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DOI
10.2495/TDI-V1-N2-212-224

Publication date
2017

Document Version
Final published version

Published in
International Journal of Transport Development and Integration

TOWARDS A METHOD FOR BENCHMARKING ENERGY CONSUMPTION AT TERMINALS: IN SEARCH OF PERFORMANCE IMPROVEMENT IN YARD LIGHTING

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ABSTRACT

The growth in container volumes over the last decades means an increase in container handling at terminals around the world. Notwithstanding the economic benefits, container handling causes additional pressure on the surrounding infrastructure and the environment. This is happening precisely at a time when environmental issues, in particular CO_2 emissions, are the main concern of the energy and climate change debate. Although not specialized in the field of energy consumption, many policymakers and managers need to make decisions about reducing CO_2 emission. This paper provides a six-step approach to make energy consumption (and hence CO_2 emissions) easily transparent. The approach is illustrated using the energy consumption of yard lighting. It can be concluded that our first attempt to understand the energy consumption of yard lightning gives promising results that can contribute to an improved benchmark for the CEN EN 16258 standard.
Keywords: benchmark, energy consumption, terminals, yard lighting.

1 INTRODUCTION

Over the last decades, global freight transport has grown spectacularly; no less than 90% of all freight cargo worldwide takes place via the oceans and ports [1]. So much welfare in today's world is facilitated by ports and their related activities: ports are the locations where trade, logistics and production converge. This phenomenon is particularly reflected in the advances achieved in container transport. The maximum capacity of containerships, for instance, doubled within 10 years from 10,000 TEU (twenty-foot equivalent units) to 20,000 TEU. The container terminals in deep-sea ports are facing the big challenge of handling export, import and transhipment by an increasing number of containers [1].

The European Commission is very active in providing a framework to foster a sustainable energy policy. With 1990 as the reference year, the European Union (EU) is committed to reducing greenhouse gas emissions to 80%–95% by 2050. The EU's ten-year growth strategy *Europe 2020* sets five key targets, one aiming at climate change and energy sustainability, describing the 20-20-20 goals (reference year 1995):

- Greenhouse gas emission 20% lower;
- 20% of energy from renewables;
- 20% increase in energy efficiency.

For a long time, reducing container terminals' energy consumption was not considered a priority. An important reason is that terminal operators work under contractual agreements with vessel owners to berth the vessel within a strict and mostly tight time frame. As a consequence, these operations are placed centre stage in terminals' policies, and the energy bill

ISSN: 2058-8305 (paper format), ISSN: 2058-8313 (online), http://www.witpress.com/journals
DOI: 10.2495/TDI-V1-N2-212-224

is secondary. This mechanism becomes even stronger when terminal operators receive a discount for their high energy consumption. Investments in new equipment and operational processes to reduce energy consumption are always assessed against contractual obligations to ship owners and the price of energy.

Container terminals are under permanent pressure to increase productivity. A governing factor in equipment purchase, therefore, is the expected contribution to increasing productivity. Often, this results in installing bigger power units than required to fit with the terminal's process flow. It does not make sense, e.g. to increase ship-to-shore lifting and trolley speed if the ground equipment is not able to cope with this. Thus, one way to improve energy efficiency is to use smaller power units.

Nonetheless, energy consumption accounts for a large share of total operating costs, and there is fierce competition between different container terminals. This leads to a highly competitive market where rivals are very conservative in the publication of internal data relating to energy. Therefore, from an external policy perspective, it is hard to know/estimate their energy consumption.

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 taken mainly on the basis of the best berth for ships [2]. According to Verbeeck [3], most businesses pay no – or only very limited – attention to their energy consumption. In the design process for a container terminal, energy efficiency plays a key role, e.g. for stacking areas [4]. However, in practice, the layout of container terminals is often restricted by the local situation, and it may not be possible to go for the best design.

On the assumption that world trade will recover and return to healthy annual growth rates, transport will also grow. In order to meet the EU's 20% targets, the transport sector will be required not only to reduce its 1995 carbon footprint by 20%, but also to compensate for the growth that has occurred since 1995. This is a very ambitious target. Of course, the transhipment nodes, ports and terminals within the global supply chain contribute only a very small share to the overall transport carbon footprint. Although this is caused mainly by ships' emissions, the public and politicians have turned their attention to the ports. Besides ships, hinterland transport by trucks in many cities (see Antwerp and Hamburg) is also a significant source of emissions. Their resulting carbon footprint does not, however, cause much concern, although the PM (fine dust) from diesel is increasingly causing headaches.

The EU-facilitated GREEN EFFORTS project, a collaborative research project aiming to reduce energy consumption at terminals, commenced in 2012 and ended mid-2014 [5]. This paper, as part of that project, illustrates how to understand and eventually benchmark the energy consumption profile of a terminal, in this case more specifically for yard lighting. Detailed information on the project can be found in Cao [6].

This paper is organized as follows. Section 2 gives an overview of the policy initiatives to create a benchmark for energy consumption at terminals and positions our research. Section 3 describes our methodology for analysing and benchmarking energy consumption at terminals. Section 4 contains the methodology for measuring the energy consumption of yard lighting. Section 5 ends with a discussion and conclusions.

2 ENVIRONMENTAL STANDARDS AND BENCHMARKS

The European Bank for Reconstruction and Development (EBRD), partly owned by the EU, now includes sustainability requirements in its infrastructure financing contracts. Ports and terminals must submit an Energy Efficiency Action Plan when they apply for funds. The ISO

50001 standard provides some guidance to establish an energy management policy. There are, however, many other standards relating to energy management. This complicates identification of the most effective and efficient method.

The ISO 14000 family of standards provides a rather bulky framework for environmental management systems (EMS) and methods. This places quite a burden on managers with operational responsibility and who hence cannot focus solely on standards. It is obvious that a pathfinder is required. In the literature, the EcoPorts/ESPO provides guidance for a port-related management framework (called the port environmental review system (PERS)) jointly with the self-diagnosis methodology (SDM) [7]. Other standards that look beyond a management system towards measurements and calculations to achieve measurable results are:

- ISO 50001:2011 energy management systems – requirements with guidance for use. It deserves special attention because it provides a framework and a structure for an Energy Efficiency Action Plan.
- EMAS (Eco-Management and Audit Scheme) is an environmental management scheme based on EU Regulation 1221/2009.
- EN 16258 (CEN Standard) is a methodology for calculating and declaring energy consumption and greenhouse gas emissions in transport services (all modes, goods and passengers).

The new CEN standard EN 16258 – published spring 2013 – provides calculation methods to determine the carbon footprint of transport carriers such as trucks, ships, railways and airplanes, resulting in a carbon footprint figure per individual consignment. The introduction to the standard states: 'It is anticipated that future editions of the standard may have a broader scope boundary, to include additional aspects such as, transport terminals, transhipment activities, and other phases of the lifecycle.'

Investigation has shown that CEN EN 16258, as a product-oriented standard, does not meet the calculation and reporting requirements of ports and terminals. 'Product-related' in this context means that it is not only the total carbon footprint of a transhipment centre that must be reported, but also the share per product sold. A transport service moving commodities from A to B is also considered as a product. The difficulty lies in determining the footprint factors that must be derived from the average energy consumption of a container class. Currently, sufficiently comprehensive data are not available; therefore, the gaps must be filled by a model approach based on theoretical considerations, validated wherever feasible and later continuously improved over time. In cooperation with the authors of CEN EN 16258 therefore, the ISO working group agreed to draft a supplementary standard, meeting the needs and the opportunities of ports and terminals. It is a European standard, not yet accepted in the US and Asia. Therefore, this draft is still open for discussion.

3 THE SIX-STEP METHODOLOGY

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

In general, there are two types of modelling approaches: analytical and simulation [8]. Analytical models are abstract models to construct a systematic analysis of reality. If the analytical approach is applied, the actual situation and related problems will be simplified to enable formulation of a mathematical model. Such models, based on multiple criteria, will show the complex nature of terminal operations. In order to analyse overall performance, there is often a (hierarchical) subdivision for different sub-processes (see e.g. [8]). The advantage of these models is that they can provide a full and precise image of a system. The limitation of these models is that computational complexity could cause the inclusion of too high levels of detail. Such models therefore may not cover all the needs of professionals in specific fields.

To cope with the complexity of terminal operations, a common approach is to use simulation models to evaluate performance [9]. Simulation 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 to build a detailed and validated model. The advantage of the methodology developed in the GREEN EFFORTS project is that both an analytical model and a simulation model of a container terminal have been developed using the same database, so the outcomes will be coherent and comparable. To cope with the complexity of terminal operations, (micro-) simulation models are used to evaluate performances (see, for instance Refs [9–11]). The micro-simulation models break down to the smallest measurable connected components [12] and can be applied to any scenario involving complex vehicle interactions. They have been used to modal roads, railways and air- and seaports (see for instance Refs [13–15]). Angeloudis and Bell [16] provide a complete review of container terminal simulation models. With the exception of some publications [8, 17], most terminal simulation models, according to the literature review, are more focused on process optimization, and less attention is paid to improving energy consumption.

To build 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, a systematic and well-structured approach is used to determine the energy consumption of a container terminal as a whole and the sub-processes. Our approach consists of six consecutive

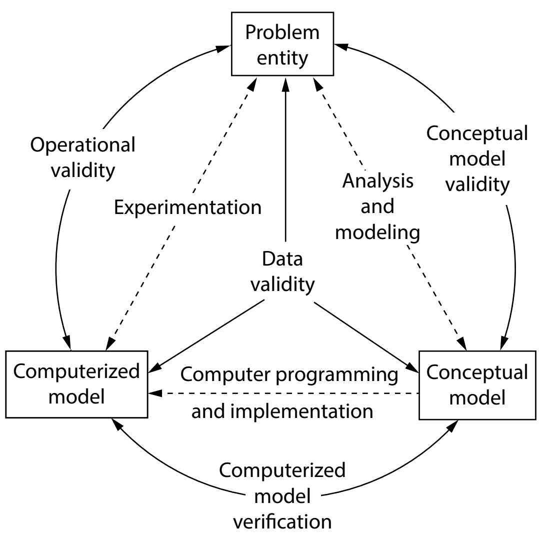

Figure 1: Simplified model of the modelling process [18].

steps that together provide a detailed insight into the energy consumption of each of the sub-processes at a container terminal. The six-step approach is congruent with Sargent's modelling paradigm [18] (see Fig. 1).

3.1 Methodology description

The first step is to describe the processes actually happening at a terminal (= *analysis and modelling*). The transhipment of containers at 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 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 in the model is to describe in detail the specific sub-processes at a terminal. This makes it possible to make substantiated estimations of the total energy consumption within a terminal process.

The second step is to construct a conceptual model of the observed activities of the sub-process (= *conceptual model validity*). In the analytical model, a detailed conceptual model of all the sub-processes is built. To create the analytical model, the same pattern is followed as described in the first step. So first all the sub-operations of a container terminal are analysed, and these insights are combined into a full model of the container terminal. In this model, both the equipment that is used in a sub-process and the energy consumption of this equipment are combined as an activity. This leads to a systematic overview of the different activities at the container terminal and explains how energy is used by the movement of containers at the terminal.

The third step is to translate the observed processes and the related conceptual model into a computerized model (= *computerized model verification*). With the computerized model, the total sum of energy consumption of a terminal sub-process can be calculated. To construct the algorithm, the various types of equipment, their contribution to the sub-processes and their energy consumption are taken into account.

The fourth step is to apply the model via a simulation (= *computer programming and implementation*). In this step, the constructed models are applied via a simulated container terminal based on both real and estimated data. With these simulations, it is possible to make a very precise estimation of the energy consumption of a container terminal.

The fifth step is to validate the data coming from the simulation (= *operational validity*). The simulations are based on a combination of real and estimated data. So the simulation models have to be validated in order to determine their deviation in comparison to the actual energy consumption of terminal equipment.

The final step is to make policy recommendations. Once the data are generated and validated, detailed policy recommendations regarding the energy usage of container terminals can be made by setting up experiments (= *experimentation*).

3.2 Application of the six-step approach to terminal operations and equipment

The development and application of this approach for the calculation of equipment's energy consumption in terminal processes have been well documented [19, 20]. The conceptual model shows the relevant factors that influence the consumption of fuels and electricity. Important factors for determining the total energy consumption are the average distance per container movement, total container throughput and terminal configuration. The research was validated for 95% of all the container terminals in the port of Rotterdam and three additional inland barge terminals. The estimations of energy consumption for electricity and diesel show close approximations of the real consumption patterns. This research shows that diesel-powered equipment is largely responsible for the total CO_2 emissions at terminals, largely caused by the terminal layout, which influences the duration of movements by terminal equipment. New designs of current terminal layouts could save up to 70% of current emissions. The first suggested policy recommendation is to achieve this reduction by minimizing the total distance covered by diesel-generated equipment. For example, currently most container terminals have a shipping line/import/export/feeder/truck/railway-governed stacking order. However, there is a good understanding of the energy-saving potential of stacking according to minimum transport distances and minimum re-stacking (only possible when pick-up data and mode are known; this often is still not the case), and terminal operating system manufacturers work to include this feature in their new generation of operating systems. The other suggested policy recommendation is to achieve a reduction by mixing the currently used diesel with biofuels. However, the research did not include the energy consumption of terminal lighting, and therefore this extended adaptation of the six-step approach is illustrated in this paper.

4 YARD LIGHTING ENERGY CONSUMPTION

At many terminals, the container operations continue on a 24-hour basis, and at night-time (almost half of the day) the yard lighting system is indispensable for operational processes. Adequate illumination results in safer and more efficient container terminal operations. Yard lighting accounts for a significant part of the energy consumption at a terminal. For example, at the Noatum container terminal Valencia (NCTV), yard lighting consumed 2,881,060 kWh electricity in 2012 or about 15% of yearly energy consumption [21].

For terminal operations, there are some standards for lighting design and arrangement. In order to meet the requirements for safe container handling and staff safety, the luminance in a whole stacking yard should be more than 20 Lux everywhere. There is also a recommended average luminance for ports and terminals categorized in different areas of the port. The following port and terminal lighting illumination requirements are derived from the Illuminating Engineering Society (IES) designer's handbook [22, 23]:

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

4.1 Conceptual model of the CO_2 footprint yard light energy consumption

In general, it is assumed that the lighting type used in the stacking yard of a container terminal for illumination is a floodlight on a high mast. The stacking yard is a large open area, and the floodlights arranged in this area could be assumed as 'point light'. To assess the lighting energy consumption, Fig. 2 shows the conceptual framework that provides a method for estimating the energy consumption and the related carbon footprint of the stacking yard lighting.

The model starts with the number of bulbs per light and the power consumption per bulb. The dark blue parts are the parts to be calculated. The number of bulbs and power consumption per bulb, the height of the lighting pole and the total yearly light working time are the input to this model. The illumination requirement of a container terminal is a constraint

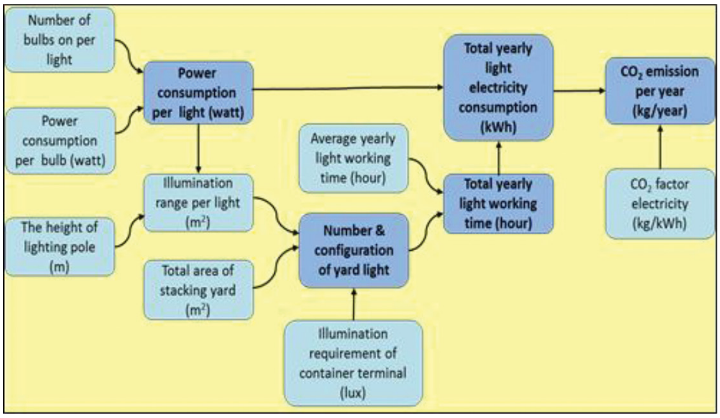

Figure 2: The conceptual model of CO_2 footprint yard lighting energy consumption.

depending on the area of the port [22]. The number of lighting poles can now be calculated. Based on this and the average yearly light working time, the total yearly electricity consumption can be calculated and subsequently be converted into CO_2 emissions.

4.2 Computerized model

The conceptual model of the yard lighting carbon footprint can be expressed in the following way:

$$M_L = S_T / S_L \times N_L \times P \times 365 \cdot T_L \cdot F \; (\mathrm{kg}), \tag{1}$$

where
S_T: The area of terminal stacking yard (m^2);
S_L: The area of each lighting illumination range (m^2);
N_L: The number of bulbs on each high-mast light;
P: The power of each bulb (assume that one terminal uses the same bulbs) (W);
T_L: The average light working time each day (hour);
F: The CO_2-factor electricity (Kg/kWh) (0.37) [15].

In eqn (1), the number of bulbs on each high-mast light, the wattage of each bulb and the average lighting working time are variables that can vary in different container terminals. The next step is to determine the number of light poles in the stacking yard. This can be done in a straightforward way, assuming a rectangular yard layout. The whole stacking yard is discretized into a grid consisting of small unit squares. Then, the illumination at each square in the matrix is calculated to check whether it meets the requirement (20 Lux), finally providing an estimate of the number of lights in the stacking yard. The algorithm can be described in the following way:

A. At first, the matrix is empty, and the value for each cell is zero.
B. Put the light as the '*I*' rows and '*i**rate' ('rate' is the relationship of length and width) columns, which split the row and column averagely ('*I*' starts from 1).

C. Calculate the illumination level in each cell of the matrix on the basis of the equation $E = (H/\sqrt{(H^2 + X^2)}\cdot I)/(H^2 + X^2)$ [24], specifying the relationship of luminosity for different heights and distances,

where

H = the height of the pole (m)

I = luminous intensity (Lux) and

X = the dimension the lighted area vis-à-vis the pole (m).

D. Check for all cells whether the calculated E is below 20 Lux, and then repeat step C ($i + 1$).
E. When all the cells in the matrix have an illumination level of just above 20 Lux, this cycle stops.

4.3 Validation of the model

As a validation step, the Rotterdam Delta terminals (ECT and APM) were used to validate the model. Figure 3 shows the Google earth map of the ECT Delta terminal. The total length is around 2,700 (m) and the width around 1,000 (m), measured by Google earth. The high-mast lights are all marked as red points.

From the map, it can be determined that in reality there are 70 lights positioned in the stacking yard. The input parameters for this case are the length 2,700 (m), width 1,000 (m), height 40 (m) and the lights are 300,000 (cd). In this specific case, the overall area is divided in two: the ECT Delta terminal and the APM Rotterdam terminal. The model calculated 75 lights for the whole area, with 27 lights in the APM terminal and 48 lights in the ECT Delta terminal (Fig. 4). Compared to the 70 lights in reality and the 25 lights in the APM terminal, the results show valid outcomes.

Figure 3: Lighting configuration of ECT and APM Rotterdam.

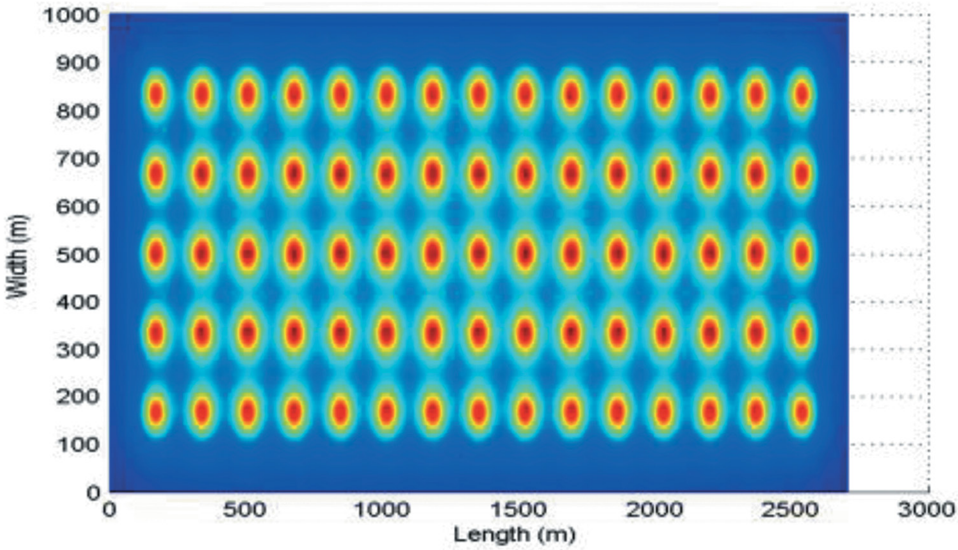

Figure 4: Lighting results of the model for ECT and APM Rotterdam.

To validate the lighting model, some other cases were used to verify the model's outcomes. All these cases are shown in Table 1.

From the results in Table 1, it can be concluded that the deviation of errors varies between 0% and 11%. From Table 1 and Fig. 5, it can be derived that the model shows better results for larger terminal spaces. Small deviations have a smaller effect when the number of lighting poles is higher. The average difference – 5.82% – is quite low; for rectangular-shaped terminals, it can therefore be concluded that this model provides a good indication.

(X axis = hectares, Y axis = number of yard lights)

4.4 Final CO_2 footprint calculation for the yard lighting at ECT and APM

The last step is the calculation of the energy consumption and the related carbon footprint by the application of eqn (1). From the model calculation, it was found that (40 m high, 300,000 cd intensity):

Table 1: Yard lighting validation results.

Terminal	Length (m)	Width (m)	Height (m)	Light (cd)	Estimated number	Real number	Deviation (%)
DELTA	2,700	1,000	40	300,000	75	70	7
APM	1,500	500	40	300,000	25	27	7.5
Antwerp	1,100	400	25	250,000	27	28	3.6
Hamburg	500	235	20	200,000	16	18	11
Los Angeles	1,800	750	40	300,000	50	50	0

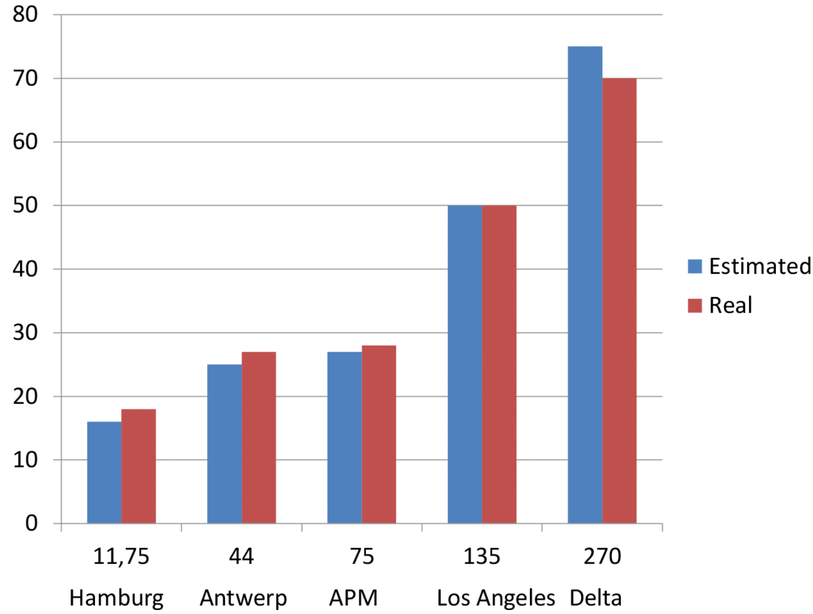

Figure 5: Yard lighting validation results estimated versus real number of yard lights.

48 lighting poles are needed for ECT Delta terminal, giving an electricity consumption of

48(NL) × 16(Nb) × 2 kW(Pb) × 365·12 h(TL) = 6.7 million kWh

27 lighting poles are needed for APM Rotterdam terminal, giving an electricity consumption of

27(NL) × 16(Nb) × 2 kW(Pb) × 365·12 h (TL) = 3.7 million kWh

It should be mentioned here that 12-hour lighting operations are presumed necessary during a working day (24 h). As the CO_2 emissions per kWh generated are 370 g in the Netherlands [15], the yearly carbon footprint for yard lighting energy consumption at ECT Delta and APM Rotterdam is, respectively,

$$6{,}700{,}000 \text{ kWh} * 0.37 \text{ kg/kWh} = 2{,}479{,}000 \text{ kg} = 2{,}479 \text{ tons } CO_2$$
$$3{,}700{,}000 \text{ kWh} * 0.37 \text{ kg/kWh} = 1{,}369{,}000 \text{ kg} = 1{,}369 \text{ tons } CO_2.$$

4.5 Policy recommendations

At the moment, the ECT Delta terminal is lit by high pressure sodium (HPS) lamps, but alternative, more energy-efficient lamps are available, i.e. light emitting diode (LED) lamps. However, the initial investment cost is higher compared to HPS lamps, and therefore LED lamps are not perceived as more efficient, although the LEDs have longer lifetimes and a shorter warming-up period. For the ECT Delta terminal, justification for the recommendation to change to LED lamps is calculated as in Box 1.

Box 1: Calculation underlying policy recommendation for the ECT Delta terminal

Present HPS lamps

Number of masts (computerized model outcome): 48

Number of bulbs/mast: 16

Average working hour per day: 12

Energy consumption per hour per conventional bulb: 1 kW

Price of one kWh electricity power supply: €0.13/kWh

Emission factor: 370 g/kWh

LEDs alternative

Energy consumption per hour per LED bulb: 0.15 kW

Price of one LED bulb: €1000

Lifetime of LED bulb: 50,000 h ≈ 11.5 year

Economic aspect of replacement

Savings during lifetime

= Savings per hour * Lifetime investment cost

= (Energy consumption per hour by conventional bulbs – Energy consumption per hour by LED bulbs) * Unit price of electricity * Lifetime – Number of masts * Bulbs per mast * Cost/LED bulb

= Number of masts * Bulbs per mast * (kW by conventional bulb – kW by LED bulb) * Unit price of electricity * Lifetime – Number of masts * Bulbs per mast * Price per LED bulb

= 48 * 16 * (1 – 0.15) * 0.13 * 50,000 – 48 * 16 * 1,000 = €3,475,200

Savings per year

= Savings over lifetime

= 5,430,000/11.5 = €302,191

Return on investment

= Investment cost/Savings per year

= 48 * 16 * 1,000/302,191 = 2.5 years

Reduction in CO_2 emission per year

= Emission factor * Savings in kW per hour * Working hour per year

= Emission factor * Number of masts * Bulbs per mast * (kW by conventional bulb – kW by LED bulb)

= 370 * 48 * 16 * (1 – 0.15) * 12 * 365 == 1,058 ton/year

To conclude, the calculation shows that a shift from HPS to LED lamps could lead to annual savings of €302,191 electricity, mostly driven by reduced energy consumption. Consequently, the CO_2 footprint could be reduced by 1,058 ton CO_2 per year, a significant reduction. This shows that this policy recommendation can have genuine economic and environmental benefits. An additional benefit of LED lamps is that the light does not disperse as much as from HPS lamps and hence causes less light pollution, which is an issue for residents living in the vicinity of a terminal.

5 DISCUSSION AND CONCLUSIONS

From the application of the six-step approach to calculate equipment's energy consumption in terminal processes [19, 20], it can be concluded that our first attempt to understand the energy consumption of yard lightning shows promising results. The yard lighting model provides good indications for five different international container terminals. The ECT Delta terminal case study shows that a shift from HPS lamps to LED lamps could lead to K€ 300 annual savings on electricity, and the CO_2 footprint could be reduced by 1 Kton CO_2 per year. At this moment, the methodology is also being applied to get more insight into the energy consumption of reefers. The six-step approach, moreover, provides transparency in relation to energy consumption at terminals and therefore contributes to stakeholders' discussions about terminals' sustainability. It can be concluded that, with a stepwise refinement of the methods applied, it is possible to contribute to the new ISO standard, currently under development, which will compensate for the weaknesses of CEN EN 16258.

ACKNOWLEDGEMENTS

We thank Yang Cao and Jan Wouter de Waal for working on our ideas and concepts. We also thank Professor Joan Rijsenbrij and Jianbin Xin for their critical reflections.

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