

The Cost of Cruise: Estimating a Shadow Price of Carbon for the Port of Seattle's
Shore Power Infrastructure

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Abstract

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The Port of Seattle outlined emissions reductions of 80% of 2050 levels for Ocean Going Vessels (OGVs). They are pursuing shore power infrastructure at Pier 66 to avoid at berth emissions. This research aimed to answer the following three questions: 1. What is the shadow price of carbon (SPC) as it relates to shore power infrastructure? (Establishing a MAC), 2. With the shadow price applied to ships using bunker fuel, is it more affordable for the cruise liner to burn bunker fuel or connect to shore power? 3. How long would it take to pay back shore power infrastructure using funds from SPC revenue, if applied. To do this, a model was created to calculate shore power marginal abatement cost to be applied as a shadow price of carbon per metric ton of CO₂ avoided by carbon abating infrastructure, in this case, shore power specifically. The cost per metric ton of CO₂ by connection rate ranged from \$197/MTCO₂ to

\$299/MTCO₂. This research found that the cost of bunker fuel at berth was more than double the cost of electricity at berth through shore power when accounting for externalities with shadow pricing. Finally, the repayment timeline ranged from about 5.5 years to 12.5 years. The Port of Seattle should pursue a carbon pricing policy on cruise ships to incentivize shore power plug in and finance shore power.

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Acronym Glossary

BTU- British thermal unit

Sox- Sulfur Oxide

CO₂- Carbon dioxide

UN- United Nations

CO₂e- Carbon dioxide equivalent

WHO- World Health Organization

The City- The City of Seattle

EA- Emissions avoided

GHG- Greenhouse Gas

HE- Hoteling Emissions

IC- Infrastructure Conversation

IPCC- Intergovernmental Panel on Climate
Change

kWh- Kilowatt hours

KW- Kilowatt

MAC- Marginal Abatement Cost

MTCO₂- Metric tons of CO₂

OGVs- Ocean going vessels

O&M- Operations and Maintenance

The Port- Port of Seattle

PSCAA- Puget Sound Clean Air Agency

SCC- Social Cost of Carbon

SCL- Seattle City Light

SP- Shore power

SPC- Shadow Price of Carbon

1. Introduction

Context: Reducing Carbon Emissions at the Port of Seattle

Ports are centers of economic activity and, consequently, are also large-scale sources of carbon emissions. This puts ports in a unique position. They must oversee and encourage the growth of lines of business and commercial traffic; but they also have an obligation to exercise police powers to protect the health, safety, and general welfare of the public. While finding a balance between these two mandates is often not easy, it is necessary, and an increasingly common challenge taken up by ports across the United States.

In Washington State, the Port of Seattle is a special district responsible for regulating the import and export of goods in service of economic development while also staying committed to its own ambitious environmental goals. To this end, in 2012, the Port adopted a long-range plan called the “Century Agenda”, a set of high-level emissions reductions goals designed to shape its next 25 years. Included in the Agenda are a set of sustainability goals aimed at making the Port “the greenest port in North America” (Port of Seattle, 2017). Central to this vision is a plan to decarbonize the Port’s operations by reducing its carbon emissions, including those from ships berthing at its facilities. Specifically, the plan sets a target of emission reductions from ocean-going vessels (OGV) by 80% of 2005 levels by 2050. To accomplish this goal, the Port is exploring several mitigation strategies.

Emissions sources are classified into subgroups called “scopes”. The Port of Seattle’s Century Agenda follows the Greenhouse Gas (GHG) Protocol and refers to emissions using Scope Classifications. The GHG Protocol Corporate Standard includes three broad classifications:

Scope 1 Emissions- direct emissions from owned or controlled sources.

Scope 2 Emissions- indirect emissions from the generation of purchased energy.

Scope 3 Emissions- all indirect emissions (not included in scope 2) that occur in the value chain of the reporting company, including both upstream and downstream emissions”

(Kaufman, 2017).

Emissions from OGVs account for about 1/3 of total Port of Seattle maritime emissions and are, therefore, an important part of the Port’s overall emission reduction plan. However, not all emissions can be easily regulated. The Port of Seattle has no jurisdiction over emissions while OGVs are not tied up to the dock. Similarly, transiting, and maneuvering emissions within the Puget Sound Basin fall within Scope 3, which means the Port has some influence over them, but not direct control. It is only when OGVs are at berth – or hoteling – that their emissions fall under Scope 1, which means they can be regulated through policy and tenant contracts set by the Port. Together, hoteling and maneuvering make up about 13% of total OGV emissions (Starcrest Consulting Group, 2018). However, while both are opportunities for emissions reductions, this paper focuses on hoteling emissions in particular, since this is when the Port has the greatest influence over ship behavior and the most control over regulatory and infrastructure changes that support long-term emissions reductions.

Hoteling is the energy a ship is consuming to run all the “hotel” amenities like lights, hot water, cooking, etc. while at berth. Hoteling energy consumption can come from electricity by plugging into shore power or by burning bunker fuel. One method of reducing hoteling emissions is to connect ships to what is called “shore power”, a process also known as “cold ironing”. Shore power is an onshore electrical hookup that ships can plug into while at berth. By drawing on electricity provided by the Port and Seattle utilities, ships can turn off their bunker fuel burning engines and still maintain their needed electrical supply. In Seattle, where electricity

is generated mostly from renewable resources, turning off ship engines can dramatically reduce the overall carbon output of a hoteling ship and thereby lower the Port's overall carbon production.

While the use of shore power can be applied to all OGVs, this study is particularly concerned with its application to cruise ships. Cruise ships make up an important share of the total number of ships using the Port's services and are a vital part of the Port's long-term economic plans. Supporting the cruise industry also has an important economic benefit to the downtown Seattle area specifically. Cruise ships bring in about \$500 million in annual business and tourism revenue to Seattle businesses. On average, each party of four people spends about \$1,500 during their time in the city (Starcrest Consulting Group, 2018). This revenue is in addition to profits made by the Port in lease agreements for pier and terminal use while ships are at berth.

Currently, Terminal 91 is the primary berth for cruise ships visiting Seattle (Henderson, 2008). Terminal 91 is also the only terminal with shore power plugs. However, according to Port of Seattle shore power data provided by Cochran Marine, only 57% of cruise ships that came to berth at Terminal 91 were shore power capable. Of those 57%, there was a 79% plug in rate. In other words, roughly two thirds of the cruise ships that berthed at Pier 91 were either not shore power capable or did not plug in when they could. Improving this shore power connection rate is currently the Port's best opportunity for reducing at berth emissions. One way the Port plans to increase shore power hook ups is by expanding the number of piers that are shore power capable¹.

¹ As a former Port's Maritime Environmental employee, I bring my work experience on the Air and Energy team to this research. This shore power research is not affiliated with or funded by the Port of Seattle



Figure A: Current and future shore power

The Port has goals to electrify all major piers and terminals in Elliot Bay. Pier 66 has been identified as a prime candidate for improvements. As the pier closest to the heart of downtown Seattle, electrifying Pier 66 would not only bring more cruise ships closer to the city, it would also reduce tourists' and residents' period of carcinogenic exposure to PM 2.5 created by cruise ships hoteling with bunker fuel in downtown Seattle.

However, electrifying Pier 66 is not easy, and it is not clear that all cruise companies would decide to continue calling at Seattle if shore power hoteling was mandated by the Port. While 60% of cruise calls scheduled to berth at Pier 66 are currently shore power capable, the Port does not have policies or incentives for shore power hook up. Shore power conversion is also extremely expensive. The Pier 66 plugs are estimated to cost \$17 million to install, an expense that the Port views as a “sunk cost”, meaning that it would provide no direct return on investment. Sunk costs can be challenging for economic drivers like the Port of Seattle to take on because it is not aligned with their mission. Additionally, an internal calculation found that even if the Port of Seattle electrified every terminal and pier and reached a 100% connection rate, it

still would not reach its total emissions reductions targets. In other words, shore power and total electrification will not solve the Port's carbon emissions problem alone. They are, however, a necessary minimum step if the Port is to reach its total emissions goals. Despite these challenges, the Port's commission approved funding for shore power at Pier 66 in November of 2019. It has not, however, allocated money for the project because of the perceived high cost of and is instead seeking a public/private partnership to fund the needed improvements (Port of Seattle, 2019).

There is some urgency to this research. The Port has an opportunity to reduce hoteling emissions through infrastructure development, policies, taxes, and fees incentivizing plug-ins. While the COVID-19 pandemic of 2020-21 halted all cruises coming to the Port of Seattle during the 2020 cruise season, which dramatically reduced carbon emissions, it is expected that the industry will bounce back quickly. Upgrading its piers before the cruise ship industry rebounds will ensure that the season is minimally impacted by construction. Moreover, due to the economic downturn, bonds, which are commonly used by municipalities to finance large-scale infrastructure, are at a low rate (Cheng et al., 2021). This period of economic recovery is the time to consider long-term investments like shore power while interest rates are low.

Pricing the Cost of Carbon

One reason that investments in sustainable infrastructure such as shore power installations are often seen as an expensive "sunk costs" by government agencies is because they are not always accounted for in terms of their abatement benefits, only by the cost per ton of carbon that is annually removed from the atmosphere. Thus, as in the case of the Port, shore power is viewed as a large capital investment with little financial return on investment because cruise lines – and the Port itself - does not have to internalize the external costs of carbon emissions that are associated with burning bunker fuel. If these externalized costs are also

included, then the relative costs of such infrastructure developments can be comparatively low – or at least lower than government agencies tend to view them.

The problem of accounting for externalized costs is a common one, particularly as they apply to climate change mitigation. “The greenhouse problem stems from the failure of Western industry to pay the full cost of their production since the industrial revolution” (Andrew, 2008). However, as the World Health Organization (2013) and Tempest notes, when considering the health implications of poor air quality, “health and economic impacts should be assessed” (Tempest, 2016) (World Health Organization, 2013). Baiardi and Menegatti claim that there are two policy instruments that are most important for pricing environmental degradation. The first is abatement policy, which is an intervention (such as shore power) financed by taxation that directly improves environmental quality. The second is a Pigouvian tax which is a tax on economic activities that create externalities (Baiardi & Menegatti, 2011). “Opponents of monetization argue that the way economists measure cost and benefit produces an inequity. However, a cost is any loss of wellbeing, and a benefit is any gain in well-being” (Pearce, 2003) and (Fleurbaey et al., 2019). Therefore, pricing externalities is pricing well-being where it is not currently being accounted for since externalities are often born by unrelated third parties. Echoing Baiardi and Menegatti and supporting the recommendations of the Stockholm Environment Institute, Stanton and Ackerman agree that “a shadow price and enforcing policy must be established in tandem” (Stanton & Ackerman, 2008).

The shadow price of carbon (SPC) can be used as an abatement method to calculate the social benefit of carbon-abating infrastructure (or social costs of non-carbon abating infrastructure) in cases that include health and equity considerations. “Carbon pollution is a negative externality because it imposes external costs on people who did not create the pollution.

“The social cost of carbon (SCC) refers to the cost of an additional ton of carbon dioxide pollution” (Marlow, 2019). In other words, the social cost of carbon measures the full cost of carbon today by considering the sum of the cost of the damage it produces during its full life in the atmosphere (Price et al., 2007). The social cost of carbon is useful when considering broadly applied, socially-beneficial mitigation policies and is frequently discussed when considering, for example, carbon taxes.

The shadow price of carbon can also be used as a mechanism to price externalities that are otherwise not being priced. In this case, the shadow price of carbon is informed by the *marginal abatement cost*, or MAC, which “reflects the cost of reducing emissions rather than the damage imposed by creating emissions” (Price et al., 2007). This research focuses on establishing a shadow price of carbon based on a marginal abatement cost. Currently, the Port evaluates investments on an abatement “cost per metric ton of CO₂” basis (tons reduced/project cost) but has yet to compare the hoteling cost of shore power and bunker fuel or apply the abatement cost as a shadow price to its pier retrofits.

In a report commissioned by the Port of Seattle, the Stockholm Environment Institute states that because the Port already pursues low carbon projects, “an internal carbon price would do little to change decision making” (Stockholm Environment Institute, 2019). However, the report also suggests that the development of a shadow price would help the Port create a consistent “Port-wide benchmark for evaluating different projects and measures against each other in relation to the Port’s GHG reduction goals” (Stockholm Environment Institute, 2019) and suggests the development of a shadow price to internalize the cost of carbon in life cycle cost analysis. Establishing a marginal abatement cost (MAC) for the Port’s shore power infrastructure would also help quantify the carbon reduction benefit in dollars during budgetary

decision making and might, most importantly, help the Port and the public better understand the costs associated with meeting the Port's Century Agenda emissions goals, particularly as they relate to providing shore power for cruise ships.

Research Question: Establishing the MAC of Shore Power Infrastructure

This research aims to establish a marginal abatement cost for shore power infrastructure at Pier 66 and apply it as a shadow price to ships burning bunker fuel so the Port can evaluate shore power infrastructure investments for their carbon reduction benefit. To do this, three interrelated questions are answered. First, this paper attempts to determine the true hoteling costs of cruise ships when normally unaccounted for externalities are included in bunker fuel pricing. To do this, we are creating a “sub” shadow price of carbon based on the marginal abatement cost of shore power that is estimated and then applied as a multiplier to each metric ton of CO₂ emitted by a ship not connected to shore power, creating an additional cost of the cruise line on top of money spent on fuel costs. In this paper we just refer to it as a “shadow price”. Normally, shadow prices are agency-wide calculations but due to limited data, this research is an infrastructure specific calculation and not agency-wide. Second, by comparing the true costs of hoteling using bunker fuel with the SPC included to the costs of hoteling using shore power, this research attempts to calculate which hoteling fuel source, bunker fuel or shore power, is most cost effective. And third, this research attempts to determine whether internalizing the external cost of carbon into ships hoteling with bunker fuel makes it financially feasible for the Port of Seattle to invest in shore power infrastructure to meet its carbon-reduction goals. The questions are:

1. What is the shadow price of carbon (SPC) as it relates to shore power infrastructure?
(Establishing a MAC)

2. With the shadow price applied to ships using bunker fuel, is it more affordable for the cruise liner to burn bunker fuel or connect to shore power?
3. How long would it take to pay back shore power infrastructure using funds from SPC revenue, if applied?

Document Outline

In Chapter 2, the literature review discusses the case for the shadow price versus social cost of carbon, policy recommendations, and the foundation of climate action policy, as well as modern day approaches like the Paris agreement. Chapter 3 describes the methods to create this model including assumptions where data was missing and substituted proxies grounded in literature and the detailed process of calculating each piece of the model. Chapter 4 outlines limitations to the model and results. The model is in Appendix A, and will be referenced throughout this paper, but can also be built upon and refined in future research. Chapter 5 is the discussion section, which reviews the question of who is responsible for bearing the cost of externalities as it pertains to the changing climate policy landscape. This chapter reviews potential policy considerations for the Port based on the outcomes of the model and next steps to build on this research. Policy recommendations in the “Discussion” section are based on the findings that can be considered by the Port to reach its Century Agenda Goal to reduce greenhouse gas emissions from ocean-going vessels while operating and expanding the cruise industry. Chapter 6 is the conclusion, summarizing the main points from this research.

1. Literature Review

Introduction

The purpose of this thesis is to measure emissions related to cruise ships to calculate a shadow price of carbon. However, shadow pricing is ineffective without policy measures to employ price guidelines, so this paper also reviews feasible project-specific policy measures related to alliances and pricing of air pollution emitted by cruise ships to promote higher shore power connection rates and shore power infrastructure development. Understanding the potential impact of carbon pricing policy to change emitter behavior can help policy makers, developers, planners, and businesses evaluate options which promote economic development and air quality protection. A system of policies that encourage shore power connection rate and general understanding of the true cost of carbon will allow the Port to maintain a cruise industry, contribute to the local economy, and protect the shared resource of air.

This chapter introduces the empirical literature relevant to the economic climate issues related to natural resource externalities. First, this chapter examines economic theory related to taxes and fees and externality pricing tools to understand the factors and pricing mechanisms that could influence the cruise industry. This discussion provides an economic foundation for exploring the challenges presented by high carbon emitting tourism and overall emissions issues faced by ports across the world.

Next, this chapter explores literature of practice and examination of policies which currently guide the air protection policy discussion in the nation and, more specifically, the Pacific Northwest region today. This research began with a review of existing literature on climate policy, fuel types, the electrification movement, carbon pricing, economic theory on externalities, and technology for OGVs.

Theory

Health implications related to exposure to elevated diesel particulate matter and PM 2.5 are well documented in the literature. Increased exposure can lead to pulmonary issues, diabetes, depression, anxiety, shorter life expectancy, etc. The list of adverse health impacts is long and most often, poor air quality affects low-income communities and communities of color (Stockholm Environment Institute, 2019). The World Health Organization states that health effects of PM 10 and PM 2.5 are well documented and there is no research or evidence stating that there is not a “safe level of exposure or a threshold below which no adverse health effects occur” (World Health Organization, 2013) and air emissions exposure is classified as a carcinogen (U.S. Department of Health and Human Services, 2014). Reducing all possible emissions is important to the shore power discussion and at berth emissions because emissions usually tend to sit in place unless wind moves the particulates through a region. The proposed shore power location of Pier 66 is a half mile to downtown Seattle and popular tourist attraction. Pike Place Market alone receives 10 million annual visitors with peak visitation in summer months when cruise ships are at berth positioning patrons to be exposed to associated emissions. Although it is known in the literature and documented in the Maritime Emissions Inventory, ship emissions at berth are lower than emissions at sea, but ports located near cities make air quality and emissions reductions an important concern (Stockholm Environment Institute, 2019).

The focus of this research is on air quality, but it is important to note that overall mental and physical health is impacted by air *and* noise pollution, (World Health Organization, 2013) which cruise ships contribute to while at berth. Despite the known adverse effects of loud ships contributing large scale air emissions, there’s little research on the impact cruise ships have on local population health outside of the general call to reduce emissions due to health concerns.

Acknowledging the health concerns associated with proximity to hoteling emissions further bolsters the need for cruise ships to plug into shore power, as it can reduce local emissions (Sciberras et al., 2016). However, this paper is focused on pricing as an incentivization mechanism to improve local population health and climate. When considering the health implications of poor air quality, the WHO recommends that health and economic impacts should be assessed to understand the full impact of poor regional air quality (Stockholm Environment Institute, 2019).

Pricing carbon, which is known as an externality, is currently not included in the total cost of operating cruise ships at the Port. “The greenhouse problem stems from the failure of Western industry to pay the full cost of their production since the industrial revolution. Costs of pollution have been externalized wherever possible and thus born by members of the wider community” (Price et al., 2007). Supporting the statement of Price et al., Rezai et al. suggests that “creating the correct price signal for GHG emissions (by whatever means, including cap-and-trade permits, Pigouvian taxes, or direct regulation) is sufficient to internalize the negative externality of global warming” (Stockholm Environment Institute, 2019). Rezai, Andrew, and Bergqvist and Monios all echo areas of the literature that state there is an issue with air quality, health, and pricing high carbon emitting behavior (Andrew, 2008) (Bergqvist & Monios, 2019);(Rezai et al., 2012). In the context of cruise ships, the literature identify how ports should address the true cost of operating. Operating to include the costs of air quality, some believe, would return costs in shorter time frames in other industries such as health, asserting that the “external health costs would balance the capital cost in harbor-side infrastructure in 12–13 years” (Ballini & Bozzo, 2015). This is especially due to how high emission producing, localized activities like cruise can impact a region. “Emissions in the 5 nautical miles area represent almost

32% of the total in-port emissions, while for the latter ships stay for 7.2 hours and the out-of-port emissions are 54% of total in-port emissions” (Maragkogianni & Papaefthimiou, 2015). Echoing the claims of WHO, air quality researchers and health advocates, Maragkogianni & Papaefthimiou state that emissions from cruise ships moving close to ports could have significant health impacts to adjacent areas due to the pollutants sitting in an area (Maragkogianni & Papaefthimiou, 2015). Near-city pollution is specifically relevant to Seattle which experiences higher levels of pollution settling in the Duwamish Valley and is inhabited by people of predominately diverse and lower income than the rest of Seattle.

Pricing Mechanisms

When GHG emissions are unpriced, the costs of climate change are borne by third parties unrelated to the activities generating the emissions. A carbon price shifts these costs from society or the general population experiencing the adverse impact of the pollution to those who participate in markets which trade carbon-intensive products (Stockholm Environment Institute, 2019). When carbon is priced more appropriately, many buyers and sellers will be guided by financial self-interest to reduce emissions. A carbon price translates societal costs of climate change into explicit costs to electricity producers, and the price of electricity will incorporate these additional costs (Stanton & Ackerman, 2008). In the case of the Port of Seattle, the electricity is not available without a shore power plug, therefore, the cost must be priced into the cost of plug access or carbon pricing applied to the at berth contract. Carbon pricing include cap and trade, carbon taxes such as the social cost of carbon and shadow price, as well as applied fees. Although cap and trade and carbon prices have the same goal, both pricing mechanisms deliver different results. A cap-and-trade program can promise a precise level of emissions reductions with near certainty, whereas a carbon tax cannot (Stockholm Environment Institute,

2019). However, Kaufman et al. found that a carbon tax is more likely to lead to larger-than expected emissions reductions (Kaufman et al., 2016). Overall, the two aforementioned carbon policies encourage emission reductions actions within energy intensive sectors making either policy suited to catalyze change within the transportation sector to help agencies achieve their emission reduction goals (Price et al., 2007).

Pigouvian Tax

“These mitigation costs, however, are small compared with the gain of obviating GHG emissions. “Averting climate change can represent a non-trivial Pareto improvement” (Rezai et al., 2012) or the idea that there are no “losers” if we collectively avoid climate change. The idea of the cost of inaction outweighing the cost of mitigation leads to questions of pricing services that produce carbon and correct pricing of those which reduce it. This is often in the form of a Pigouvian type tax, which is broadly and more colloquially known as the social cost of carbon. “Two policy instruments are most important for pricing environmental degradation. The first is an abatement policy, which is an intervention, financed by taxation, which directly improves environmental quality” (Price et al., 2007). This is different than a “tax” that prices externalities. The second policy instrument for pricing environmental degradation is the “Pigouvian tax”, first proposed by Pigou (1924), who argued that “negative externalities due to pollution can be internalized in a competitive market by introducing a tax equal to the social marginal damage caused by environmental degradation” (Baiardi & Menegatti, 2011).

The exact dollar amount of social cost of carbon ranges from “does not and should not exist”, a theory posed by climate change deniers, to number in the thousands per metric ton. An anonymous author publishing to the Oil and Gas Journal states the social cost of carbon should be \$0 as CO₂ rise does not lead to temperature rise (Anonymous, 2013). CO₂ is shorthand for

“CO₂ equivalent or CO₂e” based on the Kyoto Protocol, which address and defines different air pollutants with different warming and climate impact. Of the air pollutants included in CO₂e, SO_x are an anomaly which exhibits a climate cooling effect, but the social cost of carbon would still consider its role in causing acid rain and other associated negative environmental outcomes (Price et al., 2007). The case for social cost of carbon varies from a low end of \$0 to a high end of \$1550 (Bellalah, 2016). However, in practice, Carlton and Loury state that “Pigouvian taxes alone are incapable of providing firms in long-run equilibrium with an incentive to operate at a scale of plant other than the one that minimizes average private cost” (Carlton & Loury, 1980) as seen in Seattle where the “carbon tax” was voted unfavorably by voters in 2019 with concerns of businesses passing costs to consumers to avoid internalizing cost. “It is only by using lump sum subsidy or entry fees that a policy maker could guarantee that both marginal production incentives and incentives for entry into the industry are efficient” (Carlton & Loury, 1980). Despite this, Marlow states that “taxation may also be easier to understand, monitor, alter, and is less subject to ‘crony capitalism’ than regulation” (Marlow, 2019).

Social Cost of Carbon

The social cost of carbon was born out of President Reagan’s requirement of federal agencies to quantify the benefits and costs of major regulations before deciding whether to impose them and how stringent they should be. As a result, federal agencies began estimating SCCs following a 2007 Supreme Court ruling which found that the cost of carbon “is certainly not zero”. This led to the U.S. government regulating carbon dioxide emissions as an air pollutant (Howard & Sylvan, 2015). A review called “Expert Consensus on the Economics of Climate Change” surveyed 1,100 experts on the economics of climate change regarding the social cost of carbon. The survey found that 69 percent said the U.S. government’s 2016 “central

SCC” estimate of \$36 per ton was too low for the benefits of emissions reductions, while less than 10 percent said it was too high (Howard & Sylvan, 2015). Experts agreed that integrated assessment models used to calculate the social cost of carbon are likely underestimating climate damages (Howard & Sylvan, 2015). Additionally, there is clear consensus among responses will be needed to avoid the major economic risk posed by climate change. “These experts also believed that market-based approaches are the most economically efficient way to reduce emissions, and that the current U.S. values for discount rates and the social cost of carbon undervalue emissions reductions” (Howard & Sylvan, 2015).

The case for the social cost of carbon as a cost paid for by agents creating pollution is an equity issue of environmental racism. The terminology, “cost-benefit” seems to be limited in definition scope in the case of social cost of carbon discussion as it asks the questions of “who?” and “to what degree?” are people being affected by a certain activity. Ackerman and Stanton argue that policy accounting the impact of climate disasters would not be framed in terms of cost-benefit calculations. “Rather, it would begin with adoption of a safe minimum standard, based on the scientific analysis of potential risks. The economic analysis would then seek to determine the least-cost strategy for meeting that standard” (Ackerman & Stanton, 2012).

“Least-cost” is how it is thought that the market operates currently by not including climate costs. However, least-cost would imply that all costs are being accounted for and managed in the most cost-effective way, in which all costs are currently not accounted for as carbon externalities persist. Since climate costs are highly debated, localized, and not well defined or enforced by policy, they are avoidable. Many estimates of social cost of carbon in the literature are created in the scope of a global market which is challenging to estimate for small-scale reviews such as cost of infrastructure damage alone. When pricing pollutants, the Port of Long Beach recognizes all

pollutants as equally harmful and that they all cost the same to abate. “Cost-effectiveness calculations divided the annualized cost of implementing cold ironing by the total mass of hydrocarbons, carbon monoxide, NOX, PM10 and SO2 emissions that would have been avoided” (Vaishnav et al., 2015).

Shadow Price of Carbon

The shadow cost includes two components. “The first component is the product of pure information cost due to imperfect knowledge and heterogeneous expectations. The second component represents the additional cost caused by the short-selling constraint” (Bellalah, 2016). “In order to rank possible measures, marginal abatement cost curves have become a tool to graphically represent the relationship between abatement costs and emission reduction” (Tomaschek, 2015). Therefore, shadow prices are often based on marginal abatement costs (Tempest, 2016). It must be noted that this number is not stagnant and must be reevaluated to ensure correct abatement pricing. “The SPC is then used as a carbon price to create incentives for greenhouse gas abatement in government projects, thereby lowering emissions and helping to move the world onto a new stabilization trajectory. It’s a chicken and egg conundrum: The assumed stabilization trajectory determines the SPC, and the SPC helps determine the actual trajectory” (Stanton & Ackerman, 2008). Ackerman and Stanton note that the work of Price et al. produces a low carbon price by incorrectly assuming that necessary action will be taken and therefore produce a mild climate change outcome. This assumption creates a risk by discouraging “the approval of policies and projects that will lead to a growth in carbon emissions” (Stanton & Ackerman, 2008). Therefore, current shadow pricing based on the MAC in tandem with policy is the best use of pricing mechanism. Stanton and Ackerman give

explanation to low shadow prices in the literature by acknowledging the incorrect assumption all necessary action will be implemented.

Shadow Price of Carbon vs Social Cost of Carbon

Considering these factors, a study was employed by consultants to review the social cost of carbon as it pertains to the Port of Seattle. “Typically, shadow prices are set at a level much higher than carbon fees. Interviews found shadow prices were set as high as \$150/tCO_{2e}, reflecting estimates of typical (internal or external) abatement costs needed to reduce GHG emissions in line with avoiding dangerous levels of climate change” (di Vaio et al., 2018). However, due to the policy implications of fees versus shadow prices and collection of such, the study found the highest carbon fee we found was around \$40/tCO_{2e}. (di Vaio et al., 2018). EPA values the social cost of carbon as the “integrated assessment models first estimate damages occurring after the emission release and into the future, often as far out as the year 2300. “The models then discount the value of those damages over the entire time span back to present value to arrive at the SC-CO₂” (Price et al., 2007). This definition is in line with the posed by the Board of Environmental Change and Society state that it is “an estimate, in dollars, of the long-term damage caused by a one ton increase in carbon dioxide (CO₂) emissions in a given year; or viewed another way, the benefits of reducing CO₂ emissions by that amount in a given year”. The EPA acknowledges that their SCC models or “integrated assessment models” and others are not complete and cannot include the full scope of climate damages and cannot be updated frequently enough to keep up with current research. “They do not currently include all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature because of a lack of precise information on the nature of damages” (EPA, n.d.). EPA proposes an average cost of \$42 a ton. Van den Bergh and Botzen describe

climate change as the greatest market failure the world has ever seen and proposes \$445 per ton of carbon for social cost (van den Bergh & Botzen, 2014). The variant pricing in the literature is a result of the flexible nature and definition of the SCC. “The SCC is the value of the climate change impacts from one ton of carbon emitted today as CO₂, aggregated over time and discounted back to the present day” (Hope, 2006). However, valuing climate change impacts varies by region and indicators included in the cost.

Pricing the SCC is challenging because it is not agreed upon to what degree the market failure of not pricing it will produce. “It is necessary to verify that it does not produce the ‘market failure’ with irreversible damage on the environment and cause the loss of social welfare. In this context, the tax represents a tool to contract production and pollution to the socially optimal level that fits in the private convenience calculations of the enterprises” (Dragulanescu, 2015). However, Ackerman and Stanton argue that the current cost-benefit approach to answering the social cost is incorrect, as damages may outweigh cost estimates (Ackerman & Stanton, 2012).

The damages from a ton of carbon dioxide emissions in 2050 could exceed the cost of reducing emissions at the maximum technically feasible rate. Once this is the case, the exact value of the social cost of carbon loses importance: the clear policy prescription is to reduce emissions as rapidly as possible, and cost-effectiveness analysis offers better insights for climate policy than cost-benefit analysis (Stanton & Ackerman, 2008).

It is impossible to know what the damages will be but the consensus in the literature is failure to price externalities related to carbon producing activities will result in a large and potentially permanent market and environmental failure.

Shadow price of carbon is a better indicator for pricing carbon externalities because there is no way to control for all global factors that modify social cost of carbon leading to an array of

results depending on the factors used by researchers. However, shadow price of carbon is a more specific indicator because it can be used on an agency or entity basis. “Whereas the SCC is determined purely by our understanding of the damage caused and the way we value it, the SPC can adjust to reflect the policy and technological environment” (Price et al., 2007). Therefore, SPC is established by calculating the capital and operating cost of all carbon abating infrastructure at an agency level and dividing costs by carbon abated results in a more adequate measure of cost to the agency to reduce carbon and a specific pricing mechanism for emission creating infrastructure.

Overall, review of the literature found that “social cost of carbon” is sometimes used as a general term for pricing carbon, whereas the terms for “marginal abatement cost” and “market price of carbon” and “shadow cost of carbon” have specific formulas. Social cost of carbon in this context is what some researchers refer to as the “shadow price of carbon” which can be adjusted to fit policy and technology changes to adequately price damages created by emissions.

Cap and Trade

A cap-and-trade program “establishes the price indirectly by placing a limit on the total quantity of emissions. This limit is enforced using tradable emission permits, typically called ‘allowances’, that any emissions source must own to cover its emissions. The market for these allowances creates the carbon price in a cap-and-trade program” (Kaufman et al., 2016). Critics of cap-and-trade point to problems that actual cap-and-trade programs like the European Union Emissions Trading Schedule and the Regional Greenhouse Gas Initiative have confronted, such as “weak emissions caps, volatility in emissions allowance prices, and overly generous allocations of emissions allowances to regulated entities” (Kaufman et al., 2016).

Empirical Research

Carbon Policy

While the terms are used interchangeably in the literature, carbon neutral, decarbonization and carbon zero are different terms with different ways of attaining carbon reductions. Carbon neutral is carbon that is offset using other methods, such as purchasing credits, to make up for the carbon emitted. Carbon neutral mitigation methods are different from carbon zero goals. Carbon zero activities do not create any carbon to begin with, whereas carbon neutral. Both carbon zero and carbon neutral are both the result of “decarbonizing” an industry which is an effort to remove carbon from carbon emitting activities. Decarbonization can lead to carbon zero emissions reductions or carbon neutral outcomes.

There is very little literature about port’s efforts to decarbonize outside of the general call to do so through policy implementation and technology innovations needed to achieve it, specifically around shore power and alternative fuels. This is due to few ports having a shore power plug because they are costly investments with no tangible return on investment. To address this gap in the literature in the context of the Port of Seattle, this thesis reviews a pricing mechanism and policy suggestions based on the outcomes as a means of reaching carbon neutral or zero emissions goals at the Port of Seattle. A review of the existing literature around key performance indicators of port sustainability found that “environmental sustainability and energy efficiency in the maritime and port industry need to be promoted and implemented through adequate regulations and policy, as well as recommendations and guidelines, issued by authorities and public institutions, but with a direct and proactive role played by port authority” (di Vaio et al., 2018). The shipping industry is not technologically advanced enough to reduce

emissions through infrastructure alone, therefore, “a market-based approach is essentially needed to address the environmental impact” (di Vaio et al., 2018).

Cui and Notteboom find that to accurately price carbon, public port governments will need to make more and stricter efforts to protect the environment in cases where they have a regional partnership or monopoly. In cases where ports are competing, they will not be able to take the measures needed to reduce emissions because they do not have a monopoly on the market (Cui & Notteboom, 2017). “Ports achieve the highest marginal environmental damage compensation ratio in the cooperation sub game” (Cui & Notteboom, 2017). Their research found that imposing a carbon tax reduced profits related to activity because it raises the service price, disincentivizing activity. However, it was found that carbon pricing creates incentives for cost-effective emission reductions (Boyce, 2018). In cases of port’s which create captive markets in strategic alliances, carbon pricing creates incentives for cost effective emissions reductions as polluters work to maintain level of service in the short term and cost reducing innovation in the long term (Dragović et al., 2018). The polluter pay principle overall proposes pricing policies to include air pollution damage in the contract and agreements for cruise berth services to assist the finance of offsets, and more electric berth infrastructure (Du et al., 2015)

Emission Control Areas

A large share of CO₂ emissions come from ships hoteling in ports. Ships are the largest source of port pollution, which create ten times more emissions than those from the port’s own operations (Tichavska & Tovar, 2015) and (Zhang et al., 2020). Zhang et al found that the positive role that the emissions control area policy plays in reducing SO₂ concentration in Shanghai is well demonstrated which echoed the findings of Tichavska et al. who demonstrated the positive outcomes of an enforced ECA policy has SO_x emissions reductions in ports (Zhang

et al., 2020). According to the Ship Traffic Emission Assessment Model (ATEAM) and AIS data, their study shows that the tons of SO_x emitted per port call at the Port of Hong Kong, which does not have an emissions control area, are more than sixteen times higher than SO_x emissions found at Port of St. Petersburg which is an ECA port (Styhre et al., 2017). In ship emissions policy, emissions control areas seem to be one of the best emissions reducing policy options outside of shore power use.

Shore Power Limitations

While shore power is the only way to reduce at berth emissions from ships, it is not always feasible for ships to simply connect to an onshore source. There can be mismatched connection standards and different AC frequency. Additionally, the ship retrofit cost and installation of shore power at the port is high which results in partnerships between ship operators that frequently berth at the same port. Additionally, the onshore supply capacity varies from port to port and may in some cases be insufficient when the power demand is high. This applies to large passenger ships such as cruise ships but also for other ship types coming to berth like cargo and tanker ships (Styhre et al., 2017). “Short planning horizons, financial risks by investing in new technology and work methods, a second-hand value of the vessel that does not reflect investments in energy efficient equipment, lack of life cycle approach when constructing vessels, and transaction costs are all further examples of barriers” (Rezai et al., 2012). Indicating a paradigm shift is needed in the cruise industry as it is ultimately in the hands of the companies to retrofit their ships. Styhre et al. outline the limits of shore power use, and these limitations apply to the Port of Seattle, especially the cruise ships which come to berth there. However, the limitations presented are mostly associated with proper planning and not the technology itself, which the literature still defines as one of the best methods of reducing hoteling emissions.

Literature of Practice

Literatures of practice review the large to small scale agencies, reporting mechanisms and recommendations that have contributed to the conversation of global climate change and responded to the literature calling for carbon reductions. Each of these agencies acknowledges the existence of climate change and the transportation sectors as a major contributor to it. Additionally, this section confirms consistent call to climate action across all levels of government.

International

Kyoto Protocol While global climate change as a result of human activity is widely accepted, there are some naysayers. However, the Paris Climate Agreement and Kyoto Protocol indicate mounting pressure to acknowledge and act to mitigate these climate responses to human activity. “There are world political efforts to implement institutions which enforce the social cost of carbon emissions on individual agents, most notably the Kyoto Protocol which created a carbon market and is international law since 2005” (United Nations Framework Convention on Climate Change, n.d.-a). United Nations Framework Convention on Climate Change led to the Kyoto Protocol which operationalizes and commits industrialized countries to limit and reduce greenhouse gas emissions in accordance with agreed individual targets. Those countries are called to adopt policies and measures on mitigation and report on their progress periodically, as the protocol only binds developed countries, and places a heavier burden on them under the principle of “common but differentiated responsibility and respective capabilities”. This is due to the recognition of large, developed countries as a main contributor and overall, largely responsible for the high levels of greenhouse gas emissions in the atmosphere (United Nations Framework Convention on Climate Change, n.d.-b).

Paris Agreement of 2016 had the main goal of adding urgency to and strengthening the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius (Allen et al., n.d.). Additionally, the agreement aims to increase the ability of countries to deal with the impacts of climate change, and make finance flows consistent with a low greenhouse gas emissions and climate-resilient pathway. To reach these ambitious goals, appropriate mobilization and provision of financial resources, a new technology framework and enhanced capacity-building is to be put in place, thus supporting action by developing countries and the most vulnerable countries, in line with their own national objectives. The Agreement also provides for an enhanced transparency framework for action and support. These two agreements echo action called for by researchers.

Intergovernmental Panel on Climate Change- The United Nations established the Intergovernmental Panel on Climate Change (IPCC) and asked it to provide a clear, consensus-based, scientific view on the current understanding of climate change and its consequences. The purpose of the IPCC is to “provide policymakers with regular scientific assessments on climate change, its implications and potential future risks, as well as to put forward adaptation and mitigation options”. The IPCC states that policies “reflecting a high price on emissions are necessary in models to achieve cost-effective 1.5°C pathway” (European Commission, 2020)

EU Directive 2005/33/EC- For ships that turn off engines and connect to shore power, the EU offers exceptions to the low sulfur fuel requirement in the case that ships connect to shore power at berth. However, this clause is null because it is not positive because ships are not ensured shore power hook up when coming to berth. Therefore, ships mooring in the EU must have a low sulfur content and connect to shore power when possible (EPA, n.d.), This is similar to

California's shore power requirement and an example of a regional alliance in practice. There currently is not a northwest ports version of this requirement. The EU's model is an example of a connection rate policy enforced through a regional alliance to avoid the captive market issue the Port of Seattle faces with cruise ships that come to berth there.

National

Clean Air Act. The Environmental Protection Agency (EPA) implements laws written by Congress by creating regulations for the law. The EPA sets national standards that states, and tribes enforce through their own regulations and the EPA works with states, tribes, and companies to understand and reach these standards if they struggle. The EPA also enforces their own regulations and states that the Clean Air Act (CAA) of 1990 calls for state, local, federal, and tribal governments to implement the Act in partnership to reduce pollution (Chan et al., 2012). Roles for local plan implementation varies depending on the nature of the air pollution problem. Ultimately, the CAA leaves work and planning for air pollution reduction to state and local governments to identify and plan for their specific needs with help and monitoring by the EPA.

The federal Clean Air Act requires EPA to set National Ambient Air Quality Standards (NAAQS) for six common air pollutants which the Washington State Department of Ecology monitors and acts if levels become unhealthy. The pollutants are:

- Carbon monoxide (CO)
- Lead (Pb)
- Nitrogen dioxide (NO₂)
- Ozone (O₃)
- Particle (or particulate matter) (PM)

- Sulfur dioxide (SO₂)

With the Clean Air Act Amendments of 1990, the United States implemented the “Acid Rain Program” to regulate sulfur dioxide (SO₂) which cause acid rain and primarily came from coal fired plants. Under the Acid Rain Program, SO₂ emissions from power plants decreased 36 percent between 1990 and 2004, despite electricity generation from coal power plants increasing by 25 percent over the same period (Chan et al., 2012).

For the sake of the discussion on shore power, the term CO₂e will be referred to its shorthand of “CO₂” to discuss some air pollutants listed above. The EPA defines CO₂e as the combination of the pollutants that contribute to climate change adjusted using their global warming potential. Adjusting for pollutant global warming potential is done manually summing the mass of the pollutants multiplied by their global warming potential factors. This research uses the EPA CO₂e calculator for shore power estimations.

Fink’s Letter. While not technically national policy, businesses and their leaders' beliefs have influence over operations and ultimately greenhouse gas emissions. Larry Fink writes an annual letter to the CEOs of the world published every January. This year the subject of his letter was about the danger of short-term thinking and climate, with Fink stating, “I believe we are on the edge of a fundamental reshaping of finance” (Fink, 2020), bringing awareness in the business and finance sector regarding the urgency of the global climate change issue in terms of finance stating, “the evidence on climate risk is compelling investors to reassess core assumptions about modern finance” (Fink, 2020).

The acknowledgement of the risk associated with a changing climate is “Research on the socioeconomic implications of physical climate risk – is deepening our understanding of how climate risk will impact both our physical world and the global system that finances economic

growth” (Fink, 2020). BlackRock, which is influential in the business world due to its holdings in many large companies, has stated they will be using their voting power against management and board directors who are not doing enough to create plans and progress toward more sustainable practices (Fink, 2020). The urgency and call to action of Larry Fink’s letter says financial wellness is dependent on the wellness of our planet. Businesses are taking a financial risk by not operating sustainably which indicates externalities within the market, such as air pollution. Fink and BlackRock are participating in the endeavor to price carbon externalities by signing the UN’s Principles for Responsible Investment and the Vatican’s 2019 statement advocating carbon pricing regimes, which they believe to be essential to fighting climate change. Fink’s call to action is not just for businesses, stating he believes that “every government, company, and shareholder must confront climate change” (EPA, n.d.). Since ports operate between governments and private entities, it is a call to the cruise liners as much as it is to ports to begin shifting toward climate conscious operations.

Fink’s letter serves as the private sectors legislative call to action, posing financial consequence to companies who do not operate or show sustainability minded progress. While international, national, state, and local policies echo the need for climate minded operation, Fink’s letter has regulatory weight in the same way the EPA does, as Black Rock has stated they will be making climate minded votes.

State

Environmental Protection Agency (EPA)- States have the option of adopting a program that provides for partial or complete delegation of EPA's authorities to implement and enforce toxic emissions standards; state programs can be no less stringent than the federal requirements (California Air Resource Board, 2020). Current state policies on air quality are built to follow

EPA but like the EPA, leave it to local jurisdictions to plan and reduce emissions they are responsible for. This heightens the need for the Port to enact policy, as call to action, measurement and regulatory bodies exist in abundance at all levels.

California Air Resources Board (CARB)- CARB's Airborne Toxic Control Measure for Auxiliary Diesel Engines Operated on Ocean-Going Vessels At-Berth in a California Port" regulation or the "At Berth" Regulation aims to reduce at berth emissions by:

1. Turning off auxiliary engines and connect the vessel to some other source of power, most likely grid-based shore power; or
 2. using alternative control technology that achieves equivalent emission reductions
- (Port of Seattle, 2018)

More specifically, this regulation requires ships with shore connection capabilities to use them while at berth. Additionally, as of 2015, the regulations prohibited non-shore power capable vessels from coming to berth at a California port. As of 2020, it also required that 80% of power used by ships at berth must be electrical. California is the only example of a US port imposing strict shore power connection policy. This is due to the state's essentially captive market, the Port of Seattle does not currently have a shore power connection rate policy. While the Port cannot enact stringent measures, they may be able to build policy that creates a captive market climate to follow a similar guideline to the "at berth" regulation.

Local

Century Agenda. Many guidance documents regarding climate change produced by governments recognize human activity as a contributing factor to climate change and are calling themselves to action by measuring the level of pollution and outlining goals to reduce it. An example of this for the Port of Seattle is the Maritime Emissions Inventory which informs the

Century Agenda. The Port of Seattle has adopted Century Agenda goals to reduce overall emissions with a goal of becoming the greenest port in North America partially achieved through a specific goal to reduce emissions from Ocean Going Vessels by 80% of 2005 levels by 2050 (Port of Seattle, 2017). This is in response to other local, state, national and international policies to reduce climate impact related to human and economic activity. To reduce hoteling emissions the Port categorizes emissions and reduce those within their direct control. Emission inventory is updated annually through the Northwest Ports Clean Air Strategy.

To address City of Seattle (City) emissions, The City came out with the “Seattle Climate Action Plan” in 2013 and updated it in 2018. In it, emissions reductions strategies include transit electrification, electric vehicle strategic charging infrastructure, updating the Green Fleet Action plan to phase out fossil fuel use in municipal vehicles(City of Seattle, 2018) and (Puget Sound Clean Air Agency, 2016). These themes can be applied to Port of Seattle’s cruise ships through policy by requiring certain plug-in requirements, however unlike the City, the Port does not own the cruise ships coming to berth. The Port is mirroring the City’s efforts to offer EV infrastructure by offering shore power capable berths.

Puget Sound Clean Air Agency. The Puget Sound Clean Air Agency (PSCAA) is a special purpose, regional government agency chartered by state law in 1967 under the Washington Clean Air Act. The agency is governed by a board of directors composed of elected officials and governs in Snohomish, Pierce, King and Kitsap counties. PSCAA receives guidance and input on agency programs and regulations from its advisory council to make decisions at the local level. The role of the PSCCA at a local level is similar to that of the EPA on a national level. Their 2014-2020 Strategic Plan Goal 1 immediately acknowledges the socioeconomic disparities in air pollution exposure by making it top of the list for reduction goals stating that

people who live near ports and major transportation corridors suffer from the increased cancer risk of diesel particulate matter exposure. Listed under the strategies to achieve the goals is strategy 4 to influence and advocate for policy regulatory improvements (Tichavska et al., 2019). One of the goals in the Strategic Plan is to become one of the most climate friendly cities in the US which aligns with the Port's Century Agenda Goal to become the greenest port in North America. The PSCAA outlines clear goals and strategies while acknowledging the need for policy that does not currently exist, especially as it pertains to ports. Therefore, this regulatory agency is helpful to the advancement of the climate conscious conversation and enforcement of EPA regulations. Outside of monitoring and enforcement, it does not offer a framework for the Port to follow in the context of their cruise industry that is not already addressed in the Ports own Century Agenda goals.

Conclusion

Within literatures of practice, all levels of jurisdiction reiterate the need to reduce emissions through sustainable financial models and long-range planning. There is a consistent call for action in terms of climate change and the recognition backed by data suggesting that the transportation sector as a large contributor to emissions at the local, national, state, and international levels. However, the literature of practice simply calls for action and leaves implementation of action to the localities to govern and act as they see fit as found in international cases such as China, "to achieve the reduction target of CO₂ emissions, the central government of China placed the burden of making these reductions on the regional governments" (Du et al., 2015) which is not dissimilar to how current US policy structures aim to function. Du et al. noted that cost abatement is location and agency specific and "should have their reduction burdens brought into line with their different marginal abatement costs" which

points to the need for a shadow price mechanism (Du et al., 2015). This is echoed by Tomaschek who states that “marginal abatement cost curves are one tool to relate emission mitigation levels with costs and allow identifying the corresponding set of measures” (Tomaschek, 2015).

Tomaschek and Du et al. all identify the need for policy in their areas of study, as the current law is not enough. Overtime, abatement becomes more costly the longer abatement action is delayed due to inflation and increased CO2 emissions (Du et al., 2015).

Although the call for externality implementation is well documented, the literature identifies the lack of externality pricing as a market failure with additional call to action by private entities which have major influence on the action toward sustainable economic development. The literature mostly acknowledges the benefit of a carbon pricing mechanism in tandem with relevant policy. However, papers identified the challenge of maintaining a market while imposing costs. More notably, there is very little literature on shore power specific policy, potentially due to the inability to impose costs in competitive markets, inciting this specific research. With little literature on the topic of carbon pricing for ports regarding shore power, this paper aims to provide recommendations to address the policy implementation goals as many of governing air quality documents request local review and policy. Relations between frameworks and atmospheric pollution from vessel operations is missing from the literature (Davarzani et al., 2016). Although the literature is sparse now, green ports, policy measures and technological solutions are in an early growth period but will continue to grow as policymakers and governments seek policy solutions to environmental and economic issues within maritime technology policy (Vaishnav et al., 2015). The literature clearly identifies the need and mechanisms to accomplish certain outcomes. This paper aims to use the Port of Seattle as a case outlining current conditions and options for action to contribute to the “how” that missing in the

literature as it pertains to shore power emissions abatement, carbon pricing, and non-captive markets.

2. Methods

The goal of this research is to calculate the marginal abatement cost (MAC) of shore power at Pier 66 for the Port of Seattle's cruise seasons and apply it to the total cost of ships burning bunker fuel to account for externalities. The purpose of this research is to use the MAC as a shadow price of carbon and apply it as a multiplier per metric ton of CO₂ produced by ships hoteling on bunker fuel. Applying a shadow price to hoteling ships using bunker fuel is an attempt to account for externalities created by bunker fuel emissions which are not accounted for in current pricing on cruise ships. This is to determine if it is more cost effective to hotel with bunker fuel or with electricity while including shadow prices on ships using bunker fuel to account for externalities. Specifically, the marginal abatement cost is a way of estimating the cost in dollars to abate each metric ton of CO₂ (\$/MTCO₂). For this research it is calculated by dividing the total estimated operating (electricity) and infrastructure cost by the total estimated emissions (CO₂) avoided. The MAC is calculated using the following formula:

$$MAC (\$/MTCO_2) = [Estimated\ shore\ power\ capital\ and\ operating\ costs / Estimated\ cruise\ hoteling\ emissions\ avoided\ per\ season\ (MTCO_2)] \times 30\ years$$

While this is a seemingly simple calculation, in practice, carbon accounting is highly variable and is dependent on the reliability of several hard data points.

As the above formula indicates, there are two steps to calculating the marginal abatement cost:

Step 1- Estimate Shore Power Capital and Operating Costs

In this case, infrastructure cost is defined as the average estimated cost of the shore power plug plus the operating costs over a period of time. Infrastructure cost is a composite of several things:

- A. Total cost of infrastructure conversion (IC) to add shore power plugs divided by amortization period.
- B. Average annual cost of operating and maintaining the infrastructure (O&M),
- C. Average annual cost of the electricity used by hoteling ships (HE)

These costs are amortized over a period of 30 years, which is the standard period for accounting large scale infrastructure.

The formula looks like this:

$$\text{Infrastructure and Operating Costs} = (\text{Infrastructure Conversion}) + (\text{Operations and Maintenance} + \text{Hoteling Emissions}) * 30$$

or

$$\text{Infrastructure and Operating Costs} = (IC) + (O\&M + HE) * 30$$

For this research, the infrastructure cost is fixed at 17 million and amortized over 30 years, and the O&M and HE costs vary annually.

In this study, the annual costs of these three elements are estimated as follows:

Infrastructure Conversion (IC) is calculated as \$17 million divided by 30 years, or about \$567,000 annually. At the time of this research, the Port proposed and internally circulated an estimated cost of roughly \$17 million for shore power improvements² (*Pier 66 Shore Power Project / Port of Seattle*, n.d.) However, the \$17 million estimate does not include fluctuating material costs, interest, and other fees which could substantially impact the total costs of converting existing Pier 66 to support shore power.

Operating and Maintenance (O&M) includes annual improvements to and upkeep of Pier 66, and the labor for the employees who plug and unplug the ships. Unfortunately, data for

² \$17 million is an internal number used by the Port of Seattle and was published in a blog post.

these costs was not available for this study and so these costs have not been included in this study's final calculations.

Average annual cost of the shore power-provided electricity used by hoteling ships (HE). For this study, calculations for this cost are amortized annually and are fixed at 81 ships per season, the number planned for the 2020 cruise schedule. Annual estimates do not include inflation or interest and are dependent on the percent of the 81 ships plugging into shore power. This study reviews a range of connection rates scenarios based on real data from Terminal 91 shore power connection rates, including 50%, 75%, and 100%.

Calculating hoteling electricity cost on shore power

To include the operating costs in the MAC and later compare the cost of hoteling with bunker fuel to the cost of hoteling with shore power, we must now calculate the average cost of shore power for a hoteling ship. Calculating the cost of electricity used while on shore power is necessary to compare against the cost of bunker fuel used while at berth. The following assumptions were used to calculate the cost of energy consumed at berth for this calculation:

- Average kWh at berth from T91 shore power data: 49,919 kWh
- Average time connected to shore power: 7:05 hours
- Seattle City Light kWh cost from 2019 Peak Hours: \$0.0979
- SCL Transformer Investment (\$/kW): \$29.11

Using the established assumptions, the following steps were used to calculate the average cost of shore power per call. This is estimated by the following formula

1. The cost of electricity is measured in KW, but shore power use is measured in kWh.

The first step, therefore, is to convert and we have kWh to, the known kWh is converted KW.

$$KW = \text{avg kWh per berth} / \text{avg time connected to shore power}$$

2. We must also add the total transformer cost to the calculation because Seattle City Light charges users for upgrades to infrastructure in specific areas.

$$\text{Transformer use cost} = KW * \$ / KW \text{ transformer cost}$$

3. We can now estimate the cost of electricity per shore power-capable call

$$\text{Estimated cost per call} = \text{avg kWh per call} * 2019 \text{ peak kWh cost} + \text{total transformer investment cost} + \text{Minimum Bill per Meter per Day}$$

4. We can now multiply that by the total estimated number of ships hoteling per year to calculate the annual cost of hoteling using shore power.

$$\text{Cost to hotel with shore power per season} = (\text{avg kWh per call} * 2019 \text{ peak kWh cost}) + (\text{total transformer investment cost} + \text{Minimum Bill per Meter per Day}) * \text{number of calls per season [81]}$$

The sum of these calculations creates the numerator of the MAC over 30 years. To complete the MAC, the estimated emissions avoided by the shore power infrastructure will be used at the denominator.

Step 2- Calculating Emissions Avoided (EA)

Cruise hoteling uses either bunker fuel or electricity. The estimated cost of electricity is needed to calculate the MAC and later needed to compare the cost of hoteling on bunker fuel and hoteling on shore power. But first the estimated average MTCO₂ must be calculated to create the MAC. This is done by using electricity data as a proxy and converting it to estimate MTCO₂.

EA requires several additional steps. Knowing the number of kilowatts (KW) consumed at berth is needed to estimate the amount of CO₂ emissions avoided through the use of shore power. Cochran Marine gives the Port of Seattle weekly reports outlining analytics including, date of call, time at berth, ship name, energy consumed via shore power at berth, time leaving

berth, and therefore number of hours at berth provides enough data points to estimate how many CO2 emissions are avoided while at berth. We need this information because we can only calculate emissions avoided with the data that is available. Internally, the Port keeps a schedule for the names of all ships calling to each Terminal or Pier. Because we do not have data for Pier 66 shore power because it does not exist, we can use data from Terminal 91 as a reasonable proxy. Terminal 91 has two berths with shore power which hosted ships for the 2019 cruise season and provides the only full year of shore power-capable cruise call data at Port of Seattle. All of the ships that were scheduled to call in 2020 to Pier 66 have called to Terminal 91 in the past, leading us to a reliable emissions avoided estimate.

Calculating the amount of CO2 emissions avoided by using shore power using the Cochran Marine data requires three steps:

1. Convert KW to kWh and then subtract 1.5 hours total for hook up and unhook time reported on Cochran Marine data (45 minutes for hook up to shore power and 45 minutes to disconnect). The standard equation for converting KW to kWh is:

$$E(kWh) = P(kW) \times t(h)$$

2. Apply the estimated kWh to the most recent Seattle City Light emissions formula to estimate avoided emissions per call.

$$MTCO_2 \text{ avoided per call with shore power} = (\text{Avg kwh per call} * 0.000695) - (\text{avg kwh per call} * 0.00002103)$$

3. Calculate the sum of shore power-capable calls to estimate annual emissions avoided.

$$\text{Annual emissions avoided} = \text{SUM} (MTCO_2 \text{ avoided per call with shore power})$$

We can estimate the number of cruise calls based on the proposed 2020 cruise schedule before COVID-19 cancelled the season. 81 cruise calls are the maximum number of calls that can be

hosted at Pier 66 at this time but could increase in the case there were improvements to the pier, the cruise season were extended or ships hotelled for shorter periods of time.

Now we have established the estimated operating and construction costs of the infrastructure, as well as the emissions avoided to create the MAC. The MAC then needs to be applied to the ships that do not connect to shore power as a multiplier.

Comparing the estimated cost of bunker fuel including the shadow price vs the cost of electricity

By comparing the cost of hoteling with bunker fuel to the shadow price applied to the cost of using shore power, we can determine whether hoteling with shore power is more cost effective than hoteling with bunker fuel. To estimate the annual operating cost of shore power compared to the annual operating cost of bunker fuel with the shadow price of carbon added to the cost of hoteling with bunker fuel, we must multiply the estimated emissions created (EA) with the best-case MAC scenario and the number of calls per season. Later we will estimate the amount of money spent on bunker fuel per berth and add it to this equation. But first we can estimate the additional cost for ships burning bunker fuel using the emissions avoided calculation used for the MAC and the electricity cost used for the MAC. This is to calculate the “shadow cost” which will be added to the estimated amount spent on bunker fuel. This research will focus on the lowest cost of 100% connection.

*Cost of bunker fuel and MTCO₂ with shadow price= (estimated average emissions per berth [64] * shadow price at 100% connection rate [\$197.86]) *(number of calls per season [81]))*

Step 3- Creating a comparison after applying the MAC

To answer the research question of whether it is more cost effective for hoteling ships to use electricity (shore power) or bunker fuel while applying the shadow price of carbon (based on the MAC specific to shore power), the estimated cost of hoteling electricity and the cost of bunker fuel must be established. The estimated cost of electricity must be established to compare hoteling bunker fuel prices to electricity prices

Calculating the cost per berth burning bunker fuel

Ideally the cost of bunker fuel can be calculated by multiplying the fuel cost by the amount of bunker fuel a ship burns while hoteling. However, the cruise liners have not provided data on the number of metric tons of fuel they burn. Therefore, we must use a proxy number to estimate the amount of fuel used while hoteling.

The proxy this analysis uses is the number of kWh that ships use while hoteling using shore power. This data is available from Cochran Marine. To do that, we need to estimate the kWh in one metric ton of IFO 380 bunker fuel.

This analysis relies on the following assumptions:

- BTU Range: 151,300-155,900
- Median BTUs in a gallon: 153,600
- Engine fuel efficiency factor: 30%
- Average cost per metric ton of US IFO 380 from April 2019-Oct 2019³ (2019 cruise season, assuming fill up in US): \$451.50

Using the following assumptions, the following steps are used to calculate the cost per berth burning bunker fuel:

³ Using 2019 fuel cost data because it is the most recent and reliable pre-pandemic data

1. Identify the range of BTUs in one gallon of IFO 380 to calculate the median.

151,300-155,900

2. Identify how many BTUs are in a kWh.

1 kWh = 3412.14 BTU

3. Calculate the average BTUs at berth by converting the estimated average kWh per call to BTUs.

Estimated average kWh at berth converted to BTU= (average estimated kWh per berth BTUs per kWh [3412.14])*

4. To estimate the BTUs in a metric ton of bunker fuel, the median BTUs in one MT of IFO 380 is applied to the estimated number of BTUs consumed in a single berth, including the fuel efficiency factor.

IFO 380 BTUs= (Average BTUs at berth/median BTUs in BTU range)/fuel efficiency factor

5. To calculate the cost of IFO380 per gallon requires converting metric tons to gallons because BTUs are measured in gallons, but cost is given in metric tons.

MT to gallons= avg cost per metric ton of UTS IFO 380/ gallons per ton of fuel (307)

6. Finally, calculate the average cost of IFO380 per berth by multiplying the average number of BTUs by the cost per gallon of IFO380 fuel.

*Average cost per berth= Cost per gallon*average BTUs at berth*

Estimating the difference between operating costs on and off of shore power:

To establish the annual cost difference between hoteling using bunker fuel and hoteling using shore power, we subtract the estimated cost to hotel with bunker fuel per season from the estimated cost to hotel with shore power per season.

*Cost difference between operating on shore power= ((estimated cost to hotel with bunker fuel per season + (average emissions avoided per berth * MAC x connection rate)- estimated cost to hotel with shore power per season)*

The emissions avoided on shore power, calculated earlier, also works for the emissions created on bunker fuel because hoteling on shore power reduces what hoteling on bunker fuel would otherwise create. The different connection rate scenarios can help the Port make financial decisions since Terminal 91 had a connection rate of 54% of total ships coming to berth in 2019. In 2020, Pier 66 was scheduled to have 57% shore power capable calls.

3. Results

This model to calculate the MAC and apply it as a shadow price of carbon is amortized over 30 years to allow for annual adjustments that could drastically shift the outcome of the estimated marginal abatement cost, fuel cost, and electricity costs, which could affect policy recommendations. Further research is needed to establish a marginal abatement cost with more firm data points to better inform policy. The following outcomes are based on the best available data sources during the time of this research.

Outcomes

The following results were used to calculate the marginal abatement cost:

Estimated average fuel cost per call	\$5,421
Estimated average electricity cost per call (2019 dollars)	\$6,540
Estimated cost of shore power	\$17,000,000.00
30 year amortization cost	\$566,666.67
Amortization period (years)	30.00

Table 1: Additional estimates to calculate marginal abatement cost

The marginal abatement cost by shore power at Pier 66 ranges based on connection rate:

SPC at 100% connection rate	\$197
SPC at 75% connection rate	\$231
SPC at 50% connection rate	\$299

Table 2: Marginal abatement cost by connection rate

Table 2 shows the cost the ships burning bunker fuel will owe more to the Port when the SPC is applied. The sum is the cost of bunker fuel added to the SPC charge. The SPC would be billed by the Port to the cruise ships.

Final estimated hoteling cost comparison- The cost of electricity while hoteling versus the Pier 66 projected connection rate:

Hoteling cost per call hooked up to shore power	\$6,540
Estimated bunker fuel cost without SPC per berth	\$5,421
Hoteling cost per call on bunker fuel (SPC applied)	\$14,433

Table 3: Comparison of estimated hoteling costs applying the SPC

Applying the marginal abatement cost of shore power to average emissions while hoteling costs an additional cost of \$7,893 per berth. Shore power only addresses hoteling emissions which make up less than 13% of all Port emissions (Starcrest Consulting Group, 2018). 13% accounts for both hoteling and maneuvering, there is not an individual calculation available for hoteling emissions. To reach 80% emission reduction of 2005 levels by 2050 the Port would need to have a 100% connection rate for all cruise calls, and it would still not be possible to reach 80%, as a majority of emissions are out of the Port's scope of control and occur in transiting and maneuvering within the air shed. Transiting and maneuvering emissions can be reduced by limiting the number of cruise ships calling to the Port of Seattle, however, without a regional alliance, these emissions could be passed on to another port in the region, moving the emissions to a different ports inventory rather than reducing true emissions in the airshed. Reducing calls to the Port of Seattle does not imply that those cruise calls will not go to

neighboring port cities in the Georgia Basin Airshed including but not limited to Vancouver, Tacoma, or Bellingham.

Finally, this analysis sought to use the SPC not only as a measure to compare bunker fuel and shore power hoteling with externalities, but to also use the revenue for the SPC to finance shore power.

Connection Rate	SPC	Money made by the Port per season at different SP connection rate	Revenue per season applying 100% SPC to different cnxn rates	Revenue per season applying 75% SPC to different cnxn rates	Revenue per season applying 50% SPC to different cnxn rates
50%	\$299	\$3,096,130	\$2,041,166	\$2,392,821	\$3,096,130
75%	\$231	\$4,785,641	\$1,360,777	\$1,595,214	\$2,064,087
100%	\$197	\$0	\$0	\$0	\$0

*Despite the outcome being \$0 made, the cost to reduce each MTCO2 is \$197 using shore power

Table 4: SPC revenue made by the port on ships not plugging into shore power at different connection rates and SPC rates.

The slowest revenue scenario is the most likely. At Terminal 91 there was a 54% connection rate in 2019 of all ships that came to berth and the shore power connection rate would likely be the same at Pier 66 unless the Port scheduled only SP capable ships to come to berth. If this revenue was applied to pay for shore power at Pier 66 the repayment timelines are estimated to be as follows:

Connection Rate	*Shore Power Pay Back Timeline (YRS)
50% plug in with 100% SPC	8.33
50% plug in with 75% SPC	7.10
50% plug in with 50% SPC	5.49
75% plug in with 100% SPC	12.49
75% plug in with 75% SPC	10.66
75% plug in with 50% SPC	8.24

*assuming numbers remain consistent

Table 5: SP repayment period at different connection rate scenarios

The most likely outcome is highlighted in green in Line One on the table to the left, where roughly half of ships plug in and the other half use bunker fuel and pay the shadow price of carbon at the lowest rate (Line 1). This would create a shore power repayment timeline of just under 8 and a half years. The second most likely outcome is also in green in Line 4. Where the Port improves the connection rate with improved scheduling of cruise calls with shore power to 75% connection rate and imposes the 100% SPC for an infrastructure payback period of about 12.5 years, the slowest payback outcome.

Even the slowest outcome in this model, is still paid back in less than half the time of the amortization period. Meaning all funds made from the SPC after this period is revenue which could be invested to create another green line of business. Applying the SPC can incentivize plug in, pay for the shore power infrastructure, and create an additional revenue stream after the shore power is paid off to pay for future electrification of other piers or habitat restoration.

Study limitations

The model created in this work has data limitations that relied on proxies and estimates to complete. Needed data improvements include:

- Information from the cruise liners on the amount of bunker fuel they burn while hoteling in Seattle and how much it costs on average,
- If bunker fuel data from the cruise ships is unavailable, then a reliable engine efficiency factor while burning bunker fuel at berth is needed to improve the bunker fuel consumed estimate
- The average cost of electricity for shore power from the Port of Seattle and Seattle City Light which the Port likely has available, but was estimated in this research
- Updated cost estimates for Pier 66 shore power infrastructure development

- Projections to adjust model for inflation over 30 years
- Projections to adjust model for interest on the bond over 30 years
- An updated cruise schedule outlining the number of cruise calls set for 2021/2022

4. Discussion

The goal of this research is to price an externality related to burning bunker fuel while hoteling by applying a shadow price of carbon based on the MAC to the estimated amount of CO₂ that cruise ships produce at berth. Burning bunker fuel creates CO₂, so adding the shadow price of carbon as a carbon pricing measure to ships burning bunker fuel at berth increases their total at berth costs. Increasing costs at berth for ships burning bunker fuel could financially incentivize shore power connection to avoid additional carbon prices. Creating a shadow price and applying it to ships per estimated ton of CO₂ emitted, we can compare the cost of bunker fuel including the externality, or the “true cost” of hoteling with bunker fuel, versus the cost of connecting to shore power, and determine whether establishing shore power infrastructure is a cost-effective approach to reducing the Port of Seattle's carbon emissions. By using the methodology outlined in Chapter 2, I was able to establish in Chapter 3 that the Port could employ a shadow price on ships that would incentivize shore power connection and provide an additional line of revenue to finance shore power. In this chapter, I will discuss the broader implications of these results as well as their limitations. I will also suggest several policy recommendations that the Port of Seattle could undertake in order to meet their Century Agenda sustainability and emissions reductions goals. Establishing a shadow price is the first step in reducing emissions because it provides a financial incentive to comply. However, the incentive cannot exist without policy to enforce compliance to achieve climate goals and solutions.

Shore Power Limitations

Currently, the Port is increasing the number of cruise ship calls to Seattle but is not increasing the level of shore power infrastructure it provides. Shore power only reduces some of the hoteling emissions and only about half of ships calling to the Port of Seattle plug in. There

are several reasons that more cruise ships do not currently connect to shore power while hoteling. These include, but are not limited to, the following:

1. Not all ships are shore power capable.
2. One cruise liner, Holland America Group (HAL), owns the shore power infrastructure at Terminal 91 and does not currently have options for other cruise vessels to connect to the infrastructure, meaning only HAL can use the infrastructure regardless of whether a shore power capable ship berths there when HAL is not.
3. Sometimes non-shore power capable ships come to berth at terminals with shore power, sending ships with shore power plugs to piers without a connection point.
4. Ships may come to berth on the wrong side of the shore power plug, making it impossible for them to reach the plug.
5. Ships have a long life and shore power retrofit to vessels are costly.

As stated before, only Terminal 91 is shore power capable, and further electrification of the Port's Elliott Bay facilities has not yet begun. Regardless, even if vessels reached an unlikely 100% connection rate, the Port would only address about 20% of OGV emissions. This does not account for the 1:45 hours of plug and unplug time when the ship engines are burning bunker fuel. Additionally, there are still emissions related to plugging in to shore power. Seattle City Light's energy mix varies in "cleanliness" and although emissions related to shore power are very low, additional offsets would be required to fully reach carbon neutrality for hoteling emissions. While shore power is necessary because it is the most feasible technological approach to reduce emissions, the focus then points toward policy where technology cannot be the only solution to attain the Port's 80% emission reduction goal. This research poses but does not answer broad social questions such as whether it is ethical to support tourism with large carbon

footprints without carbon taxes or fees and whether the Port of Seattle should scale down its workforce if cruises' contribution to climate change is greater than the economic benefit of providing jobs and stimulating downtown tourism. Future research could explore if the Port should internalize the externalities of carbon emissions or impose them on the cruise liners coming to Seattle and if the Port, as the largest landowner in King County, could move toward a greener revenue stream such as carbon credits for habitat creation.

Furthermore, results show that plugging into shore power is nearly half the cost to the cruise liner than burning bunker fuel if the Port were to impose the shadow price calculated in this research. The shadow price funds accrued annually by ships not plugging in would pay back the infrastructure cost of shore power in the first 12 years of the 30-year life cycle. This is just one possible use for the newfound "revenue" made on ships that do not plug in to shore power and burn bunker fuel. Technically, profits made from carbon taxes are simply adjusting for what would have been externalities born by another group, so the "revenue" is best used as green infrastructure funds; otherwise, if the carbon is not abated with the new-found funds, the externality still exists. Investments in more carbon abating and cost-effective infrastructure are investments in low-income communities that are more likely to experience high levels of air pollution as particulates settle in the Duwamish Valley.

Finally, this analysis only focuses on at berth hoteling emissions and does not consider maneuvering and transiting emissions in the air shed that also have an environmental impact on the region. Further research must be done to account for total airshed emissions and associated abatement costs to estimate the true cost of operating cruise in the Pacific Northwest region.

It must be noted this analysis calculates the marginal abatement cost of cruise emissions, not the damage created by the emissions, which would be measured by the social cost

of carbon. More research would be needed to calculate the social cost of carbon or the damages to the communities within the Puget Sound Georgia Basin airshed. Incentive structures must be created as the current low prices of bunker fuel without carbon taxes do not incentivize costly investments for cruise to retrofit ships to be shore power capable or plug in to shore power, and therefore, create a lower shore power demand as Zis et al. find (Zis et al., 2016). Establishment of incentive structures calls for policy implementation.

Responsibility and enforcement

As climate action becomes increasingly urgent, the question of who holds responsibility for reducing emissions and who will enforce emissions reductions becomes more important. Currently, there are several state and federal policies related to climate action that are pertinent to the Pacific Northwest region and could be applied in support of the Port's carbon abatement pricing. However, the climate action policy landscape also changes every year, especially as climate disasters spur more climate action urgency from the public. Moreover, the policy surrounding who is responsible for bearing the cost of emissions is not always clear. While public and private agencies are considering climate action, behavior change, and policy adoption, specifically those which price externalities, may help attain these goals. Currently, there is little research in the realm of carbon taxes as it relates to ports' cruise operations. Cruise is an entertainment, not necessary for the transfer of goods, and most discussions surrounding the environmental impact of cruise are monetary discussions on the health of the tourism industry, not outcomes of carbon reduction on the industry. This is because the tourism industry is often not held accountable for their emissions because they cross national boundaries and are extraneous business lines. As such, the question is "who has 'jurisdiction' over international settings when competition can thwart accountability?"

One recent court case that helped clarify the regulatory environment was the 2007 Massachusetts v Environmental Protection Agency (EPA) Supreme Court case. In this case, it was ruled that the US government needed to regulate any pollutant that endangered health, safety, and public welfare. “Massachusetts and several other states petitioned the EPA, asking EPA to regulate emissions of carbon dioxide and other gases that contribute to global warming from new motor vehicles, arguing that the EPA was required to regulate these ‘greenhouse gases’ by the Clean Air Act of 1970” (*Massachusetts v. Environmental Protection Agency*, 2007). The Clean Air Act states that Congress must regulate "any air pollutant" that can "reasonably be anticipated to endanger public health or welfare” (*Massachusetts v. Environmental Protection Agency*, 2007). This case is significant to shore power because it can possibly help define the party responsible for regulating the emissions created by cruise for health, safety, and general welfare. In the 2007 case, “the EPA denied the petition, claiming that the Clean Air Act does not authorize the Agency to regulate greenhouse gas emissions" (*Massachusetts v. Environmental Protection Agency*, 2007). Because of the denied petition, the Supreme Court heard the case and in 2007 they found “that the EPA can regulate greenhouse gases, such as carbon dioxide, as “air pollutants” under the Clean Air Act. In section 202(a)(1) of the Clean Air Act, Congress stated that EPA is to issue standards applicable to the emission of air pollutants” from new motor vehicles, as they may endanger public health or welfare” (*Massachusetts v. Environmental Protection Agency*, n.d.)

The Massachusetts v EPA Supreme Court case serves as the brittle and vague lynchpin of climate policy action as it pertains to regulating CO₂ emissions from motor vehicles. The EPA sets standards and definitions but enforcement is ultimately up to individual states, which can mandate local entities to reach specific targets.

In June 2021, a Dutch court ruled that the Royal Dutch Shell (Shell) corporation was responsible for Scope 3 emissions, which includes the emissions of its suppliers. This ruling identified the Dutch Court as a governing body responsible for regulating emissions and for holding Shell accountable for its own emissions. Significantly, the ruling on Scope 2 emissions forces the company to completely restructure its supply chain and possibly its product, which is a pollutant itself (Meredith, 2021). This ruling is considered a “landmark” decision and may push governments around the world to hold high polluters responsible for Scope 3 emissions. The Court also stated that Shell’s climate action plan was not concrete and included too many conditions to be truly effective. Instead, the court ruled that Shell must cut its emissions in half on a shorter timeline than originally proposed by Shell in their climate action plan or face undefined penalties. This ruling is considered one of the most significant judgments yet, as it highlights that companies, not just governments, may be the target of strategic litigation to reduce emissions (Bouso et al., 2021).

It is not clear at this point how the Dutch ruling might impact the Port of Seattle. However, if there were to be a ruling from Washington State urging all government agencies to reduce their Scope 3 emissions, which would include OGV emissions in the Port’s case, then the Port would need to reevaluate running cruise as a viable line of business. In Washington, HB 2815 of 2008 aims to reduce all WA state emissions and could be expanded upon to require the Port to meet metrics with penalties as incentives. Overall, although enforcement is not defined, it is up to high level courts to create and enforce legislation that local agencies can use to drive their policy decisions.

The case for policy implementation

Policies surrounding pricing carbon externalities are often implemented in the form of a carbon tax or what is sometimes called a “Pigouvian tax”. Researchers note that “estimates of the social cost of carbon (dioxide emissions), or the marginal damage cost of climate change, are an essential ingredient to any assessment of climate policy” (di Vaio et al., 2018). Policy considerations must be made beyond the use of shore power to reach emissions reductions goals. Shore power only addresses emissions from ships at berth, which contribute only a small share of total airshed emissions but are at the center of the Port’s climate action on cruise because it is within their scope of control.

This paper particularly focuses on the goal to reduce ocean-going vessel emissions by 80% of 2005 levels by 2050. To achieve this while still accommodating additional cruise berths in Seattle, more investments than shore power will need to be made and policies must be adopted to offset or reduce transiting and maneuvering emissions. Additionally, emissions reduction success is not solely dependent on the availability of shore power infrastructure. As noted above, the effectiveness of shore power to reduce carbon emissions also depends on the availability of the equipment through contracts, the ships themselves being shore power capable, scheduling berths to allow ships that are capable to come to berth where shore power is available, and coming to berth on the correct side of the equipment to plug-in.

To track the effectiveness of its efforts to achieve the greenhouse gas emission reduction targets set by the Port of Seattle’s commissioners in 2017 as part of the Century Agenda, the Port of Seattle completes the Puget Sound Maritime Air Emissions Inventory every five years. Inventory results guide the Port of Seattle's actions under the Northwest Ports Clean Air Strategy. The goals of the strategy are to:

1. Reduce port-related air quality impacts of diesel particulate matter
2. Reduce greenhouse gas emissions, and
3. Help meet air quality standards and objectives for the air shed (Port of Seattle, 2016)

To align with Century Agenda goals, emission reducing infrastructure can be reviewed in terms of their marginal abatement cost to understand their benefit to the region. Shore power is a costly investment that does not have a conventional monetary return on investment. However, this research demonstrates that assessing shore power by its marginal abatement cost and applying the cost to ships that do not connect to shore power creates a strong argument for investment. A study commissioned by the Port found that electrifying cruise operations while docked avoided about 3,000 metric tons of CO₂ from the 2019 cruise season between May and October (Starcrest Consulting Group, 2018). Shore power is the best option to reduce emissions for ships at berth but must be paired with other pricing structures and policy measures if the Port is to reach its 2050 Century Agenda goals.

Because they are competing with one another, ports are often reluctant to impose unilateral taxes, fees, or other restrictions that might drive cruise ship business away. As a result, ports as a whole are not doing enough to lower their emissions- individually or collectively. However, there are examples of ports working together to achieve a common goal, such as making a profit. For instance, to reduce the intense market competition between the Ports of Tacoma and Seattle, the Ports created the Northwest Sea Port Alliance (NWSPA), which better managed the shared cargo industry. As a result, the NWSPA and Port of Tacoma now operate cargo terminals while the Port of Seattle was left to operate cruise, which makes up a large part of its revenue. Future agreements around emissions reductions can be modeled off the NWSPA.

The same interest in making profit should be at the forefront of the Port’s interest in climate policy. Di Vaio and Varriale allude to this by stating Port staff must be aware of their role in emissions production by stressing the importance of staff training “suggested to educate and guide the human resources at all organizational levels within seaports, for supporting and developing awareness and behavioral attitudes in the direction of environmental sustainability” (di Vaio et al., 2018).

Policy Types

Policy proposals that would complement the Port’s addition of shore power infrastructure at Pier 66 should be chosen based on their likelihood of adoption given the current conditions and proximity to the conversation about pollution reduction. The following four policy options have the best chance to reduce emissions from OGVs:

1. Reduce the frequency of the pollution source by reducing the number of cruise ships scheduled to the Port of Seattle
2. Offer shore power infrastructure at all piers and terminals to reduce existing emissions
3. Establish minimum shore power connection requirements
4. Price externalities and uncovering shadow costs including but not limited to the MAC
5. Creating regional alliances to enforce shore power connection in the airshed

Outlined in greater detail are the following policy options:

1. Reducing frequency of the pollution source

Reducing the frequency of the pollution source means limiting the number of cruise calls accepted at the Port of Seattle. Limiting the number of accepted calls not only reduces hoteling emissions, but also reduces transit and maneuvering emissions. This may be the best option to reach reduction goals set in the Century Agenda because it manages to reduce emissions in all

three scopes of emission sources. Reducing the number of cruise calls creates a financial loss for the Port of Seattle. However, this loss could be partially offset by scaling other sustainable lines of business, such as the Port's recent endeavors to create carbon credits from habitat restoration. The Port of Seattle is one of the largest landholders in King County (Port of Seattle, 2018) leases land to companies running industrial uses. Allocating land to restoration and carbon credits to sell on the market to its tenants that do not reach environmental standards creates an incentive to restore more habitat along the Duwamish River. Imposing carbon pricing internally would require the Port to offset the emissions created by cruise calls to the Port and allocate all funds to habitat restoration.

2. Pricing externalities and uncovering shadow costs

Carbon pricing measures include cap and fees and Pigouvian taxes. Cap and fee are policies that limit the amount of pollution and charge a fee if the limit has been exceeded. Cap and fees are already mandated by the State of Washington on industries (many of which are Port of Seattle tenants) that do not meet environmental standards (O'Sullivan & Bernton, 2021). Plans to allow tenants to purchase offsets from the Port based on their habitat restoration sites may create a new line of business in habitat creation for the Port. Cap and fee policies set a maximum limit of emissions and charge fees to the source of pollution. The Port could impose a Pigouvian tax on hoteling vessels in the Puget Sound Georgia Basin Airshed as a carbon tax or fee. This could be an estimated carbon tax like the MAC per metric ton of CO₂ estimated to be emitted that could be applied to the contracts/ agreements on top of the lease for the pier or it could be applied as a flat fee established by another metric, also added to the cruise contracts.

Currently, the Port of Seattle's Maritime Environmental team already employs a type of pollution tax for its stormwater infrastructure. Stormwater infrastructure prices are based on permeability of the ground near a site which automatically acknowledges and adjusts for pollution associated with certain environments and activities. Built in stormwater fees imposed by the Port funded a few different metal reduction projects including the use of oyster barrels which naturally filter metal. The stormwater program successfully reduced copper pollution levels to meet WA State standards after the establishment of their stormwater team and permeability pricing.

3. Offering infrastructure to reduce existing emissions

Currently, the Port only has two plugs at Terminal 91, owned by Holland America Group. Offering more shore power infrastructure, and therefore more opportunities to hook up will reduce hoteling emissions, as this research has shown. Following the phase-out model set by the bill, SB 5116 - 2019-20, otherwise known as the Electric Vehicle Fleet Initiative in the Washington Clean Energy Transformation Act of 2019, the Port can follow King County Metro's (Metro) approach to reducing emissions. In 2017, King County Metro released their "Feasibility of achieving a carbon neutral or zero-emission fleet" (King County Metro, 2017), a plan to get to carbon neutral to prepare for achieving tiered emissions goals set by the Electric Vehicle Fleet Initiative in the Washington Clean Energy Transformation Act (the Act). The Act was adopted in May 2019 and a corresponding performance report has not yet been released by Metro to track progress. Reduced bus schedules caused by COVID-19 contributed to fewer emissions created by transit and 2020 data will not be a reliable measure. The Port should follow King County Metro's lead in moving toward only allowing

shore power capable vessels. Future analysis on the outcomes of this bill should be considered by the Port to inform their approach to cruise.

4. Establish minimum hook up requirements

Hoteling emissions reductions occur when the shore power connection rate is improved. The Port may consider imposing a minimum shore power hook up rate per cruise liner and include carbon pricing in lease agreements for those that are not shore power capable. Shore power connection targets could be imposed internally as a policy that does not allow the Port to schedule cruise calls without corresponding shore power infrastructure availability or by imposing the connection on the shore power capable ships, allowing them to come to berth only if they have shore power, are willing to pay the carbon pricing, or assist in financing the shore power plug at Pier 66. Port of Seattle's Terminal 91 plug was paid for by Holland America Cruise line and can be used as a model for Norwegian Cruises which plan to come to berth at Pier 66. Shore power connection policy can also serve as an incentive for cruise liners to retrofit ships with shore power capability or become another revenue source for the Port. Enforcing shore power connection agreements requires an established shadow price and regional alliances.

5. Creating Regional Alliances

The Port of Seattle is currently a member of the Northwest Sea Port Alliance with the Port of Tacoma. This alliance was created to protect the business interests of both ports as they are in proximity and run similar operations. Following the Northwest Sea Port Alliance model, all ports in the Puget Sound Georgia Basin Airshed as well as those in Alaska could adopt policies that would ensure that no Port gained a competitive

advantage over the others by avoiding emission reduction fees and regulations. As formally stated, hesitancy to employ carbon fees and shore power connection requirements is an outcome of the competitive environment ports operate in. By establishing a standard across all ports, the competition is absolved for common emission reduction interests. One similar model of collaboration is the Pacific Coast Collaborative, a western coast regional alliance focused on emissions reductions. They have signed the Pacific Coast Action Plan on Climate and Energy. “British Columbia, California, Oregon and Washington are founding signatories to the Under2MOU, which calls for reductions of greenhouse gas emissions to two tons per capita or by 80–90 percent below 1990 levels by 2050” (Pacific Coast Climate Leadership Action Plan, 2008) . The Pacific Coast Collaborative emissions reduction goal is more ambitious than the goals set in the Century Agenda by the Port of Seattle. “Through the Under2MOU and individual international bilateral agreements, British Columbia, California, Oregon and Washington will continue to push for national and international climate action consistent with the ambition of the Paris Agreement and rising ambition over time” (The Governments of British Columbia et al., 2016). To track the success of a regional alliance, the Pacific Coast Collaborative could review progress before and after signing and enacting the regulations by estimations of emissions reduced.

Policy recommendations inherently have gaps as they are based on a framework of questions that aim to come to a common conclusion, however, qualitative review is not exempt from bias even within frameworks. Further analysis on employing shore power connection rate improvement policy for there are very few examples in the literature of maintaining an existing

market while imposing externality pricing as it pertains to Port maritime operations, and none of the examples are in regard to shore power specifically.

The lack of this policy implementation, and therefore research, is due to the nature of shore power being a costly and relatively new infrastructure, as well as port incentives to compete as businesses. Overall, this seems to be because Port customers have flexibility in choosing other local and more affordable ports, climate policy and carbon pricing are relatively new endeavors at the local level, and there are no examples or literature of ports imposing carbon pricing on non-captive markets. Due to the lack of research on economic development and pollution policy in the context of maritime port operations, policy proposals in this discussion are hypothetical and may diverge from port specific contexts to review a general concept. An example of this would be referencing other infrastructure pricing mechanisms that include externalities, such as storm water, within the cost. Use of the shadow price of carbon to review the cost benefit of carbon reducing infrastructure can help account for externalities not typically considered in cost-benefit analysis and pricing for cruise operation at port terminals until ports employ other policy measures to reduce emissions.

Next steps

Experts say there are 8 years left to drastically reduce our CO₂ emissions if we are to save the climate from irreversible damage (United Nations, 2019). Operating extraneous business lines for short term gains is an irresponsible move by the Port of Seattle. Moreover, funds spent on shore power are large investments that may encourage cruise ships to connect to shore power by offering an option in-line with cruise greenwashing marketing efforts. More policy incentive research should be done on the outcomes of employing shore power in certain policy scenarios. Next steps could include but are not limited to:

- **Establishing a social cost of carbon for the region and comparing it to the shadow price found here-** Currently, the EPA has established the social cost of carbon to be about \$123 in the 95% percentile for 2007 (Environmental Protection Agency, n.d.). Adjusted for 2021 dollars, this is \$158.42. A more accurate social cost for the region or airshed may help create a stronger comparison
- **Refining the missing data points or locating hard data.** As stated in the “Limitations” section of the results, there are many missing data points filled with assumptions in my analysis. Improving these data points or assumptions in the model will create a more accurate outcome.
- **Defining who has responsibility to regulate-** Emissions reductions targets are usually voluntary and often recourse for not meeting an emissions reduction goal has no standing in court. The policy is changing and staying up to date, establishing stakeholders, and identifying opportunities for recourse or policy for accountability is another path to reducing emissions.
- **Policy feasibility analysis-** This “Discussion” section outlined the possible policy options the Port can explore to reach their goals. A policy feasibility analysis reviewing the proposed policy options here may provide guidelines for the Port to proceed with adoption.

Ports are governments before they are economic development drivers, which means that the Port of Seattle must first consider their police powers as they relate to public health before they promote economic endeavors like cruise, which harm public health by emitting large amounts of PM 2.5 known to cause health issues. Scaling down cruise is not an anomaly. Residents of Key West, Florida voted to reduce the number of cruise ships to preserve their

downtown culture and protect their fragile wildlife (Morin, 2021). The Port of Seattle can employ shore power and carbon policy to finance it until they follow similar steps to preserve the character and environment of Seattle's downtown area.

5. Conclusion

If all shore power capable ships connected to shore power at a 100% connection rate, the Port would not reach their emissions reductions goal as it currently stands with two shore power connections at Terminal 91. By implementing shore power at Pier 66, with 100% connection of all shore power capable ships, the Port would still not reach their emission reductions goal, although they would improve the situation by reducing emissions in the airshed. This research concludes that using a 30-year infrastructure life cycle, the SPC for shore power operating and installment at Port of Seattle Pier 66 is about \$224 per metric ton of CO₂. Cruise liners coming to berth at the Port of Seattle could accrue an additional 1.1 million dollars in operating costs if the Port imposed a carbon pricing measure for cruise ships choosing to burn bunker fuel. Before the Coronavirus pandemic, the Port had a cruise schedule set to increase the number of calls from the previous year. Increasing the number of calls will increase the emissions in the airshed, especially without shore power at Pier 66. Finally, this work does not take into consideration the cost of health care services needed from increased exposure to PM 2.5. Additional analysis to include the health care costs along with the cost per ton of carbon for a true estimate of the cost of not plugging in. The scope of this work was to create a shore power specific shadow price or marginal abatement cost. Including health care, climate change and other costs is necessary to calculate the full cost of not plugging in to shore power and increasing the number of cruise calls, known as the social cost of carbon.

Recommendations

The Port should pursue a carbon pricing measure using a cost per ton metric on non-shore power capable ships and shore power capable cruise calls that do not plug into Terminal 91. Collecting additional revenue from charging cruise calls not plugging in could be used to finance the shore power plug at Pier 66. Due to the nature of Port competition in the Northwest, an alliance between the Ports of Tacoma, Seattle, and Vancouver, like the Northwest Seaport Alliance, may be the best opportunity to act in shared emissions reductions interests to slow the number of cruise calls and reduce competition between Ports for cruise call dollars. Following the “Next Steps” section in the “Discussion” section will help the Port move forward in implementing a carbon pricing strategy and policy.

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wler&jrnl=15822559&AN=101617393&h=5sr9U3p%2f53WufSdiTYjWKE429UjW9Tspo
 zzItuZDoMCLWCbVnleDrgQyL6ZfZKRp9MFjmAoDcuzzNCrFdgyAfw%3d%3d&crl=c
 &resultNs=AdminWebAuth&resultLocal=ErrCrlNotAuth&crlhashurl=login.aspx%3fdirect
 %3dtrue%26profile%3dehost%26scope%3dsite%26authtype%3dcrawler%26jrnl%3d15822
 559%26AN%3d101617393

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Appendix A

2020 Shore Power Capable Calls

DAY	DATE	VESSEL NAME	BERTH	SP Capable	HAL and NCL Avg Kwh	Emissions Avoided	Avg SP Capable	Avg avoided per SP capable MTCO2 /Call	Avg avoided MTCO2 /Call	Total kWh	total emissions avoided	% of sp capable calls P66 w NB and NJ	% of sp capable calls T91	Avg berth time at T91	Aux Engin Size	NWJ/NWB kWh
WED	4/1/2020	Blocked for privacy	66-2	Yes	49,919	34		64	40	50,787,838	3225.69	79.01%	57%	7.12	12000	85440
SUN	4/5/2020	Blocked for privacy	66-2	NA		0										
SAT	4/25/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
TUES	4/28/2020	Blocked for privacy	66-2	NA		0										
FRI	5/1/2020	Blocked for privacy	66-2	NA		0										
SAT	5/2/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SUN	5/3/2020	Blocked for privacy	66-2	Yes	49,919	34										
FRI	5/8/2020	Blocked for privacy	66-2	NA		0										
SAT	5/9/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SUN	5/10/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SAT	5/16/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SUN	5/17/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
THUR	5/21/2020	Blocked for privacy	66-2	No		0										
SAT	5/23/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SUN	5/24/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
MON	5/25/2020	Blocked for privacy	66-2	NA		0										
SAT	5/30/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SUN	5/31/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
MON	6/1/2020	Blocked for privacy	66-2	No		0										
THUR	6/4/2020	Blocked for privacy	66-2	NA		0										
SAT	6/6/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SUN	6/7/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
FRI	6/12/2020	Blocked for privacy	66-2	No		0										
SAT	6/13/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SUN	6/14/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
THUR	6/18/2020	Blocked for privacy	66-2	NA		0										
SAT	6/20/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SUN	6/21/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
TUES	6/23/2020	Blocked for privacy	66-2	No		0										
WED	6/24/2020	Blocked for privacy	66-2	NA		0										
THUR	6/25/2020	Blocked for privacy	66-2	NA		0										
SAT	6/27/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SUN	6/28/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SUN	6/28/2020	Blocked for privacy	66-2	NA		0										
THUR	7/2/2020	Blocked for privacy	66-2	No		0										
SAT	7/4/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SUN	7/5/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
WED	7/8/2020	Blocked for privacy	66-2	NA		0										
SAT	7/11/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SUN	7/12/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
MON	7/13/2020	Blocked for privacy	66-2	No		0										
SAT	7/18/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SUN	7/19/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
FRI	7/24/2020	Blocked for privacy	66-2	No		0										
SAT	7/25/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SUN	7/26/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SAT	8/1/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SUN	8/2/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
TUES	8/4/2020	Blocked for privacy	66-2	No		0										
SAT	8/8/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SUN	8/9/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
THUR	8/13/2020	Blocked for privacy	66-2	No		0										
SAT	8/15/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SUN	8/16/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SAT	8/22/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SUN	8/23/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
TUES	8/25/2020	Blocked for privacy	66-2	No		0										
SAT	8/29/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SUN	8/30/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
FRI	9/4/2020	Blocked for privacy	66-2	No		0										
SAT	9/5/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SUN	9/6/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SAT	9/12/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SUN	9/13/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
TUES	9/15/2020	Blocked for privacy	66-2	No		0										
FRI	9/18/2020	Blocked for privacy	66-2	NA		0										
SAT	9/19/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SUN	9/20/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
WED	9/23/2020	Blocked for privacy	66-2	NA		0										
FRI	9/25/2020	Blocked for privacy	66-2	No		0										
SAT	9/26/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SUN	9/27/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
THUR	10/1/2020	Blocked for privacy	66-2	NA		0										
FRI	10/2/2020	Blocked for privacy	66-2	No		0										
SAT	10/3/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
SUN	10/4/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
MON	10/5/2020	Blocked for privacy	66-2	NA		0										
FRI	10/9/2020	Blocked for privacy	66-2	NA		0										
SUN	10/11/2020	Blocked for privacy	66-2	Yes	1,056,000	66										
MON	10/12/2020	Blocked for privacy	66-2	No		0										
WED	10/14/2020	Blocked for privacy	66-2	Yes	1,056,000	66										

*If shore power capable but did not berth at T91 during 2019, used avg hoteling (kwh/call) for 2019
*Norwegian Joy, Bliss and sun expected to retrofit for shore power, has higher hoteling load but using avg for now
* NA for missing sp info, assumes no sp

Bunker Fuel Consumed at Berth Estimate

Output	Formula	Quantity	Units	Source
BTU Range	BTUs per gallon for IFO 380 or Bunker Fuel C - most common fuel for cruise ships	151300-155900	BTUs	https://www.engineeringtoolbox.com/fuel-oil-combustion-values-d_509.html
BTU Median	attempt to use avg BTUs	153600	BTUs	NA
Avg kWh per call	Avg of all calls in 2019	49,919	kWh	From HAL 2019 T91 Data
Total BTUs per call	Used online calculator- kWh per call to BTU conversion	170330698.6	BTUs	https://www.rapidtables.com/convert/energy/kWh_to_BTU.html
Fuel Efficiency Factor	conversion factor- assuming 30% (cant find info)	0.3	gallons (?)	Calculation of Efficiencies of a Ship Power Plant Operating with Waste Heat Recovery through
Avg BTUs @ berth	BTU Median/BtU at berth	3696.41273	gallons (?)	
Avg cost per metric ton of US IFO 380	from April 2019-Oct 2019 (2019 cruise season, assuming fill up in US)	\$451.50	price per ton	https://shipandbunker.com/prices#IFO380
gallons per ton of fuel	307 gals per MT conversion factor	307.85	gallons per ton	https://qp.com.qa/ar/Pages/ConversionFactor.aspx
MT to gallons	(300 gals per MT) for cost per gallon	\$1.47		https://www.google.com/search?q=how+many+gallons+in+a+mt+of+bunker+c&rlz=1C1CHBF_enUS82
Avg cost per berth	cost per gallon * avg BTUs at berth	\$5,421.25		

Electricity Consumed on Shore Power Estimate

1. Est 2006 \$ to 2019 from T91				
			\$	Source
Cost per berth in 2006	Cost in kWh consumed		\$5,000	https://www.greenport.com/news101/energy-and-technology/hal-cold-ironing
Cost per berth in 2019	2005 dollar to 2019 dollars converter		\$6,341	https://www.in2013dollars.com/us/inflation/2006?endYear=2019&amount=5000
2. Estimating by \$ per kWh				
			Unit	Source
Avg kWh per berth	Avg kWh of all calls in 2019		49,919	From HAL 2019 T91 Data
Avg time connected to SP	7:05 hrs		7.12	From HAL 2019 T91 Data
SCL kWh cost from 2019 Peak Hours	Large General Service Downtown Network (is this correct?) should I use peak?		\$0.0979	https://www.seattle.gov/light/rates/summary.asp
SCL kWh cost from 2019	Ane time daily added cost for every day a ship comes to berth		\$29,1100	https://www.seattle.gov/light/rates/summary.asp
SCL Transformer Investment (\$/kW)	Added cost- Minimum Bill per Meter per Day		\$0.2600	https://www.seattle.gov/light/rates/summary.asp
kWh to KW	Avg kWh / avg time		\$7,011.10	
total Transformer cost	KW * \$ /KW transformer cost		\$1,822.88	
Cost for SP per call	transformer investment cost + Minimum Bill per Meter per Day		\$6,739.06	
3. Estimating by \$ per kWh from T30 (container terminal)				
			\$	Source
Cost per berth in 2006	Cost in kWh consumed		3,371	https://www.c40.org/case_studies/port-of-seattle-cuts-vessel-emissions-by-29-annually-and-saves-26-on-energy-costs-per-call
Cost per berth in 2019	2006 dollar to 2019 dollars converter		\$4,275	https://www.in2013dollars.com/us/inflation/2006?endYear=2019&amount=3371
4. Avg of 3 outcomes				
Avg of Personal Est, T91 Est		\$6,540		

MAC and Shadow Price Estimates

Port of Seattle Cruise Growth Projections										
Assumptions:										
Fuel Costs Per call	\$5,421.25	Reference Cost per berth call wo SP https://www.in2013dollars.com/us/inflation/2006/endYear?amount=3371								
Electricity cost per call (2019 dollars)	\$6,539.89	=2019&amount=3371								
Cost of SP	\$17,000,000.00	Port of Seattle internal number								
30 yr amortization cost	\$566,666.67									
amortization (yrs)	30.00									
Avg emissions avoided per SP connected call (MTCO2)	64	2020 SP Capabale Calls								
* all estimations adjusted for 2020 dollars, assuming constant number of calls, not adjusted for inflation										
Annual Operating and Shore Power Costs (\$) @ P66 (total costs)										
Year	0	1	2	3	4	5	29	30		
	2019	2020	2021	2022	2023	2024	2025	2049	2050	Total Over 30 years
# of Calls	81	81	81	81	81	81	81	81	81	2,592
Annual Change (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0
Cost of SP Per call (0% connection)	\$566,666.67	\$566,666.67	\$566,666.67	\$566,666.67	\$566,666.67	\$566,666.67	\$566,666.67	\$566,666.67	\$566,666.67	17,000,000
100% Connection Rate	\$1,096,398	\$1,096,398	\$1,096,398	\$1,096,398	\$1,096,398	\$1,096,398	\$1,096,398	\$1,096,398	\$1,096,398	\$32,891,927
79% Connection Rate (P66 actual in 2020)	\$985,154	\$985,154	\$985,154	\$985,154	\$985,154	\$985,154	\$985,154	\$985,154	\$985,154	\$29,554,622
75% Connection Rate	\$963,965	\$963,965	\$963,965	\$963,965	\$963,965	\$963,965	\$963,965	\$963,965	\$963,965	\$28,918,945
70% Connection Rate (P66 Actual in 2019)	\$937,478	\$937,478	\$937,478	\$937,478	\$937,478	\$937,478	\$937,478	\$937,478	\$937,478	\$28,124,349
50% Connection Rate	\$831,532	\$831,532	\$831,532	\$831,532	\$831,532	\$831,532	\$831,532	\$831,532	\$831,532	\$24,945,963
Annual Emissions Avoided @ P66 (MTCO2)										
Year	0	1	2	3	4	5	29	30		
	2019	2020	2021	2022	2023	2024	2025	2049	2050	Total Over 30 years
# of Calls	81	81	81	81	81	81	81	81	81	2,592
Annual Change (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0
MTCO2/Call (SP with 0% connection)	-	-	-	-	-	-	-	-	-	0
100% Connection Rate	5,221.03	5,221.03	5,221.03	5,221.03	5,221.03	5,221.03	5,221.03	5,221.03	5,221.03	167,073
79% Connection Rate (P66 actual in 2020)	4,124.61	4,124.61	4,124.61	4,124.61	4,124.61	4,124.61	4,124.61	4,124.61	4,124.61	131,988
75% Connection Rate	3,915.77	3,915.77	3,915.77	3,915.77	3,915.77	3,915.77	3,915.77	3,915.77	3,915.77	125,305
70% Connection Rate (P66 Actual in 2019)	3,654.72	3,654.72	3,654.72	3,654.72	3,654.72	3,654.72	3,654.72	3,654.72	3,654.72	116,951
50% Connection Rate	2,610.51	2,610.51	2,610.51	2,610.51	2,610.51	2,610.51	2,610.51	2,610.51	2,610.51	83,536
SPC \$/MTCO2										
100% Connection Rate	\$196.87									
79% Connection Rate (P66 projected in 2020)	\$223.92									
75% Connection Rate	\$230.79									
70% Connection Rate (P66 Actual in 2019)	\$240.48									
50% Connection Rate	\$298.62									
Annual Operating in Electricity (SP, hotelling) @ P66 (\$) (cost to cruise)										
Year	0	1	2	3	4	5	29	30		
	2019	2020	2021	2022	2023	2024	2025	2049	2050	Total Over 30 years
# of Calls	81	81	81	81	81	81	81	81	81	2,592
Annual Change (%)	0.0%	1.00	2.00	3.00	4.00	5.00	6.00	30.00	31.00	496
Cost of SP Per call (0% connection)	-	-	-	-	-	-	-	-	-	0
100% Connection Rate	\$529,731	\$529,731	\$529,731	\$529,731	\$529,731	\$529,731	\$529,731	\$529,731	\$529,731	\$16,951,388
79% Connection Rate (P66 actual in 2020)	\$418,487	\$418,487	\$418,487	\$418,487	\$418,487	\$418,487	\$418,487	\$418,487	\$418,487	\$13,391,597
75% Connection Rate	\$397,298	\$397,298	\$397,298	\$397,298	\$397,298	\$397,298	\$397,298	\$397,298	\$397,298	\$12,713,541
70% Connection Rate (P66 Actual in 2019)	\$370,812	\$370,812	\$370,812	\$370,812	\$370,812	\$370,812	\$370,812	\$370,812	\$370,812	\$11,865,972
50% Connection Rate	\$264,865	\$264,865	\$264,865	\$264,865	\$264,865	\$264,865	\$264,865	\$264,865	\$264,865	\$8,475,694
Annual Operating (no SP, hotelling) @ P66 (\$) (cost to cruise)										
Year	0	1	2	3	4	5	29	30		
	2019	2020	2021	2022	2023	2024	2025	2049	2050	Total Over 30 years
# of Calls	81	81	81	81	81	81	81	81	81	2,592
Annual Change (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0
Cost of bunker fuel per season (0% connection)	\$439,121	\$439,121	\$439,121	\$439,121	\$439,121	\$439,121	\$439,121	\$439,121	\$439,121	\$14,051,868
Annual Operating (no SP, hotelling) @ P66 (\$) (cost to cruise +SPC 100%)										
Year	0	1	2	3	4	5	29	30		
	2019	2020	2021	2022	2023	2024	2025	2049	2050	Total Over 30 years
Number of Calls	81	81	81	81	81	81	81	81	81	2,592
Annual Change (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0
Cost of bunker fuel per season *SPC (50% connection)	\$1,998,244	\$1,027,873	\$1,027,873	\$1,027,873	\$1,027,873	\$1,027,873	\$1,027,873	\$1,027,873	\$1,027,873	\$33,862,297
Cost of bunker fuel per season *SPC (79% connection)	\$1,608,212	\$1,027,873	\$1,027,873	\$1,027,873	\$1,027,873	\$1,027,873	\$1,027,873	\$1,027,873	\$1,027,873	\$33,472,266
(emissions per call * SPC at 100% *best rate* connection rate)*(number of calls)	\$1,027,873									
Cost difference between non SP (bunker fuel) and non SP+SPC	\$1,169,091									
Cost difference between SP (electric) and non SP+SPC	\$1,189,725									
Hotelling cost on bunker fuel per season	\$439,121									
Hotelling cost on shore power per season	\$529,731									
Hotelling cost on bunker fuel per call	\$14,433									
Hotelling cost on shore power per call	\$6,540									

For display purposes, years 1-5 and 29-30 to show the rates over time.