Moving Containers Efficiently with Less Impact: Modeling and Decision-Support Architecture for Clean Port Technologies

Final Report

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Abstract

Broadly framed, this study assesses environmental impacts, at the global and regional scales, associated with port container movement and models the roles of alternative routes and clean technologies (i.e. electrification) in making this movement more environmentally efficient. At the multinational scale, Chapter 2 models three factors (emissions, cost, and time) associated with the transport of a typical twenty foot equivalent (TEU) container from manufacturing facility in China to various destination zip codes. Through varying routing scenarios (eg Panama Canal vs. Port of Los Angeles) to these destinations, the model illustrates how emissions, cost, and time are affected. Chapter 5 incorporates these modeling results by presenting the initial architecture for an internet-based goods movement decision-support tool. Fully developed, this tool will allow stakeholders to improve supply chain efficiency by enabling them to identify optimal container movement routes based on user preferences, specifically carbon emissions, time, and cost. Chapters 3 and 4 focus on the regional scale by evaluating the greenhouse gas (GHG) reduction benefits of electrification of container movement equipment. Chapter 3 provides a comparative life cycle analysis (LCA) between diesel and electric yard tractors. The research reveals the even with aggressive port electrification strategies, due to an increase in container throughput the Port of Los Angeles (POLA)'s legislated reduction targets are not achievable by the target year of 2030. Chapter 4 focuses on electrification of container ships through the Alternative Marine Power (AMP) Program, using LCA-based energy emissions accounting to assess its effectiveness as a greenhouse gas (GHG) emissions strategy for the Port of LA.

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Disclosure

This project was funded in entirety under this contract to California Department of Transportation. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the Department of Transportation, University Transportation Centers Program, and California Department of Transportation in the interest of information exchange. The U.S. Government and California Department of Transportation assume no liability for the contents or use thereof. The contents do not necessarily reflect the official views or policies of the State of California or the Department of Transportation. This report does not constitute a standard, specification, or regulation.

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The primary idea behind this research (modeling emissions associated with port container movement at multiple spatial scales and providing option to make this movement more environmentally efficient) grew out of earlier research efforts. We thank Drs. Raymond Madachy, Hillary Bradbury and Robert Vos for being involved in that earlier effort with us.

In addition to the PIs, we had the assistance from a number of student researchers. We had four graduate students working on this project at different times: Alison Linder (Policy and Planning Development), Jae Kim (Viterbi School of Engineering, ISE Department), Afsin Akdogan (Viterbi Engineering, CS Department) and O Seok (Department of Geography, LAS). We also had two undergraduate students who helped us reliably and consistently: Eric Lee (Viterbi Engineering, ISE) and Olivia Lu-Hill (Viterbi Engineering, Civil and Environmental Engineering).

1 Introduction

Working groups of seaports, major global shippers, ocean freight carriers, and logistics firms are now exploring formation of new clean air policies on a global basis (e.g., the Clean Cargo Working Group). Some transnational corporations are starting to voluntarily calculate their Scope III or indirect lifecycle emissions, which include the greenhouse gases (GHGs) and air pollutants associated with the transport of goods. Others are faced with new clean air regulations, such as those from AB32. The Ports of Los Angeles (POLA) and Long Beach have responded by adopting the Clean Air Action Plan (CAAP) which will fundamentally alter operations at the Ports and in the goods movement industry in the region. This plan includes adoption of new programs, shifts in the ratio of modal transport (truck to rail), clean technologies, and alternative fuels. Faced with changing technologies and uncertain costs, goods movement stakeholders are now confronting an array of choices with potentially large impacts on the region's economy and environment. They urgently need information about how these proposed changes will affect key shipping nodes and the goods movement system as a whole. They also need to be able to weigh options and identify optimal leverage points where cost-effective changes can be made.

The research in this report seeks to address these needs by answering crucial questions, such as: 1) What are the emissions, cost and time factors associated with the transport of a typical container (TEU) from China to retail distribution centers in the U.S.?; 2) How will the adoption of modal shifts, clean technologies, and alternative fuels affect cost, delivery time, and emissions from the Port of Los Angeles to the Inland Empire and what impact will these strategies have on the overall emissions footprint of a typical U.S.-China container?; and 3) What is the most effective way to make this research accessible to decision-makers in the supply chain?

To address these questions, this report is divided into four major chapters. The overarching objective of the research is to assess the impacts of clean technologies and fuels on three factors (emissions, cost, and time) associated with the transport of a typical twenty foot equivalent (TEU) container. The focus on these technologies and fuels hinged on those new programs being implemented or considered under the CAAP and the regional Climate Action Program (CAP). Chapter 2 addresses this question at a multinational spatial scale: Factory in China to U.S. retailer. Specifically, the research team calculated the emissions, time, and cost associated with transport of a typical TEU from the factory gate in China's Pearl River Delta to six destination zip codes in the U.S. For these destinations, modules will include routing variations and the impact of deploying clean technologies and fuels for the different forms of modal transport along the supply chain. Chapter 3 focuses on a smaller spatial scale by assessing the indirect emissions from electrification of drayage trucks within the Port of Los Angeles. Chapter 4 focuses on electrification of container ships through the Alternative Marine Power program and assesses the effectiveness of this as a greenhouse gas emissions strategy for the Port of Los Angeles. Chapter 5 incorporates the modeling results from chapter 2 and outlines the initial architecture for an internet-based goods movement decision-support tool. The rationale for building this prototype architecture is to make the research results accessible and usable by those who need it most. If fully developed, this tool will allow stakeholders to improve supply chain efficiency by enabling them to local leverage points that yield the desired change for the lowest cost and period of time. To assure validity, reliability, and usefulness, this architecture was co-developed and tested through meetings with these stakeholders.

1.1 Genesis for the research

This research leverages previous work and close collaboration with the environmental management division of the POLA to test data quality and to obtain emissions, cost, and time data on relevant port-related technology initiatives. In 2007-08, USC researchers convened a group of Los Angeles business leaders from regional companies interested in *sustainable enterprise systems*. The invitation was to an 'experiment in collaborative learning' in support of a more sustainable regional economy. The Sustainable Enterprise Executive Roundtable (SEER) was subsequently formed to be a hub for pulling together learning anchored in practical collaboration for doing together what no one actor can do alone to move the region toward sustainability. Participants included decision-makers from the region's leading businesses, including the ports, an ocean freight carrier, a terminal operator, a toy manufacturer, an entertainment company, an environmental consulting company, a truck manufacturer and a marketing agency. The SEER group did not include stakeholders from labor unions or the non-profit sector. In light of the importance of the CO_2 emissions, it was argued that seeing the amount of carbon associated with each container of goods would be an impetus to deal more effectively with the challenge of "carbon management." SEER participants therefore expressed interest in a carbon calculator project, aimed at the tracking of carbon dioxide that is produced through shipping goods. As goods movement is a network in which numerous business entities connect, it also offered an opportunity for collaborative learning.

1.2 Relevance to METRANS research areas

METRANS Area 1: *Commercial goods movement and international trade*

USDOT Strategic Goals: *Global connectivity, reduced congestion, environmental stewardship*

This research is particularly relevant to Area 1 (Commercial Goods Movement and International Trade), as it advances understanding about how to move goods within, through, and beyond our mega-city in an efficient, safe, and environmentally-sound manner. The research analyzed system efficiency at the global and regional scales, with a particular focus on how the introduction of new technologies will impact container movement. Port productivity is closely linked to other components of a complex goods movement system that extend throughout the region and globally via shipping routes, intermodal facilities, port operations, and land-based truck and train transportation. To improve productivity and air quality, the San Pedro Bay ports in southern California are making significant investment in new technologies. As these technological investments are made, however, other components of the complex goods movement system will be affected, perhaps in unforeseen (and undesirable) ways. One of the concrete outcomes of the research is increased understanding of how technological innovation in the goods movement system affects emissions of GHGs and criteria air pollutants regionally and globally.

2 The Carbon Footprint of Transportation: Modeling Emissions of Shipping Containers from China to the U.S.

Abstract

This chapters offers a detailed overview of how the carbon footprint of a typical container (TEU) is calculated and how it can be recalculated to see changes with variables, the primary ones being alternative routing, transportation mode, cost, time. It demonstrates, for example, just how carbon intensive transport is by truck. It notes that the alternative scenarios, (e.g., where a Distribution Center is bypassed completely and the container is delivered directly to the retailer DC) may be preferable from a carbon management point of view, but be logistically difficult to realize given a current manufacturer's business model, which in turn underscores the utility of a multi-stakeholder scenario planning opportunity. The usefulness of the work for decision makers ultimately rests on seeing the importance of experimenting with scenarios, e.g., comparing status quo and cleaner technology options during the course of developing an integrated carbon management strategy.

2.1 Introduction

Companies worldwide are beginning to take measures to quantify and address the carbon emissions associated with products that they produce or the services they provide. Business leaders are becoming proactive in reducing CO^2, because it is the right thing to do, because it is demanded by their stakeholders, and because regulation is slowly but gradually moving towards reducing emissions. The initial step for most of these companies has been to calculate direct emissions (Scope 1) —those they directly produce primarily in their building facilities. However, some transnational corporations are starting to also tabulate their indirect emissions (Scope 2 and 3): these are emissions that span across the supply chains. However, most companies provide a service that comprises only a portion of the total supply chain: raw material extraction, manufacturing, distribution, or product use and disposal. Gaining understanding and managing carbon emissions across the supply chain, therefore, is a complex endeavor, involving multiple enterprises that can span continents. An effective method to develop a full understanding of carbon emissions across the supply chain (and identify feasible carbon-reduction strategies) is to work collaboratively, across sectors.

Faced with changing technologies and uncertain costs, goods movement stakeholders are now confronting an array of choices with potentially large impacts on the region's economy and environment. They need information about how these proposed changes will affect key shipping nodes and the goods movement system as a whole. They also need to be able to weigh options and identify optimal leverage points where cost-effective changes can be made.

This project brought together key decision-makers from companies throughout the supply chain to develop a cross-sectoral approach to calculating and managing the carbon emissions associated with goods movement. Using the unit of measurement as a 20-foot shipping container, the project calculated the carbon dioxide emissions from containers that start at factory gates in the Pearl River Delta, China and end at distribution centers of major U.S. retailers. There are three primary contributors to the carbon footprint within this system. The first is the land contribution, which is partitioned into China and United States segments, and is further partitioned into truck and rail segments. The second contribution comes from the sea, which is portioned into cruising speed, and slow speed segments. The third contribution comes from port operations for loading and unloading containers.

The primary objectives of the project were two-fold. First, the project uses data provided by a major toy retailer to calculate the carbon footprint of a typical TEU from China to selected destinations in the United States. Second, the project models a number of scenarios to reduce the carbon footprint of container movement, including alternative routes, use of clean technologies, and so on.

This chapter addresses this needs by answering a crucial question: What are the emissions, cost and time factors associated with the transport of a typical container (TEU) from China to retail distribution centers in the U.S.? For the toy manufacturer case study, what is the most efficient intermodal routing for selected U.S. destination zip codes? The optimal would be lowest emissions, at a minimal cost and time increase? What is the most effective leverage point for change?

2.2 Background

Researchers at the Center for Sustainable Cities convened a group of business leaders from regional companies interested in *sustainable enterprise*. The invitation was to an 'experiment in collaborative learning' in support of a more sustainable region. The Sustainable Enterprise Executive Roundtable (SEER) would be a hub for pulling together learning anchored in practical collaboration in doing together what no one actor can do alone to move the region, and beyond, toward sustainability. Participants included decision makers from the region's leading businesses, including a port, an ocean freight carrier, a terminal operator, a toy manufacturer, an entertainment company, an environmental consulting company, a truck manufacturer and a marketing agency.

While carbon management tackles but one dimension of an overall sustainable system, it was 'low hanging fruit' in terms of a place to start as a number of the SEER participants were experiencing early pressure from stakeholders to reduce their carbon footprints. In light of CO^2 proliferating in the atmosphere, it was argued that seeing the amount of carbon associated with each container of goods would be impetus to dealing more effectively with the challenge of "carbon management." Soon there was considerable interest in working toward a user friendly carbon calculator for reducing carbon footprint associated with goods movement. SEER participants therefore expressed interest in a carbon calculator project, aimed at the tracking of carbon dioxide produced through shipping their goods. CO^2 as a result of shipping goods from China through the port offered a potential point for positive change that connected participants. As goods movement is a process in which numerous business entities connect, it also offered an opportunity for a collaborative learning approach. Participants agreed to develop a carbon footprint of a typical container traveling from factories in China through POLA to retail destination.

2.2.1 Key leverage points in the supply network

China-U.S. container movement can be divided into six supply chain nodes or leverage points. Our previous research on the paper supply chain shows that key 'points' influence other parts of the goods movement system (Newell and Vos 2008). These points, shown in Figure 1, are as follows: 1) Transportation from China factory to China port; 2) China port operations; 3) China port to U.S. port; 4) U.S. port operations; 5) Port terminal to distribution center; and 6) Inland Empire distribution center to distribution centers beyond. Different goods movement actors can exert leverage in different ways at these key points. For the purposes of this study, we do not model scenarios for what might occur to the container with respect to leverage point #3 (China port to U.S. port). That is, we do not model hypothetical scenarios, such as what might happen to the ship after it unloads goods in New Orleans. This consideration is beyond the scope of this report.

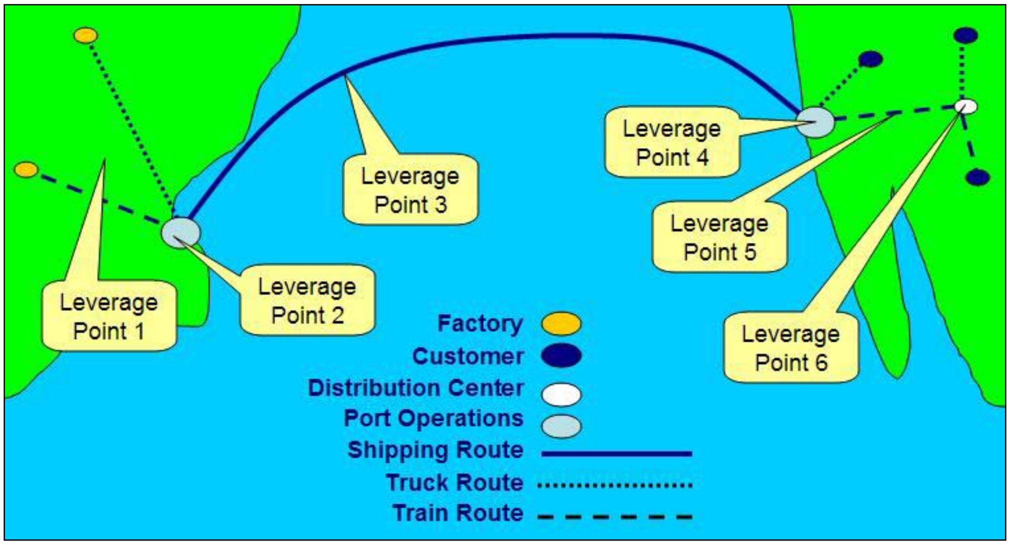


Figure 1 Key leverage points in the supply chain

From the Factory Transportation to Port, users can influence this leverage point when awarding manufacturing contracts to affect the distance to port and method of shipment. Port operations are a small factor compared to the overall carbon footprint. There is little an American company can do to influent port operation in China. However the impact on local communities is quite large with respect to criteria air pollutants. The Port to Port leverage point considers shipping routes, ship types, and fuel types. This leverage point is useful if entities are able to control which shipping routes are used, since the distance, ship efficiency and ship size all play important roles in CO^2 generation. The Terminal to Distribution Center leverage point is to the Factory Transportation to Port leverage point, however unlike the leverage point in China, U.S. customers should have greater control over the type of transportation used to influence the distance of land transportation through port and distribution.

2.3 Material and methods

Data for the study came from a number of different sources. A major toy manufacturer provided data on time, cost, distance, and transport mode (truck, train, and ship) associated with the movement of a typical TEU container from its toy manufacturing facilities in China to its two major distribution centers (City of Industry, CA and Fort Worth, TX), and to customer (retail) distribution centers in six zip codes in the United States. The consulting and engineering firm, Moffat & Nichol, provided detailed carbon dioxide emissions factors for the transport modes and modal shifts. A major shipping firm, YTI, supplied detailed ship emissions data for both old and new vessels. Proprietary online software, NetPas Distance©, was used to calculate the distance of the various shipping routes, including modal shifts. The POLA has done extensive surveys of port-related truck trips to local, regional, and national destinations, and has data on transshipment as well as projected tailpipe emissions, fuel use, and air pollution inventories under the CAAP.

A major toy manufacturer provided data on manufacturing locations and production volumes of its factories (or it OEMs) from factories in the Pearl River Delta. These included cities location and zip codes for two of its major distribution centers (DCs), Fort Worth, Texas and City of Industry, CA, in the U.S. Finally the manufacturer provided data on the DCs of size of its largest retailer clients to allow for detailed route modeling and scenario development. The consulting and engineering firm, Moffat & Nichol, provided the most robust carbon dioxide emissions factors for these three transport modes. Volume rather than weight was chosen because the generic consumer product is deemed lightweight, such that the constraining factor was the *volume* of the container rather than the weight of it. However, the model could be easily adjusted to be based on weight rather than volume of the container.

The emissions factor data was derived from sources such as the Department of Energy (DOE), Port of Los Angeles (POLA), and the Bureau of Transportation Statistics (BTS). The average emissions rate for U.S. trucks was calculated based on the age distribution of operating trucks (see POLA). Trucks in China were assumed to have emissions rates equivalent to pre-1990 trucks. The emissions rate for ships was calculated using data provided by the manufacturers and assuming cruising speeds of 20 knots. Table 3 provides a summary of the emission factors for the transport modes. It was assumed that a ship would cruise at 20 miles per hour (approximately 19 knots). It should be noted that a slower cruise speed would reduce the carbon dioxide emissions per mile. Based upon these parameters, ships turned out to be the most efficient form of transport in terms of CO^2 emitted per mile (by TEU) at .2 lbs at CO2 equivalent per TEU-mile. Train was next at .35 lbs per mile, followed by truck at 2.53 lbs per mile. Truck is nearly 10 times less efficient per mile than by train and nearly 22 times less efficient per mile than by ship.

We used Google maps and other online tools to estimate the distances from the Chinese cities to the Chinese ports and from U.S. ports to the toy distributor and retailer DCs. More than 90% of all the goods shipped from China go through the POLA. To calculate the distance of the various shipping routes, proprietary online software, NetPas Distance© was used. Some of the routes calculated include China to LA, China to Texas through the Panama Canal, and China to Texas through the Suez Canal.

Based on the toy manufacturer's data, the cost per TEU-mile for ships was estimated at $0.19 for any container originating in China and travelling across the Pacific Ocean (i.e. we do not consider routes west to the Suez Canal). The manufacturer's estimate is considerably lower than industry average (see Four Corridor Case Studies of Short-Sea Shipping Services) perhaps due to previous contracts with the shipper as well as the size of the shipper's cargo ships. For routes through the Panama Canal, an additional $54/TEU fee is required. Based on the manufacturer's data, the cost per TEU-mile for rail is estimated at $0.70. The costs per TEU-mile for truck transport were also derived from the manufacturer's data. Typically, longer distances yield lower cost per TEU-mile.

Transit time estimates for train transport and truck routes and transit times were calculated using the manufacturer's data. For alternate routes, estimates were calculated assuming an average coverage of 500 miles per day. An additional day for intermodal transport was added for certain routes.

Table 1 Sample of origin city and port data

Location	**City**	**POL**	**POUL**	**Destination**	**Volume (FEUs)**
HuMen	DONGGUAN	Yantian	LA/Long Beach	Ft. Worth	4
HuMen	DONGGUAN	Yantian	LA/Long Beach	San Bernardino	671

Table 2 Locations of selected distribution centers and retailer destinations

Distribution center name	**DC1**	**DC2**	
Distribution center city	City of Industry, CA 91744	Fort Worth, TX 76106	
Avg. distance to customer DC	587 miles	1000 miles	
Customer DC zip codes	80538	72143	45014
	85043	07836	24477

Table 3 Emissions factors for transport modes

Mode of transport	**CO_2-equiv. (lbs./TEU-mile)**
Truck (China)	2.53
Ship	0.20
Rail	0.26
Truck (U.S.)	2.16

Source: Moffat & Nichol, 2009.

Methods

We model the transport of a single twenty-equivalent-unit (TEU) from a factory in Southeastern China to a destination in the U.S. In addition to breaking down China-U.S. container movement by leverage points, for modeling purposes, it can also be broken down into nodes and arcs. The route consists of 5 (or 4) *nodes*, which represent factories, ports, distribution centers, and other shipment-related assembly centers. The nodes are connected by 4 (or 3) *arcs*, which represent the transport mode (i.e. truck, ship, and train). A complete summary of the type of nodes and arcs presented in this study is shown in Table 4.

Table 4 Summary of nodes and arcs in study

Node	**Description**	**Location**	**Description**
1	Originating factory	Various locations within Southeastern China	Manufacturer's factories in China
2	Yantian port	Yantian, China	Manufacturer's shipping terminal in China
3	U.S./North American port	Los Angeles, Seattle, Prince Rupert, Texas, New Orleans, South Carolina, Virginia, New Jersey	Potential destination ports in North America
4	Distribution center	Fort Worth, Texas or Inland Empire, California	Known distribution centers in the U.S.
5	Destination zip code	Colorado, Arizona, Ohio, Arkansas, Virginia, New Jersey	Final destination for shipment

Arc	Mode	Description	Connecting nodes
A	Truck	Heavy duty trucks in China	1 to 2

B	Ship	Large cargo ships travelling across the Pacific	2 to 3
C	Train/truck	Rail connections or heavy duty trucks depending on proximity	3 to 4
D	Truck	Heavy duty trucks in U.S.	4 to 5

2.4 Freight transport model

The modeling can be illustrated by a simple example. Currently, a typical container originating from China requires 5 nodes through 4 arcs to reach its destination. This implies that a container moves through 3 intermediary locations in 4 transportation modes from source to destination. We represent the potential paths as a network in Figure 2. The solid line, for example, represents a container originating from China (node 1) going to Ohio (node 5) through Yantian Port (node 2), Port of Los Angeles (node 3), and a distribution center in Fort Worth, Texas (node 4). Alternative paths connecting node 1 to 5 are shown in dotted lines. Certain network paths require access through all nodes (1 to 5) using strict arcs (e.g. only accessible by ship, rail, or truck). Some paths may bypass intermediary nodes using certain accessible arcs. The choice of path determines the total CO_2-equiv. emissions, economic cost, and transit time.

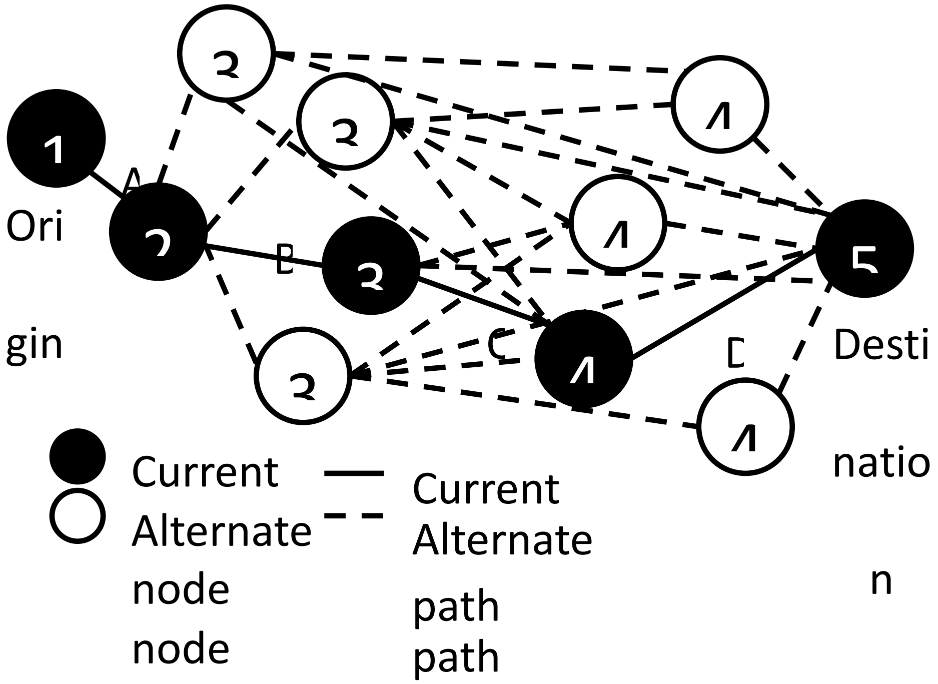


Figure 2 Potential routes from origin factory to destination zip code

2.4.1 Emissions calculations

CO_2-equivalent emissions are calculated for each path in a network. Total emissions depend on three factors: mode of transport, emission factor, and TEU-miles traveled. For each path from origin to destination, total emissions are the sum of the emissions of each connecting arc. The calculation is as follows:

$$Total\ CO_{2-equiv.}\ Emissions = \sum_{i=A}^{D} Emissions\ factor(i) \cdot Miles(i) \qquad (1)$$

where *Emissions factor (i)* and *Miles (i)* are determined by connecting arc *i*. Each arc has a transport mode and distance, respectively.

2.4.2 Cost estimates

We calculate the cost estimates based on the total miles from the origin to destination. Each intermediary arc in a path has an associated *cost per mile (i)* estimate. Then, the total cost estimates from the origin to destination is the sum of intermediary costs determined by each connecting arc:

$$Total\ Cost = \sum_{i=A}^{D} Cost\ per\ TEU\ Mile(i) \cdot Miles(i) \qquad (2)$$

2.4.3 Transit time estimates

The total transit time is an estimate of the number of days required to transport TEUs from origin to destination. Transit time estimates for sea transport is determined in two ways: (1) calculated by distance estimates from *Netpas* and assuming a cruising velocity of 20 knots, and (2) manufacturer's data. Based on the two approaches, routes from Yantian Port to Western ports (e.g. Los Angeles, Seattle, Prince Rupert) requires between 10 to 14 days. For destinations in the U.S. Midwest or U.S. East Coast, an alternative route is available through the Panama Canal.

Typically, these routes require approximately 20 to 21 days to reach a non-West Coast U.S. port (see Table 5).

Table 5 Transit time estimates from Yantian, China to North American port

Port	**Distance (nautical miles)**	**Approximate transit time (days)**
Port of Los Angeles (POLA), CA	6361	14
Seattle, WA	4983	11
Prince Rupert, BC	4603	10
Houston, TX	9349	20
New Orleans, LA	9218	20
New Jersey, NJ	9712	21
Norfolk, VA	9572	20
Charleston, SC	9395	20

Source: Author's estimations based on manufacturer's data and shipping routes.

2.5 Results

Based on the manufacturer's data, the carbon footprint was created for a container transiting from factory to destination. For the average container shipped from China to various U.S. destination zip codes, a carbon footprint of 2,821 kilograms per container per trip was determined. Transport by container ship is the most efficient in terms of CO^2 burned per mile. So it is possible for a container to travel a greater distance, yet have a smaller carbon footprint than one that uses land transportation (train/truck) for a greater portion of the distance.

2.5.1 Alternative route scenarios: case studies

To assess the tradeoffs between emissions, cost, and time, we provide four origin-to-destination case studies. All freight originates in factories scattered throughout Southeastern China in close proximity to Yantian Port. We ignore the intermodal effects (e.g. transferring TEU from ship to train to truck) because each route requires a similar number of transfer of intermodal operations.

There are emissions tradeoffs associated with route selection. In cases (I) and (II), the shipper has higher emissions for the lower cost routes. Especially for Western destinations, the alternate routes often require less cost but have higher emissions. Alternate sea routes through the Panama Canal offer significant cost advantages for destinations in the Midwest and East. In all Midwest and East destinations (Cases II, III, IV), the current route from the Port of Los Angeles was always more expesnive than those from the ports in the Gulf of Mexico and Atlantic. This cost advantage usually comes with a transit time penalty. In our cases, however, the penalty was minimal or even nonexistent (Cases III and IV).

2.5.2 Alternative route scenarios

We investigate the intermodal effects in later sections. The first case we consider is the movement of a TEU container from a factory in Baiyan, China to a destination zip code in Colorado. The second case models a TEU container originating from GuanYao, China to a zip code in Arkansas. The third case models a TEU container from GuanYao and arriving in Ohio. The fourth case models a TEU container moving from GuanYao to New Jersey. The origin and destinations of the four cases are provided in Table 6. For each case, we investigate potential alternate routes and the current routes that the toy manufacture currently uses.

Table 6 Origins and destinations for each case study

Case	Origin	Destination (zip code)

I	Baiyan, China	Colorado (80538)
II	GuanYao, China	Arkansas (72143)
III	GuanYao, China	Ohio (45014)
IV	GuanYao, China	New Jersey (07836)

Case I: Baiyan, China to Colorado (zip code: 80538)

This case study models shipment of a TEU container from a factory in Baiyan, China to Colorado (zip: 80538). The factory is approximately 156 miles from the port terminal in Yantian. From Yantian Port, the container has three potential North American port destinations: A) Los Angeles, B) Seattle, and C) Prince Rupert (Canada). The current route travels by truck through the Port of Los Angeles to a distribution center in Inland Empire, California. From the distribution center, the container is then transported by truck to Colorado. In case (I-A), we consider the current route. In cases (I-B) and (I-C), however, we consider scenarios that bypass the distribution center. Table 7 illustrates the case study transport variants.

The results of case study (I) indicate that the current path (I-A) yields the lowest CO_2-equivalent emissions. However, alternate routes do offer some advantages in terms of cost and transit time, if the distribution center is bypassed and the product is shipped directly to the retailer's distribution center, as show in Table 7.

Table 7 Estimated outputs for 3 different route scenarios for a destination in Colorado

Case	**I-A**	**I-B**	**I-C**
U.S./Canada port	Los Angeles, CA	Seattle, WA	Prince Rupert, BC
Distribution center	Inland Empire, CA	None	None

CO_2-equiv. emissions (lbs./TEU)	4,161.64	4,269.92	6,016.20
Cost ($/TEU)	3,591.18	3,344.15	3,814.52
Transit time (days)	20	16	17

Case II: GuanYao to Arkansas (zip code: 72143)

This case illustrates an emerging dilemma faced by shippers. Shipments from Asia to the U.S. Midwest or East have been traditionally moved through a Western port (i.e. Los Angeles, Oakland, and Seattle). However, increasing costs and logistic challenges have forced shippers to examine other routes such as those through the Panama Canal. The routes leading to ports bordering the Gulf of Mexico and Atlantic offer lower costs because shipping by sea is cheaper per TEU-mile than land. However, the tradeoff is a longer transit time. On average, a typical container takes approximately three days longer to reach a destination in the East Coast if it is transported through the Panama Canal (USDA 2010).

The factory is located in GuanYao, approximately 186 miles from the port terminal in Yantian. No other alternatives exist for the use of trucks from GuanYao to Yantian Port. From Yantian Port, the container has three potential North American port destinations: A) Los Angeles, B) Houston, and C) New Orleans. The current route used by the toy manufacturer passes through the Port of Los Angeles and by train to a distribution center in Fort Worth, Texas. From the distribution center, the container is transported to Arkansas by truck. Case II-A considers the existing route. Cases II-B and II-D consider routes through the Panama Canal to Port of Houston and Port of New Orleans, respectively. Cases II-C and II-E consider the ports in

Houston and New Orleans again but bypass the distribution center in Fort Worth, Texas. The results of the case are illustrated in Table 8.

Results of case study II indicate that the current path (II-A) yields the lowest CO_2-equivalent emissions. However, alternate routes (II-B, II-C, and II-E) do offer some cost advantages. By transporting directly from the Port of New Orleans to the destination, case II-E has the lowest cost. However, the route has higher CO_2-equivalent emissions versus that of case II-A. Routes using the Port of Houston (II-B and II-C) offer cost advantages but also yield significantly higher emissions.

Table 8 Outputs for 5 different route scenarios for a destination in Arkansas

Case	**II-A**	**II-B**	**II-C**	**II-D**	**II-E**
U.S. port	Los Angeles	Houston	Houston	New Orleans	New Orleans
Distribution center	Fort Worth	Fort Worth	None	Fort Worth	None
CO_2-equiv. emissions (lbs./TEU)	3,185.54	3,575.64	3,668.22	3,619.80	3,476.02
Cost ($/TEU)	3,210.73	3,116.64	3,030.99	3,288.15	2,847.05
Transit time (days)	24	25	24	26	24

Case III: GuanYao to Ohio (zip code: 72413)

We examine the same routes in case (II) for a destination in Ohio (see Table 9). The direct route from the Port of New Orleans to the destinations (III-E) yields both the lowest emissions and costs. All other alternate routes yield higher emissions than the current POLA route (III-A). The cost savings are substantial for both direct routes from port-to-destination (III-C and III-E). This case illustrates a "win-win" case where the lower carbon option also yields lower costs without a significant impact on transit time.

Table 9 Estimated outputs for 5 different route scenarios for a destination in Ohio

Case	**III-A**	**III-B**	**III-C**	**III-D**	**III-E**
U.S./Canada port	Los Angeles	Houston	Houston	New Orleans	New Orleans
Distribution center	Fort Worth	Fort Worth	N/A	Fort Worth	N/A
CO2-equiv. emissions (lbs.)	4550.66	4940.76	4931.82	4984.92	4372.42
Cost ($)	3959.83	3865.74	3713.84	4037.25	3378.9
Transit time (days)	24	25	24	26	24

Case IV: GuanYao to New Jersey (zip code: 07836)

Case IV considers a destination to New Jersey (zip: 07836). The freight again originates from GuanYao with a single route to Yantian Port. The shipper has three potential North American port options: A) Los Angeles, B) Houston, and C) New Jersey. The current route passes through the Port of Los Angeles to a distribution center in Fort Worth, Texas by train. From the distribution center, the container is then transported to New Jersey by truck. Case IV-A considers the POLA route. Case IV-B considers an alternate route through the Panama Canal to Port of Houston. Cases IV-C and IV-D consider routes from Houston and New Jersey, respectively, directly to the destination. The results of this case are shown in Table 10.

The results indicate an alternate path (IV-D) from the Port of New Jersey directly to the destination yields the lowest emissions, cost, and transit time. Again, this modeling assumes the bypassing of the manufacturer's distribution center and delivery directly to the retailer. The current route (IV-A) yields the highest cost. The use of the Port of Houston (IV-B and IV-C) does offer cost savings in both cases but a direct route to New Jersey (IV-C) offers advantages all three categories. This case demonstrates the potential advantages for a shipper to use direct routes to Eastern or Gulf of Mexico ports. The shipper does not have to pay a premium to achieve carbon emissions savings but rather pays *less* in terms of cost *and* transit time.

Table 10 Estimated outputs for 4 different route scenarios for a destination in New Jersey

Case	**IV-A**	**IV-B**	**IV-C**	**IV-D**
U.S. port	Los Angeles, CA	Houston, TX	Houston, TX	New Jersey, NJ
Distribution center	Fort Worth, TX	Fort Worth, TX	N/A	N/A
CO2-equiv. emissions (lbs.)	5822.9	6213	4931.82	4159.86
Cost ($)	4907.98	4813.89	3852.81	3385.56
Transit time (days)	26	27	25	25

Port operations play a very minimal role in terms of the overall carbon footprint of a typical container transported from China to the U.S. It follows that “Cold Ironing” provides little benefit to the importer of goods from a total carbon footprint perspective. However, the environmental benefits of cold ironing in terms of nitrous oxide and sulfur dioxide would be significant.

The toy manufacturer currently ships nearly 100% of its goods through the POLA, which is generally the shortest shipping route. This results in the lowest shipping CO^2 rates possible, however it also creates a need for additional land transportation within the United States, since a majority of the customers and distribution centers are in the Eastern Portion of the United States.

If the manufacturer were to use the alternative routes, this could lover the overall container carbon footprint. Using the Panama Canal results in 12 kg per TEU per trip, while the transiting the Suez Canal results in only 6 kg per TEU per trip.

2.6 Conclusions and discussion

Calculating carbon footprints as we have done here provides a useful static picture of the emissions of a typical container journey. However, calculating in this model is limited in that you must consider other variables such as time and cost of delivery *separately*. Using a 'systems dynamic' approach, this limitation can be overcome by integrating these variables and others such as use of clean technologies. This type of modeling, although more, offers a richer picture with which to consider scenarios, which in turn can provide robust input to decision making, about which routes to take and what technologies to consider. There is also potential for other models to create a more dynamic picture of the interplay between the three key variables (cost, mission, time), such as Multi-Attribute Decision Marking (e.g. the TOPSIS model as a possibly appropriate approach).

As noted in some of the cases, the manufacturer distribution center is bypassed completely and the container is delivered directly to the retailer DC. This may not be logistically easy to change given current a manufacturer's business model. However, based on these carbon emissions footprints, either establishing a manufacturer DC or delivering product directly to the retailer DC would be desirable from a climate change perspective.

With Panama Canal expansion by 2014, the cost advantage is expected to increase and cargo volume will shift somewhat from West Coast ports to reflect this savings. In this modeling, results demonstrate that transit time tradeoffs are not as significant as expected.

Alternate routes through the Panama Canal are often perceived as having longer delays. However, routes with longer ship transport and shorter rail and truck transport yield marginal delays for destinations in the Midwest and East. Considering the fact that freight transport from the West to East is often delayed by capacity constraints and labor unrest, this minimal difference in transit time may be valid.

Due to their modularity, the models can be customized for multiple customers and operating modes, and expanded to consider additional environmental concerns, e.g., such as quantifying criteria air pollutant emissions.

Model limitations

The model is only as good as the data that is gathered, and some data may not be entirely accurate. For instance this model does not take into account the impacts of traffic congestion, which might drive up the land CO^2 contribution associated with one or more of the supply routes. In this model, the Port contribution to the carbon footprint is limited to the ship power used while in port, and the average power of the terminal operations while the ship is in port. It does add in additional port CO^2 emission that is related to upkeep and day to day operations of the terminal. These CO^2 contributions could be added to terminal footprint by averaging these factors by the number of containers serviced over a year. This would add to the port CO^2 footprint slightly, but since it is such a small factor in the overall model, it can be ignored.

Another limitation of the model is that data from one typical container ship was used to populate the model, however it is likely that a number of different types of ships will be used for each route. These variations in ship types or operating modes can shift the carbon footprint of a container by several hundred kilograms. Future users of this model will want to use ship data based on the actual size of the ship and the routes they intend to use. The train CO^2 rate used was a generic emissions factor, but freight services may vary significantly. An improvement to the model, for example, would be to model fuel consumption for actual freight services that are being used or considered by the user.

3 Life-Cycle Emissions from Port Electrification: A Case Study of the Port of Los Angeles

Abstract

To reduce GHG emissions, ports around the world are considering electrification of their cargo handling equipment. To assess the benefits of the strategy, this study provides a comparative life-cycle analysis (LCA) between diesel and electric yard tractors at the Port of Los Angeles. Results indicate a significant reduction in life-cycle GHG emissions as the port shifts to electric vehicles and as the port's electricity supplier increases its projected use of renewable energy sources (e.g., wind and solar). The results also demonstrate that even with aggressive port electrification strategies, the port's legislated reduction targets are not achievable by the year 2030.

Key Words: Port electrification, life-cycle analysis, greenhouse gas emissions, Port of Los Angeles, renewable energy.

3.1 Introduction

With the passing of the landmark AB32 (Global Warming Solutions Act) in 2006, California has initiated an ambitious plan to cut its greenhouse gas (GHG) emissions to pre-1990 levels by 2020 and 80 percent below pre-1990 levels by the year 2050 (California Energy Commission 2007). The City of Los Angeles took a step further by adopting the *Green LA* plan, which calls for reducing GHG emissions 35% below 1990 levels by 2030 (City of LA 2007). Key regulations such as these at the state and local government levels aimed at reducing GHG emissions are prompting public utilities, businesses, and other entities in Los Angeles to plan, assess, and implement new strategies to reduce their carbon footprints, while remaining economically competitive.

One important entity is the Port of Los Angeles (POLA), which is directly responsible for approximately 919,000 jobs and $39.1 billion in annual wages and tax revenues in the Los Angeles basin (Vera 2008). As a major center of economic activity, the port is also a focus of attention due to its environmental impacts and is constantly searching for new strategies to reduce its impact locally and regionally. One such strategy is called *port electrification*: the process of transforming the port's power sources from internal combustion to electricity. Among all the operations conducted within the port's boundary, cargo handling equipment (e.g. yard tractors) is the most important one directly under the control of port management and is primarily powered by diesel fuel. But electricity is an attractive alternative. The Port of Houston, for example, has begun construction of the Bayport Container and Cruise Terminal, a $1.4 billion project that incorporates 21 electric ship-to-shore cranes and will provide infrastructure to support shore power (EPRI 2008). Furthermore, studies by the Electric Power Research Institute (EPRI) outline opportunities for electrification and assess the viability of using currently available technologies such as electric forklifts and yard tractors (EPRI 2006).

Port electrification is viewed by some as the ultimate strategy to reduce emissions within the boundary of the port (Green LA 2007). In this strategy, direct emissions are viewed as tailpipe emissions, which is zero for electric vehicles. However, looking at this strategy from a broader (i.e. "systems") view of emissions production, one needs to consider both *direct* and *indirect* emissions. In the context of this study, indirect emissions are the emissions produced during all key phases of the electricity generation cycle, not considered by most EPRI studies. To examine the effects of including direct and indirect emissions, the first objective of this study is to provide a comparative life-cycle accounting between diesel and electric yard tractors. After this comparison, the study model takes into account future transition to less carbon intensive renewable energy sources for electricity generation as well as projected increases in yard tractor use for the years 2020 and 2030.

We begin by examining emissions from the electricity generation process. POLA buys all of its electricity from the Los Angeles Department of Water and Power (LADWP), with carbon-intensive generating sources. Although LADWP treats electricity derived from solar, hydro, and nuclear as zero emissions (LADWP 2010), this treatment is both incomplete and problematic. To remedy this incomplete accounting and high uncertainty in emission factor calculations, we estimate the indirect emissions based on a literature review of previous life-cycle studies. To model increases in yard tractor use, we use the number of containers moving through the port (known as “container throughput”). Our hypothesis is that rapid increase in container throughput is the dominant driver of the overall emissions. And, electrification may not allow the port to achieve its emission targets, even with an increased LADWP renewable portfolio.

3.2 Background

As is one of the region’s economic drivers, POLA is a critical part of the continuing growth and vitality of the Southern California region. More than 7.8 million TEU (twenty-foot equivalent unit) containers moved through the port alone in 2008 alone, generating over $240.4 billion in economic activity in the United States (POLA 2010). In addition, it is associated with more than 3.3 million jobs (direct and indirect) across the U.S (POLA 2010). Furthermore, it is the gateway for international commerce -- responsible for providing entry to more than 43% of the volume of goods imported to the United States (Salin 2010). However, despite the port’s significant contribution to the regional economy, it is also a source of local and regional air pollution. For example, the emission of sulfur dioxide, nitrous oxide, and particulate matter (PM) from the exhaust pipes of diesel trucks serving the port poses severe health hazards to the local population (Kim, Teffera et al. 2000). In Los Angeles, deaths caused by ischemic heart disease are linked to the effects of $PM_{2.5}$ (Jerrett et al. 2005). Aside from these criteria air pollutants, the port is also responsible annually for 1.05 million metric tons of CO_2 and other GHG emissions and its yard tractors alone contribute about 94,000 metric tons of CO_2-equivalent emissions per year (Starcrest 2009).

To reduce the effects of GHGs, POLA has outlined plans under the regional Climate Action Plan (CAP). Although the final draft of CAP has not been officially released, preliminary drafts indicated programs for green power, alternative fuel vehicles, green buildings, and tree planting. Essentially, CAP is an attempt to emulate the success of the Clean Air Action Plan (CAAP). Under CAAP, POLA, working jointly with the Port of Long Beach aims to reduce PM pollution from port-related activities by at least 47% within five years and NOx and SOx by 45% and 52%, respectively (Port of Los Angeles and Port of Long Beach 2006). Despite the success of CAAP, achieving similar success for GHG reductions is highly uncertain, when we consider the key difference in the nature of the pollutants. Carbon dioxide and other GHGs are *global* pollutants whereas PM, NOx, and SOx are *local* pollutants. This key difference makes measuring and reducing GHGs a less geographically-bounded task: there is a need to measure both direct and indirect emissions from fuel and energy sources upstream, in addition to the emissions from the point of use.

3.2.1 LADWP Energy Portfolio

Table 11 summarizes LADWP's proportion of the energy sources for the production of power (LADWP 2008). Relative to the rest of the state generators (e.g.

Pacific Gas and Electric, Southern California Edison), LADWP has significantly higher proportions of coal and natural gas (LADWP 2008), generating a CO_{2e} emissions factor of approximately 560.86 g/kWh (LADWP 2010). LADWP expects the carbon intensity of its electricity to decrease to 342.60 g/kWh by the year 2020 (LADWP Interview 2010). However, as stated previously, these projections suffer from incomplete accounting because they do not treat the emissions from all energy sources on a complete life-cycle basis.

Table 11 Percentange of LADWP power mix of 2007

Energy Source	LADWP
Non-renewable	
Coal	42
Natural Gas	34
Sub-total	76
Renewable	
Biomass & Waste	1
Geothermal	0
Small Hydroelectric	5
Large Hydroelectric	6
Solar	0

Wind	2
Nuclear	10
Sub-total	24
Total	100

3.2.2 Emission Factor for Electricity

On a very small scale, the port has been testing the feasibility of replacing a diesel yard tractor with an electric one (POLA 2009). For the electric truck emission calculations, electricity is treated as a homogeneous commodity regardless of the source and time of generation (Balqon 2009). The actual emissions, however, differ for each source and type of electricity generation process. For this reason, it is common in emissions inventory reports to utilize average emissions factors. These factors represent an aggregate estimate of emissions from a broad set of electricity generation processes. Unfortunately, there is no standard protocol for accounting and calculating these emissions factors. Despite attempts by several studies (see BSI PAS 2008; (Marnay et al. 2002) to offer such protocols, high degrees of uncertainty exist on the proper geographical and temporal scales in calculating these emission factors. From a life-cycle assessment (LCA) perspective, we also see differing emission factors from power generation processes (Hondo 2005, Kintner-Meyer 2007, Pacca 2002).

3.2.3 Comparative Life-Cycle Analysis (LCA) and Indirect Emissions

Life-cycle assessment (LCA) seeks to track environmental impacts throughout the life-cycle, including raw material extraction, production, processing or manufacturing, transportation, distribution, storage, use, and disposal (i.e., life-cycle phases). The standard LCA method consists of sequential steps: definition of goal and functional unit, delimitation of scope or system boundary, life-cycle inventory (LCI), and life-cycle impact assessment (Curran 1996). LCI refers to the accounting of pollution and resource extraction in each life-cycle phase. LCA is particularly useful to accurately compare the respective impacts of products and processes. A comparative LCA is performed when one wishes to compare two products that have similarities in their life-cycle stages (e.g., see Boureima et al., 2009 for a comparison of hybrid, electric, LPG and gasoline vehicles). In our case study, differences exist in the fuel cycle and engine production. Other elements of the LCA are the same for both vehicles (e.g., chassis, truck body, capacity). This allows us to reduce data complexity by comparing only those elements that are different.

3.2.4 Port's Yard Tractor Fleet

Since yard tractors are directly under the control of the port's management decision hierarchy, data on emissions, usage, and future adoption rates are more accessible and verifiable. Yard tractors are vehicles that haul containers within a port's boundaries. Because they do not carry containers long distances or to final destinations, the port categorizes these trucks as "cargo handling equipment" (CHE), which encompasses other equipment such as forklifts, sweeper trucks, and cranes. Currently, about 95% of the port's CHEs are diesel-powered (1059 out of 1114), with the rest propane-powered (Starcrest 2009). Within the CHE category, the yard tractors are the largest emitters of GHGs with an annual emission of about 94,000 CO_{2e} metric tons (Starcrest 2009). It is also the case that the Port's Clean Truck Program, modernizing its heavy-duty trucks from older diesel-powered trucks, has been effective in reducing toxic pollutant emissions (NOx, SOx, and PM) (Starcrest 2009). The port's electric demonstration project (using Nautilus E30 trucks) is expected to take this an step further, requiring only three to four hours for a full charge using a 40kW output port (Balqon 2009).

3.3 Analysis and results

The first task was to calculate LADWP energy portfolio's weighted average emissions factor on a per-kilowatt-hour basis. Then, to achieve the objective of modeling and assessing the overall impacts of electrification on GHG, we perform a comparative LCA study. With a completed comparative LCA, we proceed with a modeling of the total emissions from yard tractors. Since the number of tractors in service varies with changing operational demands, we model the number of tractors based on the growth projections of container throughput. Another driving factor that determines total emissions is the changes in the energy portfolio of LADWP. Therefore, we also model the changes in the carbon intensity of LADWP's energy portfolio given current projections on renewable adoptions. Using these two projections, we simulate multiple scenarios for the total emissions.

3.3.1 Energy Source Emission Factors Based on LCA

To compute a single weighted emission factor for electricity provided by LADWP, we reviewed various published LCA studies for each energy source. It is important to note that because LCA studies by nature are confined by the scopes, system boundaries, and assumptions set forth in each study, the emission factors are unique to each study.

Therefore, we choose studies that have comparable attributes to those of LADWP's generation portfolio. For example, for wind energy, we compare the output capacity and whether the plant is on-shore or off-shore. Our computation assumes that each kilowatt of electricity supplied by LADWP is uniform in composition. That is, each kilowatt is composed of 42% coal, 34% natural gas, and 10% nuclear, and so on. This review concludes that a reasonable emission factor for coal is 1007.5 grams of CO_{2e}/kWh (National Academy of Sciences 2010). The emission factors for SOx, NOx, and PM are 7.0, 3.35, 9.78 g/kWh, respectively (Spath, Mann and Kerr 1999). We stress that our values indicated here account for not only the direct emissions but also indirect emissions from production, transportation, and waste disposal. Natural gas is the second-highest energy source for LADWP. Its emission rate is lower than that of coal at 493.5 g CO_{2e}/kWh (National Academy of Sciences 2010). The emissions factors for SOx, NOx, and PM are 0.324 g/kWh, 0.570 g/kWh, and 0.133 g/kWh, much lower than those from coal (Spath et al. 1999).

LADWP plans to expand its share of renewable sources. Its growth strategy hinges primarily on the expansion of wind energy, which is projected to make up 75% of the entire power mix in the distant future (LADWP 2008). Although the production of electricity from wind turbines generates no direct emissions, it generates indirect emissions from the production, assembly, maintenance, and disposal of the wind power plant (or "wind farm"). Based on our review of wind LCA, we conclude that the emission factor for electricity generation from wind turbines for LADWP is approximately 14 grams of CO_{2e}/kWh (e.g., see Dones 2003). The emission factors for wind SOx, NOx, and PM are 0.032, 0.048, and 0.0035 g/kWh, respectively (World Energy Council 2004).

The emission factor for small hydroelectric (less than 30 MW) was obtained using an LCA study with the latest technology in construction and maintenance of the power plant (Bergerson and Lave 2002). This study estimated the emission factor at 11 g CO_{2e}/kWh. Large hydroelectric have higher emissions because they require dam structures that lead to severe environmental damages in all phases of LCA. Sediment deposits accumulate behind a dam and release methane upon the decommissioning of the damn. Damming also causes massive flooding of biomass that releases methane. We used the emission factor of 242 grams of CO_{2e}/kWh from a complete LCA of the Hoover dam accounting for the methane release from sediment deposits and biomass flooding (Pacca 2007).

Recent data on LCA for biomass, solar, nuclear, and geothermal have been compiled for their emissions factors. The factors for biomass are from a study by the University of Michigan (Berry et al. 1998, European Commission 1997, Mann and Spath 1997, Spath and Mann 2004, Spitzley and Keoleian 2005). Although they currently make up less than 1% of LADWP's energy portfolio, solar and geothermal projects are expected to add significant capacity in the near future. The emissions factors for solar (photovoltaic and thermal) are from a comprehensive life-cycle study by Fthenakis et al. (2008), for geothermal we used a study by Energy Center of Wisconsin (2009), and for nuclear we used a study by IER (1997). These values are listed in Table 12.

Table 12 Life-cycle emissions factors for different energy sources (g/kWh)

Energy Source	CO_{2e}	SOx	NOx	PM
Non-renewable				
Coal	1007.5	7.000	3.350	9.780
Natural gas	493.5	0.324	0.570	0.133
Renewable				
Biomass & waste	30.6	0.370	0.650	0.030
Geothermal	122.0	0.000	0.000	0.000
Large hydro	242.0	0.370	0.650	0.030

Small hydro	11.0	0.027	0.074	0.005
Solar	50.0	0.365	0.182	0.000
Wind	14.0	0.032	0.048	0.004
Nuclear	19.7	0.032	0.070	0.007

Based on these values, the overall weighted average emission factor for the generation of electricity is approximately 608.57 grams of CO_{2e}/kWh. Note that by incorporating the life-cycle emissions, the weighted emission factor is significantly higher than LADWP's current estimate of 560.86 g CO_{2e}/kWh (LADWP Interview 2010).

3.3.2 Comparative LCA of Yard Tractors

Our comparative LCA considers three phases in its vehicle life-cycle: production, use, and disposal. In the use phase, we define the functional unit as the amount of emissions per operating hour. The conventional measure of emissions per mile is not appropriate since the majority of a yard tractor's daily activity is in a state of waiting or idling. We will convert this measure into emissions per vehicle, using the average number of operating hour per vehicle. We begin by examining the emission estimates of the diesel and electric yard tractors in the use phase of the life-cycle.

3.3.3 Diesel Yard Tractor Emissions Estimates

We relied on the port's extensive emissions inventory data and equipment emission factors (Starcrest 2009). This document gives the aggregate emissions generated by the diesel yard tractors, accounting for engine type, power, utilization, and so on. The POLA diesel-powered yard tractors operate at full capacity for approximately six hours per day, 300 days per year (Starcrest 2009). The average emissions of CO_{2e}, SOx, NOx, and PM were calculated with the following two assumptions: (a) the fleet of diesel yard tractors currently in operation is identical in engine-type, age, and performance, and (b) each diesel yard tractor operates an average of 1769 hours annually (Starcrest 2009). Given these assumptions, the amount of emissions attributed to each operating hour of a typical diesel-powered yard tractor is shown in Table 13.

Table 13 Emissions for diesel tractor per operation hour

Greenhouse Gases	kg
CO_2	43.631
N_2O	0.000871
CH_4	0.000871
Sub-total (in CO_{2e})	43.925
Particulates	

PM10	0.0082
PM2.5	0.0076
DPM	0.0082
Sub-total	0.024
NOx	0.287
SOx	0.0005
Total	44.2365

As expected, CO_2 is the dominant GHG emission and NOx is the dominant pollutant emission during operation. Normalized over an operation year, each diesel tractor is responsible for approximately 85.67 metric tons of CO_{2e} and 561.6 kg of NOx.

3.3.4 Electric Yard Tractor Emissions Estimates

We make the following assumptions to convert the electric truck emissions factors into the functional unit of kg per operating hour:

- Each truck requires 3.5 hours of charging at 40 kW to operate at full capacity (POLA 2009).
- E30 electric trucks operate at the equivalent capacity to that of the diesel truck (i.e. approximately six hours per day, 300 days per year).

- Hourly rate of electricity consumption (amount of power required for charge per hours of daily operation) is approximately 140kWh/6 hours (POLA 2009).

Given these assumptions, the emission factor for the operation of the E30 electric trucks is approximately 14.45 kg CO_{2e} per operating hour. The emissions factors for PM, NOx, and SOx are 99, 39, and 73 grams per operating hour, respectively.

3.3.5 Production and Disposal Phases

Diesel and electric trucks vary significantly in terms of their engine production processes. The main difference resides in the production and disposal of a high-capacity battery for electric trucks. We assume that the electric trucks utilize lithium ion phosphate batteries due to their high safety standards, low production costs, and lack of toxic heavy metals and corrosive acids and alkalis (present in other battery technologies such as lead-acid or lithium manganese). The emissions associated with the production phase are estimated using the data from a lithium manganese battery technology production in Japan (Ishihara 2002). The CO_{2e} emissions of lithium ion battery production are approximately 75 kg/kWh. The batteries used in the electric drayage trucks considered in this analysis are rated at 280 kWh. This results in a total emission of 21,000 kg CO_{2e}.

For the disposal phase, we again assume that the difference between the diesel and electric drayage trucks stems from the use of the lithium ion battery in the electric truck. Given the lack of hazardous materials present in lithium ion phosphate batteries, it is possible to recycle or simply dispose of the battery. With no metallurgical recovery from the cathode, the CO_{2e} emissions are 2.8 kg CO_{2e}/kWh with a CO_2 reduction of 2.1 kg-CO_{2e}/kWh (Ishihara 2002). With a 280 kWh battery, this equates to 784 kg CO_{2e} from recovery and a reduction of 588 kg CO_{2e} from replacement of virgin materials. With recovery of lithium from the cathode, the CO_{2e} emissions are 11.2 kg CO_{2e}/kWh with a potential savings of 4.5 kg CO_{2e}/kWh. This leads to 3,136 kg CO_{2e} emitted in recovery with a potential reduction of 1,260 kg CO_{2e}. While the recovery of lithium from the battery's cathode actually worsens the output of CO_{2e}, it is important to do so in order to mitigate concerns for depletion of lithium supply in the face of increasing future demand.

We add the emissions from all three phases to present a complete life-cycle picture for yard tractor emissions. A summary of all three phases of the comparative LCA is shown in Table 14. The E30 electric tractor generates approximately one-third of the CO_{2e} emissions of that of a diesel truck on a per-operating-hour basis over the lifetime. Although the "zero-emissions" claim made by electric vehicle proponents is disproved, one must note a large reduction in CO_{2e} emission. If we assume a lifetime use of approximately 10 years for each vehicle, then the CO_{2e} savings from the use of E30 truck accumulates to about 500 metric tons. The use of the E30 tractor also yields a reduction in the emissions of NOx. The emission of SOx and PM, however, are significantly higher which can be attributed to the high proportion of coal in the production of LADWP's electricity.

Table 14 Comparative LCA emissions for electric versus diesel tractors (kg/10 year lifetime)

Vehicle Type		Production	Use	Disposal	Total
Electric	CO_{2e}	21,000	256,000	3,136	280,000
	SOx	*	1,268	*	1,268
	NOx	*	647	*	647
	PM	*	1,644	*	1,644
Diesel	CO_{2e}	*	777,000	*	777,000
	SOx	*	9	*	9
	NOx	*	5,093	*	5,093
	PM	*	425	*	425

* In comparative LCA, these values are equal, therefore not calculated

As indicated in this table, the use phase dominates the GHG emissions. Therefore, the net effect of electrification hinges heavily on the number of yard tractors and the length of time they are in use.

3.3.6 Yard Tractor Growth Projections

We model the changes in the number of yard tractors in operation by using container throughput projections. The container throughput is expected to grow by 40% and 120% for years 2020 and 2030, respectively, from the baseline year 2006 (IHS Global Insight 2009). According to the port's forecast, the number of yard tractors to serve this throughput is expected to increase to 1,588 and 2,395 vehicles for the years 2014 and 2023 (Starcrest Consulting Group 2008). Fitting the forecasted number with historical data, the expected number of yard tractor turns out to be a second-order polynomial function. Given the container throughput projections, the estimated number of yard tractors is shown in Table 15.

Table 15 Projected total number of yard tractors at POLA

Year	Total Count
2010	1,259
2015	1,668

2020	2,112
2025	2,594
2030	3,112

Despite the electric yard tractor's emissions advantages, maintaining a high adoption rate is difficult due to the high initial investments. For example, the price of the E30 tractor is currently at $189,950 and the charger price is about $75,000 (POLA 2009). However, it is expected that the price of electric tractors to decline gradually following the price trends in other electric vehicle technologies. Therefore, we examine three different adoption rates for the electric yard tractors: 20, 35 and 50%. The resulting numbers of electric yard tractors are shown in Table 16.

Table 16 Projected number of electric yard tractors

	Adoption Rates		
Year	20%	35%	50%
2010	315	441	630
2015	417	584	834
2020	528	739	1,056
2025	648	908	1,297
2030	778	1,089	1,556

3.3.7 LADWP’s Renewable Portfolio Projections

LADWP excludes nuclear and large hydro as renewable energy in its portfolio. Under this assumption, LADWP expects to exceed 20% renewable in its energy portfolio by the end of 2010 and achieve 40% renewable by 2020 (Hodel 2010). We present three adoption scenarios where LADWP reaches a renewable portfolio of 50%, 60%, and 80% at the end of year 2030. Based on these projections, we model the emission rates on a per kWh basis. We use the emission factors for different energy sources using the data from the LCA studies given in previously. To create a more realistic set of scenarios, as the coal proportion reaches zero, we begin reducing natural gas from the portfolio and replacing the coal with wind and small hydro. Since the carbon intensities of wind and small hydro energy are much lower than those of coal and natural gas, LADWP’s overall emission rate decreases significantly with greater adoption rates. This assumes that LADWP can and will replace dirtier sources first. This would generate a “best-case scenario” under which low carbon policies can be evaluated.

We began with an estimated 20% renewable sources for all cases in year 2010. The resulting carbon intensities for three different scenarios are given in Table 17. Case I assumes that LADWP achieves 35% and 50% renewable sources in its portfolio by 2020 and 2030, respectively. In Case II, LADWP achieves a more aggressive 40% and 60% renewable by 2020 and 2030. In Case III, these two numbers go up to 50% for 2020 and 80% for 2030.

Table 17 Projected carbon intensity of LADWP portfolio (g/kWh)

Year	*Case I*	*Case II*	*Case III*
2010	489.35	489.35	489.35
2015	414.83	390.00	340.32
2020	340.32	290.65	191.30
2025	265.81	191.30	71.42
2030	191.30	143.35	27.65

The projections by LADWP show that nonrenewable sources (i.e., coal and natural gas) will remain significant in the energy portfolio, as renewable sources are projected to supply only 35% of total supplied power by 2020 (Glauz 2007).

3.3.8 Overall Emissions Estimates and Target Reductions

We are now ready to model the total emissions from yard tractors and compare against the target reductions. We calculated the emissions based on the projected number of electric and diesel yard tractors before. The emissions for a diesel tractor remain unchanged in subsequent years but the emissions for an electric tractor decrease because the carbon intensity of LADWP's energy portfolio decreases in all scenarios. We recalculate using the projections to compute the total emissions for the target years of 2020 and 2030. We condensed the results into two "snapshots" reflecting these projections. Again, we consider the same three cases mentioned above for the rate at which the LADWP renewable portfolio increases. Each case assumes a starting point of 20% renewable portfolio by the end of 2010. The results are shown in Table 18 and Table 19.

Table 18 Estimated CO_{2e} emissions from yard tractors at POLA in 2020 (metric tons)

		Projected LADWP Renewable Portfolio (2020)		
		Case I (35%)	*Case II (40%)*	*Case III (50%)*
Electric Yard Tractor Adoption Rate	*20%*	130,657	129,555	127,352
	35%	117,262	115,720	112,634
	50%	97,170	94,966	90,559

Table 19 Estimated CO_{2e} emissions from yard tractors at POLA in 2030 (metric tons)

		Projected LADWP Renewable Portfolio (2030)		
		Case I (50%)	*Case II (60%)*	*Case III (80%)*
Electric Yard	*20%*	187,594	186,027	182,247
Tractor Adoption	*35%*	165,915	163,721	158,429
Rate	*50%*	133,396	130,263	122,703

We now use these estimates to compare against targets set forth by AB32 and Green LA legislations. Assuming that the POLA is required to cut emissions to pre-1990 levels in all categories, the emissions associated with the yard tractors must also be cut proportionally. The estimates for pre-1990 emissions level, however, are still unpublished, as POLA has yet to release them officially under its Climate Action Plan. Therefore, we instead compare our projection results with the lowest emissions data currently available. The lowest reported emissions data for yard tractors are for the year 2009, when they contributed 80,252 metric tons of CO_{2e} emissions (Starcrest 2010). We set our reduction target for year 2020 at this level and 35% below for year 2030. Note that the emission levels in 1990 are most likely three times lower than those of 2009, considering the tripling of container throughput, from 2.1 million TEUs to 6.7 million TEUs (POLA 2010). For the 2020 target, even in the best-case scenario, the emissions will exceed the target by nearly 10,000 metric tons. In 2030, the situation will be worse; the emissions will exceed the target by over 50,000 metric tons. *The results of our analysis show that at any given set of LADWP renewable portfolio and POLA's electric adoption rate, these targets are unreachable.*

3.4 Discussion

The results of this study reveal that the main driver of emissions is POLA's container throughput. In other words, no amount of emissions reductions on a per vehicle basis or the lowering the carbon intensity of LADWP's energy portfolio as projected can overcome the increases in equipment use associated with increasing throughput. To reach emissions reductions to pre-1990 levels, the only option available seems to be a reduction in the port's container throughput. This result seems to indicate the port's limited control in meeting its target emissions. However, the port's decision to electrify its yard tractor fleet will lower emissions on a per vehicle basis. And, electrification does offer a significant reduction in the port's GHG emissions. Nevertheless, the magnitude of the port's GHG reduction hinges on LADWP's ability to increase its renewable portfolio and remove coal from its energy sources as modeled in this study.

In addition, GHGs are global pollutants. Policy makers need to be concerned that any net reduction in container throughput using POLA's facilities may simply be diverted to other ports in California or nearby regions. In such case, the net effect may actually be worse for the global GHG emissions, given that POLA has one of the best records on emissions compared to other similar mega-ports.

Finally, we are faced with a dilemma: to use cleaner engines, or to push the emissions upstream to the power generation sources elsewhere. And in either case, the aggressive targets of the current climate legislations seem unapproachable. One only hopes that there may be new engine technologies in the future that generate ultra low emission rates to make reaching pre-1990 levels more feasible. Another alternative would be for the power generation facilities to commit large investments in infrastructure and power distribution networks following aggressive policies on renewable energy sources, particularly wind and solar. We hope both could be done sooner rather than later.

4 An Analysis of Alternative Marine Power (AMP) as a Greenhouse Gas Reduction Strategy for the Port of Los Angeles

Abstract

Cold ironing is a relatively recent technology that involves vessels plugging into shore side power to reduce greenhouse gas (GHG) emissions. California recently passed a regulation requiring that ocean-going vessels use this technology at California ports. Originally the regulation was intended to reduce diesel emissions but has been expanded to include early action measures to reduce GHG emissions as mandated by the California under the Global Warming Solutions Act (AB 32). In determining the emissions benefits of this policy, the essential unknown is the energy profile of the source of the shore-side electricity. While the switch to shore side energy would reduce localized emissions, emissions produced off-site are dependent on the energy sources used (e.g. coal, solar, etc). This chapter analyzes the recent regulation for its greenhouse gas (GHG) reduction benefits, using the Port of Los Angeles (POLA) as an example and assuming a 4.2% growth rate in cargo at the POLA. The calculations show that

alternative marine power (AMP) will reduce emissions by either 31% or 37% as compared to a status quo scenario depending on the assumptions made about the energy profile and the means of calculating the emissions factor of each energy source. We believe that because the estimate of 31% used Life Cycle Analysis in determining the EF is a more realistic estimate of the benefits of this policy.

4.1 Introduction

This paper investigates the GHG reduction potential of the recent CARB *Regulations to Reduce Emissions from Diesel Auxiliary Engines on Ocean-Going vessels while at Berth in a California Port*, a recent regulation that requires certain berthed vessels use shore side electricity rather than auxiliary engine fuel while at berth. To evaluate this policy, the emissions benefits of applying this policy to the POLA's growing container traffic are analyzed for the year 2020. By substituting auxiliary fuel for off-site electricity, local emissions decrease; however, emissions at the location of the power plant increase. The POLA is required to obtain electricity from the Los Angeles Department of Water and Power (LADWP). Therefore the energy profile of the utility determines the net benefit of shore power at the port.

Electrification of port operations (including facilities, equipment, and cargo handling equipment) has become as a central strategy to meet mandated reduction targets. A major benefit of electrification is localized reduction of criteria air pollutants. But from the standpoint of GHG emissions, electricity is only as 'green' as the energy sources from which it is generated. Coal-based electricity, a primary source for the City of Los Angeles, generates large amounts of GHGs. However, to date, little research has been conducted to *fully* account for the GHG emissions associated with electricity used in a major port complex such as the POLA.

This chapter provides a reminder the model assumptions can influence the analysis and provides a critique of AMP regulation as a GHG reduction strategy. First, it provides a brief overview of work that has been to done to evaluate the potential of shore power as a GHG reduction strategy. Second, this chapter briefly explains analysis done by the State of California and POLA in support of cold ironing as an approach to GHG reduction. Third, a discussion of the GHG emissions associated with energy from the DWP is presented. Fourth, this chapter estimates the benefits of cold ironing as a strategy for the POLA while taking into account both indirect and direct CO2 emissions. Finally, this chapter discusses the policy implications of this analysis for alternate marine power and possibly other port electrification as a GHG reduction strategy.

4.2 Background

In December 2007, the California Air Resources Board (CARB) passed *Regulations to Reduce Emissions from Diesel Auxiliary Engines on Ocean-Going vessels while at Berth in a California Port* (CARB 2007). This regulation applies to container, passenger and reefer vessels. Vessels that were non-frequent callers, defined as being part of a fleet with less than 25 container or reefer calls per year or 5 passenger ships per year at one port were exempt (CARB 2007). Exceptions also exist for vessels using LNG or CNG. By 2014, the regulation requires that at least 50% of vessel calls of one fleet use shore power, where fleet is defined as “all container, passenger, and refrigerated cargo vessels, visiting a specific California port, which are owned and operated by, or otherwise under the direct control, of the same person” (CARB 2007).

By 2017 70% of a single fleet shall meet these requirements and by 2020, this will rise to 80%. The regulation allows for a 3-5 hour period per vessel call where the auxiliary engine may be running to allow for the transfer to shore power. Alternate compliance plans are allowed if the vessel operator can demonstrate that the same or greater reductions were achieved. This regulation applies to all ports in the state of California, but this paper examines the potential benefits of this regulation at the POLA.

Even prior to this regulation, the Ports of LA and LB made cold ironing a key component of their Clean Air Action Plan (CAAP) in 2006. The ports intended to enforce a requirement for cold ironing through lease negotiations. At the POLA, the goal was to implement shore power at all major container and cruise terminals within 5 years. Because they were starting with less infrastructure, the goal for POLB was 5 to 10 years.

Initially, both the CARB regulation and the CAAP goal intended shore power as a strategy to reduce criteria air pollutants. Now however, the strategy of cold ironing is also being viewed at as a GHG reduction strategy, particularly at the state level. In fact, the ARB includes this recent regulation in its early action measures to reduce CO_2 to meet the goals of AB 32. Under AB32, California plans to cut greenhouse gas (GHG) emissions to 1990 levels by 2020 and 80 percent below 1990 levels by 2050 (California Energy Commission 2007). In May 2007, the City of Los Angeles adopted *Green LA,* an even more ambitious plan that calls for reducing GHG emissions 35% below 1990 levels by 2030 (City of LA 2007). Thus at both the state and local level, reducing GHG has become a priority. In addition to the benefits it provides at reducing criteria pollutants, cold ironing is also being touted as a GHG reduction strategy. Because CO_2 is a global, rather than a local pollutant, the GHG reductions of electrification must be accounted for properly.

The use of shore side electricity has been investigated at other ports both as a GHG reduction strategy and as a way to reduce criteria air pollutants. However, most analysis does not consider the net benefit of the policy accounting for emissions from electricity production. Most work focuses only on the local benefit. For instance, Afon and Ervin (2008) study the potential of shore power to reduce criteria air pollutants, concluding shore power can have benefits locally, but they do not look at net changes on at broader spatial scales. Similarly, they do not examine the benefits of shore power for GHG reduction (Afon and Ervin 2008).

Based on California Air Resources Board protocol for local government operations (CARB, 2008), port emissions are based on three GHG emissions scopes. Scope 1 includes *direct* emissions from port-controlled stationary (largely natural gas combustion in buildings) and mobile sources, such as port-owned fleet vehicles and cargo handling equipment (Starcrest 2010). Scope 2 refers to *indirect* GHG emissions associated with the import and consumption of purchased electricity for port-owned buildings and operations. Scope 3 refers to port tenants' direct emissions from stationary, mobile sources, and indirect emissions associated with purchased electricity. Under the local government operations protocol, Scope 3 emissions are not mandatory for inclusion in the port's GHG inventory. However, Scope 3 emissions represent more than 99 percent of total GHG emissions associated with goods movement through the POLA (Starcrest

2010) and therefore accounting for them is crucial in order to lower the carbon footprint of goods movement systems.

The Port of Houston, for example, is constructing a $1.4 billion Bayport Container and Cruise Terminal, which will include twenty-one electric ship-to-shore cranes and infrastructure to support shore power (EPRI 2008). A number of Electric Power Research Institute (EPRI) studies outline opportunities for electrification and highlight the economic viability and environmental suitability of electric cranes, forklift trucks and drayage trucks (e.g., see EPRI 2006). EFRI studies, however, generally exclude Scope 2 and Scope 3 emissions associated with electrification. For instance, they were excluded in the major study on ship-to-shore crane electrification (EPRI 2009). We believe that this is an *incomplete and misleading inventory* of the GHG emissions and that it needs to be replaced with a full life cycle emissions accounting.

LCA seeks to track environmental impacts throughout the life cycle, including raw material extraction, production, processing or manufacturing, transportation, distribution, storage, consumer use, and disposal (i.e., life cycle phases). The standard LCA method consists of sequential steps: definition of goal and functional unit, delimitation of scope or system boundary, life cycle inventory (LCI) and life cycle impact assessment (LCIA).

LCI refers to the accounting of pollution and resource extraction in each life cycle phase (Horne et al., 2009). LCIA is a decision-support model built on LCI to measure impacts (e.g., on human health or ecosystem quality). LCA is particularly useful to accurately compare the respective impacts of products and processes.

A further obstacle for accounting purposes is that electricity is typically treated as a homogeneous commodity as if emissions from all kilowatt-hours are equal regardless of time and space. The actual emissions, however, differ for each source and type of electricity generation. For this reason, it is common in emissions inventory reports to utilize average emissions factors. These factors represent an aggregate estimate of emissions from a broad set of electricity generation processes. Unfortunately, there is no standard protocol for accounting and calculating these emissions factors. Despite attempts by several studies (see Holland 2004, Marnay et al. 2002), high uncertainty exists on the proper geographical and temporal scales in calculating these factors. As a result, numerous lifecycle assessment (LCA) studies on emissions from power generation process conclude different emission factors (Hondo 2005, Kintner-Meyer 2007, Pacca 2002).

Corbett and Winebrake (Winebrake et al. 2008) acknowledge that the benefits of shore power are highly variable and depend on the type of fuel displaced as well as the source of electricity. They compared reductions to the total emissions produced from ocean-going vessels (OGVs) and found that because shore side power displaces such a small portion of the power used during the entire marine vessel voyage they estimate that shore power will reduce total GHG by less than .5% (Winebrake et al. 2008). This estimate was made using current electricity generation fuel mixes. If the energy portfolio becomes more renewable however, the emissions reduced have the potential to increase.

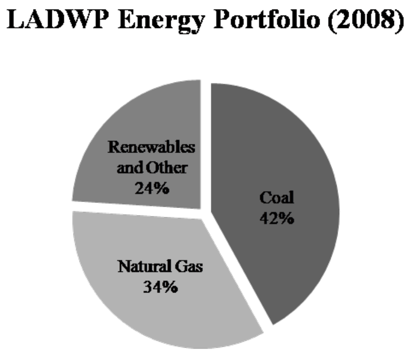
These improvements in the energy portfolio are crucial to evaluating the true benefits of shore power as an emission reduction strategy. This is evident in an analysis done by Hall (2010) of the benefits of cold ironing in different countries. By using an average emission factor for auxiliary engines of 718.6g Co2kWhe-1, he compared the energy profile of each country and showed that the usefulness of shore power as a GHG reduction strategy differs greatly depending on the energy mix at different locations. For instance, China's reliance on coal and other fossil fuels could increase emissions from vessels at berth by close to 40%. France on the other hand uses a great deal of nuclear and hydroelectric power which could lead to an 84% reduction due to cold ironing. In the United States, he estimates a GHG reduction of merely 9% using data from the International Energy Agency database (Hall 2010).

While this analysis is useful on a global perspective, that author acknowledges that on a smaller scale, great variations may also exist. It is not only regional specificity but port specificity that is required. An additional reason for location specific analysis is the need to account for transmission losses. Transmission losses increase as the distance of the power generation source from the port increases. The size of the service area also matters because when the power use of the region increases, power is drawn from more distant sources (Hall 2010). The author writes that “shoreside power must be implemented with the local electricity generation fuel mix taken into account” (Hall 2010).

This conclusion is certainly the case in California. Within the state, the ports are served by different utility companies with different energy profiles. The ARB estimates of the utility companies serving various ports range from 450 – 1300 lbs (CARB 2007b). For instance, the Ports of Oakland and San Francisco are served by Pacific Gas and Electric, which uses hydro-electric power provided by Hetch Hetchy Water and Power.

The Port of Los Angeles is served by the LADWP, with an estimated emissions factor of 1300lbs/MW-hr.

In sum, the use of shore side power is a known emissions reduction strategy but its benefits depend greatly on the local emissions profile. This is particularly important when shore side power is being implemented as a GHG reduction strategy as opposed to a criteria pollutant reduction strategy. Criteria pollutants impact the health of local residents and their impacts are generally felt closest to the source. From a regulatory perspective, the Clean Air Act defines air basins and requires them to reduce the criteria air pollutants that they produce. On the other hand, the production or reduction of green house gases has impacts on the global scale as the impacts of climate change are not limited to the location where the emissions are produced.



Source: Green Power Annual Report, LADWP, 2008.

Figure 3 LADWP energy portfolio, 2008

Therefore, a strategy of displacing emissions to where the electricity is produced might be more palatable for criteria air pollutants but not acceptable for greenhouse gases. For this reason, an estimate of the benefits of shore power is needed that accounts for local electricity production. Before demonstrating how this method can be applied, using the example of the POLA, we first discuss how the benefits of this regulation have been previously accounted for by the POLA and the ARB.

4.2.1 CARB and POLA calculation of shore power benefits

The ARB uses three methods to evaluate the benefits of shore power. The first two are based on marginal power generation and the third uses the current power supply portfolios of the utility companies.

Because at least initially, shore power will require utilities to provide more power than they usually would, the utilities will draw from sources that are generally used for marginal electricity production. The utilities reported to ARB that they produce marginal power from natural gas fired power plants using a combined-cycle gas turbine (CCGT). The first estimate done by the ARB uses the CA Energy Commission and CA public utilities commission estimation for unspecified sources of electricity. This estimate uses an emission factor of 1100lbs CO_2/MW-hr.

The second estimate for an emissions factor was made by the Climate Action Team Economics subgroup. They included assumptions about marginal electricity production, renewable, transmission losses, and sources of electricity and estimated the emission factor for avoided electricity to be 690lbs CO_2/MW-hr. The third estimate differs for each port. Based on the 2005 estimate, the ARB uses an emission factor of 1300lbs /mW-hr for the POLA which uses DWP as their electric provider.

Using these different emissions factors, they calculate the benefit of the switch to shore power to be the difference between emissions produced if the berthed vessel was powered by fuel and if the vessel was powered by electricity. The equation[1] isolates the two variables in question, the emission factor and the hours at berth. The ARB assumed that the emission factor for the auxiliary engine was 690 grams per KW hour or 1520 lbs per megawatt hour. This figure was provided by Entec. These estimates are based on the current energy profile and do not consider changes made to the energy profile into the future.

4.2.2 POLA calculation of benefits

At the POLA, the use of AMP is a key component of the Clean Air Action Plan and also a potential GHG reduction strategy. Without accounting for the power plant emissions,

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[1] (EF electricity – EF Aux engine) * MW hrs used by vessel fleet in 2020)/2200lbs/metric ton. This would be the simplest calculation. This calculation doesn't calculate the fleet emissions produced before and after – it only calculates total tons reduced.

they assume a reduction of 95% of the at berth auxiliary engine emissions per vessel call. If they were also to include indirect emissions, the benefit would be less.

The Port of Los Angeles (POLA) counts indirect emissions from electricity under Scope 2 and 3 in its emissions inventory (see 2008 Expanded Greenhouse Gas Inventory). Because POLA is required by law to buy all of its electricity from the Los Angeles Department of Water and Power (LADWP), the total indirect emissions from purchase electricity under Scope 2 and 3 are determined by the LADWP's energy portfolio. Under the *Green LA* initiative, LADWP is supposed to increase its renewable energy portfolio to 20% by 2010 and 40% by 2030 (Sharma 2009). However, today, LADWP (2008) electricity is generated largely from nonrenewable sources, primarily coal and natural gas (see Figure 5).

Currently, 76% of LADWP's portfolio is composed of coal and natural gas which are high in carbon intensity (LADWP 2008). Renewable sources make up the rest of the portfolio. Although these renewable sources are less carbon intensive, uncertainty exists in accounting for the emissions from these renewable sources. For example, LADWP treats electricity derived from solar, hydro, and nuclear as zero emissions. This treatment is both incomplete and problematic. Some renewable sources may have zero direct emissions but all have indirect emissions. In order to remedy this incomplete accounting, we offer an alternative estimate of the indirect emissions from purchased electricity based on LCA studies.

Therefore by providing more complete emissions factors for the DWP energy profile and accounting for displaced as well as local benefits, we provide a more accurate analysis of the emissions benefits of alternate marine power (AMP).

4.3 Research questions and methods

The above discussion demonstrates the need to evaluate the benefits of cold ironing as a strategy for GHG reduction. By moving emissions off-site, the strategy has potential to reduce criteria pollutants locally, but since GHGs have global impacts it is necessary to account for the emissions reductions of this policy both locally and off-site. In addition, while doing so, we argue that LCA must be done in order to properly measure off-site emissions. In order to evaluate the potential of alternate marine power to reduce GHG at POLA, we propose the following questions.

1) How does LCA accounting clarify emissions benefit estimates?

2) Given these estimates, what is the expected GHG benefit of this policy at POLA in 2020?

In order to evaluate the potential of AMP as a GHG reduction strategy and demonstrate how LCA can be used to clarify emissions benefit estimates, we will estimate the emissions benefits of this policy using an emission factor (EF) provided by the LADWP for the year 2020 and an EF for the year 2020 that more greatly reflects LCA. The LCA EF that we propose has been developed based on an extensive literature review of renewable and non renewable energy sources that accounts for spatial differences that impact the carbon intensity of each source. The method of calculating the 2020 emissions estimates and the LCA EF will now be discussed.

4.3.1 POLA calculation of benefits

The calculation of emissions from OGVs follows an equation where emissions are equal to the product of energy consumed and an emissions factor. The energy required is further determined by the engine power, a load factor and activity hours. A conversion factor is then applied to obtain the proper units.

The formula used to calculate the emissions from the auxiliary engine for one vessel call is:

*E = MCR*LF*TIME*FCF *EF*CF, where*

E= Emissions

MCR= Maximum Continuous Rated Power for the engine

LF= A load factor that expresses the proportion of engine power being used to what is possible to use.

TIME = the length of time the engine is in operation

FCF= Fuel correction factor

EF= Emissions Factor.

CF=Conversion Factor = 10^-6 . This converts the emissions produced in grams to metric tons.

In this research, E = the CO_2 equivalent emissions produced per vessel. By multiplying the per vessel emissions by predicted vessel numbers future emissions can be obtained. By dividing per vessel emissions by the TEU carried for each vessel the total emissions per TEU can be calculated. Alternatively, per TEU emissions can be calculated by determining the total fleet-wide emissions and dividing by the total number of predicted TEU. Other components of the equation are described below.

Maximum Continuous Rated Power (MCR) – this was averaged by vessel type based on data from POLA 2008 inventory.

Load Factor (LF) –The LF was calculated by dividing the net hotelling load by the average MCR of the vessel engine. The net hotelling load was provided in the POLA 2008 emissions inventory.

Time –This refers to the number of hours at berth. According to the CARB regulation, the vessels are permitted 3-5 hours to transfer to electricity. In order to create a conservative estimate it will be assumed that 5 hours of each vessel call is still using residual oil rather than electricity. The average number of hours at berth per vessel type for 2008 will be used as provided in the POLA 2008 emissions inventory.

EF fuel –This research uses a CO2 equivalent of 693g CO2e/kw-hr, incorporating CO2, CH4 and N2O assuming that un-electrified vessels will be using residual oil. The CO2 equivalent was calculated by summing the EF of each individual pollutant and then multiplying by the appropriate ratio found in the POLA Expanded Greenhouse Gas Inventory (POLA 2008). The result was 692.778 and was rounded up to 693 g/kw-hr in all calculations (Table 20).[2]

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[2] This EF can be used for all fuels regardless of their sulfur content. For some low sulfur fuels, a fuel correction factor is needed. However, this does not apply to a calculation of CO2 and in the calculation of CO2 equivalents, the correction applied due to the use of a cleaner fuel would be negligible.

Table 20 Calculation of emissions factor for CO2 equivalents – auxiliary engine residual oil

Pollutant	**Emissions factor for aux engines using residual oil - g/kw-hr**	**Ratio**	
CO2	683	1	683
CH4	0.008	21	0.168
N20	0.031	310	9.61
CO2e emissions g/kw-hr			**692.778**

Source: 2008 POLA emissions inventory

EF electricity – The emission factor for electricity will be the main variable in question. Two EFs will be tested. The first is the EF provided by the DWP. The second is an EF recalculated by us based on LCA studies. The EF provided by the DWP for the year 2020 is 342.6g/kw-hr. As explained below, the EF that we calculate based on LCA is 399.7 g/kw-hr.

4.3.2 Calculation of DWP Emissions Factor using Life Cycle Accounting

As a result of the literature review of LCA studies of non-renewable and renewable energy sources provided in the appendix of this report, we determine the most appropriate emissions factors to use for each energy source, as shown in the table below.

Table 21 Emissions factors for each energy source

Energy resources	**$CO_{2\text{-equiv.}}$ (g/kWh)**
Non-renewables:	
Coal	1007.5
Natural gas	493.5
Renewables:	
Biomass & waste	30.6
Geothermal	122.0
Large hydro	242.0
Small hydro	11.0
Solar	50.0
Wind	14.0
Nuclear	19.7

Using these EFs and the expected DWP energy portfolio we calculate a new EF as shown in the table below. The exact mix of the DWP energy portfolio in 2020 is unknown however based on materials circulated by the DWP we are able to offer an approximate percentage of each source in use in 2020. For instance, the DWP states that their goal for 2020 is to increase renewables to 35%. They suggest that at least 7% of LA's electricity needs will be powered by solar by 2015 and that most of their renewable energy by 2020 will be wind powered. They do not consider large hydro or nuclear to be renewables.

Our predicted DWP energy mix in 2020 is shown in the 4th column. By multiplying the LCA based EF for each source by its percentage in the energy portfolio, we calculate a LCA EF for 2020 to be 399.7g/kwhr.

Table 22 Expected DWP energy portfolio in 2020 and weighted emission factor

Energy source	**LADWP mix 2007**	**Emission factor for each source (based on Appendix 7)**	**Projected Energy portfolio 2020**	**Weighted 2020 EF based on LCA EF)**
Non-renewables:				
Coal	42%	1007.5	26%	261.95
Natural gas	34%	493.5	23%	113.505
Nuclear	10%	19.7	10%	1.97
Large Hydroelectric	6%	242	6%	14.52
Sub-total:	92%		65%	391.945
Renewables:				
Biomass & waste	1%	30.6	1%	0.306
Geothermal	0%	122	0%	0
Small Hydroelectric	5%	11	6%	0.66
Solar	0%	50	8%	4
Wind	2%	14	20%	2.8
Sub-total:	8%		35%	7.766

Total:	**100%**		399.711

4.3.3 Calculation of the future fleet energy demand

Based on available data, certain assumptions were made in order to construct a forecast of 2020 emissions. Where possible a conservative estimate is constructed with respect to future GHG emissions. The following sections discuss the assumptions made in this study related to the emissions calculation and future cargo growth.

Share of fleet using AMP

The ARB requirement for shore power in 2020 is that 80% of vessels that are part of fleets that are greater than 25 vessel calls per year use shore power. Given available data, it is not possible to predict the division of individual vessels into fleets. All 2020 calculations will assume that 80% of the total fleet is using shore power, although in reality, due to the exemption for small fleets, less than 80% of vessels will be required to use shore power. While this assumption may slightly overestimate the local emissions reductions by overestimating the number of vessels using shore power, this is a valid assumption due to desired implementation of the POLA. As stated in the Clean Air Action Plan (CAAP) the POLA plans to create lease terms that require 100% utilization of available infrastructure as terminals as are equipped with alternative marine power capabilities (Starcrest 2010b)[3]. Though this goal is contingent on several factors including the timing of lease negotiations, and the ability to complete both shore side infrastructure and vessel retrofits on schedule, the ports desire to go beyond the CARB goal will likely counteract the inclusion of exempt fleets in this estimate.

4.3.4 Assumptions: Fleet volume and composition

Several existing studies were consulted to determine a conservative estimate of future growth for 2020. First, the CARB used measures of historical NRT between 1994 and 2005, and predicted that cargo growth at each port would be proportional to their historic NRT growth rates. Predicted growth rates follow this nine year trend. Additionally, the state assumes that the share of containerized cargo will increase the most, with some reefer cargo moving to be carried by container ships. The CARB suggests that the annual growth rate for container ships at the San Pedro Bay ports will be 6.2% per year by 2020.

In addition, the Tioga Group and IHS Global Insight (2009) have predicted that TEU at the POLA and POLB will have an average annual growth rate of 4.2% between

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[3] " As soon as a berth is equipped with shore power infrastructure, that berth will be used to the maximum extent feasible. Ultimately, after all berths at a terminal are electrified, the goal is 100% utilization of shore power by candidate vessel calls at that terminal." From 2010 CAAP p 92

2008 and 2030. This projected growth rate is lower than the state estimate for container ships for two reasons. First, this estimate takes into account the recent decrease in cargo in 2008. The recent decline in economic activity is reflected in this adjusted forecast. Second, this estimate takes into account the entire mix of the vessel fleet. Although the percent growth for the entire fleet is predicted to be 4.2% per year, this growth may be distributed differently among different vessel types where container ships are projected to grow the most. In order to be more conservative with our estimate of future cargo growth the 4.2% per year growth rate will be used.

In addition to predicting the TEU growth of the entire container ship fleet in 2020, it was necessary to make a prediction about the composition of the vessel fleet. Due to the economies of scale possible with larger vessels, the industry trend foreshadows that large containerships will replace smaller container ships. The CAAP technical appendix for 2010 (Starcrest 2010c), offers predictions about the numbers of ships of each size to call at the port in 2023. In order to determine the distribution of vessel calls by ship size in 2020, the predicted percentages provided by the CAAP technical appendix for 2023 were applied to the projected number of ships in 2020 using a 4.2% growth rate. In their prediction, the port combines the 8000TEU and 9000TEU categories into one with a combined share of 12%. In order to make this prediction compatible with 2008 data, it was assumed that vessels of 8000TEU and 9000TEU would each have 6% of the total fleet share in 2020.

Table 23 shows the current 2008 number and distribution of vessel types in the fleet and the projected number of vessel calls (one call = one arrival and one departure) from the CAAP technical report index.[4]

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[4] This prediction is based on a Mercator report scenario named “Base Case- Medium Growth and no Change to Panama Canal Dimensions” The Mercator scenario was based on unconstrained growth, meaning there were no capacity limitations. When technical constraints were taken into account, the numbers above were determined.

Table 23 Distribution of vessel type, 2008 and 2020

Vessel Type	**Number calls of each ship type in 2008 (one call = one visit)**	**Percent of calls of each vessel type in 2008**	**# of ships in 2020 - assuming 4.2% growth**	**% of ships of each type in 2020 (%s taken from Starcrest predictions for 2023)**
Container-1000	176	12.0	0	0
Container-2000	96	6.5	143	6
Container-3000	142	10.0	239	10
Container-4000	365	25.0	668	28
Container-5000	341	23.0	286	12
Container-6000	200	14.0	239	10
Container-7000	99	7.0	286	12
Container-8000	29	2.0	143	6
Container-9000	8	0.5	143	6
Container-10000+	0	0.0	239	10

4.3.5 Assumption about Hotelling Hours

There is some discussion about changes in hotelling hours required to load and unload cargo over time. The ports claim that shore side efficiency will increase over time, leading to a reduction in total hotelling hours. The increased efficiency comes from the purchase of additional cranes, terminal densification and operational changes (Starcrest 2010c). In order to accommodate future cargo growth, the study claims that these efficiency changes are necessary. Though it is likely that efficiency will increase in the future, it is not possible to calculate the berthing hours reduction in the future. Therefore future emissions calculations will use 2008 berthing hours. This perhaps leads to an overestimate of future emissions.

As stated above, the second assumption being made is that all vessels will have a 5 hour period where they can transition from fuel to shore power. Depending on the vessel type, the CARB regulation requires that vessels transition in either 3 hours or 5 hours. Because it is not possible to know which vessels are subject to which requirements, the calculations below will conservatively assume that all vessels have a 5 hour period in which they can transition.

While the 2020 prediction includes a vessel category of over 10000TEU, the there are no vessels of this size, and therefore no estimates of the berthing hours for this vessel category. It was assumed that this category would have an average time at berth of 97 hours. As a conservative estimate the vessel characteristics including auxiliary engine MCR and load factor were considered to be the same as for the container 9000 vessels.

Though the power would likely be larger, vessel characteristics were not available for this vessel class. This may result in a slight underestimate of future emissions.

4.4 Results and discussion

Using the equations and assumptions described above, several estimates of CO2e emissions for 2020 were calculated. Assuming that the fleet grew by 4.2% and adjusting for the changes in fleet composition described above, if the shore power policy were not in place total emissions for vessel auxiliary engines while at berth would be 103195.5 metric tons per year. Assuming that 80% of the fleet uses electricity while at berth in 2020, and that DWP can make their goal of 35% renewables by 2020 as shown in Table 24, the total metric tons per year would be between 65081.75 metric tons per year and 71292.64 metric tons per year. The benefits of this policy would therefore be between 31902.87 and 38113.75 metric tons in 2020 or between 31-37% as compared to a do nothing scenario. This range is due to the different emissions factors used for the calculation. This illustrates the importance of LCA accounting.

Table 24 Results table

	Emissions total 2020 Metric Tons	**Benefits 2020 Metric Tons**	**Percent emissions reduction**
E 2020 Aux Fuel Only	103195.5	NA	NA
E 2020 Shore Power (DWP EF)	65081.75	38113.75	37%
E 2020 Shore Power (LCA EF)	71292.64	31902.87	31%

The results show that with a highly renewable energy profile the implementation of the CARB shore power reduction can reduce GHG at the port by 31% in 2020. However, when LCA that was geographically and temporally relevant was not used, the benefits were overestimated to be 37%. This shows the importance of incorporating the CO_2 produced by the energy source into evaluations of this policy. The benefits of this policy are highly dependent on the CO_2 efficiency of the energy source.

Moreover, the proper estimation of the emissions factor for the DWP energy profile was a complicated process as described above. Life cycle analysis is based on many factors, so not only must the composition of the profile be predicted but studies where similar sources of energy produced under the most similar conditions possible would be looked at. There is much work in the field of life-cycle analysis that could clarify these estimates.

The research has been designed to identify optimal strategies to achieve GHG reduction targets for the POLA, and, by extension, other major seaports in the U.S. More broadly, the results will inform policymakers, port authorities, local and regional association of governments of the full environmental (i.e. climate change) costs of port electrification.

5 Development of a Route Selection Decision Tool Interface

Abstract

This section describes the initial development of a web-based intermodal goods movement visualization tool. The main purposes of this tool are to enable the analysis of different transportation modes in a global scope, and to suggest a user defined optimal route selection based on a pre-defined criteria (e.g. cost, emission, and time). We reduce this multi-criteria optimization problem to a family of data analysis queries and propose *path skyline queries (PSQ)* that have been studied by the database community. Through the development process we had weekly group meetings to discuss user requirements, target user groups and the progress of the development of the tool. For user requirement analysis, we also made a presentation to port officials at the Port of Los Angeles to get their feedback during the development phases. Finally, we identified three user types (port officials, retailers, and shippers) most likely to benefit from this tool and built the system accordingly. However, since the tool has been developed in a modular way, new user types can be added easily without any modification of the current system. The

graphical user interface of the tool consists of a left and a right pane. The left pane contains all of the system components which the user enters input and changes the parameters. The right pane has a Google style (just like on the http://maps.google.com web page) world map where the user can clearly see the different route options, ports and distribution centers. To provide the best possible interactive web-based map user interface we applied the modification of Nielson’s heuristics (Nielsen 1990) and Schneirderman’s principles of interface design (1998).

5.1 Introduction

Faced with changing technologies and uncertain costs, across the entire goods movement system, manufacturers, shippers, truckers, port authorities, and other transit-related stakeholders are now confronting a bewildering array of choices for goods movement with potentially large impacts on the economy and environment of regions and the nation. They urgently need methods/tools that enable weighing options and identifying optimal leverage points where cost-effective changes can be made. Such methods will allow them understand how intervention in one part of their goods movement system affects the other components of the system; a crucial understanding for sound decision-making. In turn, this understanding provides the context necessary to identify key leverage points for improvements in emissions, cost and time of goods movement.

We had two goals in creating this tool. The first goal was to analyze the tradeoffs of the different transportation modes to move freight from its origin to destination. The second was to suggest a user defined optimal route selection base on a pre-defined criteria e.g. cost, emission, and time. We begin with the underlining theoretical framework for our route optimization and then give details on the user interface design conceptualization and prototyping.

5.2 Tool Development Using Skyline Queries

In this section we discuss the technique which is being used to calculate the routes with given the cost, emission and time parameters. This tool can be used to identify *cost*, *environmental* and *time* tradeoffs associated with intermodal goods movement. Such an intermodal good movement planning problem can be formalized as a multi-criteria optimization problem. In turn, such multi-criteria optimization problems can be reduced to a family of data analysis queries, termed *path skyline queries (PSQ)* by the database research community.

Skyline queries are used to identify the preferred items among a universal set of items, when there are two or more complementary (and often contending) preference criteria. For example, suppose one is looking for the hotels that are both inexpensive and close to the beach (thus, price and location are her preference criteria). Considering that the hotels located at better localities are often more expensive, obviously there is a good chance that the least expensive hotel is not located at the best locality. In such a case, one approach to identify the preferred hotel is to first find all hotels that are not worse than any other hotel in both preference criteria. We call this set of “dominating” hotels the *skyline* set. From the skyline, one can then pick her final choice, thereby weighing her personal preferences for price and location. Correspondingly, the generic skyline query (Borzsonyi, Kossmann and Stocker 2001) is formally defined as follows. Given a universal set P of multi-attribute objects, we say an object x dominates another object y if and only if x is equivalent to or “better” than y (according to the user preference) in all attributes and strictly better than y in at least one attribute. Accordingly, the skyline query finds the subset p of objects from P, where for every object x in p, x is not dominated by any other object y in P.

Various types of skyline queries are introduced and studied in the literature. For instance, we introduced the spatial skyline query (Sharifzadeh and Shahabi 2006), where we considered the spatial domination of the objects given a set of query objects. Among different types of skyline queries, we believe *path skyline queries* to be best model and address multi-criteria goods movement planning problems. With goods movement planning, a transportation path for moving goods from a source location to a destination location is generally a multimodal path, where a specific combination of shipping options (e.g., transportation route, transportation mode, choice of fuel) is selected for each segment of the path; hence many alternative paths. Suppose one needs to identify the "best" path (among all possible transportation paths) for moving a shipment from origin (o) to destination (d), where the best path is defined based on multiple complementary preference criteria, such as total emission, cost, distance and time of travel along the path. We have used path skyline queries to answer such goods movement planning problems as follows.

Let the aforementioned preference criteria define the attributes of a path. Accordingly, a path skyline query finds the set of dominating paths among all paths, where each path x in the skyline is at least as good as any other path y with respect to all attributes/criteria and there exists at least one attribute where x is preferred to y; hence, skyline effectively identifies the set of best paths as required. In Figure 4, the blue points are referred as skyline points and the empty circles are not taken into account since are dominated by the skyline points in all route attributes.

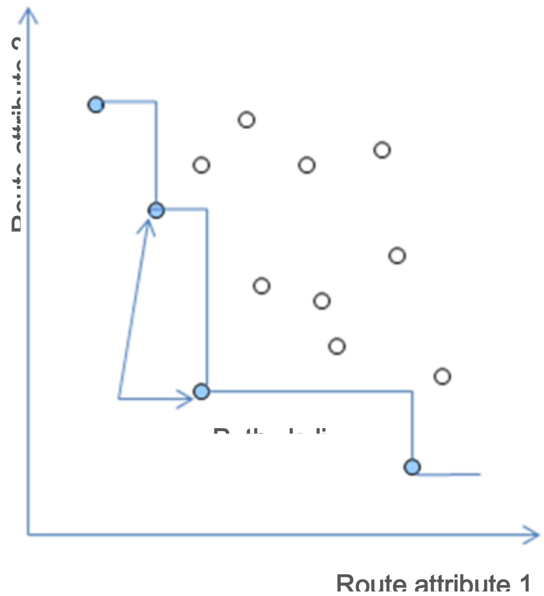


Figure 4 Skyline points

Several commercial systems such as car navigation devices and online route planning services already provide optimal path planning based on a single preference criterion. However, to the best of our knowledge, none of these systems can compute the skyline of the paths given multiple user preference criteria.

With a naïve approach to answer a path skyline query, one must evaluate all possible paths between an origin and a destination based on the path attributes (the preference criteria) to find the skyline set. This approach obviously fails to scale in real-world scenarios where the size of the transportation network and the number of shipping options for each path segment is very large. Therefore, one must develop a strategy to prune the unnecessary paths for which it can be guaranteed that they are not extendable into a member of the path skyline. To the best of our knowledge, Schubert et al (2010) is the only available study on path skyline query computation. Therefore, we used this approach in our web-based tool development. However, this work makes the significant simplifying assumption that the travel-expense (e.g., travel time, travel cost) for each edge of the transportation network is constant, whereas in real-world the travel-expense of an edge (which often corresponds to major optimization criteria) is time-dependent, i.e., the actual travel-expense of an edge depends on the time of arrival to the edge. For example, the amount time it takes to transport goods from the port of Los Angeles to Inland Empire significantly varies depending on the time of day. We are currently developing novel and efficient solutions to compute various forms of path skyline queries in the PSQ family assuming multimodal time-dependent transportation networks.

5.3 Interface design

This section provides a brief description of underlying technologies and programming languages used in the development process. The tool has been developed with three-tier architecture (presentation tier, query-interface tier, and data tier) that allows users to present different route options by changing the cost, emission, and time parameters and see the results of their changes in real-time.

1. The presentation tier is the topmost level of the application and is implemented with HTML, JavaScript, CSS and AJAX. For the interactive map we used Google Maps API which lets us embed Google Maps (as on the http://maps.google.com web page) into our tool.
2. The query-interface tier is pulled out from the presentation tier and it controls the application's functionality. This piece of the project is implemented with Java EE technology. Both presentation tier and query-interface tier hosted on Tomcat Server.
3. The data tier is a spatial database management system built on Oracle 10g. We specifically use Oracle Spatial components since it aids users in managing geographic and location-data through abstract data types.

5.4 User requirements

Users of web-based tools don't just look at information; they interact with it in novel ways that have no precedents in paper document design. For example, as the user begins to define variables in the query system, he/she visualizes path rendering, manipulates certain lines (defined by the heuristic) and then decides to change the route selection, experiments with different routes and makes the decision to perform certain tasks. However, these are not done by all types of users. For example a retailer wouldn’t likely be interested in the emission rates. Therefore, the user interface should be customized according to user needs and should only display relevant information and components. So, the expected set of user requirements is:

- Easily change Origin/Destination pair
- Define (add/delete) distribution centers
- Maintain visual contact with all decision variables
- Hide variables that are not of interest
- Easily see route selection output in the form of color coded lines on Google Maps
- Visualize statistics using graphs
- Display a table of route options versus decision variables (time, cost, emissions)

5.5 User groups

One of the major problems in such a system where there are several user types is that each of the user group only needs to see its own relevant information. There are three different types of user groups in the system: shippers, retailers and port officials. In table 25 we rank user groups (L: low, M: medium, H: high) in four different categories.

Table 25 User group rankings according to four different metrics

	Technical background	**Usage level**	**Data needs**	**User interactivity**
Shippers	H	H	H	M
Retailers	M	H	L	M
Port officials	H	M	M	L

5.6 Design conceptualization

To make the graphical user interface more usable and receptive to the user's needs, we split the screen into two vertical panes. The left pane contains all of the system components which users enter input and change the parameters. As mentioned in the previous section different user groups should only see relevant information to them. The right pane has a Google style world map where users can clearly see the different route options, ports and distribution centers. There are two advantages of this design. First, it allows users to see the routes on the map and the parameters affecting these routes together so that they can map the parameters and drawn routes in their mind. Second, it provides flexibility to handle, add and remove user groups because for each user groups only the left pane needs to change and the right pane remains the same.

To move the design further into the design conceptualization, we applied a modification of Nielson's heuristics (1990) and Schneirderman's principles of interface design (1998). We have followed each one of these heuristics for our design conceptualization and prototyping:

1. Consistency
    - Consistent sequences of actions in similar situations
    - Identical terminology in prompts and menus.
    - Consistent color, layout, capitalization, and fonts.
2. Reduce short-term memory load
    - Humans tend to store an optimum of 7 (plus or minus 2) pieces of information in their short term memory. We reduce short term memory load by designing screens where options are clearly visible, or using pull-down menus and icons with minimalist design. For example, we placed the same icons on the map

right next to the text fields in the left menu to reduce the number of components on the screen.

3. Design dialogs to yield closure
    - Sequences of actions organized into groups. For example, origin, destination and distribution center fields are grouped together in a sequence.
4. Easy reversal of actions
    - The same icon was used to drop or collapse the menus and the submenus.
5. Error prevention and simple error handling
    - If users make an error, the error is detected and simple, constructive, and specific instructions for recovery are offered. For example, if the entered origin address cannot be found, an appropriate error meesage is shown to the user.
6. Informative feedback
    - For every user action, the system responds in specific way. For example, a slider will show the button will make a clicking sound or change color when clicked to show the user that the system responded with feedback.

5.7 Prototyping

This section provides some screenshots of the graphical user interface. Each figure will be explained separately. Figure 5 shows the main page view of the graphical user interface. The left panel contains the components that users interact with and manipulate. At the bottom of the left panel, there are two tab options called *home* and *data visualization* respectively. The *Home* panel is the default panel that has all the components mentioned above. The *Data visualization* panel provides statistics, graphs and figures from the route options displayed on the map for the given user parameters. The map panel responds by displaying the route options drawn for a given origin and destination. We have used Google maps API; therefore, it has all the capabilities that Google maps have such as zooming, panning, various map styles, etc.

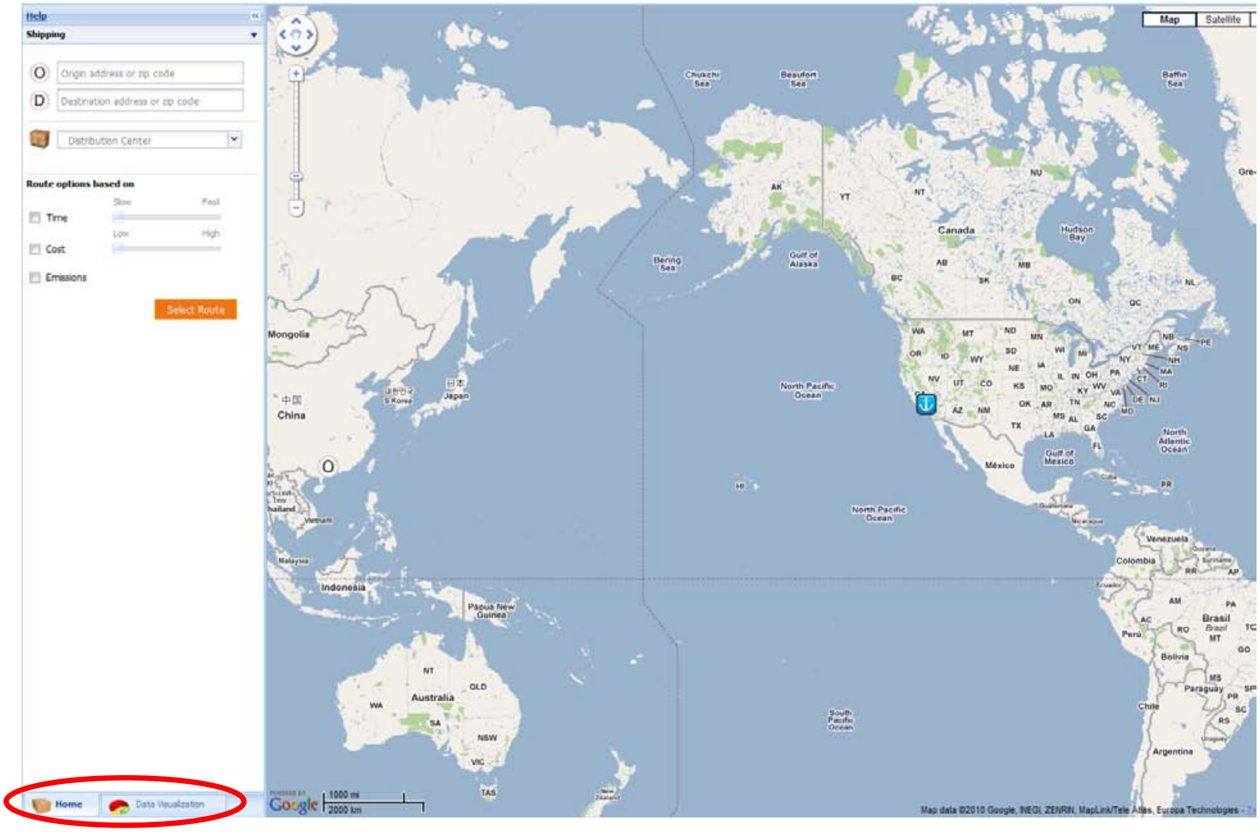


Figure 5 Main screen

A zip code or a complete address is needed in the origin and destination fields to begin the process. Once the input is taken from the user, the system places origin and destination icons on the map (*O* for origin, *D* for destination). Distribution

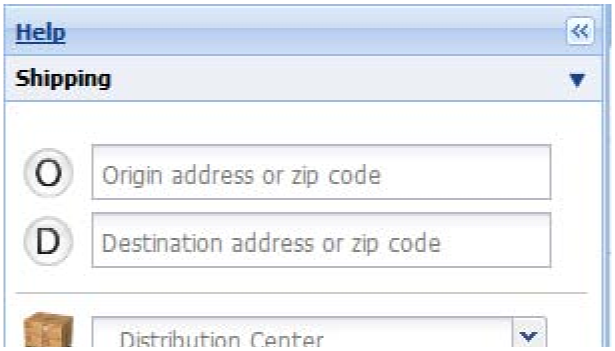
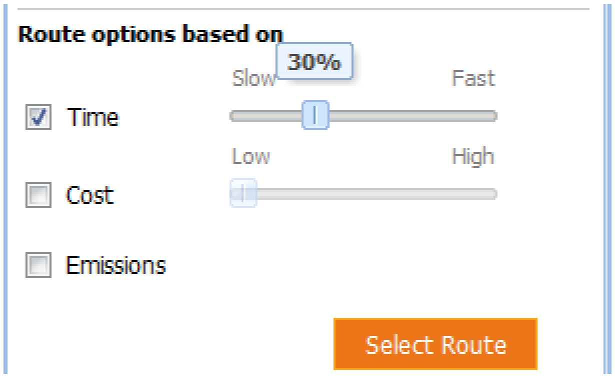


Figure 6 Origin & destination

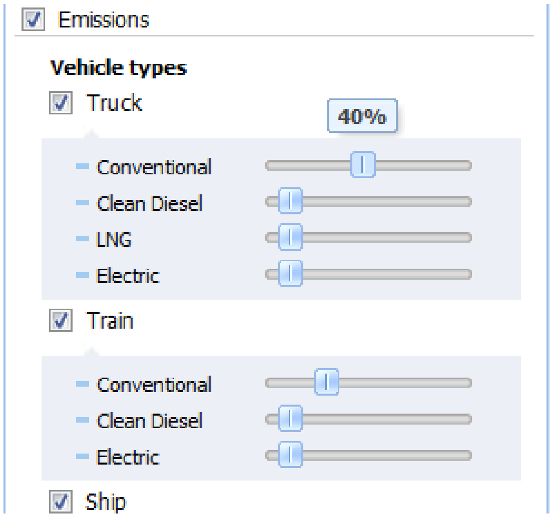
center selection is optional and if it is selected, the routes will be drawn to pass through the distribution center.

As mentioned in the first section of the report there are three criteria affecting route options: time, cost and emissions. Figure 7 shows how users can set their preferences. For example; for a shipper operation cost might be more important than time, or vice-versa. In this design the preferences are defined in percentages because they are relative to other items within the same category. For instance, time is 30% important while operation cost is 70%.



Route options based on
☑ Time: Slow – Fast, 30%
☐ Cost: Low – High
☐ Emissions
Select Route

Figure 7 Parameters



☑ Emissions
Vehicle types
☑ Truck
- Conventional: 40%
- Clean Diesel
- LNG
- Electric

☑ Train
- Conventional
- Clean Diesel
- Electric

☑ Ship

Figure 8 Vehicle types for multi-modal operation.

As we mentioned previously, this system is designed to consider multi-modal route planning. The vehicle types are categorized into 3 groups: truck, train and ship. Also, each vehicle type has sub categories as shown in Figure 8. The system contains a database with different types of vehicle emission rates. For example, if a shipper has only conventional trucks, the slider next to conventional truck should be set to 100%. Other combinations can also be created to analyze how vehicle types affect total emissions.

5.8 Future development

In this project we developed a web-based simulation tool aiming at identifying *cost*, *environmental* and *time* tradeoffs associated with intermodal goods movement. We have used path skyline queries for the route calculation and built an interface that allows the users to make these tradeoffs in real-time. However, this work makes the significant simplifying assumption that the travel-expense (e.g., travel time, travel cost) for each edge of the transportation network is constant, whereas in real-world the travel-expense of an edge (which often corresponds to major optimization criteria) is time-dependent, i.e., the actual travel-expense of an edge depends on the time of arrival to the edge. For example, the amount time it takes to transport goods from the port of Los Angeles to Inland Empire significantly varies depending on the time of the day.

Moreover, the approach proposed in Borzsonyi et al (2001) does not apply to planning multimodal transportation paths. In contrast, we are currently developing novel and efficient solutions to compute various forms of path skyline queries in the PSQ family assuming multimodal time-dependent transportation networks. In addition to the development of more accurate algorithms for path skyline queries, the connections between trucks, trains and ships should be taken into account in an optimal solution. As a next step we plan to model the connectivity and include it in the route calculations. Similar work by Winebrake et al (2008) has focused on incorporating the intermodal time-dependent features for a small freight network (including sea going vessels) in the Great Lakes region of the United States. We estimate the cost and other resources needed to perform the additional research indicated above to be: three graduate research assistants for a year, for a total of about $300K.

From a user interface design perspective, we need to test this system with real actors in the goods movement industry. This will give us the ability to compare the actor's behavior as they go through their multi-criteria decision process. As users make decisions based on the multiple criteria, the system should be able to give numerical data on each route option versus decision variables. For example, we are planning to add a data table output for each decision making session, such as the one in Table 26.

Table 26 Sample data table output

	Time	**Cost**	**Emissions**
Route 1	26 days	$5,500	5,800 pounds
Route 2	27 days	$5,000	5,800 pounds

Table 26 illustrates that route 1 is the best option in terms of travel time, but slightly more expensive. This clearly shows the need for tradeoff analysis. We feel that we should give the user the ability to see and work with this type of table and perform his/her own tradeoff based on other important business concerns. From an implementation perspective, we envision a tool that gives the user a third tab option called: Tradeoff Analysis (in the lower left of the Home screen). When the user clicks on this tab, a table similar to the one given above would show the user all the route options and all the decision variables selected (in the left pane). The user then clicks on a row (e.g., route 1) and that row changes its color, indicating that the user's interest to manipulate that route option. The system would draw that route on the map. Then, the user would also be given the ability to change the numbers inside each cell (e.g., from 26 days to 25 days) and the system would either redraw a line for a new route or would inform the user that there is no route for the new value(s). In the case that there is no route for the given parameter(s), the system would suggest the next closest route. The resources we need to add this capability are: one student for a year for a total of $50K.

6 Conclusions and recommendations

The conclusions and recommendations below refer specifically to Chapter 2, 3, and 5. For recommendation specific to other chapters, please refer the chapters themselves.

Multinational Scale: Route options from China to U.S.

Our first effort in this research attempts to model the carbon footprint of a container in its supply chain. Based on data from a major U.S. toy manufacturer, we have modeled widely used container movement patterns from China to six destination zip codes in the United States. In order to get a sense for a baseline comparison, given nominal conditions and reasonable assumptions, we calculated an "average" carbon footprint to be 2,821 kg of CO2 equivalent emissions per container for one trip from China to the U.S. We then began estimating more accurately the emissions, the cost and the travel time, for different transportation modes, different cost variables and different destination ports, generating route specific data tables, given the six leverage points and the arcs connecting them.

To assess the tradeoffs among each route option based on each decision variable (emissions, time and cost), we built five case studies, each with multiple alternative route scenarios. In these scenarios we generated and used specific data relevant to each case and its associated scenarios. For example, in the case of shipment from China to a zip code in New Jersey, the container may originate in Guan Yao with a single route to Yantian Port in China. For the four possible alternative routes indicated, the values for the three variables were calculated as shown below. The choice of using the last alternative is rather obvious from this table.

Table 27 Emission, cost and transit time for 4 different route scenarios

	Los Angeles (with DC)	**Houston (with DC)**	**Houston (No-DC)**	**New Jersey (No-DC)**
Emission (CO2-e, lbs)	5823	6213	4932	4160
Cost ($)	4908	4814	3853	3386
Transit time (days)	26	27	25	25

Source: Authors' calculations.

One conclusion from this table is that using alternative routes through the Panama Canal offers significant cost advantage for destinations in the Midwest and the East. We also observe that there are significant emissions tradeoffs associated with route options. Next, we saw that time tradeoffs were not as significant as expected. Considering the fact that freight transport from POLA/POLB to the east must go through some of the most congested routes in urban Los Angeles, the small time saving may not be justified at all times.

The modeling approach used here seems to be powerful yet simple enough to capture container movement routes across the six leverage points. It is also modular and expandable to consider other decision variables and leverage points, and used by multiple customers and operating modes. And, one can easily add any other environmental impact variable considering the transportation mode, new technology implementation, new regulation, etc. For example, the IMO has set voluntary standards on sulfur emissions for international maritime shipping (Sulfur Emission Control Area). Our model is capable of assessing the sulfur emissions for the shipping component of the entire system and compares the tradeoffs against other decision variables. We feel that the model is also flexible enough to be used by any customer in the complex supply network.

Model limitations: As mentioned previously, we began our modeling effort top-down, and began building model accuracy in the leverage points and their connecting arcs as we moved the project forward. In general, as the system granularity increases, one has more difficulty obtaining data from the multiple actors across the supply chain. In certain areas, such as port operations, we made a simplifying assumption by discounting the effects of the cargo handling equipment. In another system component, we used an average ship emission factor for all route options. Including a specific ship emission factor for a specific route would increase model accuracy. And, due to data unavailability, we used rough estimations on the land distances and emissions from the Chinese land side transport. Future efforts focusing on the Chinese land side will help model accuracy.

Regional Scale: Port electrification-- Life-cycle emissions of yard tractors at POLA

Increasing container throughput at POLA has raised concerns over its environmental impacts in a dense urban population center. As we discussed in the global scale container movement study, POLA is a key system leverage point. For this study, we have considered the electrification of yard tractors as a case study of how a major modern port could reduce its emissions as a key transshipment point along the global supply chain. The question we posed was that if the port considers their emissions of the yard tractors on a life-cycle basis, would it be able to meet its mandated GHG reduction by the year 2030.

Yard tractors are the largest mobile source emitters of GHGs at POLA (1,114 units producing about 94,000 metric tons of CO2-equivalent per year). We used the assumption that the entire fleet would turn into electric engines eventually, using the DWP power generation portfolio. One important contribution of this study was that all emission calculations were on a life-cycle basis. This means that comparisons could be made including the indirect emissions of both diesel and electric vehicles. Highly specific considerations such as engine efficiency, hour for charging, load equivalency, etc. were also used to make the comparison realistic.

Our results show that for the target year of 2030, emissions will exceed the 35% reduction target by over 50,000 metric tons. In sum, the analysis shows that any given set of LADWP renewable portfolio and POLA's electric adoption rate, the target is unachievable, largely because of the growth in container throughput.

7 Implementation

Perhaps, the most daunting challenge of this research is to transform the analysis that we have provided and make it useful for goods movement stakeholders. As mentioned earlier, the system is complex and each one of its nodes and arcs are controlled by different stakeholders, interested in our decision variable outputs in differing degrees. Therefore, in the last part of our research (Chapter 5), we developed a web-based framework and a decision tool to make it easier for the stakeholders to develop their own decision-making scenarios. We have described the development of the web-based intermodal container movement visualization tool in this report (Chapter 5), and here we just highlight its capabilities for future development and implementation. There are two parts to the implementation of this tool: 1) Reduce the system complexity on a simple web-based interface, and; 2) Introduce this tool to the actual users and begin testing it in the “real-world.” This second part is a future implementation since the tool has only been prototyped and not been tested and verified for a large-scale use yet (see Future Development section of chapter 5).

The main purposes of this tool are to enable the analyses of different transportation modes in a global scope, and to suggest a user defined optimal route selection based on a pre-defined criteria e.g. cost, emission, and time. We have used the standard Human-Computer Interaction methodology to develop the tool interface and begin testing it in our own lab. The response from the rest of our research team has been positive. After some minor modification of the original prototype, we decided to take the tool to our counterparts at the POLA. Four port employees with expertise in different portions of the system were present and critiqued the system. Our demo included not only describing the interface components (buttons, sliders, maps, etc.) but also the possible uses and misuses for each interface function. The comments and concerns of the port employees were discussed in detail and helped us to redesign parts of the system. We did not have the time and the resources to take this tool to the “real” stakeholders for a large-scale interview, testing and verification. This step requires a significant amount of resources and personnel for a period of one year at a cost of U.S. $25,000. If we decide to develop a two-way interactive data query system (again, see Future Development of the tool section), then we will need $50,000.

8 Appendix

8.1 Life Cycle Analysis (LCA) studies of selected energy sources

This appendix aims to most accurately represent emission rates for LADWP¹s non-renewable and renewable energy sources. There are few U.S. life cycle assessments for energy plants, thus a comprehensive review of multiple life cycle assessments was composed based on geographic location, plant capacity, capacity factor, and plant lifetime. The following table represents the range of all the studies for each energy source with an equivalent average.

Table 28 Estimated emissions for selected energy sources

Energy source	**CO_2 – equivalent range (g/kWh)**	**CO_2 – equivalent avg. (g/kWh)**
Non-renewables:		
Coal	960 - 1050	1005
Natural gas	469 - 518	493.5
Renewables:		
Biomass & waste	15 - 52	33.5
Geothermal	15	15
Hydroelectric (small)	11	11
Hydroelectric (large)	128 – 380	254

Solar	21 - 71	46
Wind	2 – 29	15.5
Nuclear	15 - 25	20

Source: Authors' calculation based on literature review

The National Academies Press is a compilation of life cycle assessments across various geographical regions. The goal is to provide a comprehensive analysis from 'cradle to grave' of the emissions associated with the construction, on-site erection and assembling, transport, operation, and dismantling of renewable energy plants. However, because there is no universal standard for LCAs, differences in assumptions, boundaries, and methodologies arise. The two types of LCAs covered in this table are economic input/ output (EIO) and process analysis (PA). Major factors that affect LCA results and cause discrepancies among analyses include power plant capacity, plant life expectancy, and energy infrastructure. Therefore, in order to encompass all of the LCA studies, a range of emission factors is included and an average of g CO_2e/kWh for each energy source is generated.

8.1.1 Coal

The following studies were included in the National Academies Press for coal emissions: Denholm 2004, Hondo 2005, Odeh and Cockerill 2008, Spath and Mann 2004, Spath et al. 1999, White 1998. The studies are based on traditional pulverized-coal plants, but emissions can vary based on carbon capture and storage technologies. With new coal technologies included such as low-emission boiler system, UK super critical pulverized coal plant, and UK integrated gasification-combined cycle, the emission range may experience a moderate drop to 757 to 879 g CO_2e/kWh in the future. The lowest range 43 to 255 g CO_2e/kWh, included future carbon capture and storage methods, including absorption by monoethanolamine and selexol. Two hypothetical U.S. average coal plants emit approximately 250 g CO_2e/kWh, however U.S. plants co-fired with biomass residues had a reduced emission of 43 g CO_2e/kWh, but this study did not account for the production, regeneration or disposal of monoethanolamine.

8.1.2 Natural gas

The following studies were included in the National Academies Press for natural gas emissions: Denholm 2004, Hondo 2005, Meier 2002, Odeh and Cockerill 2008, Spath and Mann 2000. Emissions are affected by plant efficiency and natural gas losses from production and distributions. Upstream emissions are more significant in the natural gas fuel cycle, thus carbon capture and storage technologies will not have a large impact emission rates. A higher value 608 CO_2e/kWh was found for only gas-fired plants.

8.1.3 Biomass & waste

The following studies were included in the National Academies Press for biomass and waste emissions: Berry et al. 1998, European Commission 1997, Mann and Spath 1997, Spath and Mann 2004, Spitzley and Keoleian 2005). CO_2e emissions from biopower vary depending on the yield, fertilizer and fuel used to harvest the feedstock, as well as differences in the specifics of the plant itself. In the National Academies Press found most CO_2e values from biomass derived from feedstock ranged from 15 to 52 g CO_2e/kWh. Some studies included found negative emissions (Spath and Mann 2004), therefore acting as a greenhouse gas sink. These studies give credit for the avoided GHGs, which would have been emitted under normal waste disposal.

8.1.4 Geothermal

The following studies were included in the National Academies Press for geothermal emissions: Bertani and Thain 2002, Bloomfield, Moore and Neilson 2003, Hondo 2005, Serchuk 2000. Calculating the total CO_2e emissions from geothermal electricity power plant includes emissions associated with production of the facility and emissions during operation. Emissions during the operation depend on the reservoir gas composition and if during the electricity generation the gas is vented to the atmosphere. The Japanese Hondo case included by the National Academies Press, which analyzed a double-flash geothermal facility and assumed a lifetime of 30 years, found an emission for the plant of 15 g CO_2e/kWh.

8.1.5 Hydroelectric

The following studies were included in the National Academies Press for Hydroelectric emissions: Gagnon and van de Vate 1997, Hondo 2005, Spitzley and Keoleian 2005. A Japanese LCA done on a small 10 MW hydroelectric power plant and with an assumed plant life of 30 years and capacity factor of 45 the resulting emission factor was 11 g CO_2e/kWh. When a dam is constructed newly flooded biomass will decompose and result in greenhouse gas emissions. This particular study did not account for those associated emissions (Hondo 2005). Another study done on large (>30 MW) hydroelectric power plants in the United States (i.e. Hoover and Oahe) found full cradle to grave emissions associated with such power plants, including emissions associated with construction, flooded biomass and the eventual decommissioning the dam. The global warming effect due to dam decommissioning is normalized to the total electricity produced over the lifetime of each power plant. They found estimated global warming emissions due to large hydroelectric power plants ranges from 128-380 g CO_2e/kWh.

8.1.6 Solar

The following studies were included in the National Academies Press for solar emissions: Denholm 2004, European Commission 1997, Frankl, Corrado and Lombardelli 2004, Fthenakis et al. 2008, Hondo 2005, Meier 2002, Spitzley and Keoleian 2005. Solar emission rates vary based on the energy mix used to generate the electricity required for manufacturing. The emission rates are related to conversion efficiencies, where solar panels with lower conversion efficiencies have higher emission rates. However, advances in technology expect to produce higher conversion efficiencies, reducing the emission range from 21 to 54 CO_2e/ kWh.

8.1.7 Wind

The following studies were included in National Academies Press for wind emissions: Chataignere et al 2003, Chataignere et al 2003b, Chataignere et al 2003c, Denholm 2004, European Commission 1997, Hondo 2005, Spitzley and Keoleian 2005b, Spitzley and Keoleian 2005c, Spitzley and Keoleian 2005, White 1998. The low value corresponds to two larger wind farms in class 6 and 4 wind areas, while the high value corresponds to a wind farm with a low, 20 percent generating capacity. The emission rates for Vestas, Ecoinvent, and CASES was calculated using the CO_2/ kWh, CH_4/ kWh, and N_2O/ kWh provided by the LCA study. Based on the metrics for expressing greenhouse gas emissions, the methane and nitrous oxide were translated into CO_2 equivalents. The global warming potential for methane is 21 and nitrous oxide is 310. The following emissions were then multiplied by their global warming potential and were then summed to produce a total carbon dioxide equivalent per kilowatt-hour. These studies are not included in the average of g CO2e/kWh, but demonstrate that studies outside the scope of the National Academies Press fall within the study's expected range of emission rates for wind farms.

Table 29 CO2 equivalent emissions of wind, by source

	National Academies Press	**Vestas**	**Ecoinvent**	**CASES**
g CO_2/ kWh	-	5.60	9.60	9.10
g CH_4e/ kWh	-	0.09	0.00	0.32
g N_2Oe/ kWh	-	11.78	11.97	7.87
g CO_2e/ kWh	2 - 29	17.47	21.57	17.30

Source: Compiled by authors from multiple sources

8.1.8 Nuclear

The following studies were included in the National Academies Press for nuclear emissions: Denholm 2004, European Commission 1997, Fthenakis and Kim 2007, Hondo 2005, Storm van Leeuwen 2008, Vattenfall 2004, White 2006. Although the range of g CO_2e/ kWh values is from 15 to 25, there are two outliers beyond this range. The low value outlier of 2 g CO_2e/ kWh from Vattenfall (2004) analyzed Swedish reactors whose operating capacity was 85 percent and had a 40-year life expectancy. The study used PA methods and a centrifuge performed 80 percent of the fuel enrichment. The high value outlier of 108 g CO_2e/ kWh is from Storm van Leeuwen (2008) using EIO methods where gas diffusion performed the fuel enrichment, operating capacity was at 82 percent, and the plant had a 30-year life expectancy.

9 Research Team

The research team was carefully coordinated to ensure that the research and associated product deliverables were completed in an efficient, rigorous fashion. The team combined the disciplinary expertise of economic and transport geography, industrial and system engineering, computer simulation and software engineering, as well as environmental specialists at the POLA. This multidisciplinary research team has collaborated since 2007 on port-related and container movement projects, including a project to quantify the carbon footprint of supply chains (Newell et al. 2008). The research team includes undergraduate and graduate students, who are included in the biographies below.

Josh Newell (P.I.) is a Research Assistant Professor at the Center for Sustainable Cities in the School of Policy, Planning, and Development at USC. He is trained as an economic geographer and received his PhD from the University of Washington in 2008. Newell has expertise in supply chain analysis and tracking, carbon and sustainability footprinting of products, processes, and regions, and policy analysis that relates to his modeling. He has led development of the project, *The Carbon Burden of the Paper Cycle: A Comparison of U.S. and Chinese Production Processes*, which calculated the carbon burden associated with paper production, from the emissions associated with timber harvest to the manufacturing of paper. He used GIS and related geo-coding tools to model the transport of the timber, pulp, and paper. He and Robert Vos used LCA and emission factors derived from IPCC, EPA, and other standard protocols to determine emission factors for each phase of the paper cycle (Newell and Vos 2008, Vos and Newell 2009)

Mansour Rahimi (PI) is a professor at the Epstein Department of Industrial and Systems Engineering, USC. His expertise relevant to this research includes: the link between transportation and environment, life-cycle analysis (LCA) of fuels and energy systems and environmental economic input-output impact analysis. His faculty affiliations include AT&T Fellow in Industrial Ecology, USC Fellow in Urban Initiative, a collaborative research faculty position in the *NSF/USC Environmental Sciences, Policy, and Engineering Program*, a co-organizer of an NSF/USC Symposium on Eco-Industrial Systems, a Faculty Affiliate at the USC's Center for Sustainable Cities, and a committee member for the USC Energy Institute. In these roles, he has been involved in the application of life-cycle analysis to industrial and transportation systems. He also uses joint optimization techniques to integrate both operational and environmental variables for sustainable transportation systems. His research projects related to industrial ecology include an NSF funded project (Material Use, Science, Engineering and Society) on optimizing service and environmental impacts of a reverse logistics system (Pourmohammadi 2008). In 2007, he was the recipient of a grant from the USC's Future Fuels and Energy Initiative on meta-modeling of environmental life-cycle analysis for alternative transportation fuels. Two related projects conducted with METRANS funds, include modeling dispatching services in transit operations and developing a joint optimization framework for both service and environmental considerations in a large transit service provider in Los Angeles. He has published his Metrans work in top-quality journals such as *Transportation Research, Industrial Ecology,* and *Maritime Economics and Logistics*.

Student Researchers

Afsin Askogan is a second-year PhD student in Computer Science at USC. He received his Masters degree from Cornell University. His research is focused on database systems with an emphasis on route planning and parallelizing spatial queries (k-nearest neighbor, reverse nearest neighbor, range queries, etc.) on distributed systems. Currently Akdogan is an active member of USC InfoLab.

Zhaohu Fan is a Master's student in Operations Research in Industrial and Systems Engineering at USC. He received his bachelor from Beijing University of Technology. Mr Fan has a background in modeling, optimization, and simulation.

Jae Kim is a second-year PhD student in Industrial and Systems Engineering at USC. Hw received his Masters degree from UC Berkeley. Kim has a background in mechanical engineering, optimization, and simulation.

Alison Linder has a PhD (2010) in Urban Planning at the USC School of Policy Planning and Development at USC, with a focus on transportation and environmental policy. Alison has worked at the Port of Long Beach on sustainability programming and has done research for RAND Corporation as well as several USC research centers on AB 32, infrastructure planning, environmental challenges at the San Pedro Bay ports and parks and open spaces. For her dissertation, Alison studied voluntary air quality programs at the San Pedro Bay ports to learn more about alternative approaches to achieving environmental improvements.

Eric Lee is an undergraduate in Industrial and Systems Engineering with minors in Business Administration and Jazz Studies at USC. His previous experience includes evaluating emission factors for paper mills and writing literature reviews on the life cycle analysis of integrated pulp mills domestically and internationally. He was involved in the initial development of a system dynamic model for the U.S.-China container movement.

Olivia Lu-Hill is an undergraduate student at the University of Southern California in the department of Civil-Environmental Engineering. She has previous research experience with USC Center for Sustainable Cities in finding methodologies for estimating greenhouse gas emissions from paper in landfills, and trends in international timber trade.

Figure 9 Metrans Research Team, 2009-2011 (from left to right, Afsin Askogan, Mansour Rahimi, Josh Newell, Alison Linder, Olivia Lu-Hill, Jae Kim, Eric Lee)

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