehicle Rotation	Opportunity Charging	Battery Swapping	Depot w. Staggered Breaks	
Energy consumption (kWh/hr)	**16**					Based on TCO model
Moves per hour (#/hr)	**6**					Based on TCO model
Charge rate (kW)	**250**	**250**	**350**	**250**	**250**	Based on TCO model
Battery capacity (kWh)	**250**	**250**	**250**	**250**	**250**	Based on TCO model
Vehicles per charger (#/charger)	**1**	**15**	**20**	**15**	**3**	Based on TCO model, except staggered breaks → assumes 3 break groups
% Additional vehicle/batteries because of charging strategy (%)	**0%**	**6%**	**4%**	**7% additional batteries**	**0%**	% Additional based on TCO model

Sources: ZEPA TCO Model, Stakeholder input

Key inputs and logic for untethered vehicles – Straddle Carrier

Parameter	SC + Charging Strategy					Notes
	Depot Charging	Vehicle Rotation	Opportunity Charging	Battery Swapping	Depot w. Staggered Breaks	
Energy consumption (kWh/hr)	**55**					Based on TCO model
Moves per hour (#/hr)	**9**					Based on TCO model
Charge rate (kW)	**500**	**500**	**500**	**250**	**500**	Based on TCO model
Battery capacity (kWh)	**500**	**500**	**500**	**500**	**500**	Based on TCO model
Vehicles per charger (#/charger)	**1**	**9**	**8**	**5**	**3**	Based on TCO model, except staggered breaks → assumes 3 break groups
% Additional vehicle/batteries because of charging strategy (%)	**0%**	**11%**	**7%**	**19%**	**0%**	% Additional based on TCO model

Sources: ZEPA TCO Model, Stakeholder input

Key inputs and logic for untethered vehicles – Automated Guided Vehicles (AGV)

Parameter (AGV)	AGV + Charging Strategy					Notes
	Depot Charging	Vehicle Rotation	Opportunity Charging	Battery Swapping	Depot w. Staggered Breaks	
Energy consumption (kWh/hr)	**20**					
Moves per hour (#/hr)	**6**					
Charge rate (kW)	**250**	**250**	**350**	**250**	**250**	
Battery capacity (kWh	**250**	**250**	**250**	**250**	**250**	
Vehicles per charger (#/charger)	**1**	**15**	**20**	**15**	**3**	
% Additional vehicle/batteries because of charging strategy (%)	**0%**	**6%**	**4%**	**7%**	**0%**	

Sources: ZEPA TCO Model, Stakeholder input, Portwise, Performance assessment of minimised AGV apron

Key inputs and logic for untethered vehicles – Reach Stackers

Parameter (RS)	RS + Charging Strategy					Notes
	Depot Charging	Vehicle Rotation	Opportunity Charging	Battery Swapping	Depot w. Staggered Breaks	
Energy consumption (kWh/hr)	50					
Moves per hour (#/hr)	12					
Utilization factor	50%					Used only for Reach Stackers, to reflect vehicle being used only for specific tasks in operations
Charge rate (kW)	400	400	400	400	400	
Battery capacity (kWh	500	500	500	500	500	
Vehicles per charger (#/charger)	1	9	10	5	3	
% Additional vehicle/batteries because of charging strategy (%)	0%	11%	7%	19%	0%	

Sources: ZEPA TCO Model, Stakeholder input, Kalmar Global (2021)

For tethered equipment coincidence factors are assumed

Coincidence factor per number of equipment:

Equipment	Coincidence factor (Highly draft)								Notes/ Assumptions
	1	3	5	10	15	20	50	>100	
Ship to Shore Crane (STS)	**1**	**0.37**	**0.26**	**0.20**	**0.18**	**0.17**	**0.16**	**0.15**	Electrified STS cranes have near-continuous availability but operate in task-based cycles, not all peaking simultaneously. Regenerative braking reduces net demand. Tethered equipment assumed to have an electrical efficiency of 95%.
Rubber-Tired Gantry (RTG)	**1**	**0.60**	**0.46**	**0.35**	**0.32**	**0.30**	**0.26**	**0.25**	Electrified RTGs operate in multiple shifts but usually not all simultaneously. Tethered equipment assumed to have an electrical efficiency of 95%.
Automated Stacking Cranes (ASC)	**1**	**0.58**	**0.46**	**0.36**	**0.33**	**0.31**	**0.28**	**0.26**	Fully automated, electric ASCs have asynchronous cycles, controlled via software with minimal overlap in peak. Lower diversity factor expected than RTGs. Tethered equipment assumed to have an electrical efficiency of 95%.
Shore power	**1**	**0.83**	**0.76**	**0.72**	**-**	**-**	**-**	**-**	OPS systems draw stable continuous load while ship is berthed. Diversity only applies across multiple berths. which is limited in size. Shore power assumed to have an electrical efficiency of 89%.
Reefers	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**0.3**	Reefers assumed to converge to ratio of peak load divided by average load. Reefers assumed to have an electrical efficiency of 95%.

Note: Values have been calculated using an asymptotic relationship. More information can be found in the Excel shared with members.

Source: Expert input; EPRI (2009). Electric Ship to Shore Cranes: Costs and Benefits; Van Duin, J. H. R., Geerlings, H., Tavasszy, L. A., & Bank, D. L. (2019). Factors causing peak energy consumption of reefers at container terminals. *Journal of Shipping and Trade*, *4*(1), 1.

Logic and key inputs for BESS

User input

Include BESS system?

Yes | No

Energy capacity: 0.0 MWh

Power capacity: 0.0 MW

Estimated cost: $0 USD

Operational Logic

- Assume the battery is fully charged at the beginning of the operational day (00:00), assuming the previous operating day was a not ‘peak day’
- If total load < grid capacity and battery SoC < 90%: battery charges at battery power rate, or lower rate if load + battery power > grid capacity
- If total load > grid capacity and battery SoC > 10%: battery discharges
- Else: battery does not charge or discharge

Cost and power assumptions

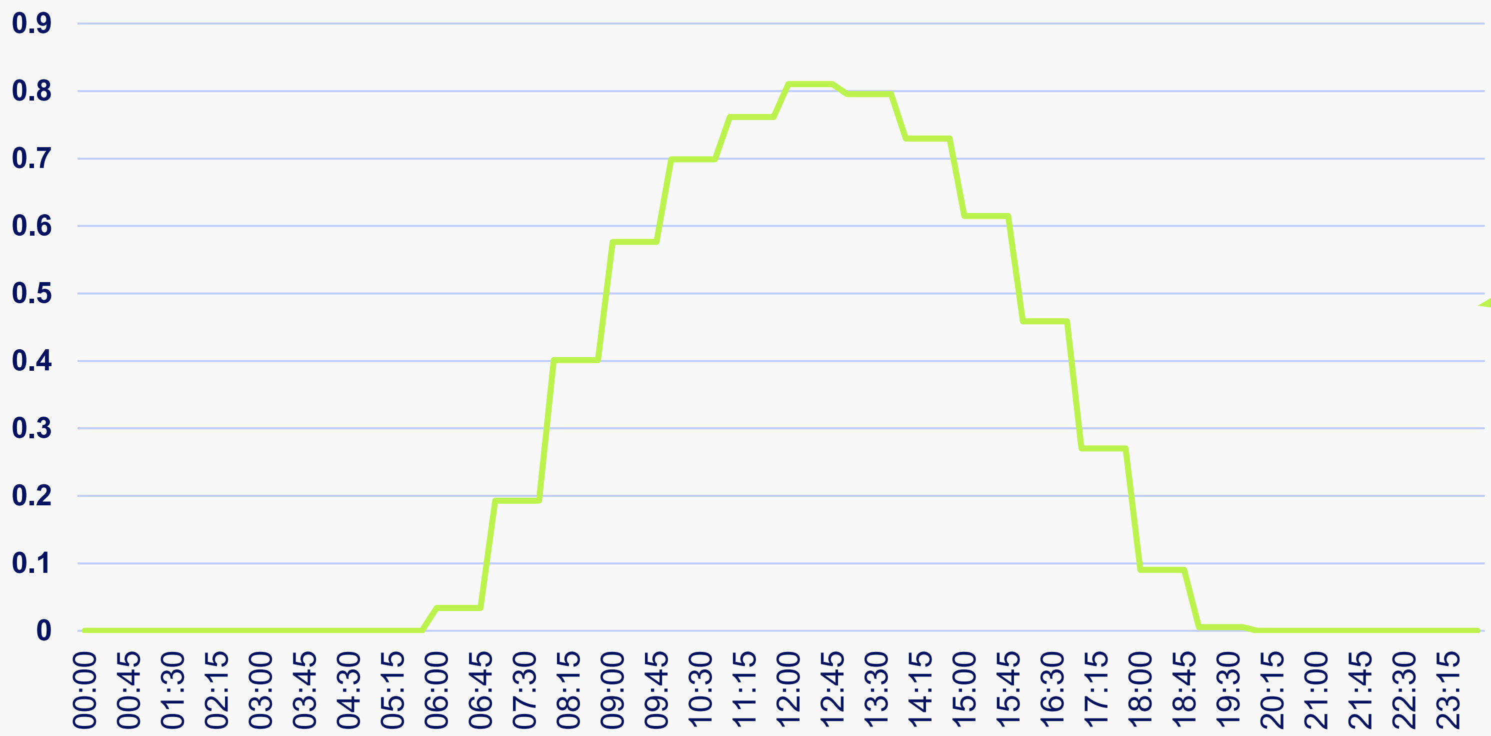
- Power: Energy capacity (MWh) * 1/4
- Cost for energy: ~$220/kWh

Note: both battery size and battery operations are not optimized.

Source: NREL (2024) Electricity ATB; Commercial Battery Storage

Potential add-on: on-site solar PV load

Generation profile for on-site solar PV load (MW)



Note: this is an example solar PV profile. Users are encouraged to add a solar profile for their own location and size to the ‘Solar PV’ sheet in the model. Tools like renewables.ninja can generate profiles for every installation size and location.

Note: this is an example generation profile for a site in the Netherlands using 1 MWp solar PV on a spring day.

Note: the explorer models “the worst day of the year” (load-wise).
Users should consider if Solar PV generation is likely on that day before choosing to incorporate a Solar PV load.

Source: Renewables.ninja

Disclaimer

The ZEPA Secretariat provides this report for informational purposes only. The data and comprehensive analysis it contains reflect our commitment to delivering accurate, insightful findings. While we have worked diligently to make sure the report is reliable and clear, we recognize it may have areas needing further refinement. Information contained in this report is made as at the date of publication. The ZEPA Secretariat does not have any obligation to update or otherwise revise any information reflecting circumstances arising after the date of publication.

To the extent permitted by law, nothing contained in this report shall constitute any representation or warranty and no responsibility or liability is accepted by the ZEPA Secretariat as to the accuracy or completeness of any information supplied herein.

Decisions made by individuals or entities based on information in this report are their own responsibility. The ZEPA Secretariat shall not be held accountable for any outcomes resulting from the use of this information. Users are encouraged to conduct their own research and consult with qualified professionals before making decisions related to this material.

Acknowledgements

The Zero Emissions Port Alliance (ZEPA) is a cross-value-chain port alliance set up by its members to tackle BE-CHE adoption challenges together. ZEPA has multiple members for the 2025 Work Programme, whose activities span the container handling sector.

This report has been developed by Systemiq and constitutes a collective view of participating organizations in the Zero Emission Port Alliance. ZEPA members have supported and validated the analyses, and have agreed to endorse the findings as presented in this report.

We would like to thank other expert collaborators for providing valuable contributions to this report, , especially:

ZEPA Zero Emission Port Alliance

For further information

see www.zepalliance.com

or email zepalliance@systemiq.earth