The Contribution of Terminals to Reduce the Carbon Footprint of Maritime Transportation – Analyzing Energy Supply Options from Renewable Sources for a Seaport Container Terminal

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Abstract

Seaports play a vital role within the maritime supply chain. Reducing the carbon footprint of seaport terminals can contribute to a low carbon maritime transportation.
One option to reduce the carbon footprint of a container terminal is to use renewable energy sources such as solar and wind energy. These renewables are controllable only up to a certain extent as they depend on environmental conditions. Possible reactions to this challenge are to install energy storage facilities or to exchange power with the electricity grid. Another possibility is to adjust the terminal operations – and therefore the energy consumption – to the available power.
Thereby, the following questions arise:

- Which renewable energy supply options exist besides solar and wind?
- Which operations can be flexibly adjusted to an unsteady energy supply?
- Which share of renewable energy is feasible for container terminals without interfering with productivity?

Contributing to answer these questions, this paper develops a framework to analyze the characteristics of a renewable energy supply and the interdependencies with container terminal operations. It reflects recent results from the EU-funded research project Green EFFORTS. First, supply options are investigated and, second, relevant operations are analyzed and characteristics derived which are related to energy consumption.

Keywords: Green container terminal, renewable energy supply, demand side management, load shedding, smart grid, Green EFFORTS

1. Introduction

In principle, there are two main approaches to reduce greenhouse gas emissions. First, fossil fuel consumption can be reduced. On a container terminal, this can be achieved by reducing the equipment's energy consumption (Edwards and Cheng, 2008). Another possibility is to optimize container handling operations e.g. by minimizing the distances travelled. Furthermore, the handling personnel can be trained to use the equipment more economically as e.g. truck drivers get trained.

The second option to reduce greenhouse gas emissions is to use energy sources that contain less carbon. This implies to use renewable energy sources as biomass, hydropower, wind, photovoltaic or other sources. Compared to traditional fossil energy sources such as diesel, coal or natural gas that are available when they are needed, some renewable sources as wind and solar depend on environmental conditions. Therefore, energy supply becomes volatile if these sources are implemented.

The available electrical power supply has to match the power consumption in order to keep the frequency of the power grid stable. Therefore, either storage facilities are necessary as buffer or the consumption of electrical power has to be adjusted to the unsteady supply (demand side management) (Saint-Drenan et al., 2009). For a container terminal aiming to reduce its carbon footprint by using renewable energies this implies that energy consuming operations have to be identified which can be shifted within a defined time frame according to the available power. Therefore, the overall aim of this paper is to investigate how energy supply and demand on a container terminal can be combined ideally in order to reduce the terminal's carbon footprint economically?

The idea behind this question leads to smart grids and demand side management. These topics are addressed by several projects and research programs as E-Harbours, Grid+, Web2Energy, Grid4EU, ETP SmartGrids, E-Energy, and others. Thereby, the E-Harbours project includes one showcase on the Shetland Islands that follows a similar approach for a small fishing port.

In the following, this paper develops a framework to serve as a basis in order to analyze the potential of adjusting container terminal operations to a renewable energy supply. First, the characteristics of energy supply options from renewable sources are discussed focusing on the possibilities to use them on or close to a container terminal. Second, energy consumption of terminal operations is discussed and processes are identified that are non-critical (within a certain time frame) and that can be shifted if not enough renewable energy is available. Based on this analysis, a framework is constructed that allows further research on the potential of demand side management on container terminals.

2. Characteristics of Renewable Energy Supply

2.1. Renewable Energy Supply Options

Typically, container terminals are connected to the public energy grid. In that case, the terminal management is not able to directly influence the source which is used to generate the electrical power. However, in various countries it is possible to purchase green electricity by contract (PricewaterhouseCoopers, 2009). This implies that the electricity provider guarantees to produce the amount of electricity the customer consumes using renewable sources. This would be an external option for renewable energy supply of a container terminal and the most uncomplicated solution as nothing would have to be changed. The source mix of the electrical power would depend on the type of renewable sources used by the energy provider.

It might also be feasible to produce some renewable electricity by the terminal itself. This would be an internal option. This can either imply e.g. to install wind turbines or photovoltaic cells on the terminal respectively port area (e.g. APM Terminals, 2009) or to invest e.g. in a wind farm outside the terminal area (e.g. Antwerp, 2011) to use the energy produced for terminal operations. In this case, the terminal can influence the source of the energy supplied. Also subsidies might be an incentive to invest (Savage et al., 2004).

The most common renewable sources for energy production in Europe are biomass and hydropower (including tide, wave and ocean energy) (Eurostat, 2012). There are various other options as e.g. wind power, photovoltaic power, geothermal energy, biogas, osmosis power and solar heat. In 2010, the share of renewable energy of gross final energy consumption in the EU was estimated 12.4%. The contribution of electricity generation from renewable sources to gross electricity consumption was 18.2% in 2009 (Eurostat, 2012). The following section analyzes specific characteristics of an energy supply from renewable sources for container terminals.

Liquefied natural gas (LNG) is also considered in the following study although it is no renewable but a fossil source of energy. As the unsteady supply of renewable sources causes some challenges for container terminal energy supply, the use of a LNG turbine to produce electrical power on a terminal might be a reasonable option when renewable sources do not provide sufficient electricity especially if onshore power supply for ships is also considered. A gas turbine would be a more efficient way to burn LNG instead of gas engines installed in the terminal equipment. This would minimize methane slip (as a disadvantage of LNG) and would provide flexibility for terminal operations. Especially in Emission Controlled Areas (ECA), the availability of LNG on terminals is expected to increase (DMA, 2012). This is assumed as LNG is one option for ships operating in ECAs to reduce sulfur and nitrogen oxide emissions.

2.2. Specific Characteristics of Renewables Compared to Traditional Energy Production

Resulting Emissions

Using renewable sources for power generation shows various characteristics that are different from traditional energy production. First of all, during energy production no greenhouse and other harmful gases are released to the atmosphere. This is one of the main reasons to use renewable energies for power production. However, from a holistic environmental point of view it is reasonable to conduct a life cycle analysis to be sure that the overall effects on the environment do not exceed the positive effect of less greenhouse gases during power generation.

Dependency on Environmental Conditions

The efficiency of power generation from renewable sources depends very much on environmental conditions (e.g. weather, geologic conditions) and therefore on the location of power production. Photovoltaic plants are most efficient close to the equator and at places with high sunshine duration. Tidal, wave or osmosis power is only reasonable in certain areas at the sea. Producing electrical power anywhere and consume it somewhere else would cause losses during transportation. Therefore, local power production depending on the environmental conditions is feasible.

Considering a seaport terminal, most water-related methods appear reasonable except for pumped-storage hydropower as this requires a certain gradient which is rarely available in coastal areas. Wind intensity is also quite strong close to the sea. This would require space for wind turbines on the terminal area or close by. Solar panels (photovoltaic as well as solar heat) are an option for roof areas on the terminal.

Power Output

Power plants for renewables sources are typically smaller than traditional power plants (REN21, 2011). Therefore, a single generation unit produces less energy. An onshore wind turbine e.g. produces around 3.5 MW while a single coal power generation unit produces around 1000 MW. These numbers have to be seen economically in relation to e.g. required space, investment costs or others.

Investment and Operating Cost

Furthermore, costs are essential. This includes investment costs as well as operating costs. Regarding renewable energies, there are no costs for fuel as wind, sun, geothermal heat etc. are unlimited and free available. This does not imply that operation costs are zero, but it becomes more and more important as prices for fossil fuels increase. Subsidies also play an important role in investment decisions (Savage et al., 2004).

Power Generation Pattern

Generating electrical power from renewable sources involves another challenge. Some renewable sources such as wind and sun are volatile. Therefore, power generation by using these sources is limitedly controllable. For traditional power generation, base, mid and peak load power plants are used depending on the power requested by energy consumers. If the share of renewable energy generation is increased, the other power plants have to be more flexible to ensure a constant frequency in the electricity grid. This would result in less base load plants and more peak load plants. Other options can be to either store an oversupply of energy or to adjust the energy consumption to the power generation. Some energy storage options exist such as batteries, power to gas, generate hydrogen or others. These storage options are very reasonable but work only to a certain extent and imply energy losses.

Predictability
If power generation is volatile and only to a certain extent controllable and energy consumption is supposed to be adjusted to the available supply, it is advantageous if the unsteady power generation is at least predictable as this reduces the complexity of controlling energy consuming processes. While wind and photovoltaic power generation is relatively volatile and difficult to predict, biomass and geothermal power generation are more constant and also more predictable. Ocean power like tidal energy is volatile but predictable (DNK, 2011).

Considering the option to adjust energy consumption to supply, some research projects investigate possibilities how to control energy consumption most efficiently. One of these projects is the EU-FP7-funded Green EFFORTS project that investigates how to measure, control and reduce greenhouse gas emissions of seaport and inland waterway terminals. Focusing on the reduction of greenhouse gases, the question arises, whether and how e.g. container terminal processes can be flexibly adjusted to an unsteady energy supply. Therefore, the following section focuses on container terminal operations and identifies characteristics of the related energy consumption in order to propose possibilities to adjust energy consumption on a container terminal.

3. Container Terminal Operations and Energy Consumption

3.1. Container Terminal Operations

Primary purpose of a container terminal is to handle containers between ships and means of hinterland transportation, i.e. truck, train or barge. Thereby, three options exist: first, import implies container handling from ship to hinterland; second, export implies container handling from hinterland to a ship; third, transshipment implies container handling from a ship to another ship (see Figure 1).

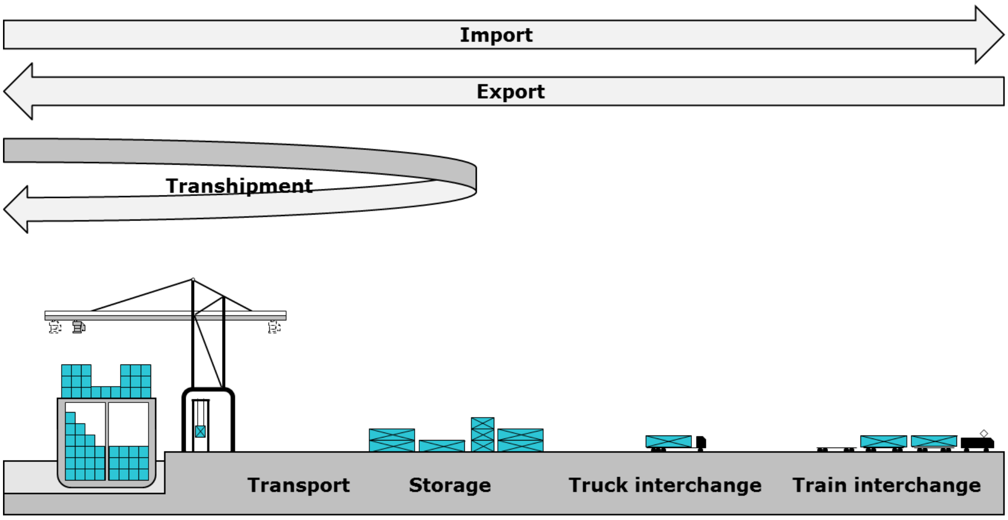

Figure 1: Schematic Side View of Container Terminal Operations
Source: Adapted from Jahn (2010)

Exemplarily, the core import processes are described in the following as they consume most energy on a container terminal. However, also for administrative and other processes energy is necessary. Therefore, a detailed process map is created in the Green EFFORTS project to ensure that the entire energy consumption on a terminal is considered.

After a ship's arrival, a container for import is discharged and moved to the quay side. From the quay side, the container is transported horizontally to a storage area and stacked in a specified position. One important process regarding energy consumption during storage is keeping the temperature of a temperature-controlled (also called reefer) container at the specified degree or range of degrees. Following, the container is picked up by truck, train or barge. In the case of truck transportation, the truck enters the terminal and the container is loaded on the truck either directly in the storage area or in a special interchange area. In the case of train transportation, the container is transported horizontally to the train area and either directly loaded onto a train wagon or pre-stowed in the train area and later loaded onto a train wagon. In the case of barge transportation, the container is transported horizontally to the quay side and lifted onto the barge. Export and transshipment processes take place accordingly (Kim and Günther, 2007).

3.2. Energy Consumption on Container Terminals

Corresponding to the characteristics of renewable energy supply identified, this section investigates energy consumption on a container terminal regarding the following characteristics:

- Required amount of power
- Predictability of consumption
- Flexibility of consumption
- Investment and operating costs including costs of flexibility.

Thereby, the focus is set on the terminal equipment that is used for container handling. A prerequisite to be considered for using renewable energy supply on a terminal is equipment that is electrical and not diesel-driven.

Quay Side
On the quay side, quay cranes (also called ship-to-shore cranes) are used for loading and unloading containers. Quay cranes are typically electrical although a few terminals use diesel-driven quay cranes. Electrical quay cranes consume approximately 6 kWh/move (Geerlings and van Duin, 2011). Quay cranes run on rail-tracks and are connected with a cable to the grid. The process to unload and load a ship by quay cranes consumes a large share of the total energy consumption by the terminal and is therefore an important issue (Saanen et al., 2006). However, the process is only limitedly suitable for shifting energy consumption in time as ships aim to stay as short as possible in a port and usually need to be served without delay. If sailing depends on the tide as e.g. in Hamburg delaying the (un)loading process expecting renewable energy in the near future might be considered for a short time frame.

Horizontal Transport
For horizontal transport, straddle carriers, terminal tractors (also called prime movers) or automated guided vehicles are used. These vehicles are typically diesel-driven as power supply with a cable connection is not possible. Nevertheless, few terminals test electric vehicles for horizontal transport with batteries (HHLA, 2012). For horizontal transportation, energy consumption is difficult to specify as it depends strongly on the distances on the terminal. Numbers vary between 0.8 and 1.3 l/move respectively 1.8 and 4.0 l/km (van Duin and Geerlings, 2011). For (un)loading operations these vehicles are assigned to a certain quay crane and therefore hardly flexible. However, they offer one interesting option if they are electrically-driven: the spare batteries in the charging station can to a certain degree be used as a buffer for an oversupply of energy and they can also be discharged if electricity is needed. This option is already under investigation for electric cars e.g. in the RegModHarz-project in Germany.

Stacking Area
In the stacking area, straddle carriers, rubber-tired gantry cranes, rail-mounted gantry cranes and – in some cases – reach stackers are used. Typically, rail-mounted gantry cranes are electrically-driven and all other equipment mentioned is diesel-driven. However, some terminals invest in electrical rubber-tired gantry cranes that can keep their capability to move between storage blocks if they are not connected to the grid by a cable but by a bar and if they are also equipped with an additional diesel engine. This is especially the case for rubber-tired gantry cranes that are retrofitted with electric power systems (Le, 2012).
Energy consumption of straddle carriers and reach stackers depends on the distances covered. Geerlings and van Duin (2011) state 3.5 to 5.0 l/km. Thereby, in the case of straddle carriers it has to be considered that transporting a container between quay side and stacking area and lifting the

container into the stacking area happens in one move. Gantry cranes consume between 5.0 and 7.25 kWh/move respectively 18 to 22 l/h which corresponds to approximately 1.5 l/move.
Stacking containers and removing them from the stacking area usually has to take place exactly if the container has to be transported to a ship, truck, train or barge. Frequently, one or more other containers are stacked on the container requested which causes extra moves. These additional moves could be made earlier (if the relevant information is available) in case of an oversupply of energy. Therefore, optimizing the position of containers to be loaded next is a promising process for shifting energy consumption.
Another source of possible flexibility is temperature-controlled containers. There are two different types of these containers. The first type (chilled mode) is not suitable for shifting energy consumption as it has to keep a very precise temperature inside. The second type (frozen mode) seems to be promising as it needs to keep a range of temperature inside (Fitzgerald et al., 2011). This range can be used to switch on the cooling aggregate if there is an oversupply and to switch it off if there is an undersupply of renewable energy. Verbeeck (2012) estimates a flexible time frame of 5h per 1° temperature range in case of an outside temperature of 20°C. An important prerequisite thereby is the possibility to measure the temperature from outside and to control the cooling unit of the container.

Truck and Train Interchange
In the truck and train interchange area, reach stackers, forklifts, straddle carriers and rail-mounted gantry cranes are used. Forklifts are similar to reach stackers. Therefore, energy consumption is analogical. Truck interchange is only flexible if truck arrivals can be controlled. This is usually not the case. Train interchange flexibility depends on the train schedule and is usually not as critical as a ship's schedule. Therefore, this can be seen as another partly flexible energy consumer.

4. Potentials to Adjust Terminal Operations to Energy Supply

In order to investigate the interrelations between an unsteady energy supply from renewable sources and the possibilities to flexibly adjust energy consumption by terminal operations a reference terminal is designed. This reference terminal reflects typical characteristics of existing container terminals (e.g. throughput, equipment productivity, number of equipment etc.) and offers the possibility to test different settings in a simulation.

The simulation model includes energy consumption characteristics (i.e. required amount of power, predictability and flexibility of consumption, investment, operating and flexibility costs) as well as characteristics of renewable energy supply (i.e. resulting emissions, dependency on environmental conditions, power output, investment and operating cost, power generation pattern, predictability). Also included in the simulation model will be a price mechanism that weighs operating costs versus flexibility costs.

This simulation model will offer the possibility to gain benefits by using an optimal energy mix depending on the terminal operational situation and the choice of energy alternatives available. Resulting output of the model are values of greenhouse gas emissions and costs. These values offer the possibility to find an ecological and economical solution. The energy mix values in the model include shares of public grid, electricity from renewables (classified in wind, sun, geothermal, biomass, and hydropower), electricity from LNG turbines and energy storage.

In a first step, the simulation model will allow to conduct what-if analyses to test e.g. modifications in the energy mix for the terminal. This can support decisions e.g. whether or not to install a wind turbine on the terminal or whether or not to retrofit rubber-tired gantry cranes with electrical drives.

In a second step, the simulation model will be enhanced to optimize a container terminal's energy mix. This will also result in an analysis tool that provides recommendations on energy mix optimization and how to adjust terminal operations to the respective energy mix. Ideally, this tool allows for forecast values and experienced data and combines them in order to adjust to the specifics of a terminal.

5. Conclusions

This research contributes to investigating the potential of implementing smart grid technologies in a container terminal. It proposes a two-step simulation model that, on the one hand, allows investigating effects of modifications in the terminal's energy mix on the terminal's ecological and economic performance in terms of greenhouse gas emissions and operational costs. On the other hand, the simulation model allows optimizing a container terminal's energy mix.

Thereby, the results – if applied – contribute to reduce greenhouse gas emissions of container handling while at the same time keeping energy costs and therefore the operational costs down. This contributes to the overall aim of low carbon shipping. Further research could extend the model to other terminal types and combine several different terminals. This kind of cooperation could increase operations flexibility and therefore support demand side management.

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