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EXTENDED ABSTRACT

THE PROSPECTS OF COLD IRONING AS AN EMISSIONS REDUCTION OPTION

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INTRODUCTION

Maritime shipping is considered the most fuel efficient mode of transport with the lowest contribution in CO_2 emissions. However, the sector has seen increasing pressure to improve its environmental performance, particularly when it comes to SO_x, NO_x, and PM emission pollutants. The majority of academic literature is focusing on the full journey environmental aspects of maritime transport, and less attention is given to ports. Davarzani et al. (2016) conduct a literature review on greening ports in order to identify research areas for further investigation (*1*).

Cold ironing is the process of providing shorepower to cover the energy demands of vessels calling at ports. In California six ports are included to the At-Berth regulation that constitutes mandatory the use of the technology for ocean going vessels (70% of total vessel calls, up to 80% by 2020). The EU regulation on at-berth emissions is targeting only SO_2 emissions, the reduction of which is also the objective of Emission Control Ares (ECAs). Therefore, a ship can switch to ultra-low sulfur fuel while at berth or within ECAs, or alternatively use scrubber systems to comply with the regulation (*2*). The scrubber solution reduces PM emissions as well, but has a limited effect on NO_x. A paradox is evident; between 2005 and 2015 (the sulfur limit was 1% within ECA, 0.1% at berth) a vessel calling at EU ports would have a higher incentive to invest in cold ironing as it would replace the use of ultra-low sulfur fuel at the port.

The objective of the paper is to start a discussion on the future prospects of cold ironing as a viable option to reduce in port emissions, as well as to present a quantitative framework that can be useful to stakeholders deciding on whether to invest in this technology or not.

METHODOLOGY

The fuel consumption $FC_{B,k}$ (tons) at berth (B) of a ship k can be given through equation 1.

$$FC_{B,k}(ton) = 10^{-6} \cdot (SFOC_{a,k} \cdot EL_{a,k} \cdot EP_{a,k} + SFOC_{b,k} \cdot EL_{b,k} \cdot EP_{b,k}) \cdot t_{B,k} \quad (1)$$

Where $SFOC$(g/kWh) is the specific fuel oil consumption, EL(%) the fractional load of the nominal power EP(kW) of the auxiliary engines (α) and boilers (b), and $t_{B,k}$ is the duration of berth. Bottom-up emissions methodologies are retrieving emissions generation $\varepsilon_{i,j,k}$ (kg of pollutant) through multiplication of fuel consumption $FC_{i,j,k}$ (kg) of each engine i on board vessel k, during activity phase j with appropriate emission factors $EF_{i,j,k}$ (kg pollutant / kg fuel) as in equation 2.

$$\varepsilon_{i,j,k}=FC_{i,j,k}\times EF_{i,j,k} \quad (2)$$

This study used the emission factors as suggested in the literature (*3, 4*). Through the use of cold ironing there are always local environmental benefits since the auxiliary engines of participating ships are turned off for a large part (or even throughout) of the berthing time. However, there are induced emissions at the source of energy generation that now powers to the vessel at berth.

To quantify these emissions, it is vital to know the energy mixture powering the port, and the relevant grid emission. A typical SFOC (g/kWh) for an auxiliary engine is 220 to 230 g/kWh which if multiplied with the CO_2 emission factor for MGO results in a range of 678 to 709 grams of CO_2 per kWh. In comparison, a coal factory has a CO_2 emissions factor of around 940g/kWh. Figure 1 shows a comparison of the global emissions balance when using cold ironing, as a function of grid emission factors for four pollutant species.

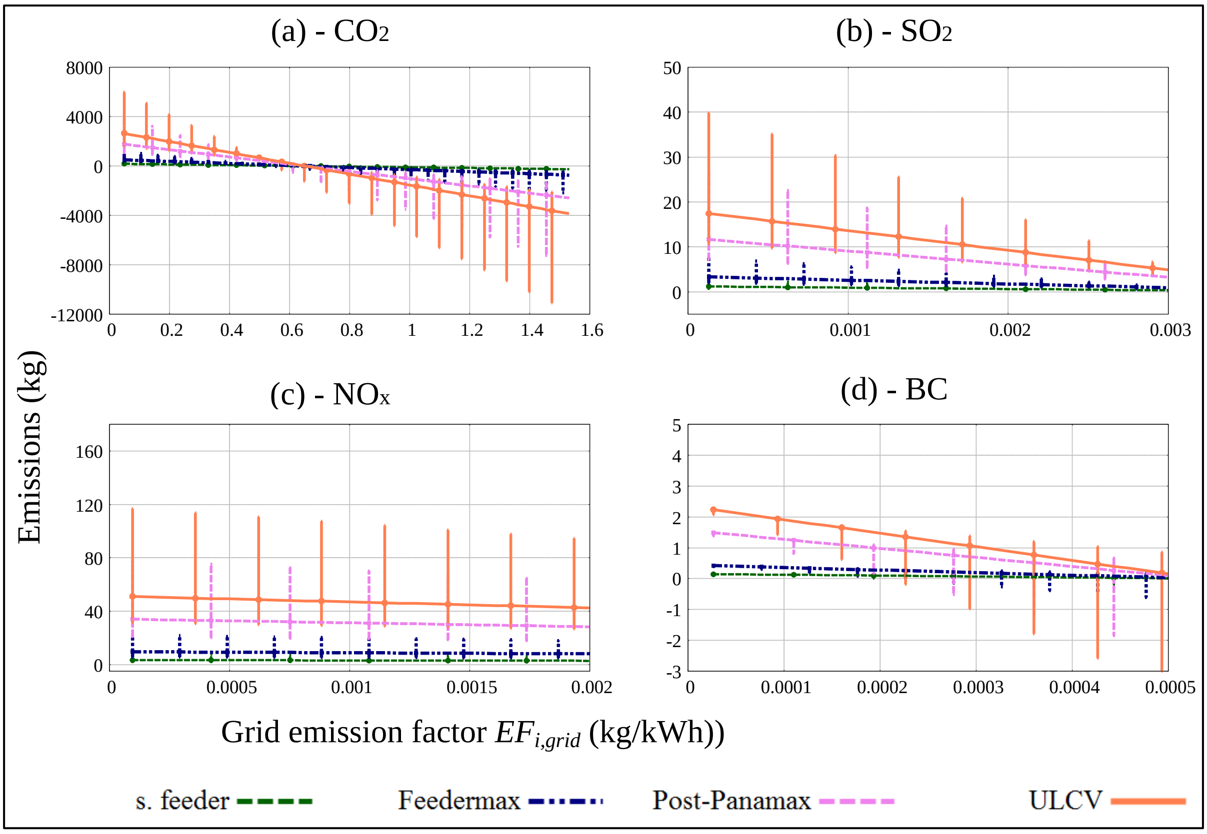

Figure 1: Balance of Global Emissions when using Cold Ironing, as a Function of Grid Emission Factors. Source (*5*)

The point where each line intersects the x-axis is essentially the point where the grid emissions factor considering conversion and transmission losses is equal to the emissions factor of the auxiliary engine.

The shipowner may have to retrofit the vessel to be able to receive shorepower with significant capital required $C_{R,k}$. During each year, the economic balance (cost or benefit) of ship k calling $N_{c,k}$ times at ports with cold ironing capability (c) and receiving shore power is found by equation 3.

$$\Delta C_{AMP,k} = \frac{C_{R,k} - S_{R,k}}{(1+r_k)^y} + N_{c,k} \cdot (t_{L,AMP,k} \cdot C_{t,k} + P_{AMP} \cdot E_{AMP,k} - FC_{a,B,k} \cdot P_{f,a} - R_{AMP,P,k}) \quad (3)$$

Where $S_{R,k}$ is a potential subsidy provided by a port towards retrofit costs and the first term (fraction) is the present value of the initial retrofit costs y years after the retrofit assuming an interest rate r_k. The term $t_{L,AMP,k}$ is the time lost during each call for plugging and unplugging the vessel with a value of time $C_{t,k}$. Finally, $R_{AMP,P,k}$ is any incentive provided per call from the port authority P to the vessel. The annual costs depend on:

- the number of berths N_B able to provide shorepower,
- the annual operating costs $C_{AMP,O,P}$(including maintenance, staff costs)
- the number n of vessels k using AMP at their calls,
- the price P_{grid} per kWh sold by the grid,
- the price $P_{AMP,k}$ per kWh sold to the calling vessel k,
- monetary incentives $R_{AMP,k}$ provided to a ship and finally
- potential subsidies $S_{R,k}$ provided to a ship towards retrofitting costs
- the discount rate r_P

The previous are summarized as annual costs through equation 4.

$$C_{AMP,P} = N_B \cdot \frac{C_{AMP,I,P}+C_{AMP,O,P}}{(1+r_P)^t} + \sum_{k=1}^{n} \left(\frac{S_{R,k}}{(1+r_P)^t} + R_{AMP,k} + P_{grid} \cdot E_{grid,k} - P_{AMP,k} \cdot E_{AMP,k} \right) \quad (4)$$

With the exception of California where cold ironing is heavily promoted and complemented by local regulations, it can be expected that a vessel would only use it, if financially beneficial. The economics of cold ironing has been a recurring theme in technical and academic literature with most studies emphasizing the importance of prices per kWh (*6*, *7*).

FINDINGS

This section considers the perspective of a ship owner and a port operator that opt to invest in cold ironing, for a few illustrative case studies.

The first case study considers the perspective of a ship operator that invests in retrofitting the vessel to be able of receiving shorepower. A typical investment (*CAPEX*) of $0.4 million is assumed (*8*) for the investment to retrofit a small Ro-Ro vessel with an auxiliary power of 6000kW and an engine load at berth of 30%. Assuming that the electricity cost (AMP_{kWh}) was 0.12$/kWh in 2013 and 0.09$/kWh in 2015, the payback period *N* of the investment can be estimated using equation 6, for the *N* that NPV becomes equal to zero:

$$NPV = CAPEX + \sum_{t=0}^{N} \frac{P_{fuel} \cdot FC_{aux} - AMP_{kWh}}{(1+r)^t} = 0 \quad (5)$$

where FC_{aux} (tons) is the fuel consumption of the auxiliary engine, and P_{fuel} the fuel price ($/ton) at berth. The Ro-Ro vessel is sailing four times a week between two ports A and B, with average berth duration of 8 hours at each port and a sailing time of 34 hours. The resulting payback period is shown in Table 1 assuming the fuel prices of 2013 (very high) and 2015 (very low) for different policy combinations.

TABLE 1: Payback Period for Ro-Ro Vessel AMP Retrofit (years)

Case Study	Payback period of retrofitting vessel with AMP capability	
	2013 fuel prices	2015 fuel prices
1 port has AMP, both outside SECA	56	NA
2 ports have AMP, both outside SECA	18	
1 port has AMP, both in SECA	8.6	71
2 ports have AMP, both in SECA	4.1	19.6

The results show that it is critical for the investment to be successful that both ports have AMP capability, and that it is a better option for vessels calling at ports with low sulfur requirements, or operating at times of high fuel prices. Due to the currently low number of ports that offer cold ironing, from the ship operators' perspective it may be better for Ro-Ro vessels in comparison to containerships that call into multiple terminals per year, and as a result will have less time using the AMP infrastructure.

The second case study considers the perspective of a port authority that seeks to maximize the emissions reductions of a specific pollutant from vessel activity in its proximity. The problem is essentially how to spend a given budget to minimize CO_2 emissions in the port, with the available options being the installation of 1or more cold ironing units in the berths, or providing a monetary incentive so that ships reduce speed in the port proximity (similar to a Vessel Sped Reduction Programme; VSRP).

The case study considers a typical container terminal of a 1.3 million TEU annual throughput, with 1700 vessel calls per year. A 2-week cycle is assumed for the terminal that has 3 discrete berths. The VSRP is considered for a 40NM radius around the port, with a reduction at 12 knots (as in POLA and POLB), and a monetary refund of 30% towards the port fees of the first day of dockage. The total costs for a full participation (all 1700 vessels) is estimated at $2.6 million per year. Berth costs are assumed at $1.5 million to build, which translates in an annual cost of $105000 assuming an interest rate of 6% in a 30 year investment plan. Under the assumption that 10% of the visiting vessels are able of using cold ironing, the following cost per ton of abated CO_2 is estimated in Table 2.

TABLE 2: Cost per abated ton of CO_2 using AMP and VSRP

Available Budget ($ million)	**Max CO2 reduction (tons/2weeks)**	**Cost per ton of CO_2**
4	4478	34.36
3	3608	31.98
2.6	3388	29.52
2.2	2753	30.74
1.8	2150	32.2
1.4	1580	34.1
1	1040	37.02
0.6	530	43.6

The analysis considered that the port is charging 0.11$/kWh and is not making profit (essentially sells power at the price it buys power). The results show that for tighter budgets only cold ironing is used, and as the budget allocation is increasing a VSRP is offered to the larger vessels.

CONCLUSIONS

The methodological framework constructed in this work can be useful to terminal operators and shipowners in deciding whether to invest in AMP applications. The analysis showed that some of the environmental regulation can have a positive impact on the further development of AMP as a technological solution. However, at the same time regulation that affects the whole journey of a ship (e.g. SECAs) may result in ship operators in investing in universal solutions such as scrubbers. From the port's perspective, a vessel using cold ironing is preferable to one having a scrubber or using MGO at berth. In addition, cold ironing is shown to offer a better cost value to the port authority than a VSRP, despite the currently low penetration rates of the technology on ship operators. It is probable that cold ironing will play a bigger role as a technological solution to improve the environmental performance of ports. Interesting research questions include the impact of a potential induction of the maritime sector in emissions trading systems (ETS) that the European Commission is contemplating, and the integration of berth scheduling problems in the presence of cold ironing berths.

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