Green EFFORTS

Green and Effective Operations at Terminals and in Ports

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A top-down methodology to calculate the CO_2—footprint for terminal operations; the 6-step approach

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A top-down methodology to calculate the CO_2—footprint for terminal operations;

the 6-step approach

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LIST OF ABBREVIATIONS / GLOSSARY

AGV	Automated Guided Vehicle CO_2 Carbon dioxide
Del	Deliverable
ECH	Empty Container Handler GPS Global Positioning System
GCW	Gross Combination Weight: The actual weight of the fully loaded tow vehicle plus the towed vehicle (trailer, car, boat, etc.), including all cargo, fluids, passengers, and optional equipment.
H_2	Hydrogen
HP	Horse Power
Hr	hour
kW	kilowatt
kWh	kilowatt hour
lt	liter diesel
LNG	Liquid Natural Gas
MJ	Mega Joule
PEMA	Port Equipment Manufacturers Association QC Quay Crane (= Ship-to-Shore crane)
RMG	Rail Mounted Gantry
RTG	Rubber Tyred Gantry
RS	Reach Stacker
SCS	Straddle Carrier (= Van Carrier)
TEU	Twenty Equivalent Unit of Container
TJ	Terajoules
TT	Terminal Tractor (= Yard Tractor)
VC	Van Carrier (= Straddle Carrier)
WP	Work Package
YT	Yard Tractor (=Terminal Tractor)

Executive summary

There is an increasing need for green and effective operations at terminals and in port due to existing and upcoming stricter air quality standards and regulations. At the same time there is an increasing awareness of the need to reduce energy consumption of ports and terminals and to focus on the carbon footprint which is dependent not only on equipment and operations, but also the energy mix and the management of energy consumption. This is an important for objective for the terminals but also for a wide variety of stakeholders, such port authorities and transport service clients.

Sustainable terminal operations require a good insight in terminal configurations, the use of equipment and the availability of reliable data about the energy consumption on the terminal. This information is in many cases not available for a variety of reasons, such as the very competitive environment and the competition between terminals, sometimes simply because the information is not known. In this deliverable an innovative top-down approach is presented to calculate the CO_2-emissions of terminals. This methodology is named 'the 6-step-approach'. This approach can be considered as an easy applicable tool to get a brief and coherent overview of the total energy consumption of a terminal. The 6-step approach is a standardised methodology which is coherent with CEN standard CEN 16258 "Methodology for calculation and declaration of energy consumption and GHG emissions of transport services (freight and passengers)". The CEN standard contributes to the standardisation, comprehensiveness, transparency, consistency, generalization and predetermination.

The methodology consists of 6 steps:

1- the operations on the terminal (what is actually happening?)
2- the construction of an analytical model of activities
3- the development of an algorithm based on the analytical model
4- application of the model (preferably with real data, presently mostly based on estimations)
5- valorisation of the outcomes of the model
6- policy recommendations

In coherence with the consumption scheme based on the GHG Protocol or to ISO 14064 standard and the CEN EN 16258 standard, the methodology concentrates on three domains of energy consumption: the terminal operations and related equipment, the consumption of reefers and the lighting of the yard. These three elements cover more than 95% of all energy consumption at a terminal.

An important contribution of the 6-step approach to the port community is the fact that the model delivers outcomes that can function as the basis for tailor made recommendations that cover almost all activities. Therefore the main objective of the tool is that it can function as a benchmark tool for companies, port authorities, E.U., WorldBank/IMF/OECD, etc. (policy investment). Furthermore the application of tool can be considered as a basis for evaluation (rising awareness and motivation to use energy competently and thoughtfully), organizational investments (modifying operations to increase productivity versus energy consumption), technical modification investments (modifying equipment and systems to reduce consumption/increase productivity), technical purchase investments (put new equipment/systems into operation).

But overall, the 6-step approach is a source for inspiration, it gives structure to process and the methodology recognizes the new challenges: to apply the model as a a pro-active methodology that addresses the economic (profit), environmental (planet), and social objectives (people) in one coherent strategy. By doing this, the 6-step approach offers an opportunity for cooperation and interaction between the private firms such as the terminal operators, the wider port community, governments and civil society to fulfil the changing needs of society.

Given the competitive environment with respect to terminal operations, this report makes only use of data publicly available. The GreenEFFORTS team has the availability of other data as well, but the dissemination of this data is restricted due to Confidentiality Agreements.

1 Introduction

In general, the role of emissions is not a decisive factor in the design of a terminal. @@Decisions are nowadays mainly taken on the basis of the best berth for ships (Murty et al., 2005). According to Jef Verbeeck (www1, 2013) most of the businesses pay no – or only very limited – attention to their energy consumption.

There are several studies on the relationship between transport and the environment, but no specifically related to energy consumption in container terminals. For other sectors, there are models to calculate energy usage and CO_2-emissions. But many of these models are based on (often difficult) mathematical formulas and algorithms.

The main goal of this deliverable is to introduce a new method for assessing energy consumption from container terminals and in extension the CO_2-emissions. First we construct a methodology to calculate the energy consumption, then we apply the method to generic terminal equipment.

The approach used in this project, which is called the 'systems approach' (Findeisen and Quade, 1985), is particularly useful for analysing problems involving complex systems about which there is insufficient knowledge and which are characterised by 'deep uncertainty'. Lempert et al. (2003) define deep uncertainty as "the condition in which analysts do not know or the parties to a decision cannot agree upon the appropriate models to describe interactions among a system's variables to represent uncertainty about energy consumption. The systems approach is well suited to helping us understand the potential energy consumption patterns as a interrelationships among the elements of the system.

Van Duin & Geerlings (2011) took a first step by developing a model that easily makes clear how much energy is consumed at container terminals for transhipment of containers processes. Although their model was validated for 95% of the container terminals in Rotterdam and 3 barge terminals in the Netherlands (2012), terminal operators indicate that the handling these processes causes only 30% of energy consumption. Over 40% is accounted for refrigerated containers, called reefers. The terminal illumination causes another 20% of the energy consumption and 10% is consumed by other processes (for instance showering, heating etc.). These processes and their energy consumption are described in deliverable 4.4. In this report we focus on the calculation of the energy consumption of all terminal operations.

2 Setting the Scene

2.1 Position of Container Terminals

In international transportation, the primary proportion of freight transportation is transported by container. Container terminals are central hubs in these transport systems. At container terminals, containers are used for the storage, and transit of containers to other modes of transport deep-sea, short sea, road, rail and barge.

In recent years the world container traffic continued to grow from 28.7 million TEU in 1990 to 152 million TEU in 2008. When split, this leads to a yearly growth of 9.5% per year. In the same period the container throughput in ports and terminals increased from 88 million TEU to 530 million TEU. This leads to an even larger yearly growth of 10% per year.

Because of this growing market we make two observations. The first is that there is a lot of competition between different container terminals. This leads to an highly competitive market where contenders are very conservative in the publication of internal data. This is one of the main problems assessed in this report, i.e. energy consumption has the largest share in the total costs of a terminal.

The second observation is that, in general, the energy consumption of operations is not a decisive factor in the design of a terminal. Decisions are nowadays mainly taken on the basis of the best berth for ships (Murty et al., 2005). According to Jef Verbeeck (www1, 2013) most of the businesses pay no – or only very limited – attention to their energy consumption.

2.2 International Positioning European Standards

The objective of the model is to investigate opportunities and requirements to measure, monitor and control port and terminal emissions. It practice it appears to be difficult to collect precise data on the energy consumption of equipment and rolling stock. The energy consumption data used in this model is derived from assessments on existing terminals, terminal clients and expert opinions.

Standards can act as a supportive tool when it comes to the coherent and comprehensive measurement and monitoring of terminal operations and benchmarking. An intensive use of standards looks desirable as they act as a constraint on behaviour and an impetus to look for the most cost-effective solutions. We also know that well-defined standards have the advantage that they define the total playing field: all competitors in the market are influenced by the same constraints. In addition, international agreement on standards could be effective in the expanding world market of terminal operations. Imposing standards in the total market creates the opportunity for terminal operators to internalise the costs of operations to the price of the product.

The most recent and universal standard used is the ISO 14001 standard. This standard is inspired by the Environmental Management Systems (EMS) to realize an environmental management system. The ISO 14001 sets out the criteria for an environmental management system. It does not state requirements for environmental performance, but maps out a framework that a company or organization can follow to set up an effective environmental management system. It can be used by any organization that wants to improve resource efficiency, reduce waste, and drive down costs

A recent development that is applied in the GreenEFFORTS-project forms the carbon footprint per individual consignment. This is covered by the CEN standard EN 16258, entitled "Methodology for calculation and declaration of energy consumption and GHG emissions of transport services (freight and passengers). This standard, which is published in 2013, provides calculation methods to determine the carbon footprint of transport carriers such as trucks, ships, railways and airplanes resulting in. The CEN EN 16258 can become applied for sea and inland navigation terminals. CEN 16258 fulfils some basic requirements of being standardized, transparent, consistent, predetermined and SME compatible. These are all characteristics that are essential to allow benchmarking.

The question arises who are the stakeholders that are interested in the carbon footprint of terminals. The "Clients" for a carbon footprint measurements of terminals are:

- Terminals, The carbon footprint is an indication for the energy consumption and because cost of energy continuously is increasing improving energy-efficiency which is a core business activity of a terminal,
- The shipping liner,
- Transport service clients to satisfy the information needs of their customers in order to allocate the appropriate carbon footprint share on their products (usually transported in cargo units such as containers),
- the society through a public body (e.g. port authority, community). The total carbon footprint of the enterprise according to GHG protocol reporting or to ISO 14064 (social responsibility of enterprises),
- the consumer.

2.2.1 A calculation methodology for container terminals

It was found that CEN EN 16258 in its current version does not fulfil the correct "assessment criteria" stated above and hence another calculation method must be developed for sea and inland navigation terminals. The most uniform operations are encountered on container terminals therefore this terminal type was selected to commence development.

The GHG-reporting is also described in the GHG Protocol or to ISO 14064. The total emissions from "Scope 1" (direct combustion of fuels on a terminal) and "Scope 2" (purchased energy, usually only electric energy but it also can include gas from gas grid, heat from district heating or steam from an external steam producer) can simply be calculated according to the energy consumed and the bills paid. This will require stock-taking at the end of the year known from material inventories to not include energies purchased but not consumed into the annual calculation. Emissions according to "Scope 3" (emissions from processes required to provide own service, such as e.g. business trips or delivery of purchased goods, but not under the control of the terminal) will require adequate reporting from external operators. Scope 3-emissions within a coherent carbon footprint measurement system will be counted double, once for the originator and once of the actor benefitting from the service. The idea is to achieve awareness for these emissions by those purchasing the external services. Scope 3 emissions will not be further considered here. The result of GHG-reporting is the total carbon footprint of the terminal. Below a scheme (see Figure 1) is presented that serves to cluster consumers but is not sufficient to serve as a KPI-scheme which needs to consider additional conditions such as layout of terminals, etc.

Quay	Ship-to-Shore Cranes
Yard	Movers Stackers Lighting Reefers Packing (e.g. "out of gauge")
Interchange	Movers Loaders/Unloaders
Workshop(s)	Facilities Tools Equipment
Premises	Buildings Showers Canteen(s) IT Offices Parking (outside yard)
Off-Yard	Empty Storage Facilities Transport to and from remote storage areas
Other Services e.g.	Freight Station Coldstore(s) Cleaning and Repair

Figure 1: Terminal Energy Consumption Scheme based on GHG Protocol or to ISO 14064

2.2.2 Reporting to transport service clients (analogous to CEN EN 16258)

From the total energy consumption of a terminal it is required to identify the consumption which must be allocated to container transhipment activities. Coldstore consumption e.g. may not be counted as container-initiated consumption. Also the energy consumption of other business activities, not directly associated to the handling of containers, such as packing and cleaning and repair of containers, need to be excluded from the total terminal consumption to result in the box handling-related carbon footprint to be allocated.

The crucial question, however, is to what detail the container operations need to be broken down. Differences which are not resulting in significant figures of energy consumption should not be taken into account, following a similar principle accounting is applying to allocate overhead costs. It is then needed to investigate which container types, cargo and operations result in significant differences of energy consumption.

Containers can be classified into

- Empty boxes 20'/40'/45'
- Laden boxes 20'/40'/45'
- Reefer boxes with deep frozen cargo 20'/40'
- Reefer boxes with chilled cargo 20'/40'

Currently it does not give sense to accurately take a container weight into account because often it is not known and it is assumed that the energy consumption of e.g. a crane will not too much differ depending on smaller weight differences (This assumption has to be proven!). Individual measurements shall result in a carbon footprint allocation model which can automatically be taken into account by the terminal's IT.

Because reefer containers are significantly contributing to a terminal's energy consumption, the evaluation of reefer consumption factors requires some effort. It is obvious that deep frozen cargo and chilled cargo results in significant differences in energy consumption. Further measurements must show if more than those two temperature classes need to be distincted. Because environmental conditions (ambient temperature) are relevant for the reefer consumption, these must be taken into account, too. Container handling operations on a terminal can be classified into

- Ship to stack and vice versa
- Stack to truck and vice versa
- Stack to railway and vice versa
- Stack to depot (empties) and vice versa.

However, it appears sufficient to capture the total energy consumption for all these operations and not base it on the terminal history of an individual box which also depends on random coincidences such as re-stacking to access a container stacked below. The calculation formula then is:

Total container handling-related carbon footprint = ∑∑ containers class $_{1-n}$ x footprint-factors $_{1-n}$

The difficulty lies in the determination of the footprint-factors which must be derived from the average energy consumption of a box class. There are currently not sufficient comprehensive data available, therefore the gaps must be filled by a model-approach from theoretical considerations but validated wherever feasible and later continuously improved over time.

2.2.3 Box-related carbon footprint

As stated under the "assessment criteria" above, predetermination of the carbon footprint per box is of importance, serving as a factor to base selection of transport services upon. To allow this, it is proposed to base current carbon footprint calculation on the figures of the prior year, similar to the overhead calculation as it is a common accounting principle.

3 Ambition

In recent decades, greenhouse gas emission has been one of the most concerned worldwide issues. The main source of the greenhouse gas emissions is the modern industry. Nowadays the transport sector is one of the biggest contributors to world wide the carbon dioxide emission.

One of the main reasons of why this is a growing concern is that the amount of freight transport keep arising. This means that the energy consumptions, and thereby the CO2 emission, is also increasing.

Container terminals have a central position in this logistic chain. The primary part of freight transport is done by container and the terminals are the central connection between deep-sea transport and hinterland transport.

The ambition of this report is to develop and validate a methodology to estimate energy consumption of container terminals on the level of their operations. With this model it will be possible to determine the energy consumption of container terminals and thereby estimate the emission of greenhouse gasses.

3.1 The six-step Methodology

The main ambition of this report is to present and formalize a bottom up methodology to analyse the energy consumption of container terminals. The model provides insight into the energy consumption of the processes related to container transhipment at the terminals, the energy consumption of reefers and the characteristics of the terminal, in particular with respect to lighting. The outcomes of the model are used to calculate the contribution for the CO_2-emissions of the container terminals.

In general there exist two types of modelling approaches: analytical and simulation.

Analytical models are abstract models to construct a systematic analysis of reality. By applying the analytical approach the actual situation and related problems will be simplified to be able to formulate a mathematical model. Such models, based on multiple criteria, will show the complex nature of terminal operations. In order to analyse the overall performance, there is often a (hierarchically) subdivision for different sub-processes. The advantage of these models is that they can provide a full and simplified image of a system that can be understood by a wide audience form both a technical and an organisational perspective. The limitation of these models is that they lack the more detailed aspects of a system and therefore they may not cover al the needs of professionals in specific fields.

To cope with the complexity of terminal operations it is a common approach to use simulation models to evaluate performance (Saanen & Rijsenbrij, 2007). Simulation models have a more mathematical background. These models provide a detailed overview of a system and are based on algorithms that can simulate and predict real life situations. The disadvantage of simulation is the time needed for building a detailed and validated model.

The advantage of the methodology we develop in the GreenEFFORTS-project is that we develop an analytical model and a simulation model of a container terminal that is based on the same database, so the outcomes will be coherent en comparable. On the overall objective to come with a simple and applicable methodology whereby the outcomes are easily understandable for a wide audience but also form a robust analytical basis.

3.2 The construction of the model

To compose a bottom-up model of container terminal operations and performances, it is important that the outcomes are valid for all terminal operations. To develop such a model we use a systematic and well-structured approach to determine the energy consumption of a container terminal as a whole and the sub-processes. Our approach consists of six consecutive steps that together provide a detailed insight in the energy consumption of each of the sub-processes on a container terminal. The six-step approach is congruent to the modelling paradigm of Sargent (2010, p. 170).

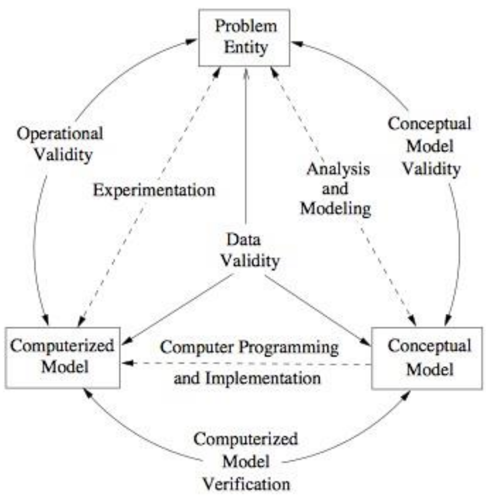


Figure 2: simplified model of the modelling process (Sargent 2010)

The first step is to describe what is actually happening on a terminal. The transhipment of containers on a terminal takes place with different types of equipment. The type of equipment and the use of this equipment determine the energy consumption, and consequently the amount of CO_2-emissions. The energy consumption of the transhipment processes or the lighting can be directly measured via the energy consumption of the equipment used.

So the first step of the model is to give a detailed description of the specific sub-processes on a terminal. This gives us the ability to make substantiated estimations of the total energy consumption within a terminal process.

The second step is to construct an analytical model of the observed activities of the sub-process. In the analytical model we build a detailed conceptual model of all the sub-processes. When creating the analytical model we follow the same pattern as described in the first step. So first we analyse all the sub-operations of a container terminal and combine these insights to a full model of a container terminal. In this model we combine both the equipment that is used in a sub-process and the energy consumption of this equipment. This leads to a systematic overview of the different processes on a container terminal and the way energy is used by the movement of containers on a terminal.

The third step is to translate the observed processes and the related analytical model into an algorithm. With an algorithm we can calculate the total sum of energy consumption of a terminal sub-process. To construct the algorithm we take in account the various types of equipment, their contribution to the sub-processes and their energy consumption.

The fourth step is to apply the model via a simulation. In this step we apply the constructed models via a simulated container terminal based on both real and estimated data. With these simulations we can make a very precise estimation of the energy consumption of a container terminal.

The fifth step is to validate the data that comes from our simulation. The simulations are based on a combination of real and estimated data. So the simulation models have to be validated in order to determine the deviation they show in comparison to actual energy consumption of terminal equipment.

The final step is to make policy recommendations. After generating and validating the data we can make detailed policy recommendations regarding the energy usage of container terminals. We call this methodology the six-step-approach.

4 Operations

At a container terminal there is a lot of productivity. Containers arrive by ship, are taken of the ships by cranes, are transported within the terminal, are stacked in the container stacks, are moved within the stack by stacking cranes, and finally they are further transported.

In all these processes there is some sort of energy consumption. The first observation is that there are many different types of equipment, all of which use different sources of energy. These sources vary between electricity, diesel fuel and eco-diesel. In addition, there is also equipment that uses combinations of these energy sources these are called hybrids. To make it even more complex, the most recent development is equipment which in itself can recapture energy. This is done by dynamos in cranes that generate electricity when lowering containers.

4.1 Step 1: Description

So what is actually happening in the operations? At a terminal there are usually five separate processes that can be identified. The first process is the arrival of a container by ship and the unloading of the ship, the ship to shore process. The second process is the transport from the shore to the container stacks, the shore to stack process. The third process is the stacking of the containers, the stacking process. The fourth process is the inter-terminal transport of containers, from the stacks to other modalities or within the stacks. The sixth process is the loading of containers to other modalities like trucks, trains and barge ships.

We describe these processes in detail and describe the energy consumption within these processes for different types of equipment.

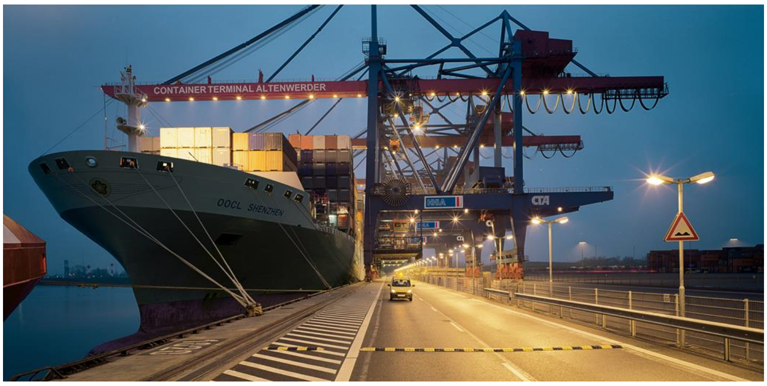
4.1.1 Process 1: Ship to Shore

Most containers arrive at the terminal by ship. Upon arrival the containers are lifted form the ship to the shore. At most terminals this is done by Quay Cranes (QCs). These electric cranes lift the containers from the ships and move them to the shore. At the shore the containers can either be put directly on a tractor or automatic guided vehicle, or the container can be made ready for subsequent transfer to a straddle carrier or van carrier.

Quay Cranes are electrical driven equipment. They utilise two different methods of operation. There are one trolley systems and double trolley systems. One trolley systems are faster when the containers, which are unloaded, are picked up by Van carriers, because there is no time needed for changing the trolley systems. Double trolley systems are faster when the containers, which are unloaded, have to be positioned exactly on trucks or automated guided vehicles (AGV) because exact positioning is carried out by the second trolley while the first one can already unload the next charge.

There are four main sources of consumption when it comes to QC operation, namely

(1) the move of a container (hoisting, lowering and horizontal movement), (2) move of gantry from one quay to another, (3) crane lighting and (4) standby consumption.



Source: www.hhla.de

4.1.2 Process 2: Shore to Stack

On the shore the containers are moved from the quay to the container stacks. The container is placed by a quay crane on an automated guided vehicle (AGV), a lift-automated guided vehicle (LAGV) or a terminal tractor and is moved to the container stacks.

AGVs are unmanned vehicles designed for the horizontal transport on container terminals. AGVs are able to handle 2 x 20', 1 x 40' or 1 x45' containers. They drive autonomously between QCs and the stacking cranes. The AGVs are directed by a radio transponder grid, which is counter-sunk in the terminal surface and allows a positioning accuracy of ±25 mm. In addition to the radio transponder grid the AGVs are controlled by GPS. The AGV receives the destination of the container by radio from the quay crane and directs its way automatically according to the radio transponder grid.

Due to the width of an AGV which is close to the width of a container and the fact that automatically positioned AGVs can be exactly adjusted, the AGVs can be positioned to fit exactly to tandem or triple spreaders of quay cranes. This makes the use of these spreaders more efficient than other prime mover equipment.

There is one main source of energy consumption when in comes to AGV energy consumption, namely the movement of the AGV. Nowadays most AGVs are electrical powered, they use batteries that are charged at central charging areas on a terminal. In addition, early AGV models are diesel-powered hydraulic-driven.

Normally AGVs have to wait at their destination to be unloaded. If the stacking cranes are already busy, this decreases efficiency. The lift AGV has the possibility to lift the containers and to unload them to elevated container posts from where the stacking cranes can pick them up later. This increases the efficiency of the AGV, or on the other hand reduces the number of needed AGV. Operation of the Stacking cranes and AGV are decoupled so that no mutual waiting time is needed any more.

Source: www.porttechnology.org

Straddle carriers (SCs) are very flexible units. Straddle carriers can stack up to three containers (1 over 0, 1 over 2 and 1 over 3). One of the key features of SCs is that they can be used both for horizontal and vertical transport. This means that they can be used both for lifting containers form the quay and for stacking. The disadvantage of the usage of van carriers as only terminal equipment is the fact that containers cannot be stacked close to each other because the space for the wheels of the van carrier must be available between the container rows.

Source: www.konecranes.de

Straddle carriers operate with diesel engines. The engine provides the power for the traction drives and the power for the hoisting drives as hydraulic power. With these drives all energy which is released when the containers are lowered is wasted in brakes.

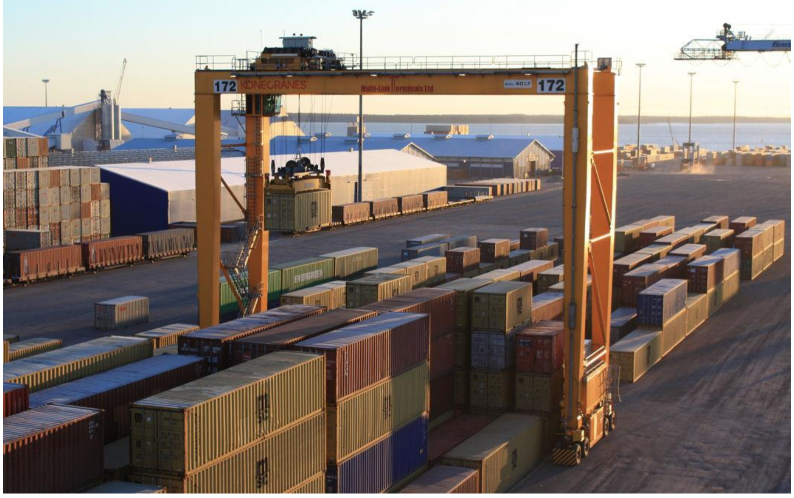
Terminal trucks (or tractor trailer units) are used to move containers via trailers. They can move containers in two ways. The first is that a crane puts a container on a trailer that is attached to the truck. After the container is placed the truck moves to the stacks. The second is that the trucks move trailers around the terminal, trailers are then disconnected from the truck at the destination point.

Source: www.terbergbenschop.nl

Terminal trucks operate with both a diesel engine and a hydraulic motor. They can convert energy into compressed hydraulic fluid when the tractors break. This is stored in an accumulator tank to power the tractor during acceleration instead of using the energy from the diesel engine.

4.1.3 Process 3: Stacking

At the container stacks the containers are placed for short-term storage. When containers arrive at the stacks, they are picked up by stacking cranes: mostly Rail mounted gantry cranes (RMGs), Rubber tired gantry cranes (RTGs) and sometimes with Reach Stackers (RSs)or Fork Lifts. Within the stacks containers can be moved to other places for easier transhipment.



Source: www.mlt.fi

Rubber tired gantry cranes (RTGs) are mobile gantry cranes, which are able to move around and stack containers side by side. RTGs are equipped with a movable crane trolley system that can move the containers within the container stacks.

Standard RTGs are powered by a diesel engine. The diesel engine powers hydraulic drives for horizontal movement, trolley movement and hoisting. With these drives all energy which is released when the containers are lowered is wasted in brakes. There are also electrical driven RTGs that use electricity to power the hydraulic movement.

Rail mounted gantry cranes (RMGs) are gantry cranes that are placed on rails. The use of RMGs asks for heavy foundations for the rails in the terminal surface. RMGs can be fully automated. Due to the rails RMGs can stack containers very close to each other. When compared to RTGs, RMGs have a bigger lift capacity and a higher gantry travelling speed. The positioning of the crane can also be more accurate because the rails guide them.

RMGs are electrical driven and have energy recuperation capabilities like the Quay Cranes.

Source: www.konecranes.com

Reach stackers are vehicles for handling containers in terminals. Reach stackers are flexible vehicles that can transport a container very quickly on short distances. They can lift containers (ia from the quay) and are able to stack the containers as long as they have side access to the stack. Reach stackers are equipped with a spreader that connects to the top of a container.

Source: www.konecranes.de

Fork lifts are used to handle empty containers. They can stack up to 9 rows high and are able to handle 2 empty containers on top of each other at the same time. They are very flexible, can pick up containers from the quay. They need side access to the empty storage stack.

Source: www.nauticexpo.com

Both the reach stackers and fork lifts as mobile equipment are operated with diesel engines, which provide the power for the traction drives and the power for the hoisting drives as hydraulic power. With these drives all energy which is released when the containers are lowered is wasted in brakes.

4.1.4 Process 4: Inter terminal transport

From the container stacks the containers are moved to other modalities for further transport. The main goal of inter terminal transport is to move the containers from the stacks to another modality. It depends on this modality how the containers are moved and what type op equipment is being used. On a typical terminal there are a few options for further transport: trucks, trains, barge or vessel. Hence these different movements we will describe them separately.

Regardless of the mode of transportation, the first move is to get the container from the stacks. This is done by the same equipment as described in process 3; RMGs, RTGs, ASCs or RSs. The cranes lift the containers and bring them to the ends of the stacks.

Truck

When the container is moved by truck there are a few possibilities for inter terminal transport. The first option is that the terminal had truck scales. This is a place were trucks wait to be loaded with a container. The container can be moved to the truck with a SC or a RS, both can put a container on the truck. The second option is that the trucks are loaded with gantry cranes. The containers have to be moved to the gantry cranes by AGV, LAGV or RS, and are then loaded on the trucks with a RGC or RTG. The last option is one that we see in modern terminals. Modern terminals can have a truck scale at the container stacks. This generates the possibility to load the trucks directly at the stacks by RGC or RTG.

Train

When the container is moved by train the container has to be moved to the rails. This is done by SCs or RSs. When the container arrives at the trains there are several options depending on terminal layout. Containers can be put on the train by a rail crane or put directly on the train with the SC or RS.

Inland shipping

When the containers are transported by barge ships the containers are moved from the stacks to the bare quay. This is done by SCs or RSs. At the quay the containers are picked up by barge or quay cranes and put on the ships.

4.2 Step 2: Analytical model

The second step in the six-step approach is to construct an analytical model. In the first step we gave a detailed description of all terminal operations, in this step this leads to a schematic model of the terminal operations.

If we look at the process from a distance then there are a number of fixed patterns to discover. These patterns are applicable for all the processes described above, regardless of the equipment that is used within the process.

The first pattern is that all equipment consume energy when moving a container and that this energy consumption varies by type of equipment. Based on the full specifications of the equipment the energy use per container movement can be calculated. This leads to the energy consumption per container movement.

The second pattern is that the number of movements within a process is important in the calculation of the energy consumption. Each additional movement creates an increase in energy use. These movements take place when handling a container, but also when the equipment is moving without containers or when the equipment is in idle state.

Based on energy consumption per movement and the number of moves a total energy consumption of the equipment can be calculated.

These patterns are displayed in the following model:

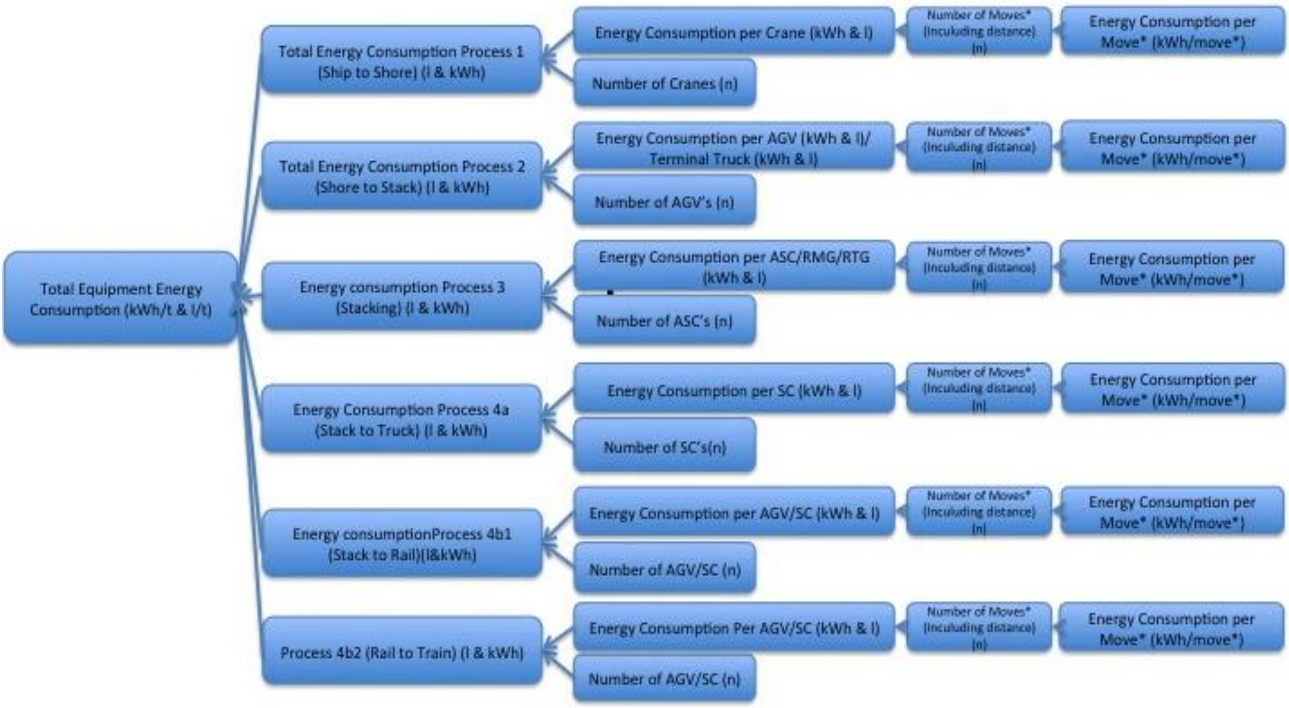


Figure 3: Analytical model energy consumption operation

4.3 Step 3: Algorithm

The energy consumption of the operations are measured on the basis of the yearly consumption of diesel in litres to modality and the yearly power consumption of electricity (kWh) to modality.

Apart form the total consumption it is important to differentiate the energy consumption to the various sub-processes on the terminal. So to calculate the total energy consumption and thereby the total Cos-emissions of a terminal we need to take the total sum of emissions by equipment (i) and the sub-processes to tranship to another modality (j). This leads to the next formula:

$$W_X = \sum_{i=1}^{N} \sum_{j=1}^{M} \left(\left(v_{i,j} \times f_D \right) + \left(P_{i,j} \times f_E \right) \right)$$

where:

W_x = Total weight of CO_2-emission produced at terminal x

$V_{i,j}$ = Yearly consumption of diesel in litres with equipment *i* to modality *j*

f_D = Emission factor in kilogrammes of CO_2-emission per lit diesel (= 2.65)

$P_{i,j}$ = Yearly power consumption of electricity in kWh for equipment *i* to modality *j*

F_E = Emission factor in kilogrammes of CO_2-emission per kWh (= 0.52)

N = The number of different equipment at the terminal

M = The different transport modalities at the terminal.

combined with:

$$V_{i,j} = n_{i,j} * (C_{i,j}+c_{i,j}) \qquad \forall i, j \in T$$

$$P_{i,j} = n_{i,j} * (p_{i,j}) \qquad \forall i, j \in T$$

where:

$n_{i,j}$ = Number of rides with equipment i to modality *j*

$C_{i,j}$ = Fixed usage (for example lifting operations) per ride in litres

$c_{i,j}$ = Variable usage per km in litres

$_{i,j}$ = Distance travelled according Manhattan-metric for equipment *i* to modality *j*

$p_{i,j}$ = Fixed usage per ride in KWh Table 1 for equipment *i* to modality *j*

4.4 Step 4: Application of the Model

In order to apply the described model we need to understand the energy consumption of the terminal equipment. The energy consumption will depend on average distances, coupled with standard routes and average energy consumption. For the calculations is it important to have accurate input variables.

Average energy consumption

The average energy consumption of equipment is difficult to acquire. Manufacturers are not only restrained in giving this information, but it also will differ between different types of equipment, the number of working hours and the wear of the equipment. This combination of factors makes it difficult to get an accurate view of the energy consumption. In order to make assumptions that are as accurate as possible we use two main sources of information. The first is a study of the environmental performance of an automated terminal in Rotterdam, called the Delta terminal, conducted by the Dutch research institute TNO (Oonk, 2006). The second is the detailed description of terminal equipment presented in Deliverable 4.1 of the GreenEFFORT project.

This leads to the following average consumption pattern of typical terminal equipment:

	Fixed	**Variable**
QC: Quay Crane	5.3 kWh/move	
BC: Barge Crane	4.00 kWh/move	
RC: Rail Crane	5.0 kWh/move	
ASC: Automated Stacking Crane	5.0 kWh/move	
RSC: Rail-Mounted Stacking Crane	7.25 kWh/move	
RMG: Rail Mounted Gantry Crane (Electric)	2.52 kWh/move	54.40 kWh/hr
RTG: Rubber Tyred Gantry Crane	1.78 lt/move	20.7 lt/hr
Hybrid	1.15 lt/move	13.33 lt/hr
P: Platform	5.00 kWh	
AGV: Automated Guided Vehicle	1.85 lt/move	7.20 lt/hr
electric	3.62 kWh/move	14.2 kWh/hr
SC: Straddle Carrier	1.85 lt/move	22.22 lt/hr
hybrid	1.3 lt/move	15.6 lt/hr
TT: Terminal Tractors	1.33 lt/move	8.00 lt/hr
hybrid	1.1 lt/move	6.4 lt/hr
MTS: Multi Trailer System		4.30 l/km

RS: Reach Stacker/Top Lifter	1.7 lt/move	15.7 lt/hr
FL: Fork lift	0.6 lt/move	9 lt/hr

4.5 Step 5: Validation

The next step is to validate the data calculated by the model. We did this by making a comparison of the model estimations and the real consumption of a number of terminals in the port of Rotterdam. When we look at the figure we can conclude that there is a small difference between the model estimations and the real consumption. The only terminal with a big difference is the ECT Hanno terminal. This terminal is used for straddle carrier driver training purposes. Because SC drivers train on this terminal there are more movements and a bigger energy consumption.

Diesel: Terminal	Model Estimates			Real consumption			
	l/year	*l/TEU*	*l/cont*	*l/year*	*l/TEU*	*l/cont*	*difference %*
ECT Delta	15,005,338	3.52	5.81	17,654,322	4.14	6.83	-15.0
ECT Home	4,577,564	4.40	7.27	4,190,952	4.03	6.65	9.2
ECT Hanno	324,718	5.62	9.28	684.000	11.84	19.54	-52.5
APM	11,827,265	5.38	8.87	Unknown			
RST	2,285,928	2.29	3.78	1.900.000	1.65	2.72	20.3
UNIPORT	1,366,188	3.87	5.73	1.100.000	2.91	4.32	24.2
BCT	90,222	0.38	0.58	99,788	0.42	0.64	-9.6
CTN	69,099	0.41	0.69	61,429	0.36	0.61	12.5
WIT	140,731	0.76	1.35	154,390	0.83	1.48	-8.8

Electricity: Terminal	Model Estimates			Real consumption			
	kWh/year	*kWh/TEU*	*kWh/cont*	*kWh/year*	*kWh/TEU*	*kWh/cont*	*difference %*
ECT Delta	45.503,821	10.67	17.61	47,142,857	11.06	18.25	-3.5
ECT Home	4.691,736	4.51	7.45	7,500,000	7.22	11.90	-37.4
ECT Hanno	640,544	11.09	18.30	1,250,000	21.65	35.71	-48.8
APM	10,489,636	4.77	7.87	Unknown			
RST	9,498,600	8.24	13.59	11,000,000	9.54	15.74	-13.6
UNIPORT	6,313,260	16.70	24.78	6,960,000	18.41	27.31	-9.3
BCT	480,401	2.03	3.10	505,976	2.13	3.25	-4.7
CTN	301,276	1.78	2.99	315,501	1.87	3.13	-4.5
WIT	232,628	1.26	2.23	219,788	1.19	2.11	5.8

Figure 2: Validation model estimations and real consumption

Based on the validation we can conclude that our calculations give a fair outcome. However there are several interfering factors that might influence the results. We summarized these:

- Weight of the container. It takes more energy to lift a heavy container than a light container. So the weight of containers might interfere with the overall energy consumption of equipment.
- Wind conditions. Due to the wind it is not always possible to lift containers in a stable way. When there are cross-winds cranes consume more energy to lift containers.
- Driver behaviour. Energy consumption is dependent on the way equipment is operated. It is known that engines that run on full speed consume exponentially more energy than equipment runned on lower speeds. This also applies for the following interfering factors:
- Speed of operations.
- Efficiency of operation (distances, stacking process, etc.)
- Maintenance condition equipment. Good maintained equipment uses less energy. So the way equipment is maintained affects the equipment energy consumption.

4.6 step 6: Policy Recommendations

Based on the calculations we can make policy recommendations. We formulate our recommendations in three parts. The first part is aimed at the lay out of the terminal, the second part is aimed at the terminal hardware and the last part is aimed at the org-ware. We also make a distinction between new and existing terminals. We made this distinction because terminals that are in operation are almost never shut down for big adaptions. To do this, operations has to be shut down which is a very costly thing to do.

The most radical measure to reduce energy consumption is to adapt the terminal layout. By constructing compact terminals where stacks are directly at the quayside, horizontal transport can be minimalized. In this compact layout equipment can operate in a more efficient way than we see in existing terminals.

A more simple measure is to replace equipment by new, more energy efficient, equipment. The aim of this recommendation is to increase the efficiency of the equipment of the terminals. In recent years there have been many technical developments that make equipment more energy efficient. New engine technologies make equipment more energy efficient. And the use of lighter materials to build equipment makes equipment lighter so that they use less energy to operate. There are also improvements possible in equipment design. Good examples are the lift-agv's that make the inter-terminal transport more efficient. Another development is equipment that can handle more containers or equipment that can stack containers higher.

The last recommendation is using alternative fuels. Blending biofuels can reduce the emissions of diesel fuel. But using electricity has the most potential. Electricity cannot only be generated in a more clean way, but can also be recuperated by equipment. This makes the use of electricity a more energy efficient way of operating equipment.

Adjusting the logistical system to a more energy efficient organisation. In modern terminals we observe a shift from hardware to orgware. This shift can lead to more energy efficient terminal processes. By making smart adjustments to the logistical process there can be made big improvements. On container terminals there is a trade-off between speed and energy efficiency. Equipment that is operating at full speed uses exponentially more energy than equipment that is operated on more moderate speeds. Time is often a leading factor in terminal operations, but the question is if it is always necessary to maximize the speed of logistics. This process needs smart managing.

We also recommend more efficient use of equipment. This means that idle runs have to be minimize. One of the developments on this process is the use of double loading cycles of Quay Cranes.

This brings us also to the human factor in terminal operations. Most equipment is still operated by humans and the way in which equipment is operated is directly connected to the energy consumption of equipment. Therefore we recommend good and regular driver training to make changes in driving behaviour.

The last recommendation is using energy management systems to operate load shifting and energy balancing in smart grids. These systems can balance the energy consumption throughout the terminal in a way that energy is used in an efficient way.

5 Reefer Containers

A reefer is a container in which temperature can be controlled. Reefers can transport temperature sensitive goods, like fruits, vegetables and frozen food. It is important that the reefers keep the intended temperature at a stable level. In the calculation of the energy consumption of container terminals reefers is an important factor. On a typical terminal, reefers are responsible for up to 40% of the total energy consumption. Over the last years we can observe a strong growth in the number of reefers that is transported. The Port Authority argues that in the near future the reefers will have a market share of about 80% of all refrigerated transport. This is confirmed by research company Drewry Maritime Research, which states that in 2014 about 74% of perishable goods will be transported by reefer. Most goods transported are fruit, vegetables, meat, fish and dairy products. But also bulbs and photographic materials are usually transported by reefer. The refrigeration are therefore exposed to temperatures ranging from -40 ° C to 40 ° C.

5.1 Step 1: Describing the Process

To regulate the temperature a reefer has two cooling systems: a primary cooling system and a backup. The primary cooling system is an integral refrigeration unit powered by electricity. In normal operations the reefers are - both on ship and shore - connected to a electricity network. Therefore terminals have special reefer stacks and ships have special reefer connections. When reefers are transported - both inter terminal transport and transport outside the terminal - they are powered by an internal generator. The internal generator is diesel powered. These generators are also used when the primary cooling system fails. A large part of the reefers is cooled by cold air. The refrigerant flows in a reefer are shown in the Figure below. There are also reefers to be cooled with ice or a water system. This system is shown in the following figure 6.

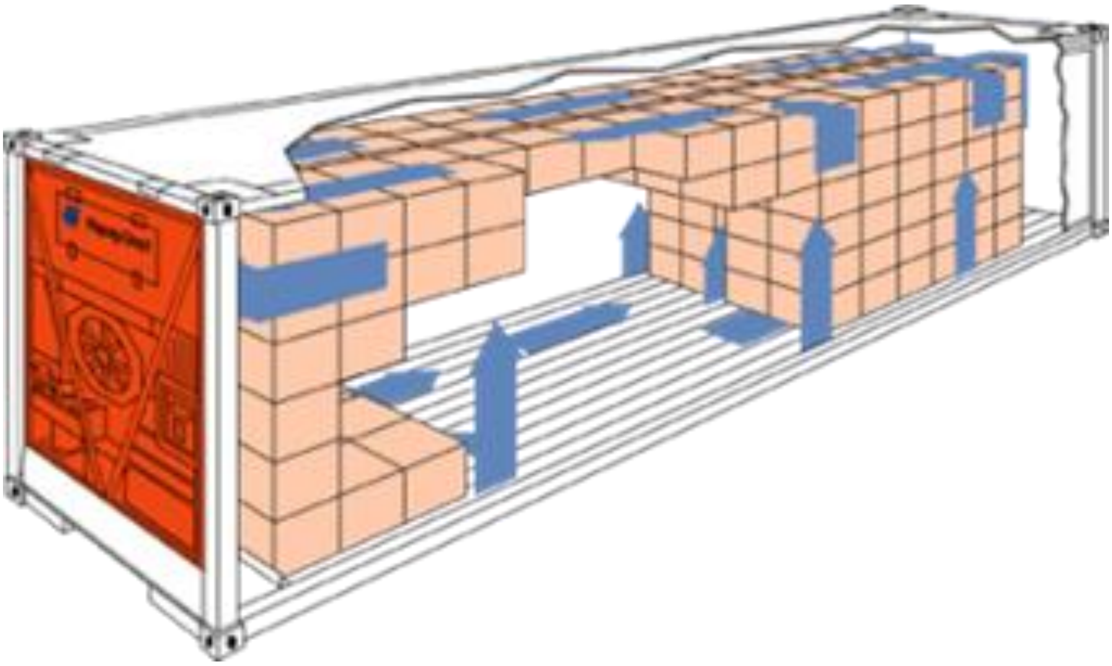


Figure 6: Cool air ventilation within a reefer

During the deployment of the terminal, reefers are especially remote inspected by computers. Based on the digital monitoring irregularities can be quickly traced, and any defects can be corrected quickly. This is to prevent damage to the cooled products, if a cooling system fails or does not function sufficiently.

With respect to the power consumptions of the reefers there are strong deviations due to the fact different container types are on the market. In addition, Carrier Transicold Container (producer and developer of reefers) contributed to our research by providing the energy consumption of cooling systems of three types of reefers: The Thin Line, Elite Line and Prime Line. The Thin Line is the oldest type of reefer and has spent 25 years on the market. The Elite Line was introduced in 2001 and delivers optimal performance in extreme conditions at sea, in particular by a patented built-in compressor. The Prime Line is the newest of the three types of containers and provides better performance in terms of energy consumption. This is the Prime Line is the most energy-efficient reefer in the world. These energy consumption data are presented in Table 1.

Table 1: Part Load Power Consumption @ 60Hz (Unit operating with no heat load inside box) (Carrier Transicold Container (2012))

Setpoint / Ambient °C (°F)	Goods	ThinLINE kW	EliteLINE kW	PrimeLINE kW
14/25 (57/7)	Bananas	4.7	4.1	2.7
5/25 (36/77)	Pharmaceutical goods	4.9	4.2	3.1
2/25 (33/77)	Fruit & Vegetables	5	4.2	3.1
-18/25 (0/77)	Meat & Poultry	2.2	2.4	1.8
-29/25 (20/77)	Seafood	3.1	3.0	2.6

Another fact causing different energy consumptions are the different temperatures within the reefers. Since only five temperature interval are given, we have made the following assumptions to complete the whole temperature interval from -25°C until 26°C:

- The temperature between the four provided temperatures (-29°C, -18°C, -1°C en 14°C) follows a linear line;
- The energy consumption (in kW) above 14°C is equal to the consumption of 14°C (straight line);
- The maximum interval is from-26°C to 25°C, because these values have been recorded by ECT during the month May 2012.

The following graph (Figure 7) was constructed.

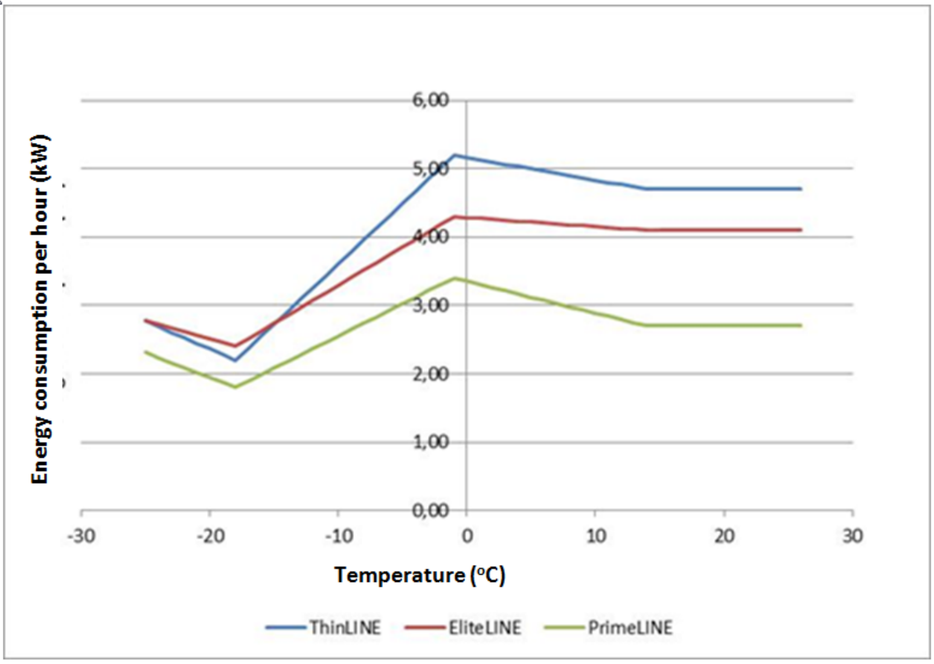


Figure 7: Energy consumption (kW) per reefer type reefer between -26°C and 25°C, based in Table 1

Knowing the main seaborne reefer cargo distribution and the power consumption patterns for the three representative "Carrier™" reefer types, the reefer dwell-time (in the stacking yard) is also an important variable, which affects the reefer energy consumption directly. Based on the interview with Mr. Stef Capelle (June, 2013), the environmental manager of Rotterdam ECT terminal, the average reefer dwell time is 5.33 days, most likely with a deviation of less than 2 days. This implies that most of the reefer containers at the ECT terminal have a dwell time between the 3 days and 7 days (Stef Capelle, 2013).

Transferring this information into real data we assume that the container dwell time fits well the normal distribution represented by $n(5.33,1)$. Based on this normal distribution the container dwell times can be represented in the following figure 8:

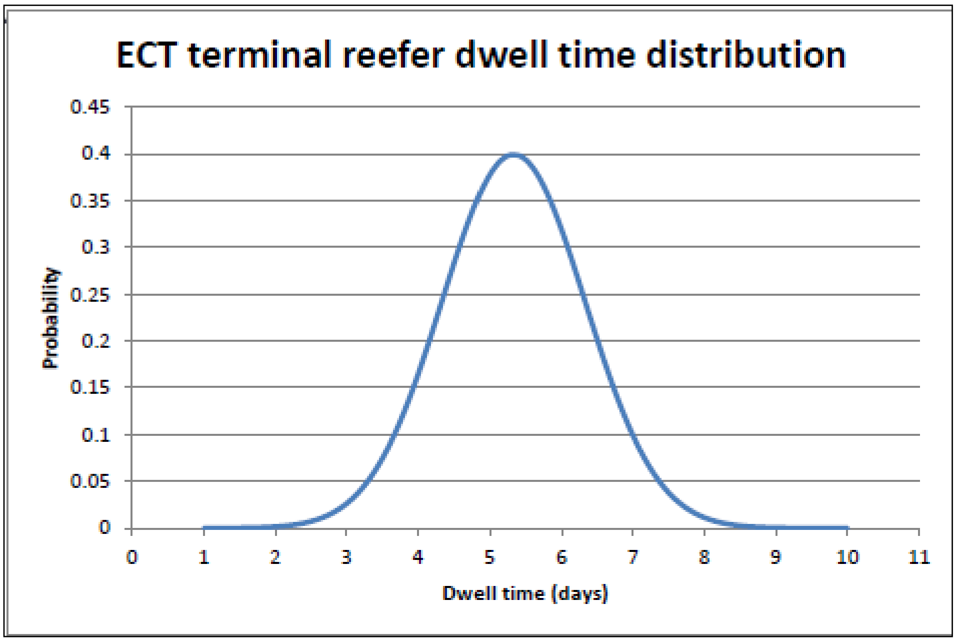


Figure 8: Dwell time distribution at ECT

5.2 Step 2: Analytical model

The energy consumption of reefer containers is determined by two main factors.

The first factor is the cooling power (watt) of a reefer. The cooling power is largely determent by the type of reefer (manufacturer etc.) and the set-temperature of the reefer. Depending those factors the reefers consume a certain amount of energy.

The second factor is the (average) stay of a reefer at a container terminal, this is called the dwelling time. When a reefer arrives at the container terminal by vessel it has to be transported to the stacking yard for further transport. During this dwelling time the reefer container consumes electricity to maintain normal working conditions. The longer the dwelling time the more energy is consumed by the reefer containers.

The third aspect of reefer energy consumption is the number of reefer containers at a container terminal. The more reefer containers there are, the more energy is consumed by reefer containers.

Based on these factors we can construct a analytical model (figure 9) which describes the total energy usage of reefer containers.

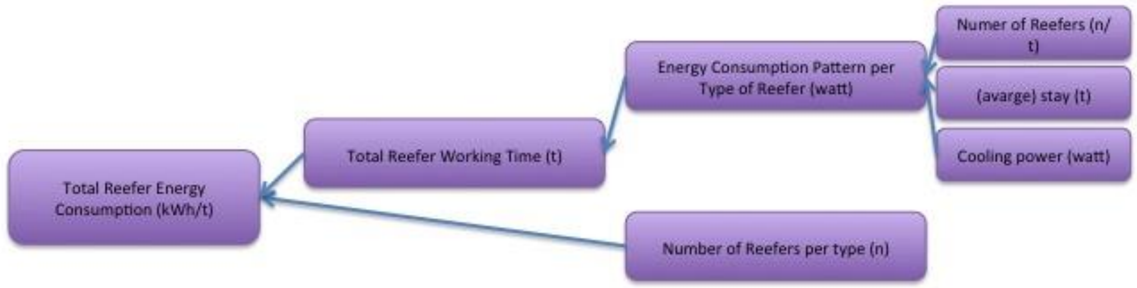


Figure 9: Analytical model energy consumption reefers

5.3 Step 3: Algorithm

The energy consumption of the reefers is measured on the basis of the power (in watts) of the cooling systems in the reefers. One watt is equal to one joule per second. If a device with an output of 1kW (= 1000 J/s) for one hour (= 3600 seconds) is on, this amounts to a total energy of 1000 joules / second x 3600 seconds = 3.6 million joules, or 1 kWh.

Because it is so important to know how many hours reefers at the terminal have been, first the number reefer hours are calculated. The number reefer hours (H_r) are measured by the annual number of reefers (N_r) multiplying the average duration $Tavg_r$(in hours) of a reefer.

$H_r = N_r * Tavg_r$ (hours)

Next step is calculating the total energy per year by multiplying the total number reefer hours (H_r) multiplied by the power consumption of the reefers (P_r). in kWh.

$P_{tot} = H_r * P_r$ (kWh) **(2)**

Then, the total CO_2 emissions are calculated by multiplying the total energy consumption (P_{tot}) with an emission factor. This emission factor is 0.625 kg CO_2 per kWh (Ministry of Economic Affairs, Agriculture and Innovation).

5.4 Step 4: Application of the Model

Because large amount of reefers stacked at the terminal, the various reefer cargo, the different types of reefer and the stochastic dwell times implies that the individual reefer energy consumption varies quite randomly. "Monte Carlo" simulation is a feasible solution for this random process, with a large amount of repeated experiments, this large amount of date results will give a rough realistic estimation of the reefer energy consumption. The following Figure 10 shows the algorithm for the of Monte Carlo simulation:

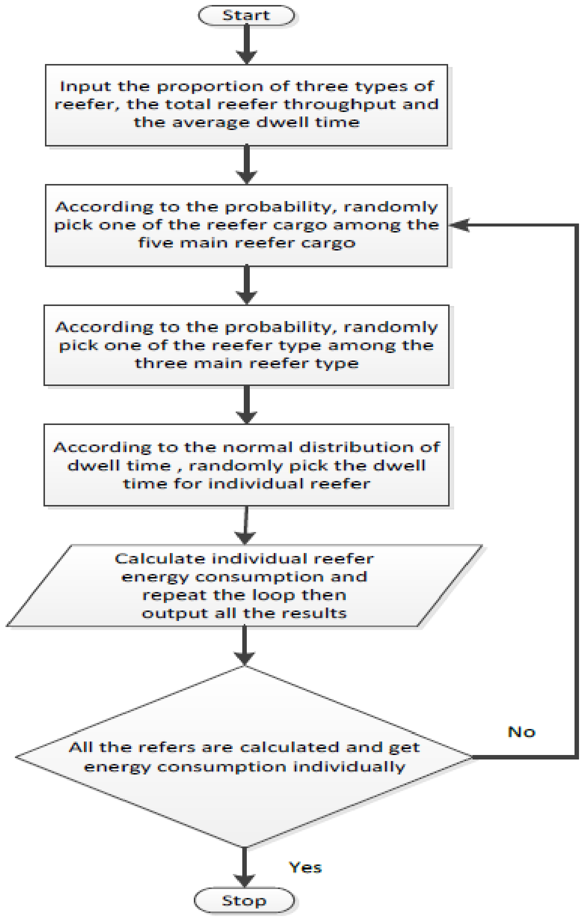


Figure 10: Flow diagram of the Monte Carlo simulation of the reefer energy consumption

As an example of a simulation experiment based on an assumed proportion of 40% "ThinLine", 35% "EliteLine" and 25%"PrimeLine", equal cargo distribution and an average dwell time of 5.3 days he following simulation results are obtained for 1500 reefers:

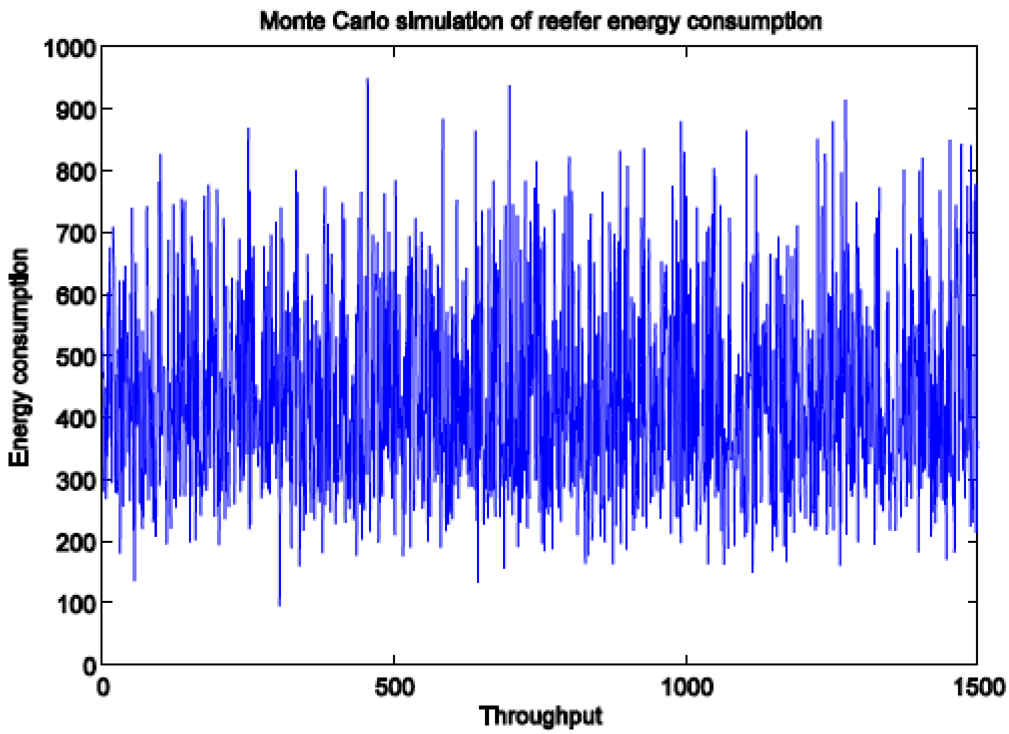


Figure 11: Simulation of the individual reefer energy consumption

In the above Figure 11, the Y-axis represents the energy consumption of individual reefers in kilowatt hour (kWh); the X-axis represents the throughput number of reefers.

After the simulation of all the individual reefers, the total energy consumption can be calculated. In the above Figure 11, the total energy consumption is 650,991 kWh for 1500 reefers. The average energy consumption is 434 kWh with a standard deviation of 158 kWh, minimum value of 95 kWh and maximum value of 949 kWh. The following figure 12 can be obtained from the calculations:

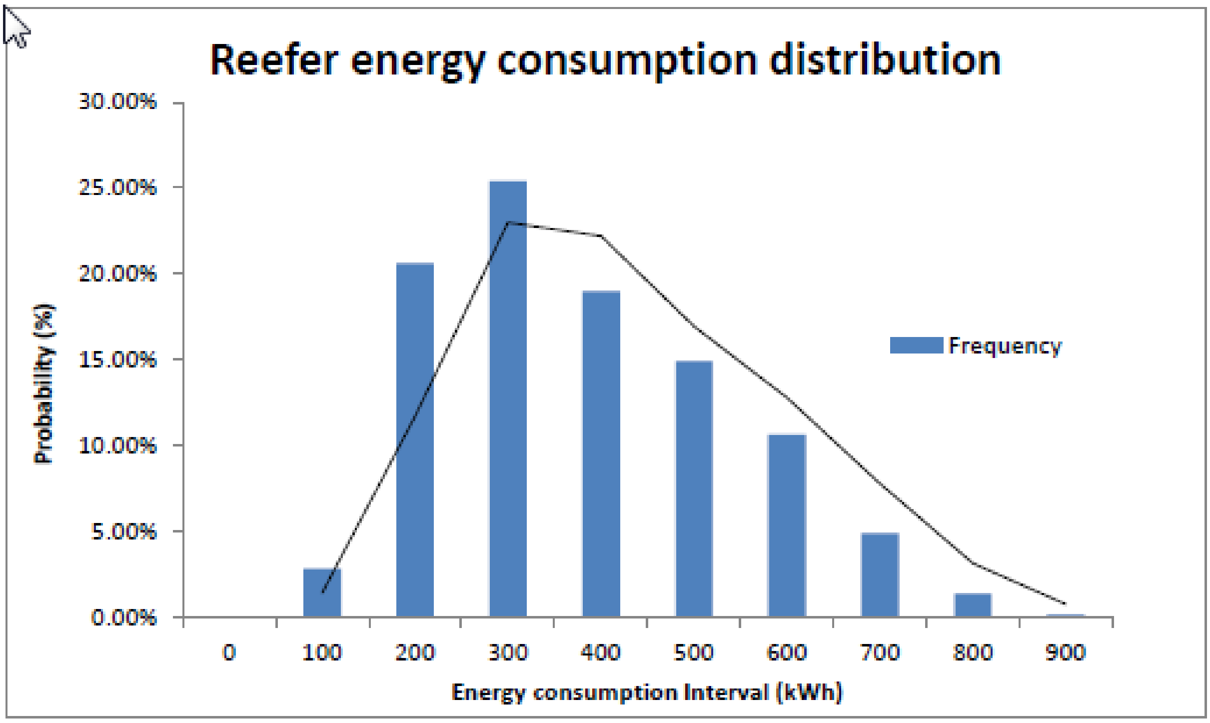


Figure12: Probability diagram of reefer energy consumption based on (40%/35%/25%) reefer type, equal cargo distribution, n(5.3,1) dwell times (number of reefers 1500)

Remarkable in Figure 12 is still a Gamma-shaped distribution instead of the shape of a normal distribution. The influence of the reefer-types is well visualized. This indicates the importance of their usage.

5.5 Step 5: Validation

According to the reference, the Rotterdam ECT terminal handled 15831 reefers for the month May of year 2012, with a mean dwell time 5.33 days (van Duin & Geerlings, 2013). Until now the sensitivity analysis is based on the following twelve scenarios.

Table 2: Specification of the scenarios

Scenario	ThinLine(%)	EliteLine(%)	PrimeLine (%)	Throughput	Mean Dwell time (day)
1	33.33	33.33	33.33	15831	5.33
2	100	0	0	15831	5.33
3	0	100	0	15831	5.33
4	0	0	100	15831	5.33
5	50	50	0	15831	5.33
6	50	0	50	15831	5.33
7	0	50	50	15831	5.33
8	33.33	33.33	33.33	17414	5.33
9	33.33	33.33	33.33	15831	5.86
10	23.33	33.33	43.33	15831	5.33
11	32.33	23.33	43.33	15831	5.33
12	23.33	43.33	33.33	15831	5.33

Summary results from the scenarios can be shown in Figure 13:

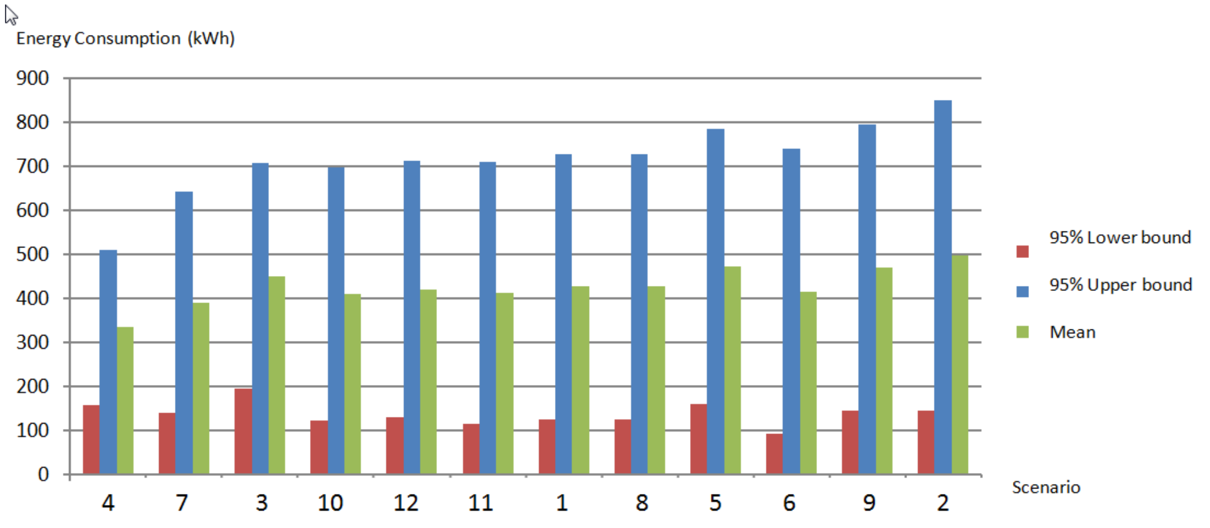


Figure 13: Average reefer energy consumptions in the scenarios

Interesting is the comparision between scenario 1 and scenario 10, where only 10% of ThinLine usage is changed to PrimeLine. Here the average reefer energy consumption decreases with 17 kWh and the standard deviation also decreases with 7. Another interesting comparison is scenario 1 and scenario 11, where 10% EliteLine changed to PrimeLine. Here the average value decreases 14kWh, and the standard deviation decreases with 2. In general we can conclude that the reefer type has the most dominant influence on the total energy consumption. Scenario 4 with 100% usage of Primeline reefers supports this conclusion with the lowest average energy consumption of 334 kWh and the smallest 95%-confidence interval, which is important since the energy tariff structures are based on peak prices. This conclusion can provide us new directions for policy advices.

Interfering factors that might influence the results:

- Sun light intensity. The energy consumption of reefers is mainly determained by the energy that is used for cooling. Environmental factors can influence this process. When a reefer is in a cold environment it needs less cooling power in comparison with warmer environmental conditions. This also applies for the sun light intensity. When reefers are placed in direct sunlight the containers assimilate heat that leads to more energy consumption.
- Storage conditions. Directly derived from above the storage conditions (sun shading, wind shading, roofs etc.) of reefer containers influence the energy consumption.
- Certification of container

Figure 14: Interfering factors

5.6 Step 6: Policy Recommendations

Based on our findings we can construct recommendations. The first recommendation is to promote the use of more energy efficient reefer types. Newer reefer types are becoming more energy efficient, so the use of these newer types leads to less energy consumption.

There are also improvements possible on the terminal. We found out that the reefer energy consumption is heavily influenced by external factors and by eliminating these we can make big improvements. The first recommendation is to use sun shading above reefer stacks. On most terminals reefers are places in stacks just like normal containers. But the sunlight can warm reefers so that they need more energy to maintain their temperature. By shading the reefers from the sun we can make improvements. This can be done by using reflective paint on reefers but also by placing a reflective roof over the reefer stacks.

The last recommendation is to use smart grids for energy recuperation.

On most terminals reefers are stacked on a place that is reserved for reefers.

6 Yard Lighting

Lighting is one of the important consumers of energy at terminals. The container operations at many terminals is 24-hours handling, so during night-time the lighting system is an absolute necessity to safeguard the operation process. At these 24-hours operation terminals their lighting systems for the stack areas and quay walls are working almost half of the whole day. For this reason the lighting system is also an important part of the energy consumption, which should not be neglected. For example The Noatum container terminal Valencia (NCTV), which is the main terminal at Valencia port, the terminal lighting consumes 2.438.803 kWh electricity, which counts 13% of total yearly electricity consumption (2011).

6.1 Step 1: Describing the Process

The light in the stack area of terminal is almost everywhere high mast lighting, which consists of poles with horizontal arms to support the lamps. The lighting category is floodlight, which is emitted by high pressure sodium (HPS) lamps, which are the prime used lamps for both crane and mast lighting. Some ports have introduced a new technology of lighting which reduces the electricity consumption, for example LED (Light Emitting Diode). According to the literature comparing the LED light with the conventional light, LED light consumes only one third of energy consumed with traditional light (Anderson, Edition 54). Except for the high mast lights additional illumination is needed for other parts of the terminal. For example for the quay operations there are also light equipped cranes.

At the port, the high-mast lighting with high power are always used for the terminal operation area and the stacking area. The setting of high-mast lighting is quite important to the whole port operation. Arrangement of the lighting infrastructure affects the operation efficiency of night working conditions and the safety of people directly. With the increasing amount of container throughput at the terminals, the terminal operators pay more attention to the issue that how to reduce the energy consumption of lighting and to ensure visibility and security. The high-mast lightings of stacking yard are always settled at the edge of the stack area or road, which makes enough lighting in operation area, less affected by the obstruction to satisfy the minimum illumination requirement in some place far from the lighting source.

According to the port lighting construction standard, the height of the high-mast lightings should between 30m to 40m, and the intervals between two adjacent high-mast lights are 3-5 times the mast length (Walls, Edition 28). The average luminance in stacking yard should more than 15 Lux. For some areas it is some recommended to change the average luminance. The following port and terminal lighting illumination data are from the "Illuminating Engineering Society" (IES) designer's handbook for reference only:

Large open areas	5-20 Lux
Buildings/Containers	5-20 Lux
Perimeter fence	5 Lux
Entrances	100 Lux
Gatehouses	30 Lux

The light at the port should give the good light control, less light overspill, decrease upward light and glare.

Abacus® lighting is a world leading lighting producer, especially in outdoor lighting with large open areas. In order to obtain some approximate technical information we used Abacus lighting as reference as input for our model, such as the height of high-mast light, the number of bulbs which are installed on a single light, the power consumption (wattage) and the luminous flux (lumen)of each bulb. These data could be used as reference to give an approximate range for the each parameter in the lighting estimation model, which could lead to acceptable outcomes.

From the production recommendation of Abacus®, the "Challenger" series floodlights is feasible for large open area, especially the type "Challenger 1" and "Rhea" are suitable for port lighting, produced by Philips®. The following table 3 shows the technical information of lamps used in floodlight of ports:

Table 3: Technical data flood light lamps (Abacus)

Production code (Philips)	Lamp wattage	Color temp	RA	Lamp lumen output	Lamp current	Supply voltage	Total circuit power
MHN-LA2KW400V/842	2kW	4200K	80	220,000 lm	9.6A	380/400/415V	2105W
MHN-LA2KW400V/956	2kW	5600K	90	190,000 lm	10.3A	380/400/415V	2113W
MHN-LA1KW230V/842	1kW	4200K	80	100,000 lm	9.3A	230/240V	1040W

MHN-LA1KW230V/956	1kW	5600K	90	90,000 lm	10.1A	230/240V	1040W
MHN-FC2000W/740	2kW	4200K	60	210,000 lm	10.1A	380/400/415V	2032W
MHN-FC1000W/740	1kW	4100K	65	93,000 lm	10A	230/240V	1040W

These lamps are installed on the fixed high mast or base-hinged mast. Each high mast lighting generally has the capacity of 10-18 floodlight lamps (see Table 4).

Table 4: Technical information of high masts (Abacus)

Production code	Height (m)	Max head load (kg)	Floodlight capacity
GL52025SL	25	260	10
GL52025SH	25	530	17
GL52030SL	30	260	10
GL52030SH	30	340	12
GL52035SL	35	200	8

6.2 Step 2: Analytical model

The yard lighting energy consumption can be described in three separate factors. The first factor is the power consumption per light. The energy consumption of a light is determent by its energy consumption. The higher wattage is needed to deliver a certain amount of light the more energy is used. The second factor is the number of lights. Each light consumes energy, the more lights that are used for the yard lighting the more energy is consumed by these lights. The last factor is the yard lighting operating time. The longer the lights are operating, the more energy is consumed by these lights.

Based on these factors we can construct a analytical model which describes the total energy usage of yard lighting (figure 15).

Figure 15: Analytical model energy consumption lighting

6.3 Step 3: Algorithm

Some basic optics terminologies are described in the Appendix XXX. The Luminosity "E" can be calculated by the height of the light pole is "H" (the bulbs are installed on the head of the pole), the distance between the bottom of the pole and illumination point is "X", and the distance from the head of pole directly to the illumination point is "Y". According to Pythagoras theorem, the relationship among X, Y and H is as Figure 16:

$Y=\sqrt{(X^2+H^{2)}}$

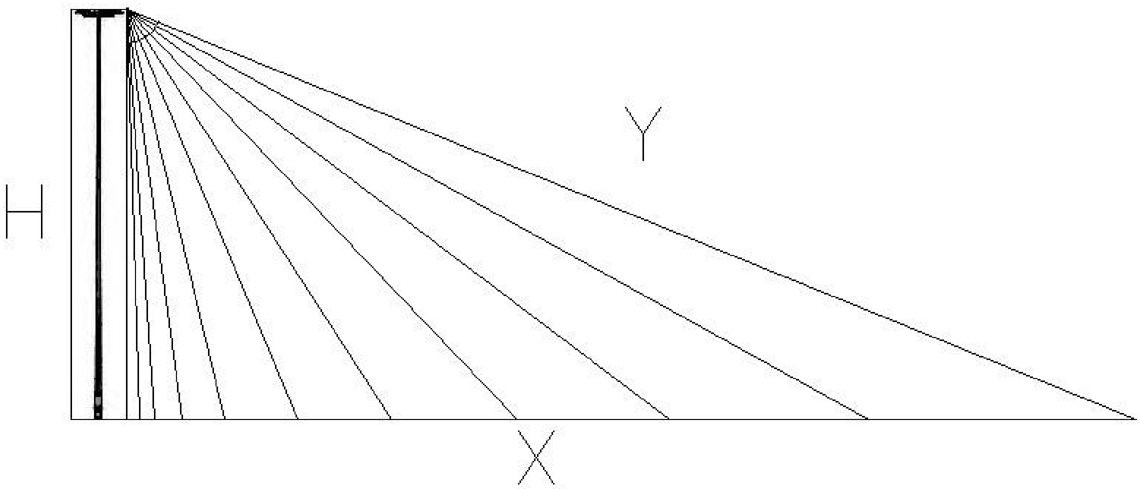


Figure 16: Single light illumination

This leads to:

$\cos\alpha = H/Y = H/\sqrt{(X^2+H^2)}$

where α is the angle between the mast and the light arrow.This will be combined with luminosity formula where "I" is the luminous intensity an :

$E = I \cdot \cos\alpha / R^2 = (H/\sqrt{H^2+X^2}) \cdot I/(H^2+X^2)$

This formula expresses the relationship luminosity and luminous intensity with different distance, if the height of pole H is fixed, the variables will be the luminous intensity "I" and the ground distance "X".

The lighting illumination range is normally distributed as a circle, the luminosity decreases progressively from the center to edge. If we observe the luminosity from top, the following Figure 17 can be produced (in matlab) where the different colors mean the different illumination levels, so the color changes slowly from the center to the edge.

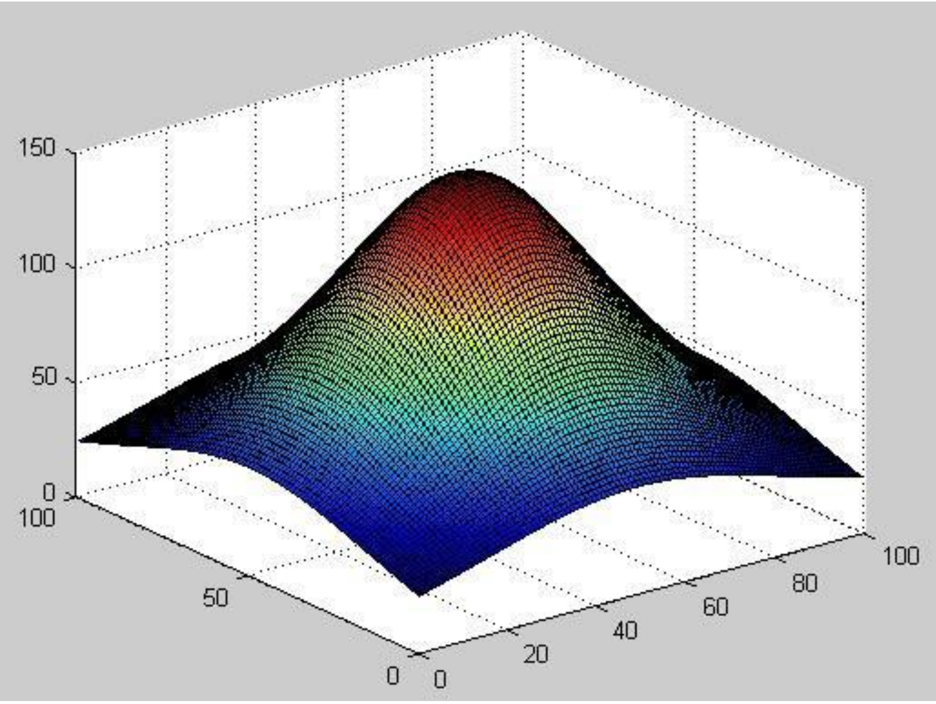


Figure 37: Single light illumination decreases progressively(3D original view)

In the above figure 17, the X-axis and Y-axis are the length and width of stacking yard in meters, the Z-axis represents the illumination intensity(E) in Lux.

As an example application of luminosity formula is shown for a lighting pole with a height of 40 meter and an illumination intensity of 255000cd leads to the following Table 5.

Table 5: Single light illumination with distance (H=40m,I=255000cd)

X=distance(m)	5	10	15	20	25	30	35	40	45	50
E=illumination intensity (lux)	155.7	145.5	130.8	114	97.1	81.6	67.9	56.3	46.7	38.8
X=distance(m)	55	60	65	70	75	80	85	90	95	100
E=illumination intensity (lux)	32.4	27.2	22.9	19.4	16.6	14.2	12.3	10.6	9.3	8.1
X=distance(m)	105	110	115	120	125	130	135	140	145	150
E=illumination intensity (lux)	7.1	6.3	5.6	5	4.5	4	3.6	3.3	2.9	2.7

6.4 Algorithm to calculate the lights needed

For this method the whole stacking yard is represented as a matrix consisting a small square. The lighting luminosity is calculated with the previous formula. The algorithm starts:

A. At first, the matrix is empty; the value for each cell is zero.

B. Get the rate of the length and width of rectangle stack yard.

C. Put the light as the "i" rows and "i*rate" columns which split the row and column averagely ("i" start from 1).

D. Calculate the illumination level in each cell of the matrix, as the new value for each cell. The new value will be added to the previous value for each cell.

E. Check value of all cells, if the value for some cells is below 20 Lux, then repeat step C (i+1).

F. Until all the cells in the matrix the illumination level is just above 20, stop this algorithm.

6.5 Step 4: Application

This algorithm is programmed in Matlab. As described inputs are the length and width of stacking, the height of high-mast light and the total illumination intensity of one light. Based on these four variables the automated lighting configuration will be determined a feasible configuration. In Table 6 an example is given for a light pole of 40 meter height and illumination intensity of 300000cd of one light.

Table 6: Single light illumination with distance (H=40m,I=300000cd)

Size of stack yard	Result number of rows	Result number of columns
L: 500m W: 300M	2	4
L: 1000mW: 500m	4	8
L: 1300m W: 700m	4	10
L: 2000m W: 1000m	6	12
L: 3000m W:1000m	6	18

6.6 step 5: Validation

In our case we selected the Maasvlakte I-terminals (ECT+APM) as an example to validate the model. The next Figure 18 is the terminal map obtained with "Google earth"; the length of the terminal is around 2700 meter and the width of the terminal around 900 meter. The high-mast lights are all marked as red circles.

From the map it can be observed that approximately 70 lights are arranged in the stacking yard in reality. Based on our model calculations with length 2700m, width 900m, 45m height, and 280000cd lights the calculated light configuration is 5 rows and 15 columns, so totally 75 lights. Accordingly these numbers are rather close and also the calculated Figure 19 shows almost an identical configuration.

Figure 18: Lighting configuration at Maasvlakte I-terminals

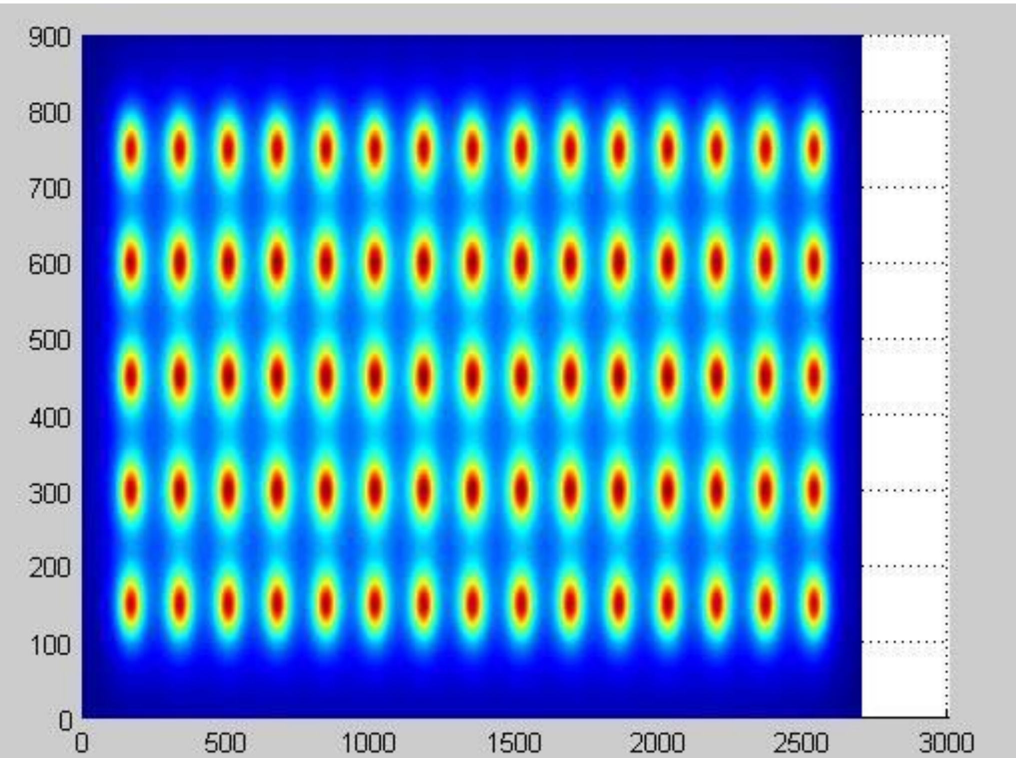


Figure 19: Theoretical configuration lighting Computerized model of the lightning configuration at Maasvlakte I using light poles wit h=45 m and I=280000cd

Interfering facts that might influence the results:

- Security requirements (US Home Act). Due to security requirements there are guidelines for the light intensity on container terminals.
- Maintenance requirements
- Working and safety conditions (LED). LED's become a good, low energy, alternative to more traditional lights. However LED lighting can have side effects. Some people experience health issues, like headaches and nausea, caused by the LED's.

6.7 Step 6: Policy Recommendations

Based on our calculations we come to the following recommendations regarding terminal lighting. The first recommendation is to promote more energy efficient lights on terminals. Switching to LED lighting can make significant progresses. LED's can generate the same amount of light as conventional lights but use far less energy. But besides LED there are more technological developments in this area like using infrared lighting or use high-pressure sodium lights.

Improvements can also be made on organisational levels. Nowadays most terminals are fully illuminated which cost a lot of energy. We recommend to make differentiations in the lighting of different area's. for instance only full illumination for areas with work activities. This recommendation may interfere with security requirements but there can be tailor made solutions like combining visible lighting with infrared lighting for monitoring.

7 The complete model

The 6-step approach, an analytical model to calculate the energy consumption and related CO_2-footprint of container terminals, appears to be a useful tool for analysing the energy consumption of all terminal operations. The structure of the model is based on three clusters of sub-modules of processes that cover more than 95% of all energy consumption at the terminal. Each cluster is supported by a software tool and a data base which makes it possible to calculate the energy consumption of one specific terminal or to benchmark more terminals in a systematic way. The three modules combined are presented in figure 20:

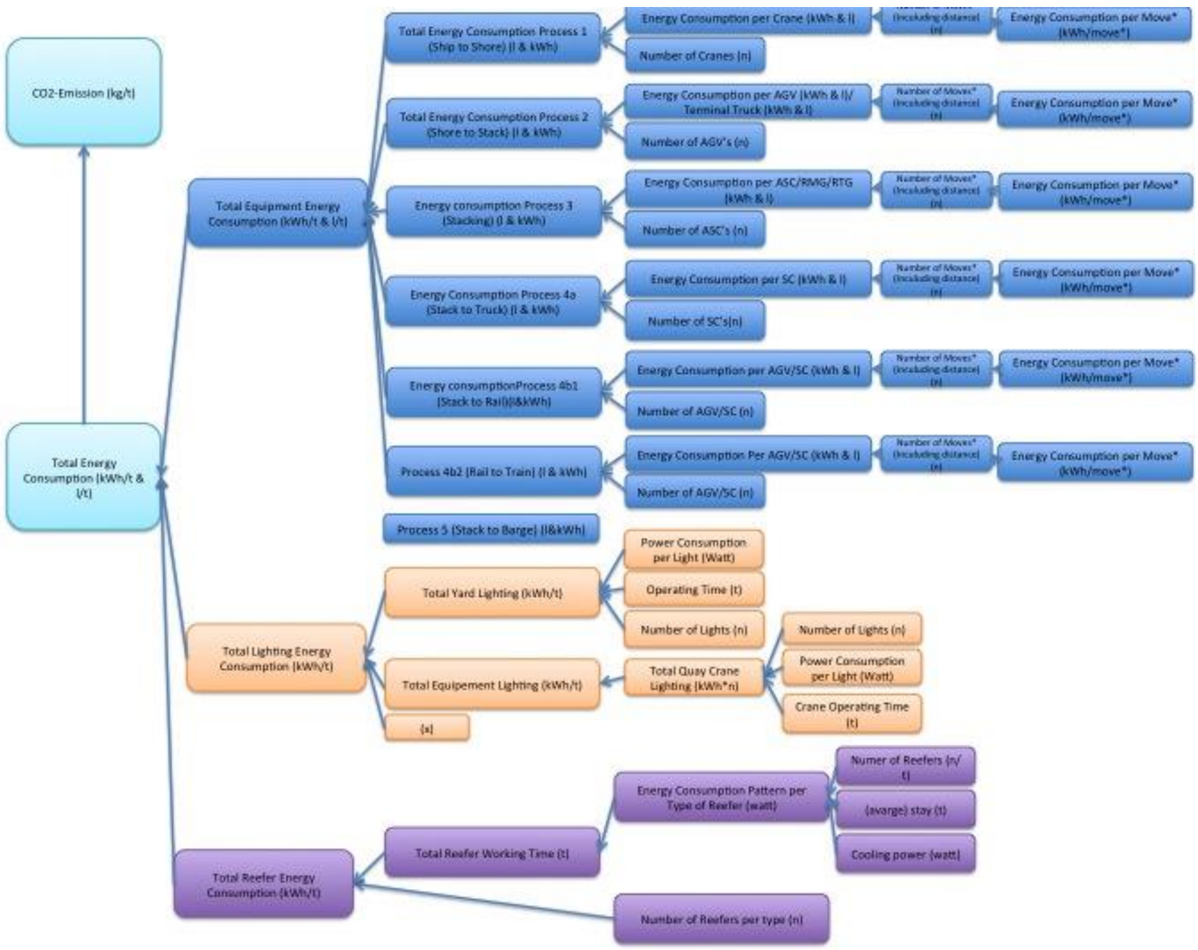


Figure 4:Complete configuration of the 6-step approach

Another important characteristic of the 6-steps approach is the fact that the methodology is coherent with the CEN standard CEN 16258 "Methodology for calculation and declaration of energy consumption and GHG emissions of transport services (freight and passengers)". This CEN standard contributes to the standardisation, comprehensiveness, transparency, consistency, generalization and predetermination of the calculations of the energy consumption in the 6-steps approach.

Therefore, the outcomes of the 'top-down model' offers good opportunities for generic recommendations as well as specific and tailor made recommendations. In general a classification can be made between suggestions in terms of hardware, orgware and terminal lay-out. But the outcomes of the model also indicate that it will become more relevant to make a distinction between old and new terminals as well. The old terminal operate with equipment and rolling stock fuelled by diesel and many of the recently constructed terminals, especially in Western Europe such as the three latest terminals in Rotterdam, are nowadays 100% electricity driven.

By this observation we enter a new domain of solutions/recommendations. Within the GreenEFFORTS-project a lot of attention is given to new phenomena's such as peak-shaving, idling conditions of cranes, smart grids, lighting of the terminals and cranes, etc. We see that now already new trends are coming up. As an illustration: until three years ago, the operations at the terminals were mostly motivated by the speed of operations, nowadays we see that not the logistic processes, but the capabilities and capacity of the equipment determine the operations. Another observation is that the focus until today has been one sided on efficiency, nowadays we see some signs of a new awareness raising with respect to the costs of energy and the fact that there might be a trade-off between efficiency and energy consumption. We also see a development toward specific requirements, like requirements based on the US-home security act, the negative external effects of terminal operations, etc.

This brings us to the final conclusions with respect to the implementation of the 6-step approach. We are convinced that there is a wide range of interested stakeholders that can use this new top-down model. These are: terminals, the port business community, port authorities, governments (local, regional and national), the E.U. and internationally operating agencies such as the WorldBank/IMF/OECD, etc. As these organizations serve different goals, we come to the following generic conclusions:

- It is important that stakeholders understand and respect the complexity of the field of energy consumption in terminals. But it is important to stress the need for sustainability in port operations;
- When the 6-step approach is carefully implemented the application of tool contributes as a basis for training investment (rising awareness and motivation to use energy competently and thoughtfully), organizational

investment (modifying operations to increase productivity versus energy consumption), technical modification investment (modifying equipment and systems to reduce consumption/increase productivity), technical purchase investment (put new equipment/systems into operation).

- In the management culture attention has to shift towards the moderation of concerted demand - supply management of port industries;
- An upcoming priority will become the reduction of ship-induced emissions from vessels berthed, management of peak shaving and smart use of energy also in nonpeak hours
- Terminal operators act in a very comparative environment. This makes that that there is a lot of confidential data at stake. It should be respected that this data cannot be easily distributed into the public domain.
- Therefore it would be an important step forward when port authorities and governments facilitate, an independent knowledge base and network that can report on the progress made - There is a need for a 'white knight' that can maintain a clearing house.

Therefore, the 6-step approach is a source for inspiration, it gives structure to process and the methodology recognizes the new challenges: it can be applied as a pro-active methodology that addresses the economic (profit), environmental (planet), and social objectives (people) in one coherent strategy. By doing this, the 6-step approach offers an opportunity for cooperation and interaction between the private firms such as the terminal operators, the wider port community, governments and civil society to fulfil the changing needs of society.

Given the competitive environment with respect to terminal operations, this report makes only use of data that is publicly available. The GreenEFFORTS team has the availability of other data as well, but the dissemination of this data is restricted due to Confidentiality Agreements.

References

Findeisen, W., & Quade, E. S. (1985). The methodology of systems analysis: an introduction and overview. *Handbook of systems analysis: Overview of uses, procedures, applications, and practice*, 117-149.

Geerlings, H., & Van Duin, R. (2011). A new method for assessing CO 2-emissions from container terminals: a promising approach applied in Rotterdam. *Journal of cleaner Production*, *19*(6), 657-666.

Lempert, R., Nakicenovic, N., Sarewitz, D., & Schlesinger, M. (2004). Characterizing climate-change uncertainties for decision-makers. An editorial essay. *Climatic Change*, *65*(1), 1-9.

Murty, K.G., Liu, J., Wan, Y., Linn, R., 2005. A decision support system for operations in a container terminal. Decision Support Systems 39, 309e332.

Oonk, H., 2006. Emissions to Air Due to Activities on Container Terminals and Future Developments as a Result of Autonomous Developments and Additional Measures. TNO Built Environment and Geosciences TNO, Apeldoorn.

Saanen, Y., & Rijsenbrij, J. C. (2007). Which system fits your hub?. *Cargo Systems*.

Sargent, R.G., (2010). Verification and Validation of Simulation models. In B. Johansson, S. Jain, J. Montoya-Torres, J. Hugan, & E. Yücesan (Eds.), *Proceedings of the 2010 Winter Simulation Conference* (pp.166-183). Piscataway, New Jersey: IEEE.

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