ERG Port of Charleston Shore Power Analysis

Developed for John Kaltenstein, Friends of the Earth

By Richard Billings and Heather Perez, ERG
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Background

The Port of Charleston is ranked ninth in the country in container volume,[1] handling nearly 2.4 million TEUs in 2019.[2] With opening of the new Hugh K. Leatherman Terminal anticipated in March 2021, SCPA is preparing for a doubling of port capacity and the ability to handle mega containerships with 19,000 TEU capacity. This volume of traffic can have a significant impact on local air quality, specifically during the extended period that a vessel is dockside unloading and loading cargo. During this time, auxiliary marine diesel engines operate to maintain onboard power and assist in cargo handling operations.

Shore power provides an alternative to running auxiliary engines that has the potential to reduce air pollutant emissions in a cost-effective manner. The electricity ships need to power their ancillary systems while at berth can be produced with fewer emissions using land-side electricity generation power sources (e.g., power plants) when compared with onboard diesel-powered auxiliary engines. Currently the Port of Charleston does not have shore power at any of its terminals. The construction of the new Hugh K. Leatherman (HKL) terminal provides an opportunity to consider how new visiting vessel fleet profiles and shifting traffic patterns might impact port construction and shore power adoption in the future.

The magnitude of potential emission reductions depends on the mix of electricity generation power sources which can vary by location. The mix of power sources from Dominion Energy (formerly South Carolina Electric and Gas Company) includes a diverse variety of energy sources (Figure 1) which are collectively priced below marine diesel fuel, such that shore power is an economically viable option for reducing air emissions.[3]

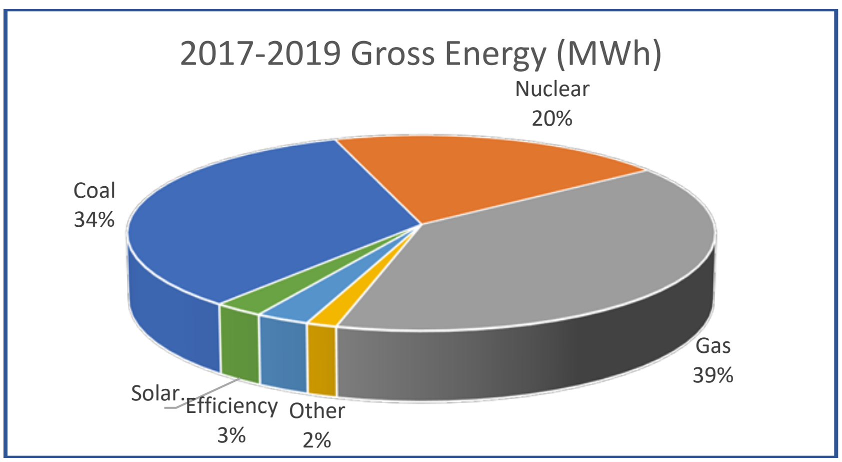

Figure 1. Dominion Energy Fuel Mix by *Source*

1 South Carolina Ports Authority, Top Ten U.S. Seaport Districts in Dollar Value of Good Handled, Calendar Year 2018, http://scspa.com/about/statistics/cargo-value/

2 South Carolina Ports Authority, SC Ports reports record cargo volumes, 9% uptick in FY19, http://scspa.com/news/sc-ports-reports-record-cargo-volumes-9-uptick-in-fy19/

3 SACE, SCEG Fuel Mix 2010-2025 spreadsheet (received Aug. 16, 2020), on file with authors.

Methodology

Friends of the Earth provided the 2018 vessel movement data for the Port of Charleston that was used for this study, which was originally transmitted by the Charleston Harbor Pilots through the South Carolina Ports Authority (SPA). The log provided the vessel name, IMO number, and entry/exit timestamps for each of the 1,347 containership calls in 2018. Average time spent at berth was approximately 16 hours per call. The trips were associated with 390 unique containerships. The IMO numbers were matched to Clarkson's database of marine vessel characteristics to confirm ship-specific vessel type and obtain build year and auxiliary engine horsepower.

Of the 390 containerships that visited Charleston, all but 76 of the vessels had power data for auxiliary engines in the Clarkson database (19%). To gap-fill the missing auxiliary engines, a default was calculated by averaging the Charleston fleet that did have power ratings to obtain a value of 10,400 kW. The port may want to consider collecting auxiliary engine data for visiting vessels to provide more accurate estimates of power demand and emissions.

Vessel calls were grouped by auxiliary power to remove vessel-specific data (per use agreement with Clarkson), and vessel trips were summed. EPA's Shore Power Emissions Calculator[4] was used to estimate emissions for both vessel-auxiliary emissions as well as shore power emissions. Anticipated reductions in emissions and financial savings of using shore power were calculated. Savings by terminal were calculated based on the port-provided predicted shift in activity as the new HKL container terminal reaches various construction milestones. Projected shore power estimates were developed for the years 2021, 2026, and 2032.[5]

Emission Estimation Approach

eGRID Emission Factor Development

The U.S. EPA's Emission and Generation Resource Integrated Database (eGRID) has comprehensive data on the environmental characteristics, including air pollutant emissions, of electric power generated in the U.S. eGRID provides emission factors that account for the mix of different energy generating units for each state or sub-region. SCE&G's electric power mixes from 2010-2025 were provided by Friends of the Earth, via information from the Southern Alliance for Clean Energy. To estimate future SRVC electric power mixes, fuel-specific growth rates from Dominion Energy were applied to the SRVC region. Linear extrapolation was used to estimate electric power mixes for 2026 and beyond as shown in Table 1 below.

Table 1. Projected Dominion Energy Mix by Year and Category

Gross Energy [MWh]	2017-19 avg	2021	2026	2032
Coal	8,210,543	7,410,003	7,891,131	8,430,718
Nuclear	4,918,737	5,062,152	5,069,086	5,077,408
Gas	9,573,955	9,239,307	10,148,921	11,301,657
Other	377,593	616,145	616,989	618,001
Efficiency	664,347	785,915	434,638	24,893
Solar	617,086	2,122,288	2,375,270	2,663,875

4 U.S. EPA Ports Initiative, Shore Power Technology Assessment, 2017, https://www.epa.gov/ports-initiative/shore-power-technology-assessment-us-ports

5 Projection years were originally selected to align with HKL construction phases. Per SPA, the Phase II completion date has since shifted from 2026 to 2028.

Emission factors for CO_2, CH_4, NO_x, and SO_2 were calculated in pounds per megawatt hour for each fuel type represented: biomass, coal, gas, hydro, nuclear, oil, other unknown/purchased fuel, solar, and wind. Emission factors for $PM_{2.5}$ and VOCs were calculated from 2017 NEI[6] data for the SRVC subregion. To ensure consistency across data sources, facility IDs from NEI were mapped to a list of power plants in the SRVC subregion. Although it was not possible to match every SRVC facility using this approach, the facilities captured represent 95% of 2018 generation and 99% of 2016 generation in the SRVC subregion. Emission factors for black carbon (BC) were calculated from the mass fraction of BC present in $PM_{2.5}$ from GREET 2019.[7] Table 2 below shows the eGRID emission factors for the state of South Carolina in terms of g/kWh that were used to estimate the emissions contribution of shore power.[8]

Table 2. Emission Factors for South Carolina Electrical Grid Mix [g/kWh]

Weighted emission factors*	CO_2	CH_4	NO_x	SO_2	$PM_{2.5}$	VOC	BC
2018	354	0.03	0.21	0.13	0.04	0.06	0.003
2021	315	0.03	0.20	0.14	0.04	0.07	0.004
2026	323	0.03	0.20	0.13	0.04	0.07	0.004
2032	323	0.03	0.20	0.13	0.04	0.07	0.004

* Include transmission and distribution loss of 4.88% per eGRID 2018 Technical Support Documentation.

<u>Vessel Emission Factor Development</u>

Auxiliary engine emission factors were obtained by the latest U.S.EPA report "Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emission Inventories" and are shown in Table 3 below. They are Tier-based as determined by the age of vessel and assume medium speed diesel engines using Emission Control Area compliant fuels with 0.1% sulfur content.

Table 3. Auxiliary Engine Emission Factors (assuming medium speed diesel using marine gas oil (0.1% S) (g/kWh)) [9]

Build Year	Tier	NO_x	SO_2	CO_2	CH_4 [10]	$PM_{2.5}$	BC[11]	VOC
< 2000	Tier 0	10.900	0.424	695.702	0.01	0.174	0.100	0.4212
2000-2010	Tier 1	9.800	0.424	695.702	0.01	0.174	0.100	0.4212
2011-2015	Tier 2	7.700	0.424	695.702	0.01	0.174	0.100	0.4212
≥ 2016	Tier 3	2.000	0.424	695.702	0.01	0.174	0.100	0.4212

6 2017 National Emissions Inventory (NEI), February 2020, https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data

7 The Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) Model, Series 1: Fuel-Cycle Model, https://greet.es.anl.gov/

8 Emissions & Generation Resource Integrated Database (eGRID) 2018, version 2, released: 1/28/2020, revised: 3/9/2020.

9 U.S. EPA, Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emission Inventories, February 2020, EPA-420-D-20-001, https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YFY8.pdf, accessed 2 July 2020.

10 Methane emission factor from the Fourth IMO GHG Study 2020 – Final report, https://safety4sea.com/wp-content/uploads/2020/08/MEPC-75-7-15-Fourth-IMO-GHG-Study-2020-Final-report-Secretariat.pdf, accessed 11 August 2020.

11 Black Carbon Emissions and Fuel Use in Global Shipping 2015, https://theicct.org/sites/default/files/publications/Global-Marine-BC-Inventory-2015_ICCT-Report_15122017_vF.pdf

Emissions Calculations

The EPA's default auxiliary operating load factor for containerships is 17% which is considered a low load operation that typically generates more emissions. Consistent with other regional studies that indicate that containership operators may turn off certain auxiliary engines to maximize load and increase efficiency while in port, the calculations continue to use the 17% load factor but do not include the standard low load adjustment. Note that the EPA shore power tool has built-in flexibility to change this assumption as well as to calculate emissions for any engine load.

Annual dockside power demand was calculated for each vessel in the fleet using the following equation:

$$\mathrm{PD} = AP \times LF \times T$$

Where:

PD	= Hoteling power demand for each vessel visit (kWh)
AP	= Auxiliary engine power (kW)
LF	= Auxiliary engine hoteling load factor (17% for containerships)
T	= Duration per call adjusted to account for connection and disconnection time (2 hours)

This equation assumes one hour to connect and one hour to disconnect onto the shore power system to ensure that vessel emissions are for the same duration as the shore power connection period. This is a conservative estimate in line with other studies. The power demand values were used to estimate baseline emissions from the auxiliary engines while dockside using the following equation:

$$\mathrm{AE} = \sum \mathrm{PD} \times \mathrm{A}EF / 1{,}000{,}000$$

Where:

AE	= Dockside emissions (metric tons)
PD	= Hoteling Power demand (kWh)
AEF	= Auxiliary engine emission factor (g/kWh)
1,000,000	= Factor to convert from grams to metric tons

The power demand values were also used to estimate the associated landside power generation emissions using the following equation; as mentioned previously, this equation includes an adjustment in the hours to account for time spent connecting and disconnecting to the shore power system and transmission losses:

$$\mathrm{SPE} = \sum \mathrm{PD} \times SEF \times (1 + L) / 1{,}000{,}000$$

Where:

SPE	= Shore power emissions for the landside grid (metric tons)
PD	= Hoteling Power demand (kWh)
SEF	= Georgia State emissions factor (g/kWh) obtained from eGRID
L	= Transmission losses (fraction) default of 0.0488
1,000,000	= Factor to convert from grams to metric tons

The net emission reduction was calculated using the following equation:

$$\mathrm{NER} = \mathrm{AE} - \mathrm{SPE}$$

Where:

NER	= Net emission reduction (metric tons)
AE	= Dockside emissions (metric tons)
SPE	= Shore power emissions (metric tons)

Projections

Activity levels for 2021, 2026, and 2032 were developed based on historical containership data (1997 to 2019) provided from the port. Three regression models used trends derived from the historical data to estimate future containership calls, average containership TEUs, and total containership TEUs over time (Table 4). The R-squared values for the containership calls, average containership TEUs, and total containership TEUs models were 0.5219, 0.9448, and 0.7852, respectively. Predictions were also compared to other regional studies and were found to be reasonable and consistent.[12] Given these results, average TEU/vessel was used to estimate future activity levels (Figure 2).[13]

Table 4. Historical and Projected TEUs, Containership Calls, and Average TEUs/Vessel

Year	TEU	Container Vessels Docked	Avg TEU/ Vessel
1997	1,151,401	1,469	784
1998	1,259,259	1,594	790
1999	1,347,618	1,731	779
2000	1,574,467	1,789	880
2001	1,619,577	1,822	889
2002	1,509,381	1,765	855
2003	1,681,721	1,620	1,038
2004	1,724,586	1,735	994
2005	1,970,875	1,786	1,104
2006	1,978,806	1,713	1,155
2007	1,883,651	1,697	1,110
2008	1,694,504	1,526	1,110
2009	1,367,977	1,437	952
2010	1,277,760	1,186	1,077
2011	1,383,533	1,280	1,081
2012	1,432,304	1,307	1,096
2013	1,560,116	1,386	1,126
2014	1,684,907	1,374	1,226
2015	1,916,379	1,486	1,290
2016	1,943,170	1,447	1,343
2017	2,137,702	1,329	1,609
2018	2,199,873	1,299	1,694
2019	2,393,095	1,320	1,813
2021	2,842,012	1,273	2,019
2026	3,237,209	1,252	2,239
2032	3,701,459	1,231	2,492

[12] Savannah Harbor Expansion Project –Final GRR, https://www.sas.usace.army.mil/Portals/61/docs/SHEP/reports/GRR/GRR_Sec5.pdf

[13] Future TEU projections provided by SPA to Friends of the Earth on Nov. 2, 2020: 2,324,985 (2020), 2,172,919 (2021), 3,080,000 (2026), 3,701,459 (2032).

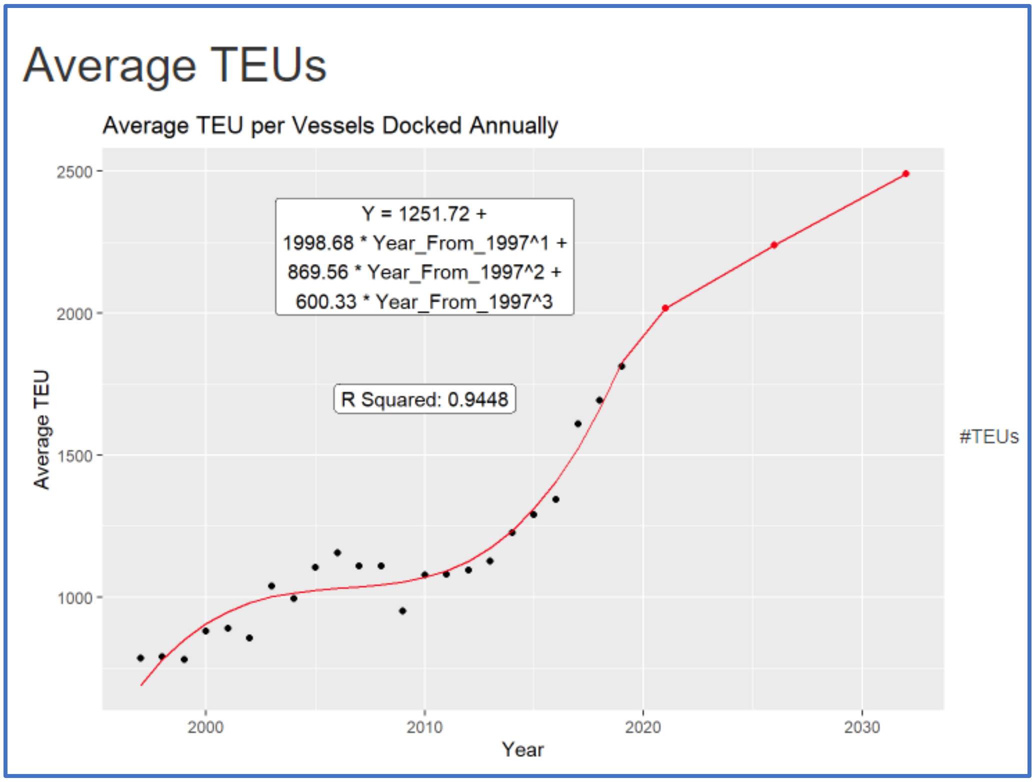

Figure 2. Predicted Average Future Containership TEUs Using a Trinomial Regression Model

Projected results reflect an increase in the number of TEUs per vessel and a decrease in total vessel calls, which aligns with an increasing population of larger containerships in the fleet. Given these trends, projected years had a downward adjustment in vessel calls as well as an increase in dockside duration to account for larger ships that require more time to off-load (Table 5).

Table 5. Future Adjustments to Vessel Call Data and Dockside Durations

Year	Containership Calls	Vessel Call Adjustment from 2018	Dockside Duration Adjustment from 2018	Dockside Duration Hours
2018	1,299	1.0000	1.0000	16
2021	1,273	0.9798	1.1916	19
2026	1,252	0.9636	1.3220	21
2032	1,231	0.9473	1.4710	24

Fleet Turnover

Adjustments needed to be made for changes in the vessel fleet as older vessels retire and new vessels (equipped with higher Tier engines) replace them. For this analysis, a vessel lifespan was assumed to be 25 years.[14] Vessels that exceed 25 years of service were replaced with a Tier 3 vessel profile to account for new emission standards. As future auxiliary power ratings for new vessels are not available, the existing AUX ratings were maintained. Because this tool combines activity data to protect confidential vessel characteristics data, activity data were adjusted to reflect vessel calls that were changed to the updated Tier.

[14] Life Cycle of a Ship, http://www.shippipedia.com/life-cycle-of-a-ship/, accessed 2 July 2020.

Financial Elements

The power demand values were used to estimate ongoing energy cost associated with the implementation of the shore power system based on the contracted industrial rate with Dominion Energy South Carolina at $0.06 per kWh.[15] This cost estimate does not include cost to retrofit vessels or the required infrastructure changes needed to implement shore power at the Port of Charleston.

Auxiliary engine fuel consumption was estimated using the assumption of 203 grams of fuel per kWh data and the estimated power demand. The net cost savings for operators using shore power was provided using the assumption that vessels operating in U.S. waters are using global ECA compliant fuels at a cost of $394.50 per metric ton of MGO.[16]

$$CS = (TED \times 203/1000000 \times 394.5) - (TED \times 1.0488 \times 0.06)$$

Where:

CS	= Cost savings
TED	= Total annual energy demand for all vessel auxiliary engines (kWh)
203	= Grams of diesel fuel/kWh
1000000	= Conversion of grams to metric tons
394.5	= Price of fuel ($/MT of fuel)
1.0488	= Adjustment to account for transmission loss
0.06	= Price of electricity to the port ($/kWh)

Note that containerships may use exhaust gas scrubber systems instead of low-sulfur fuel to comply with ECA requirements. Given lack of comprehensive data on vessels' emission control devices both now and anticipated in the future, these calculations assume the use of ECA compliant fuels for all vessels.

Results

This study indicates that using shore power at the Port of Charleston would result in significant financial and fuel savings as well as emission reductions particularly for NO_x, BC, $PM_{2.5}$, and VOC. Anticipated emissions reductions and financial savings were calculated as described above and can be found in Tables 6 through 8 below. The results below assume that both Wando Welch and HKL terminal are fully shore power enabled and that all visiting containerships are shore power-equipped and opt to use the shoreside electrical power.

Table 6. Estimated Reductions in 2018 Emissions with Shore Power Compared to Marine Diesel Fuel

	Port of Charleston							
Pollutant	NO_x	SO_2	CO_2	CH_4	$PM_{2.5}$	BC	VOC	CO_2-eq
Vessel Power Emissions (MT)	311.87	14.64	24,002.32	0.35	5.99	3.45	14.53	24,031.99
Shore Power Emissions (MT)	7.25	4.49	12,213.31	1.04	1.38	0.10	2.07	12,302.32
Net Emission Reduction (MT)	304.63	10.15	11,789.01	-0.69	4.61	3.35	12.46	11,729.67
Percent Difference	-98%	-69%	-49%	200%	-77%	-97%	-86%	-49%

[15] https://www.electricitylocal.com/states/south-carolina/, 6 July 2020
[16] Global 20 Ports Average ECA compliant fuel, 6 July 2020, https://shipandbunker.com/prices#MGO

Table 7. Estimated Emissions Reductions (MT) With Shore Power Compared to Marine Diesel Fuel

Port of Charleston								
Pollutant	NO_x	SO_2	CO_2	CH_4	$PM_{2.5}$	BC	VOC	CO2-eq
2018	304.63	10.15	11,789.01	-0.69	4.61	3.35	12.46	11,729.67
2021	362.48	11.86	15,625.49	-0.88	5.29	3.95	14.31	15,549.60
2026	343.32	12.97	16,632.22	-0.95	5.77	4.30	15.64	16,550.14
2032	327.63	14.69	18,841.96	-1.08	6.56	4.88	17.85	18,748.98

Table 8. Anticipated Monetary Savings Using Shore Power by Year

Year	Auxiliary Engine Marine Fuel Cost	Shore Power Cost	Net Savings
2018	$2,762,950	$2,076,952	$685,998
2021	$3,287,287	$2,471,104	$816,183
2026	$3,571,640	$2,805,407	$766,233
2032	$4,046,165	$3,041,564	$1,004,600

SPA is currently constructing a new containership terminal that will ultimately double the port's throughput capacity when completed. The construction, coupled with the deepening of Charleston Harbor, will also enable the port to receive new, larger containerships. The port provided an estimate in 2019 for how containership activity will shift between terminals as various phases of the construction are completed.[17] These estimates were used to apportion the total port emissions to the three terminals for each projected year (Table 9). Figures 3 through 5 visually show how NO_x, CO2-eq, and $PM_{2.5}$ emissions change over time and between the terminals (note that the projected values for 2032 represent an increase in container traffic of approximately 47%).

Table 9. Estimated Activity and Emissions by Terminal and Year

Activity Break-Out by Year and Terminal				
	2018	**2021**	**2026**	**2032**
North Charleston	37%	10%	5%	0%
Wando Welch	63%	70%	60%	50%
Hugh K. Leatherman	0%	20%	35%	50%
Total	100%	100%	100%	100%
NO_x Emissions (MT)				
	2018	**2021**	**2026**	**2032**
North Charleston	115.39	37.05	17.61	0.00
Wando Welch	196.48	259.37	211.28	168.80
Hugh K. Leatherman	0.00	74.11	123.24	168.80
Total	311.87	370.53	352.13	337.61

[17] Note that many factors of this analysis such as cost, construction timeline, volume estimates, etc. were developed prior to the COVID-19 pandemic such that more current values would likely impact projections.

Table 9. Estimated Activity and Emissions by Terminal and Year

Activity Break-Out by Year and Terminal				
CO_2-eq Emissions (MT)				
	2018	2021	2026	2032
North Charleston	8,891.84	2,859.26	1,553.30	0.00
Wando Welch	15,140.15	20,014.85	18,639.56	17,596.66
Hugh K. Leatherman	0.00	5,718.53	10,873.08	17,596.66
Total	24,031.99	28,592.65	31,065.93	35,193.32
PM-2.5 Emissions (MT)				
	2018	2021	2026	2032
North Charleston	2.22	0.71	0.39	0.00
Wando Welch	3.77	4.99	4.64	4.38
Hugh K. Leatherman	-	1.42	2.71	4.38
Total	5.99	7.12	7.74	8.77

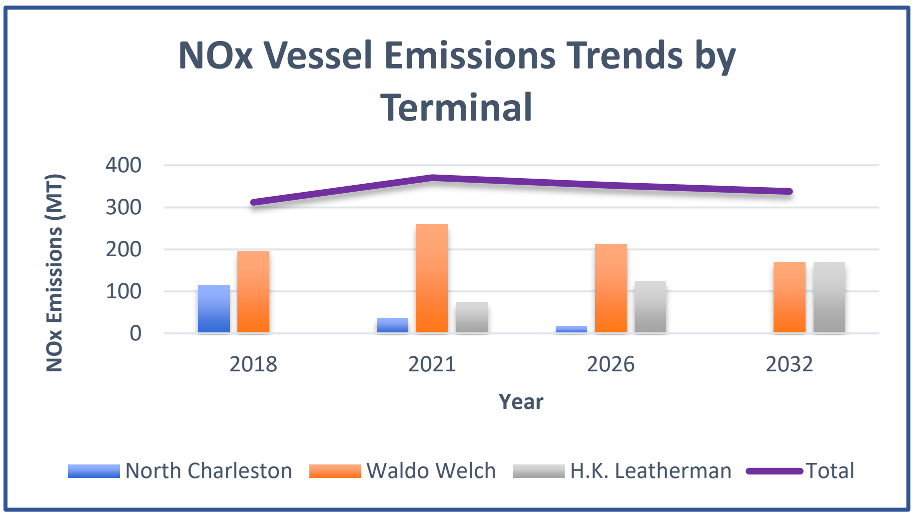

Figure 3. NO_x Vessel Emissions Trends by Terminal

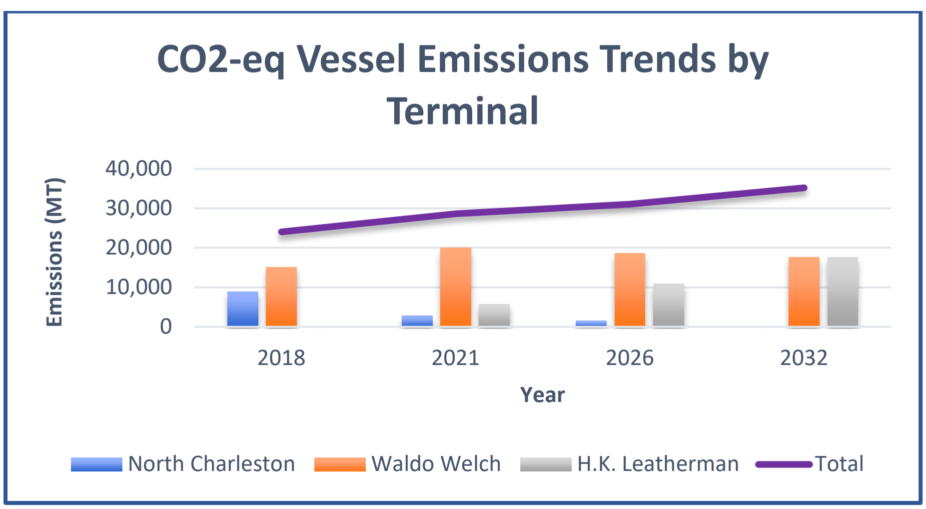

Figure 4. CO2-eq Vessel Emissions Trends by Terminal

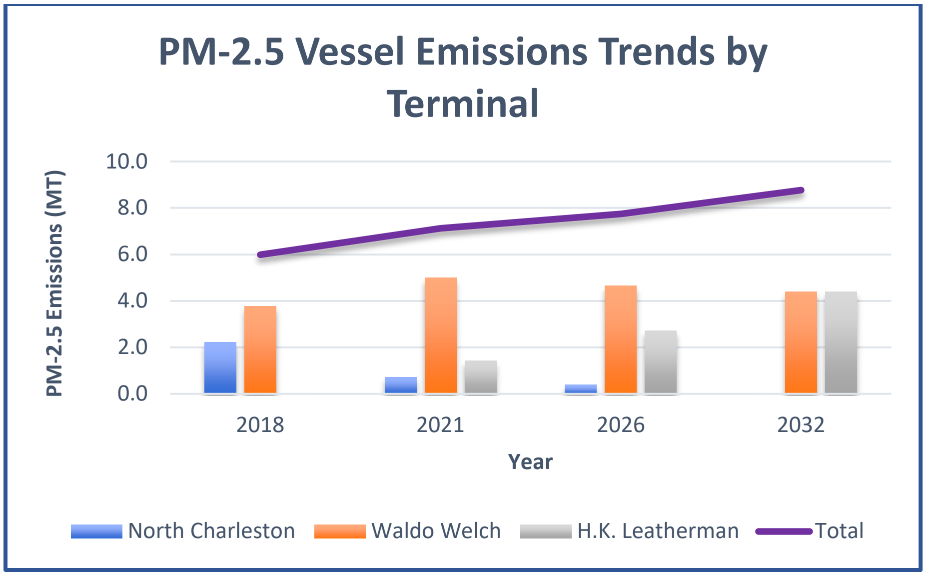

Figure 5. PM$_{2.5}$ Vessel Emissions Trends by Terminal

Conclusion

It is anticipated that dockside emissions will be increasing given the SCPA's plans to add 2.4 million TEUs of throughput capacity,[18] impacting the local air quality of adjacent communities. As noted in this study, the application of shore power can significantly reduce emissions based on the current mix of South Carolina's electrical power generating sources. Future net emission reductions are anticipated as renewable energy sources continue to be added to the local grid in South Carolina. Additionally, the price differential between what the SPA pays for electricity and the current cost of ECA-compliant diesel allows the SPA to set the price at a point that provides a cost savings to ship operators while still allowing the SPA to recover associated infrastructure costs.

[18] SC Ports' Leatherman Terminal on track for 2021 opening, http://scspa.com/news/sc-ports-leatherman-terminal-on-track-for-2021-opening/