

# Green Steaming: A Methodology for Estimating Carbon Emissions Avoided

*Completed Research Paper*

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## Abstract

*Commercial shipping cannot readily reduce its dependency on fossil fuels. Ships are large energy consumers and need to carry sufficient fuel for a voyage. The principle of green steaming, when ships travel at slower speeds to arrive just-in-time, is discussed and a methodology developed to estimate the carbon savings resulting if the industry were to adopt this practice. The method is based on public automatic identification system (AIS) data generated by commercial vessels. A speed profile is estimated for each ship, and based on observed anchoring times, potential savings are computed by back propagating the distance a ship could travel at its slowest observed speed. The methodology is demonstrated for the Port of Gothenburg. There is a discussion of how the methodology can estimate carbon emissions avoided by the global shipping industry. Also considered are the actions needed, particularly regarding digital collaboration, to realize the benefits.*

**Keywords:** Maritime Informatics, Green IS, Sustainability, Data analysis,

## The problem

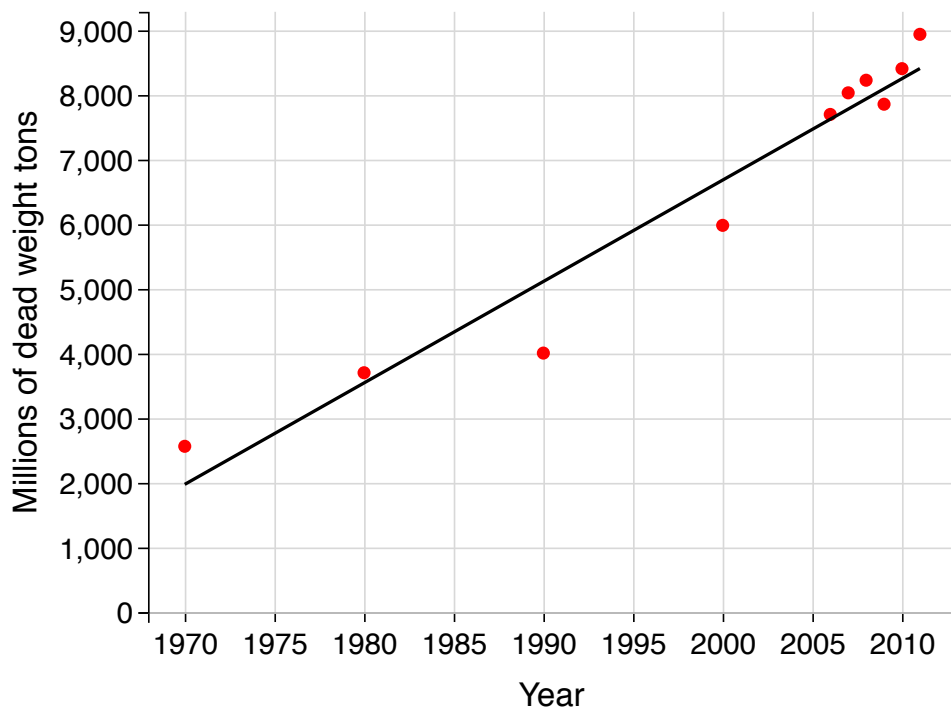
The consensus scientific opinion is that the burning of fossil fuels is causing global warming, rising sea levels, and ocean acidification. Consequently, the world has to reduce dramatically its use of coal, oil, and natural gas. For many industries, this means replacing fossil fuels with renewables, such as solar and wind. Commercial shipping, one of the world's major industries, cannot readily make such a transition, because ships are large energy consumers and need to carry sufficient fuel for a voyage, which can be lengthy. At best a ship can move to natural gas, which emits the least CO<sub>2</sub> of the three major fossil fuels (coal, oil, and natural gas). Ships will continue to use fossil fuels for the foreseeable future (Sims et al.,

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2014). Because commercial shipping cannot eliminate CO<sub>2</sub> emissions, it needs to vigorously pursue energy efficiency, sometimes referred to as the invisible fuel (The Economist, 2015). Given the importance of shipping to exploiting the comparative advantage enjoyed by different countries and regions and thus the raising of global living standards, it is imperative that scholars engage in raising the energy efficiency of the maritime industry. In particular, there is an opportunity for IS scholars to apply the principles of Energy Informatics (Watson, Boudreau, & Chen, 2010) to increase commercial shipping's energy efficiency. The European MonaLisa 2.0 project<sup>2</sup> with its intention of "taking maritime shipping into the digital age" highlights the potential of information systems to make shipping more efficient and safer and reduce its ecological footprint.<sup>3</sup>

With around 90 percent of the world's trade carried by sea, maritime transportation is essential for the global economy (Maritime Knowledge Centre, 2012). With a 4.3% growth rate in 2012, as well as a growing trend through recent decades of adding about 150 million dead weight tons per year (International Maritime Organization, 2013; UNCTAD, 2013) (see Figure 1), maritime transportation is likely to remain important in the coming years and will continue to be a significant source of carbon emissions, which result from the burning of global marine oil (GMO). Indeed, it is estimated that ocean cargo shipping produced 840 million metric tons of CO<sub>2</sub> in 2007 (Psaraftis & Kontovas, 2009), which was approximately 2.7% of the estimated global CO<sub>2</sub> emissions of 31.45 billion metric tons in 2007.<sup>4</sup> In the absence of changes in technology, policies, and regulations, CO<sub>2</sub> emissions from international shipping, according to a 2007 estimate, will grow 2-3 times by 2050 (International Maritime Organization, 2009).



**Figure 1: Growth in shipping capacity (IMO, 2013)**

<sup>2</sup> <http://monalisaproject.eu>.

<sup>3</sup> The authors are participants in MonaLisa.

<sup>4</sup> <http://co2now.org/Current-CO2/CO2-Now/global-carbon-emissions.html>

Including indirect and induced effects, the annual economic impact of the shipping industry is USD 436.6 billion (World Shipping Council, 2014b). Maritime transportation is the most efficient and cost-effective mode of transport. Container ships can carry several large warehouses of goods on a single journey, and they can be operated with a team of only 13 people, thanks to advanced computer technology (World Shipping Council, 2014a). It is also relatively fast, such that a journey of around 14,000 kilometers can be completed in 16 days (World Shipping Council, 2014a). Being capable of carrying huge amounts of goods decreases the unit cost of goods transported. For example, the cost of transporting a kilogram of coffee from Asia to Europe is only fifteen cents, or one percent of item cost (World Shipping Council, 2014a). With the appropriate use of advanced technology, the efficiency of the industry can be improved even further and CO<sub>2</sub> emissions reduced.

In this paper, we start by defining the research questions. We follow by examining the opportunities for energy efficiency gains in moving goods between ports. We then consider the principle of green steaming as an approach to enabling just-in-time approaches to ports synchronized with the readiness of the actors in the port to take the vessel to berth. This is followed by a report on a methodology developed to estimate the carbon savings that would result if the industry were to adopt this practice. We conclude with a discussion of how the methodology can be applied to estimate the carbon emissions avoided by the global shipping industry. We also discuss what actions need to be taken, particularly with respect to information systems enabling digital collaboration to realize these CO<sub>2</sub> savings.

## **Research questions**

This research contributes to creating a more efficient, safer, and sustainable shipping industry by addressing two questions.

1. What are the potential savings of green steaming?
2. What are the key features of an information system designed to achieve the savings from green steaming?

Answering the first question requires development of a methodology for computing the savings from green steaming. Moreover, measurement is an act of data creation, and the first stage of creating an information system. The research method of applied mathematics is similar in intent to an organization doing a financial analysis to justify a new information system.

The second question places this research in the practice science space because the ultimate goal is to create an information system to help achieve the goals of MonaLisa. It is not design science research (Hevner, March, Park, & Ram, 2004; Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007) because we are not focused on testing a theory, but rather solving a problem. Furthermore, we can't limit our work to a single kernel theory because practice cannot be so shackled. We apply the concept of practice science as the rigorous justification of interventions for addressing societal problems (Seidel & Watson, 2014).

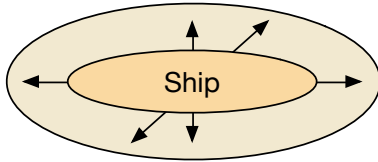
## **Two approaches to efficiency**

There are fundamentally two ways, green routing (the shortest safe distance) and green steaming (the lowest operational speed to arrive on schedule), to reduce the cost of travel between two ports. As fuel is about 35-70% of the cost of moving sea borne cargo (Wigforss, 2012), green routing and steaming align a ship owner's profitability goals with sustainability. While our emphasis is on green steaming, for completeness and comparison of effects on carbon emissions, we consider both efficiency improvement methods. While MonaLisa participants (Lind, Haraldson, Karlsson, & Watson, 2015) have raised the notion of green steaming, we can identify no rigorous prior attempt to quantify its potential benefits.

### ***Green routing***

Green routing means a ship can take the shortest route, constrained by safety and regulations. Green routing computes such efficient routes by considering current sea traffic and characteristics of the ship. Safety requires that ships continually operate within a moving zone, or safe haven (Porathe et al., 2014), and that there is sufficient distance from other ships and the shore both fore and aft, and starboard and port. Furthermore, there needs to be sufficient under keel clearance (UKC) to avoid grounding, and space

above the ship to sail under bridges en route. For mathematical modeling efficiency, we can think of a ship as an ellipsoid surrounded by an ellipsoidal safety zone (see Figure 2). Because a ship's load determines its draft and height above water level, the safety zone changes during a voyage. Thus, a fully loaded ship might not have sufficient draft to enter some harbors, and routing has to consider how to sequence a voyage based on the anticipated weight of a ship's cargo as it enters and leaves each port. Similar considerations also apply to bridges.



**Figure 2: A ship and its safety zone**

A study associated with MONALISA reports potential energy savings of 12% for commercial shipping operating in the Kattegat, a portion of the Baltic Sea between Sweden and Denmark.<sup>5</sup> It is indicative of what might be achieved, but it is limited to a small area and does not consider long ocean voyages.

### Green steaming

Green steaming recognizes that the amount of energy used by a ship is determined by its size and speed. Above 14 knots, fuel consumption is an exponential function of speed. An industry rule of thumb is that for a container ship, a 1% reduction in vessel speed results in approximately a 2% saving in fuel costs (Tozer, 2008).

When a ship arrives at a harbor before needed resources are available, typically terminal facilities for handling cargo, it has to anchor and wait. If the demand for resources could be coordinated with some reasonable accuracy, then ships could sail to arrive just-in-time and avoid anchoring outside the harbor.

The goal of green steaming is to enable ships to reduce their speed to arrive just-in-time rather than anchor and wait. Mathematically, we can compute the required speed reduction.

Let  $t$  be the total time a ship sails and anchors before entering a port. Without green steaming, this time is the sum of anchoring time ( $A$ ) and sailing time (distance/velocity). When a ship travels distance  $d$  at velocity  $v_1$

$$t = A + d/v_1 \quad (1)$$

With green steaming,  $A = 0$ , and the ship travels at velocity  $v_2$  in the same time  $t$ . That is

$$t = d/v_2 \quad (2)$$

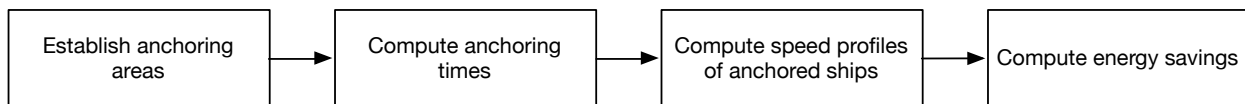
Thus, we set

$$A + d/v_1 = d/v_2 \quad (3)$$

We can then compute the distance from the port at which the ship would need to reduce its speed to  $v_2$  to avoid anchoring, which is

$$d = A * v_1 * v_2 / (v_1 - v_2) \quad (4)$$

We now describe a four-step methodology for computing the energy savings of green steaming (Figure 3).



**Figure 3: Computing energy savings from green steaming**

<sup>5</sup> <http://www.sspa.se/ship-design-and-hydrodynamics/voyage-optimisation-shallow-waters-baltic-sea>

The **Automatic identification system (AIS)** provides data about a vessel's voyage automatically every three to ten seconds, depending on the vessel's speed. In 2000, IMO instituted a requirement, which took effect in 2005, for all cargo ships above a certain gross tonnage and all passenger ships to install an AIS responder.

“The regulation requires that AIS shall:

1. provide information - including the ship's identity, type, position, course, speed, navigational status and other safety-related information - automatically to appropriately equipped shore stations, other ships and aircraft;
2. receive automatically such information from similarly fitted ships; · monitor and track ships;
3. exchange data with shore-based facilities.”<sup>6</sup>

AIS messages are not encrypted and can be collected by a variety of devices and made available for public use. For example, the U.S. Coast Guard makes available de-identified data for 2009-2012 for U.S. coastal waters in one-minute intervals.<sup>7</sup> There are Internet based services (e.g., [www.marinetraffic.com](http://www.marinetraffic.com)) that provide real-time ship position and direction data (Figure 4).



**Figure 4: Internet display of AIS data**

### Establish anchoring areas

Anchoring areas are established by examining S-57 nautical charts<sup>8</sup> and manually converting each designated anchoring area to a polygon. Because ships have some freedom to choose where they anchor, local judgment is likely required to determine the shape of the anchoring area for a specific port (Figure 5). For instance, designated anchoring areas that are relatively close could be merged into a larger polygon.

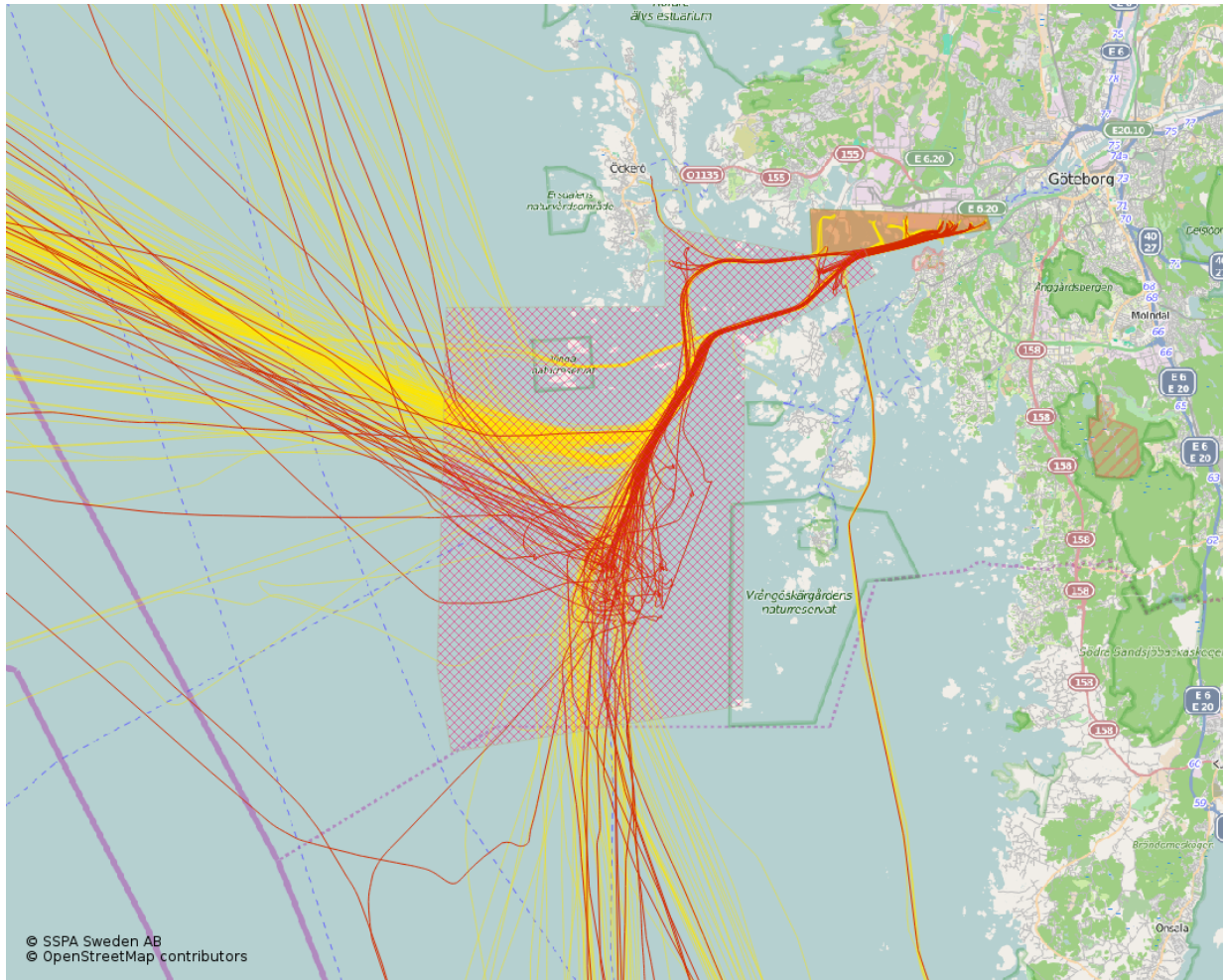
### Computing anchoring times

A ship is deemed to commence anchoring when the speed is below 0.2 knots and the ship is inside the anchoring area. Similarly, anchoring is considered to end when the speed is above 0.2 knots and the ship is inside the anchoring area. Thus, the speed constraint handles the situation where the anchoring area is set to be somewhat larger than a chart suggests. The goal is not to determine precisely where a ship anchors but rather to determine the length of its anchoring time. Furthermore, an anchoring duration must exceed one hour, and the vessel must travel from the anchoring area directly into the defined port area, in order to qualify as an anchoring arrival at a port. Bunker vessels are excluded from anchoring counts.

<sup>6</sup> <http://www.imo.org/OurWork/Safety/Navigation/Pages/AIS.aspx>

<sup>7</sup> <http://marinecadastre.gov/ais/>

<sup>8</sup> S-57 is a set of regulations approved by the International Maritime Organization (IMO) and International Hydrographic Organization (IHO) for standardization of cartographic data exchange.



**Figure 5: Gothenburg anchoring (purple) and port (orange) areas with traces for anchoring (red) and non-anchoring vessels (yellow) (based on AIS data for August-2014)**

### Computing speed profiles

Ships are not like cars. They do not have a continuous speed profile within some range, but rather a set of discrete speeds at which they can travel determined by attributes of the engine, propeller, and onboard equipment requirements. Maintaining maneuvering capability for safe sailing can set a lower limit on a vessel's speed. Thus, it is difficult to assign valid operating speeds for a vessel, since the master and the crew make such decisions based on both mechanical and structural issues as well as operational and safety related concerns. The set of possible speeds for a ship, however, can be inferred from analysis of AIS data.

For each anchored ship, we determined its observable discrete speeds to a resolution of 0.1 knots based on AIS data. To get a ship's speed profile, we weighted each speed by the distance traveled at that speed. To recognize the effects of winds, currents, and tides, we then smoothed twice by applying a linear uniform low pass filter.

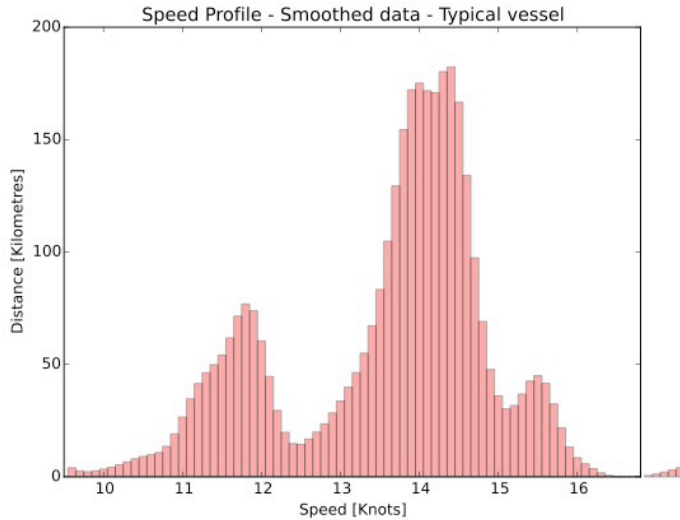
$x :=$  input speed profile

$y :=$  output speed profile

$$y(k) = \frac{x(k-1) + x(k) + x(k+1)}{3} \quad (5)$$



Figure 6 shows the profile for a ship with three observable speeds, corresponding to peaks around 11.8, 14.7, and 15.5 knots.



**Figure 6: Speed profile for a vessel**

### Compute energy savings

Using the formula  $d = A * v1 * v2 / (v1 - v2)$ , the most common speed ( $v1$ ) and the lowest speed of a ship's profile ( $v2$ ), we computed for each ship the distance from the port at which it should start green steaming to minimize anchoring time.

Fuel consumption was estimated using a model for hull resistance in deep calm water (Lars Larsson & Hoyte C. Raven, 2010) and with energy converted into the equivalent amount of Marine Gas Oil (MGO), given an approximation of the overall efficiency of the engine and the components using the energy generated (e.g., propeller).

The parameters and formulae are:

#### Resistance

$R_T$  := Total resistance

$\rho$  := Water density

$V_S$  := Velocity

$S_S$  := Wetted surface

$C_{TS}$  := Resistance constant

The principle dimensions of a vessel (length, beam, draught) were extracted from AIS data and used to estimate a ship's wetted surface. If you draw a box around the submerged part of a ship, the block coefficient ( $C_b$ ) is the ratio of the box's volume occupied by the ship. The mean block coefficient for a commercial ship, such as an oil tanker, is approximately 0.88 (Rawson & Tupper, 2001, p. 12).

$B$  := Beam

$d$  := Draught

$L$  := Length

$C_b$  := Block coefficient

$$S_S \sim (B + 2d) \cdot L \cdot C_b \quad (6)$$

$$R_T = \frac{1}{2} \rho V_S^2 S_S C_{TS} \quad (7) \text{ (Lars Larsson \& H. C. Raven, 2010, p. 13)}$$

*Energy*

E := Energy  
 $R_T$  := Resistance  
 D := Distance

$$E = R_T \cdot D \quad (8)$$

*Fuel consumption*

C := Fuel consumption  
 E := Energy  
 $e_{MGO}$  := MGO energy density  
 $\eta_T$  := Overall thermal efficiency, ~0.35

Energy density measures the amount of energy stored in a volume (MJ/l) or mass (MJ/kg) of an energy source, such as MGO. However, not all of a fuel's energy is converted into usable energy by a marine engine, and the proportion converted is measured by overall thermal efficiency, which for MGO is estimated at 35%, once you factor in engine, propeller, bearings, shafts, generators, and other components of a ship that consume energy. We developed this value from industry references on ship propulsion (MAN, 2001) and SSPA<sup>9</sup> internal working papers on estimating a vessel's characteristics. For a given energy requirement E, the amount of fuel required will be

$$C = \frac{E}{e_{MGO} \cdot \eta_T} \quad (9)$$

*CO2 emissions*

The conversion factor for converting MGO consumed to CO<sub>2</sub> emissions is 3.17 (Psaraftis & Kontovas, 2009).

$\Sigma_E$  := Emissions  
 $\Sigma_F$  := Fuel consumption  
 $\sigma$  := CO<sub>2</sub> conversion constant = 3.17

$$\Sigma_E = \Sigma_F \cdot \sigma \quad (10)$$

## Port of Gothenburg and green steaming analysis

Using AIS data from the Swedish Maritime Authority for August 2014, we analyzed arrivals at the port of Gothenburg. S-57 Nautical Charts were used to determine the anchoring areas (Figure 5). When computing the distance from Gothenburg at which to start green steaming, we realized that in some cases the distance from the port at which a ship could start green steaming would be unrealistically large given that many ships were coming from ports in the region. We were also limited to AIS data available from the Swedish Maritime Authority. Thus, we set a cutoff distance at 350km, and used

$$d = \min \left( A * \left( \frac{v_1 \cdot v_2}{v_1 - v_2} \right), D_{MAX} \right) \text{ where } D_{MAX} = 350 \text{ km} \quad (11)$$

Over 90% of the anchoring vessels had originated beyond 350 km. The maximum distance translates to approximately 10 – 20 hours of green steaming, depending on a vessel's speed. Because day-ahead weather forecasts are quite accurate, we expect that captains can meet a suggested arrival time with precision.

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<sup>9</sup> <http://www.sspa.se> is a consulting company specializing in efficient shipping solutions.



We initially determined that there were 55 anchoring vessels, but as some of these had a low average speed prior to anchoring, which suggests they might have been green steaming, we discarded them. As a result, 39 vessels qualified for green steaming analysis. They represent 12% of the 320 vessels in the sample. Full details of the analysis are presented in Table 1.

**Table 1: Gothenburg results**

Measure	Value
Non-anchoring vessels	265
Anchoring vessels	55
Qualified anchoring vessels	39
Average speed reduction (knots)	2.8
Total anchor time (hours)	1,005
Median anchor time (hours)	17.9
Reduction in anchor time by green steaming (hours)	183
Calculated MGO consumption of anchoring vessels over the back propagated distance (max. 350km) (metric tons)	97
Calculated MGO savings of anchoring vessels by green steaming (max. 350km) (metric tons)	33
Calculated CO <sub>2</sub> savings from green steaming (metric tons)	105
MGO reduction for anchoring vessels for the green steaming section of the voyage	34%
MGO reduction across all vessels	4.1%

The total anchoring time was 1,005 hours, and the estimated reduction totals only 183 hours. This small reduction of 18% is due to two reasons. First, we set a cut-off of 350km because of AIS data limitations. Some ships originating beyond this limit could have green steamed sooner. Thus our estimate is conservative. Second, if ships are coming from a port near Gothenburg, they have limited hours for which they can green steam at a safe operational speed. They might be able to go slower, but this could be unsafe because it would limit maneuverability.

The analysis for August 2014 for Gothenburg indicates that there is a potential energy and emissions saving of 34% for vessels approaching at their slowest safe speed in order to minimize anchoring time. Across all commercial vessels entering the Port of Gothenburg in August 2014, the emissions and fuel savings are 4.1%. Clearly, as congestion rises and a greater percentage of ships need to anchor, the savings will rise, and vice versa.

## Limitations of the method

While the mathematical method is based on physics and marine engineering knowledge, several limitations need to be recognized:

1. While there are single private sources of AIS data, these can be expensive, and this increases the costs of implementation. We do not factor this cost into the method, and we used public data.
2. The determination of the speed profile of a ship requires multiple observations in a diversity of operational settings to compute the range of speeds. We assume that when we have three or more peaks in the speed profile we have captured sufficient data for application purposes.
3. Determining anchoring areas is a manual process reliant on S-57 charts and local knowledge of anchoring practices. This mainly manual process needs to be done for the world's approximately 200 high volume ports, which handle about 97% of the world's cargo in terms of metric tons.

4. The carbon emissions calculation is sensitive to the estimate of 35% for conversion of MGO to energy for operating the entire ship. The overall thermal efficiency estimate covers a range of ships using predominantly diesel engines of varying sizes and ages at varying loads. While a large modern diesel engine can exceed 50%,<sup>10</sup> many ship engines are less efficient, and keep in mind that there are efficiency losses in the various energy-consuming elements of a vessel (e.g., shafts and propeller). As the overall efficiency of installed diesel engine and energy consuming components increase, then carbon emissions will decrease. However, the gains of green steaming will not disappear.
5. Lack of data required that we make various assumptions in computations for Gothenburg, such as equating low approach speeds with green steaming.
6. For the Gothenburg calculations, we used an estimate of .82 for the block coefficient, as this is appropriate for Gothenburg's mix of small coastal ships, with an emphasis on tankers. This value needs to be adjusted for the overall characteristics of vessels using a specific port.
7. Nearly all measurement methods lack absolute precision, especially those affected by human behavior, because there are unforeseen or unusual situations that are difficult to quantify.

We foresee no negative impacts or unintended consequences from this method. It generates data for vessel operators, port authorities, and terminal operators and will enable them to plan more precisely to reduce fuel consumption. There is no requirement that a ship's captain adopts green steaming. A positive potential outcome is that the value of green steaming individually and collectively can be assessed, and this can lead to new policies and information systems that will promote its adoption and lead to reduction in carbon emissions.

## Implications

Now that we have a method for estimating the avoided CO<sub>2</sub> emissions by green steaming, we want to assess the savings for all ports. This will enable us to determine the societal value of a global adoption of green steaming in terms of reduced CO<sub>2</sub> emissions.

The world has 4,764 ports in 196 countries.<sup>11</sup> In 2013, Gothenburg handled 0.86 million metric tons of cargo and was ranked 120<sup>th</sup> worldwide.<sup>12</sup> Shanghai, the number one port, handled 33.62 million metric tons in 2013. As Figure 7 suggests, the distribution of port cargo volume is exponentially distributed. Thus, the anchoring times for the world's major ports will be the key determinant of potential CO<sub>2</sub> emissions avoided by green steaming. Indeed, in 2013, the top 20 ports handled over 50% of the world's cargo. There is also a need to examine congestion at much trafficked waterways, such as the Panama and Suez Canals and the Bosporus.

We have made arrangements to get AIS data for Rotterdam, Valencia, and Santos, which are ranked 11<sup>th</sup>, 30<sup>th</sup>, and 39<sup>th</sup> respectively. Analysis of these three ports, with the help of port officials with local domain knowledge, will be used to assess the robustness of the method, particularly its sensitivity to local conditions such as anchoring areas.

A typical daily file for Sweden is about 800 MB, which means the file for August 2014 contains about 24 GB. Processing of these data for Gothenburg took about 14 hours on a 12 core server with 12 GB of RAM. These data can be used to estimate processing and storage needs for other ports. They imply that large ports might benefit from using Hadoop (Lam, 2010) and MapReduce (Dean & Ghemawat, 2008) to handle their data volumes expeditiously. There are also some benefits from using the PostGIS<sup>13</sup> extensions of PostgreSQL for handling geographic calculations. These computational choices are issues for future research. The software used for this study is based on Python, C, PostgreSQL, and libraries for handling AIS data. The code is currently proprietary.

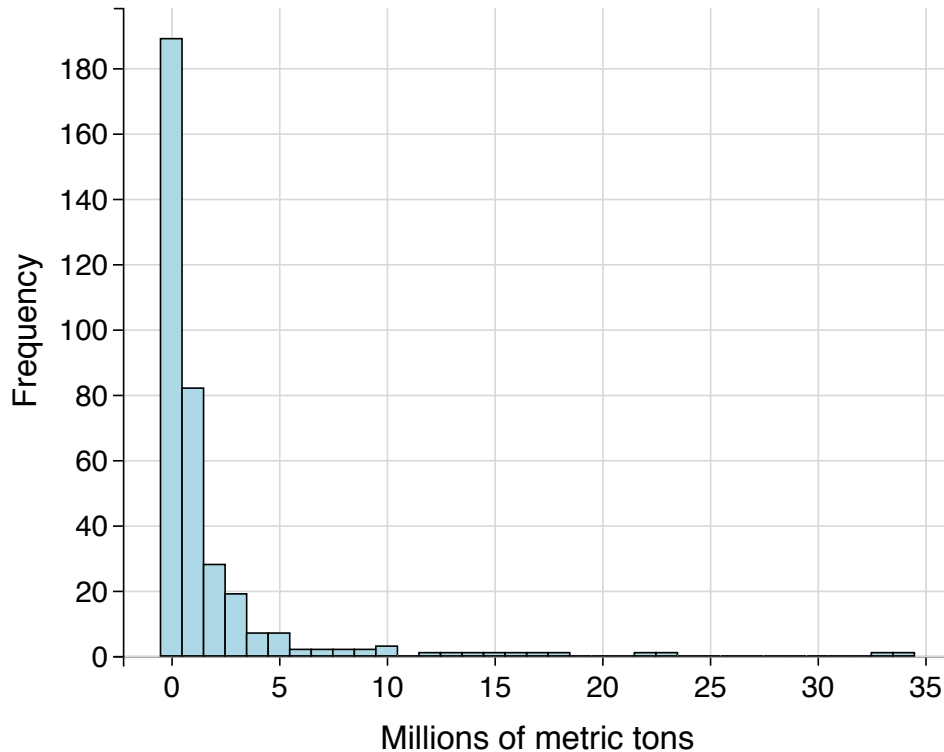
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<sup>10</sup> <http://www.amusingplanet.com/2013/03/the-largest-and-most-powerful-diesel.html>

<sup>11</sup> <http://www.worldportsource.com/index.php>

<sup>12</sup> <http://aapa.files.cms-plus.com/Statistics/WORLD%20PORT%20RANKINGS%202012.pdf>

<sup>13</sup> <http://postgis.net>



**Figure 7: Distribution of cargo volume handled of the world's ports in 2013**

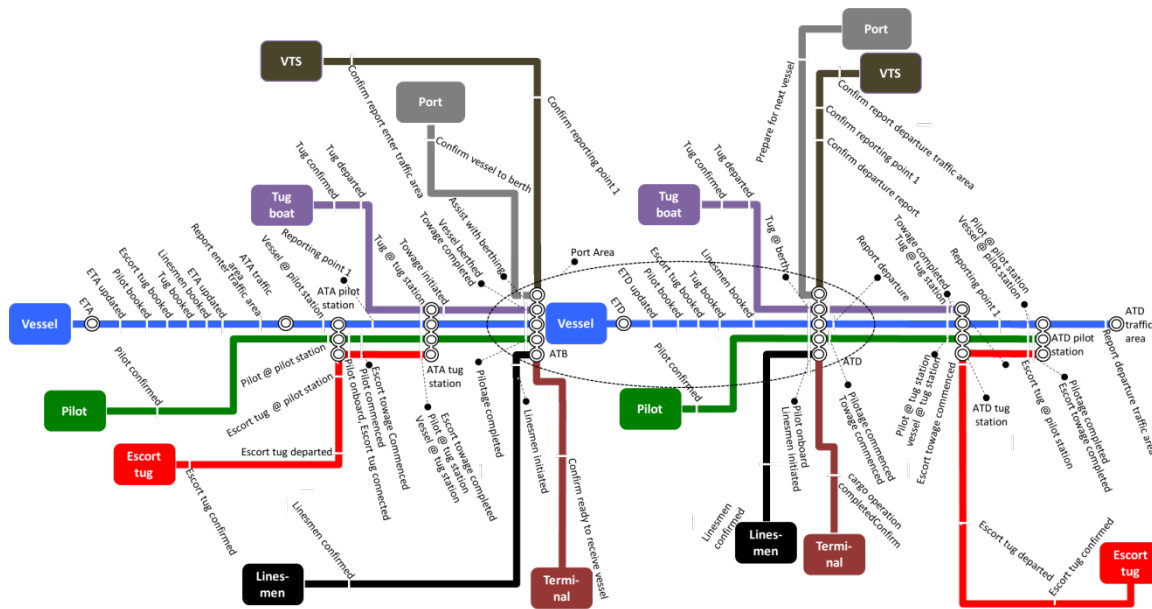
### ***Implementation***

The methodology for estimating green steaming can also be used for its implementation. Our goal is to work within the European MONALISA 2.0 framework<sup>14</sup> to design and validate a distributed service system enabling enhanced digital collaboration to realize the potential energy and emissions savings. The purpose of MONALISA 2.0 is to take shipping into the digital age, and this paper illustrates how the AIS digital data stream can help achieve this objective. Green steaming fits within the sea traffic management (STM) goal of MONALISA 2.0.

The goal of STM is to improve shipping efficiency, safety, and ecological sustainability by digitizing the data exchange between the many parties involved in the voyage of a ship between ports. The lack of data exchange, in any form, limits coordination. As a result, the various parties in the maritime ecosystem are often unaware of each other's intentions. For example, while the AIS data format contains a field for estimated time of arrival (ETA) at a port, this field might be left blank or rarely updated. While shipping agents might have some details of impending arrivals at a port, other actors might not. Thus, it is possible for the port authorities to first learn of a ship's intentions to seek a berth when it nears the harbor and seeks pilot or tug support, usually via a ship's agent.

The complex interaction of many entities (see Figure 8) means that without some form of centralized coordination, resource usage (e.g., pilot, tug, linemen, terminal) is often far from optimal. There is also sequencing to the episodic tight coupling (Watson & Boudreau, 2011) between the various parties. Thus, an approaching vessel's typical coupling order will be pilot, tug, linemen, and terminal as shown in Figure 8. This state diagram constitutes the core of Port CDM (Lind et al., 2015) pinpointing which information needs to be exchanged, as intentions and actual occurrences, among the involved actors for establishing situational awareness enabling a synchronized port call.

<sup>14</sup> <http://monalisaproject.eu>

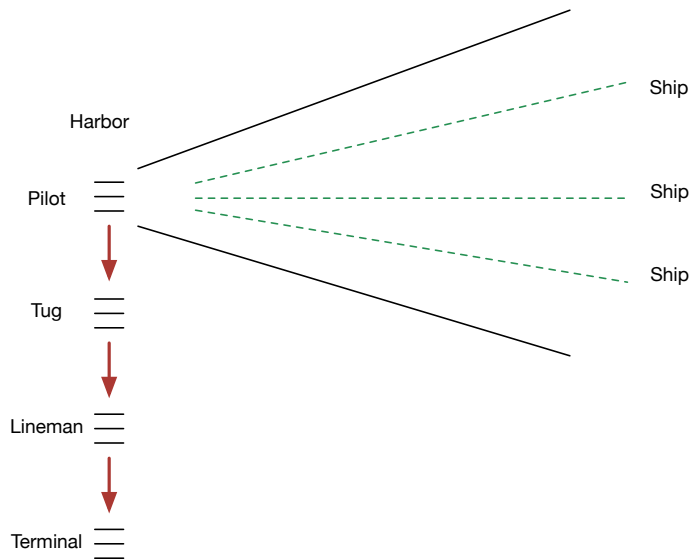


**Figure 8: The port call process (Lind et al., 2015)**

Ideally, each ship will be given a designated arrival time, based on the collective readiness of involved actors to perform operations and thereby optimize the utilization of each of these resources subject to their serial nature and resource availability. Thus, we envision ships arriving and first queuing for a pilot, then a tug, and so forth (Figure 9). When you consider pilots, tugs, and linemen, the terminal is the high cost resource. Thus, the goal should be to maximize use of each of the terminal's facilities (e.g., container handling, bulk cargo handling). Hence, investments might be sensibly made in other resources (e.g., tugs) to ensure that these are not constraints on terminal efficiency. This might not be easily achieved because each of the stakeholders in the maritime industry is likely acting in self-interest, and their personal motivations might not be in the best interests of the ecosystem.

The mathematical techniques for identifying the optimal solution rely on available data. The implementation of green steaming is dependent on each of the parties participating in the digitization of the marine ecosystem. In particular, ships need to continually indicate their ETA and port resource needs well in advance of arrival. The earlier they can start green steaming, the greater the savings. However, we recognize that a vessel's master, in order to ensure timely arrival, will likely set a speed above the computed minimum in order to have some slack time to handle contingencies, such as a storm.

A ship captain's autonomy is an important implementation consideration. A captain has complete authority and responsibility for all onboard matters. Nevertheless, a ship's owner or charterer can direct the captain to change the destination port, route, or schedule without necessarily informing customers, port authorities, or other affected parties. Traditionally, shipping is characterized by a high power culture and an autocratic management style (Goulielmos & Gatzoli, 2012)(Güven-Koçak, 2015). IMO safety regulations specify that the captain has the major responsibility for safety issues, with increased accountability in recent years (Goulielmos & Gatzoli, 2012). Thus, it is not surprising that captains are autocratic and highly independent. This is not an ideal setting in which to introduce information systems that increase the interdependencies of captains and their administrative tasks. However, the profit incentive should dampen some of the opposition. Provided the cost benefits of green steaming are clearly communicated prior to and after adoption, resistance should be manageable. Therefore, the general case for green steaming needs to be made and then the specific case for each voyage detailed. For example, we envisage a captain receiving a recommendation to green steam that estimates the savings in financial terms as well as other pertinent factors.



**Figure 9: Resource queuing**

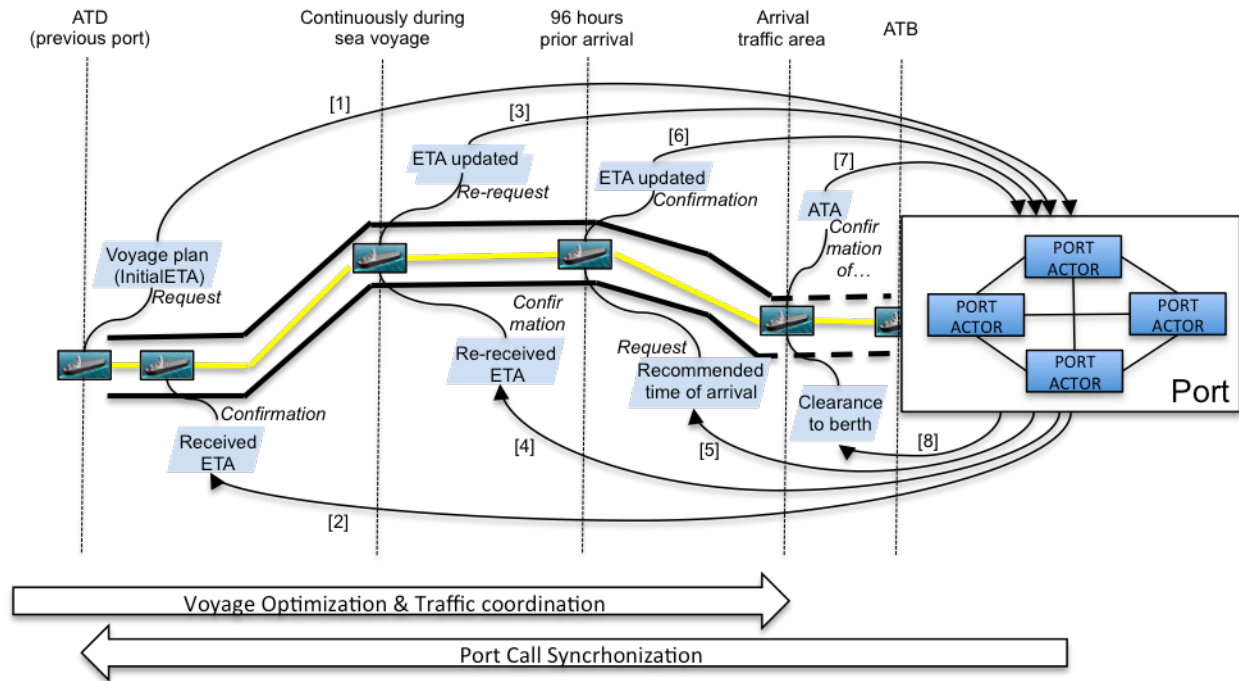
Green steaming is one of several initiatives originating as a result of MonaLisa 2.0. It integrates with three key components of Sea Traffic Management (STM), namely, Voyage Management and Flow Management (Siwe et al., 2015) and Port Collaborative Decision Making (PortCDM). STM aims to improve sea voyage safety and sea traffic efficiency, and to reduce the environmental effects of sea traffic. As it is concerned with the flow of vessels between ports, STM is a platform for enabling green steaming. The STM specification for real-time data sharing between a ship and its destination provides the data to compute green steaming starting points and speeds. PortCDM emphasizes optimizing port resource utilization. This partially requires minimizing resource queuing (Figure 9) so that high value investments, such as a terminal, are maximally deployed. The role of PortCDM is to recommend arrival times for incoming vessels as early as possible, and stage their resource usage to support optimization. Thus, PortCDM receives input from STM to determine future port resource needs and then provides input to STM to enable it to discern which vessels should be targeted for green steaming. As a ship approaches, there should be a continual exchange of data between PortCDM and STM to fine-tune arrival time and the allocation of resources, as detailed in Figure 10. The two systems will be juggling the needs of all approaching and departing ships to coordinate the efficient use of resources.

## Conclusion

This research makes two key contributions. First, we have documented a reproducible method for using nautical charts and AIS data to determine avoided carbon emissions when vessels green steam to minimize anchoring time. A port can use this method to compute the potential savings of green steaming and thus decide what expenditures are appropriate to capture these savings.

Second, we discuss the actions necessary to realize the potential savings. It is essential to implement coordinating mechanisms that can predict which approaching ships will need to anchor and for how long. Additionally, there is a need for an information service advising the captain of each of these vessels of the sailing speed to minimize anchoring. These are information systems that are not technically difficult to develop, and the challenge is more likely to be in convincing key stakeholders to change habits. The industry might need to rethink, for instance, how it writes contracts for cargo delivery to put emphasis on just-in-time behavior to promote green steaming and efficient resource usage.

Green steaming is a sensible and practical solution for vessel operators and the world's citizens. It reduces costs and emissions for an industry that will likely need to use fossil fuels for the foreseeable future. We now have a documented process, based on observed practice as recorded by AIS data, that enables ports and ship charterers to assess the potential value of green steaming.



**Figure 10: The process for integrating sea traffic and port activities (Lind et al., 2015)**

## References

- Dean, J., & Ghemawat, S. (2008). MapReduce: simplified data processing on large clusters. *Communications of the ACM*, 51(1), 107-113.
- Güven-Koçak, S. e. (2015). *Maritime Informatics framework and literature survey-ecosystem perspective*. Paper presented at the Americas Conference on Information Systems Puerto Rico.
- Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design science in Information Systems research. *MIS Quarterly*, 28(1), 75-105.
- International Maritime Organization. (2009). *Second IMO GHG study*. Retrieved from <http://www.imo.org/OurWork/Environment/PollutionPrevention/AirPollution/Documents/GHGStudyFINAL.pdf>
- Lam, C. (2010). *Hadoop in action*: Manning Publications Co.
- Larsson, L., & Raven, H. C. (2010). *Ship Resistance and Flow*. Jersey City, NJ: Society of Naval Architects and Marine Engineers (SNAME).
- Larsson, L., & Raven, H. C. (2010). *Ship resistance and flow*. Jersey City, NJ: Society of Naval Architects and Marine Engineers (SNAME).
- Lind, M., Haraldson, S., Karlsson, M., & Watson, R. T. (2015). *Port collaborative decision making – closing the loop in sea traffic management*. Paper presented at the 14th International Conference on Computer Applications and Information Technology in the Maritime Industries, Ulrichshusen, Germany.
- MAN. (2001). *Basic Principles of Ship Propulsion*: MAN Diesel & Turbo.
- Maritime Knowledge Centre. (2012). *International shipping facts and figures – information resources on trade, safety, security, environment*. Retrieved from
- Peffer, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A design science research methodology for information systems research. *Journal of Management Information Systems*, 24(3), 45-77.
- Porathe, T., Borup, O., Jeong, J. S., Park, J. H., Andersen Camre, D., & Brödje, A. (2014). *Ship traffic management route exchange: acceptance in Korea and Sweden, a cross cultural study*. Paper presented at the Proceedings of the International Symposium Information on Ships, ISIS 2014.
- Psaraftis, H. N., & Kontovas, C. A. (2009). CO2 emission statistics for the world commercial fleet. *WMU Journal of Maritime Affairs*, 8(1), 1-25.
- Rawson, K. J., & Tupper, E. C. (2001). *Basic ship theory* (Vol. 1). Oxford, UK: Butterworth-Heinemann.



- Seidel, S., & Watson, R. T. (2014). Improving the Societal Effectiveness of IS Research: The Pursuit of Prescriptive Accuracy. Available at SSRN 2477917.
- Sims, R., Schaeffer, R., Creutzig, F., Cruz-Núñez, X., D'Agosto, M., Dimitriu, D., . . . Tiwari, G. (2014). Climate Change 2014: Mitigation of Climate Change: Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. In O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, & P. Eickemeier (Eds.), *Climate Change 2014: Mitigation of Climate Change: Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Vol. 1). Cambridge, UK: Cambridge University Press.
- Siwe, U., Lind, M., Hägg, M., Dalén, A., Brödje, A., Watson, R. T., . . . Holmberg, P.-E. (2015, May 11-13). *Sea Traffic Management – Concepts and Components*. Paper presented at the 14th International Conference on Computer Applications and Information Technology in the Maritime Industries, Ulrichshusen, Germany.
- The Economist. (2015, Jan 17). Invisible fuel: The biggest innovation in energy is to go without. *The Economist*.
- Tozer, D. (2008). Container ship speed matters. *Lloyd's Register, Marine Services*.
- Watson, R. T., & Boudreau, M.-C. (2011). *Energy Informatics*. Athens, GA: Green ePress.
- Watson, R. T., Boudreau, M.-C., & Chen, A. J. W. (2010). Information Systems and environmentally sustainable development: Energy Informatics and new directions for the IS community. *MIS Quarterly*, 34(1), 23-38.
- Wigforss, J. (2012). *Benchmarks and measures for better fuel efficiency*. Retrieved from Göteborg, Sweden: <http://publications.lib.chalmers.se/records/fulltext/159671.pdf>