Digitalization for Port Decarbonization

Decarbonization of key energy processes at the Port of Tyne

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Introduction

This article presents findings of the Clean Tyne Project. This project was part of the Clean Maritime Demonstration, funded by the UK's Department for Transport and delivered in partnership with Innovate UK. Announced in March 2020, and part of the Prime Minister's Ten Point Plan to position the UK at the forefront of green shipbuilding and maritime technology, the Clean Maritime Demonstration Competition was a £20m investment from government alongside a further £10m from industry to reduce emissions from the maritime sector. The contribution of Newcastle University in the project was to provide quantifiable evidence around the benefits of digitalization, by means of a real-time supervisory and data acquisition platform, in the reduction of carbon emissions, as well as operating and infrastructural costs, at the Port of Tyne.

The main aim of this article is to report and discuss the key outputs originating from the modelling performed by Newcastle University around specific operational scenarios at the port. These are intended to highlight the value of intelligent coordination of key energy processes and reduced uncertainty of associated data, both enabled by digitalization. For this purpose, we have designed and modelled current and future operational scenarios, in which Emission Reduction Technologies (ERTs)[1] and infrastructure are introduced, alongside increased capability for coordination of energy assets and data availability. In our analysis we consider a centralized decision-making process where energy costs and carbon emissions are minimized subject to available infrastructure and data.

Our results can be divided into three categories: impact of emission reduction technologies, impact of coordination, and impact of uncertainty on investment deferral. Under certain credible modelling and data assumptions, and considering energy operational costs and emissions, our findings are that: ERTs can yield significant emissions reductions of up to 93% in year 2040 compared to a present scenario, even if imported power is not 100% zero-carbon; energy costs related with key operations can be reduced up to 45% in year 2050 compared to a scenario where assets are not coordinated; and finally, confidence in data can yield significant reductions in infrastructural investment costs for key energy assets such as energy storage; we have noted that reduction of uncertainty through data availability (due to digitalization) led to a £3.35M reduction of CapEx for a particular case considering energy storage installed at the Port of Tyne.

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[1] Emission Reduction Technologies (ERTs) refer to: 1) shore power; 2) electrification of cargo handling equipment; 3) renewables; and 4) energy storage, in this article.

We now continue by showing how we modelled port operational scenarios. We then perform a quantitative analysis of cost and carbon emission savings that can be achieved by intelligent coordination of key processes, as well as savings in the form of deferral of network reinforcement and investment in new assets and technologies due to reduced uncertainty around historical data. We subsequently present our results, key findings, and conclude this article, including some suggestions for future work.

Modelling Operational Scenarios

The aim of the modelling described in this section is to demonstrate the ways in which data availability can assist in decarbonization of key port energy processes. The objectives developed to achieve this aim are as follows:

- Construct a mathematical model of the port's main carbon emitting activities for the present day (base case) and future scenarios.
- Study the effect of key emission reduction technologies, i.e., electrification of cargo handling equipment (CHE), provision of shore power to ships at berth, and installation of onsite renewables and energy storage, on energy cost and carbon emissions.
- Study the effect of optimal asset scheduling (intelligent coordination) on energy cost and carbon emissions.
- Study the effect of reducing data uncertainty around key operations on investment deferral.

The remainder of this section presents: the modelling scope and rationale; how the processes and assets at the Port of Tyne were modelled and simulated to form the base case; a description of the future scenarios; and the asset scheduling optimization problem.

Modelling Scope and Rationale

Port of Tyne's two main sites are the International Passenger Terminal at North Shields and Tyne Dock at South Shields. For this modelling, it was decided to focus on Tyne Dock as this is where the majority of commercial cargo handling activities occurs; it has a number of berths for different ship types and cargoes, and a diverse mix of CHE associated with these. It also has a reefer (refrigerated container) storage area and various office, commercial, and industrial buildings. Altogether this gives a good breadth of activities and assets on which to investigate the effects of coordination. Modelling the processes formed by these activities and assets also enables the detail and complexity of actual port operations to be captured and is expected to yield the most informative insights.

Tyne Dock site is shown in Figure 1, with its boundary outlined in red. The areas and berths are as follows: Tyne Car Terminal (TCT), having three berths, occupies the western area of the site; moving east along the quay Tyne Bulk Terminal (TBT), the Container Terminal (CT), Riverside Quay (RSQ), and Riverside Quay East (RSQE) each have one berth. The process modelled at each of these berths, including the assets engaged and their respective energy sources, is summarised in Table 1.

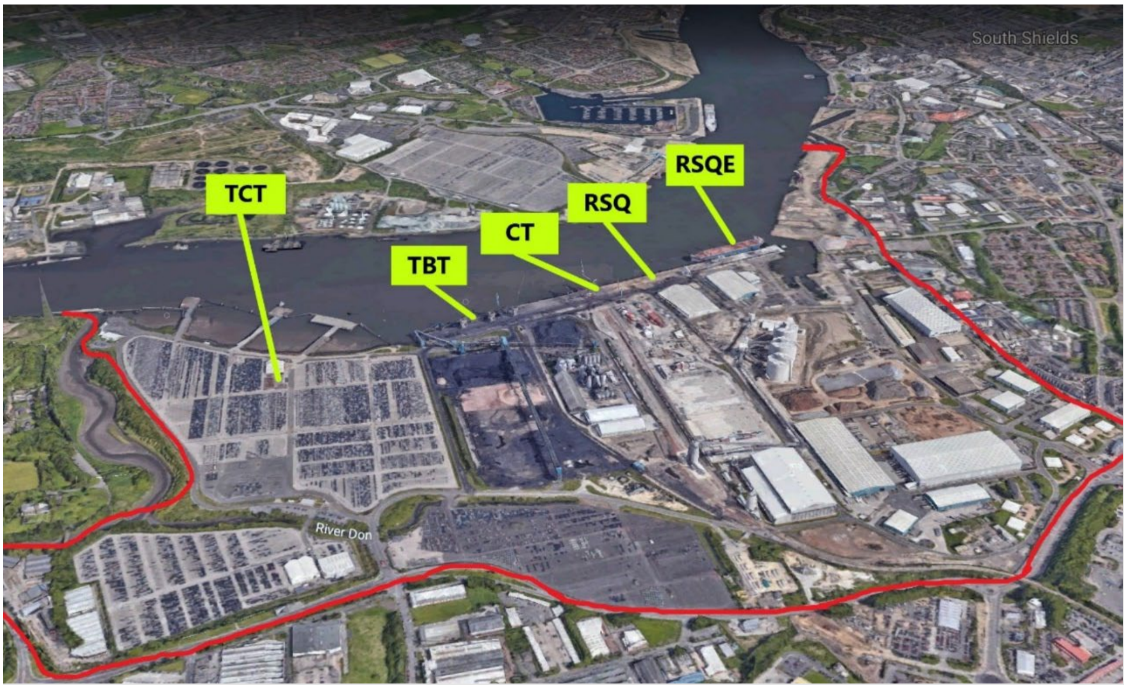

Figure 1. Tyne Dock site boundary and berths. (Source: Google Maps).

Table 1. Processes in the scope of this modelling.

Terminal/berth	Process modelled	Assets included	Energy source
Tyne Car Terminal	Ship only	2x ship Auxiliary Engines (AEs) at TCT1 & TCT2	Marine Gas Oil (MGO)
Tyne Bulk Terminal	Ship & cargo handling operation for Drax biomass import	1x ship AE	MGO
		2x electric portal cranes	Grid Electricity
		1x mobile harbour crane	Diesel
		3x eco hoppers	Diesel
		2x shovel loaders	Diesel
Container Terminal	Ship and container handling operation for container import/export	1x ship AE	MGO
		1x electric Ship to Shore (STS) crane	Grid Electricity
		Container Tractors x12 (3 in use)	Diesel
		Reach Stackers x3 (1 in use)	Diesel
		Empty Handlers x2 (1 in use)	Diesel
		Reefer storage x42 (21 in use)	Grid Electricity
Riverside Quay	Ship and cargo handling operation for plywood import	1x ship AE	MGO
		2x mobile harbour crane	Diesel
		20x Forklift Trucks (FLTs) (10 in use)	Diesel
Riverside Quay East	Ship & cranes only - biomass import	1x ship AE	MGO
		1x mobile harbour crane	Diesel
		1x mobile harbour crane	Diesel

Tyne Dock site is supplied by two Medium Voltage (MV) rings, each of which has its own Grid Supply Point: Tyne Coal 11kV ring supplies the western and central area of the site (covering TCT and TBT, and the Container Terminal berth and crane), whilst Slake Terrace 11kV ring supplies the central and eastern area (covering RSQ and RSQE, and reefer sockets in the container yard). In addition to the processes shown in Table 1, the energy demand of the office, commercial, and industrial buildings supplied by these two rings was also considered in the modelling. Other smaller CHE operating in the background – for example in transit sheds or moving cargo around the site independently of ship calls – is not considered. The processes modelled at each terminal are now described in more detail.

Tyne Car Terminal

The main operation here is motor vehicle export and transhipment. For these operations, cars are driven on and off the ship individually, and parked in the terminal area before/after. They are delivered to/from the port by road on car transporters. In this modelling, only the energy demand of the ship's Auxiliary Engine (AE) at berth is considered as there is no CHE operating at the car terminal that could be optimized. In our study, only two of the three berths at TCT are considered, as analysis of vessel call data showed that the third berth was not used.

Tyne Bulk Terminal

A bulk carrier at berth at TBT is unloaded by the port's two electric portal cranes, which lift biomass from the ship's holds into three eco-hoppers on the quay. When the biomass in the ship's holds reaches a certain level, it can no longer be accessed by the cranes, so two shovel loaders are lifted into the holds to shovel the biomass into the centre of the hold, making it accessible for the cranes again. The eco-hoppers deposit the biomass into eight-wheel tipper trucks which line up underneath and transport the biomass to storage sheds.

The assets and energy demand considered in this modelling include the ship's AE and the port's two electric portal cranes, three diesel hoppers, and two diesel shovel loaders. An additional mobile diesel harbour crane, which is also available for ship unloading at TBT, is also included. The eight-wheel tipper trucks and storage facilities are not considered as they belong to a third party and data was not available.

Container Terminal

Figure 2 explains the process followed by the arrival of a containership at the Container Terminal. When the ship arrives, containers are unloaded by the port's electric Ship-to-Shore (STS) crane. The STS crane lifts containers from the ship onto diesel-powered container tractors which are waiting on the quay, and which then transport the containers to the container yard. Within the container yard, diesel-powered reach stackers and empty handlers lift containers on and off the container tractors, and stack and move containers around the yard as needed. The process is reversed for transporting containers from the yard and loading them onto a ship. The container yard also has capacity for storing 42 reefer containers, supplied by grid electricity. The process modelled for the container terminal includes all the assets and activities described above. Road vehicles that transport containers to/from the port are not included.

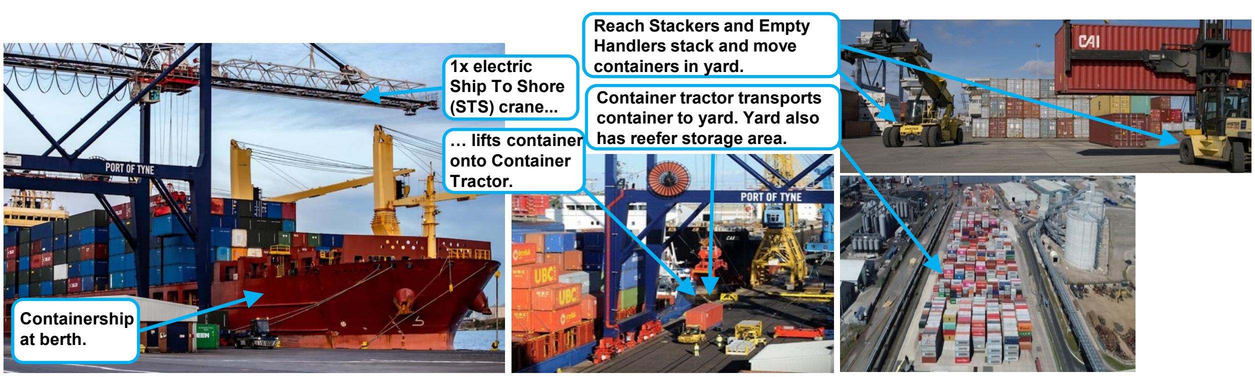

Figure 2. Process following the arrival of a containership. Ship-To-Shore Crane → Container Tractor → Reach Stacker & Empty Handler. (Source: Port of Tyne; used with permission).

Riverside Quay

The process modelled at Riverside Quay is plywood import. This includes the ship's AE at berth, two of the port's mobile diesel harbour cranes, which unload the plywood from the ship onto the quay, and the port's Forklift Trucks (FLTs), which transport the plywood from the quay to storage.

Riverside Quay East

RSQE is used for biomass import for a power station. When a ship arrives at berth, biomass is unloaded by two of the port's mobile diesel harbour cranes into two hoppers on the quay. From these hoppers, it is transported by conveyor to storage and rail loading silos. In this modelling, only the ships' AE at berth and the port's two mobile diesel harbour cranes are considered, as the rest of the CHE (hoppers, conveyors, and silos) is already electric and fully automated, with its own MV ring and separate Grid Supply Point, all operated independently by the power station company.

Building the Base Case Model

In order to quantify the impact of ERTs and asset coordination in future scenarios, a base case model was constructed to capture the present energy demand, cost, and carbon emissions of in-scope activities and assets at the port. This base case model represents the port as-is in 2022, with no ERTs or coordination of assets.

Input Data and Sources

To build the base case model, it was necessary to acquire, analyse, and combine asset data from a wide range of sources. Figure 3 summarises the main datasets considered.

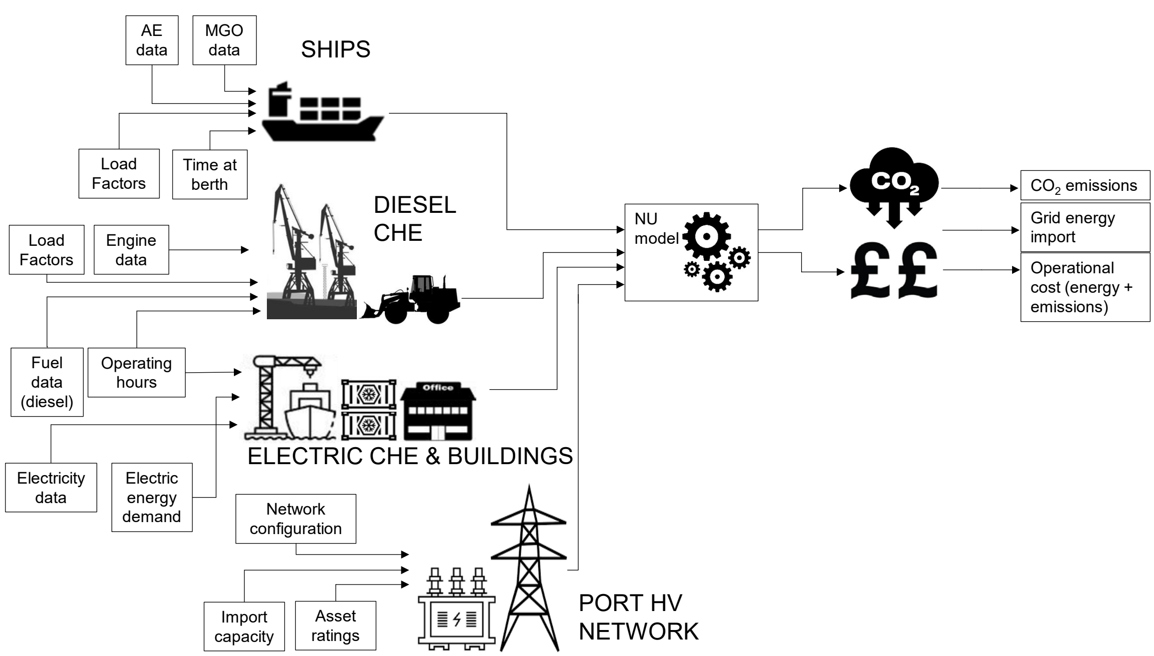

Figure 3. Input data for base case modelling.

Base Case Model Simulation

In order to estimate the carbon emissions and total cost of each energy source (Marine Gas Oil (MGO), diesel, and grid electricity) used by the assets in each process, and of the building energy demand on Tyne Coal and Slake Terrace 11kV rings, the base case model was developed and simulated in MATLAB® for a 24-hour period.

For the 24-hour simulation period, it was required to know how many assets would be operating and what their individual power demands would be. The requirement for main CHE items (such as cranes and hoppers) to be operating originates from the arrival of a ship at berth; thus, the starting point for each process was to determine the length of time a ship would be at each berth within a 24-hour period. This was done by analysing vessel call data from the port's Vessel Tracking Service; in order to obtain a broad sample, we collected this data over a continuous nine-month period. From this data, and for each berth, we summed the total duration of all ship calls in the nine months, and then took a daily average. In this way, we arrived at the number of hours a ship would be at each berth in the 24-hour simulation period.

Interviews with operational managers from the port's container and bulk and conventional cargoes business areas established the type and typical number of CHE assets allocated to each ship type. These assets, shown in Table 1, are allocated to a ship for the whole time that it is at berth, and during this time their operation is assumed to be continuous (breaks in operation for events such as refuelling or other interruptions have not been considered). To estimate the typical operating power demand of each asset, its rated engine or motor output power was multiplied by a load factor. Rated output power was obtained from manufacturer datasheets for most CHE models, but in cases where the exact model was not known or the datasheet was not available, datasheets for similar models were used. CHE load factors were taken from an emissions inventory conducted by Starcrest Consulting Group for Port of Los Angeles, which has long been at the forefront of port emissions reduction and decarbonization.

The typical power demand of ships' AEs at berth was also estimated by applying a load factor to the total installed AE power. The total installed AE power for each ship that called at each berth was identified from Clarkson's World Fleet Register using ships' IMO numbers from the vessel call data, whilst AE load factors were selected through a comprehensive literature review. The estimated at berth AE power demand for each ship type and size was compared with estimates made in the IMO 4th Greenhouse Gas Study and found to be similar. For the simulation, the average AE power demand of all in-scope ships at each berth was used.

The power demand of the ships and CHE involved in each process was multiplied by the process duration to give the energy demand of each asset. Data regarding costs and emissions factors for the different energy sources was then used to produce estimated energy cost and carbon emissions for each asset individually, and as a total for each energy source, for the 24-hour simulation period.

For the building energy demand on Tyne Coal and Slake Terrace 11kV rings, Single Line Diagrams (SLDs) and substation schematics were analysed to determine which substations the buildings were supplied from. Peak power demand for each building was estimated and load profiles were applied to produce building energy demand for the 24-hour simulation period.

Network Modelling

Considering the port's existing electrical network and site layout, points of connection for ERTs in future scenarios would be on Tyne Coal and Slake Terrace 11kV rings. Accordingly, these rings were also modelled in MATLAB® and simulated for the 24-hour period, considering the network topology, power flow, and voltage limits. Substation locations, asset nameplate data, and cable lengths were obtained from SLDs, whilst substation connected loads (buildings, electric CHE, and reefer storage) were identified from substation schematics. Establishing the base case power flow enables the effect of the ERTs installed in future scenarios to be understood.

Future Scenarios

Future scenarios considered for the Port of Tyne are summarised in Table 2. Beyond 2022, ERTs are progressively introduced so that by 2050 port infrastructure is fully decarbonised. Each scenario provides a snapshot of the port on its decarbonisation journey, with the amount of ERTs installed in each year increasing. This enables the impact of ERTs on carbon emissions and energy cost to be quantified. As more ERTs are introduced, more assets can be coordinated; thus, the degree of coordination also increases in each scenario, which allows the impact of coordination on carbon emissions and energy cost to be quantified as well. These future scenarios would of course require capital expenditure on new infrastructure and CHE; however, our modelling focuses on operational optimization and thus only considers operational (energy) costs.

Table 2. Summary of Future Scenarios.

Base Case 2022	2030	2040	2050
	50% of CHE electrified	100% of CHE electrified	
	Shore Power installed at 50% of berths	Shore Power installed at 100% of berths	
As-is	20% of planned renewables installed	50% of planned renewables installed	100% of planned renewables installed
	Cranes & reefers coordinated	50% of planned Energy Storage installed	100% of planned Energy Storage installed
		Cranes, reefers, EVs, & ESS coordinated	Increased assets & ESS; increased coordination

For clarity, the percentages shown are approximate and do not represent the exact proportions for each scenario.

Future Scenario 2030

By 2030, shore power has been installed at TCT1 and TCT2. At TBT, the diesel harbour crane and three diesel hoppers have been electrified; at the container terminal, diesel container tractors, reach stackers, and empty handlers have been replaced with battery-powered models; at RSQ, diesel FLTs have also been replaced with a battery-powered fleet; at RSQE, two diesel cranes have been electrified. All other CHE remains diesel-powered. Twenty electric vehicle (EV) charging points have also been installed across the site. Except for a single 752kW rooftop photovoltaic (PV) installation at Warehouse 21, there are no renewables or energy storage on site. In this scenario, operation of electrified cranes, charging of battery-powered CHE, and refrigeration demand of reefer storage are coordinated for cost and carbon intensity.

Future Scenario 2040

By 2040, shore power has been installed at all remaining berths (TBT, CT, RSQ, and RSQE) and all remaining CHE in scope (two cranes at RSQ and two shovel loaders at TBT) has been electrified or replaced with battery-powered versions. Forty more EV charging points have also been installed and the port is now considered 'All Electric'. To help offset the resultant increase in grid energy demand, 1460 kW of rooftop solar PV installations and two 500kW wind turbines have been installed, as well as energy storage in the form of two 1.25MW/2.5MWh batteries (one connected to each MV ring). In this scenario, coordination is extended to the operation of all electrified (mains-powered) CHE, charging of battery-powered CHE, EV charging in parking bays, and energy storage system (ESS) charging and discharging.

Future Scenario 2050

By 2050 a third 500 kW wind turbine and three 400 kW PV car park canopies have been installed, along with additional energy storage in the form of 2MW/4MWh hydrogen. The port is now considered to be operating as a microgrid/local energy system with full coordination of all connected assets and the capability to export energy to the grid.

Simulation of Future Scenarios

Each future scenario was modelled and simulated in the same way as the base case, for a 24-hour period. However, each scenario is simulated in two stages; initially, only the infrastructural changes in each scenario are simulated so that the impact of ERTs on carbon emissions and energy cost can be determined. Then, each scenario is repeated but with the asset coordination incorporated into each simulation. This enables a comparison of carbon emissions and energy costs with and without asset coordination. The following section provides a high-level overview of how the optimization problem for asset coordination was formulated.

Optimization Problem

The aim of our optimization problem is to coordinate flexible demand (and storage) in order to minimize cost of all fuels (MGO, diesel, and electricity), as well as carbon emission cost. This is an optimal scheduling problem, in which the main decision variables are flexible load power consumptions, which are adjusted (in terms of magnitude and time, i.e., how much and when), to minimize cost of energy and carbon emission cost. A high-level overview of our model is shown in Figure 4.

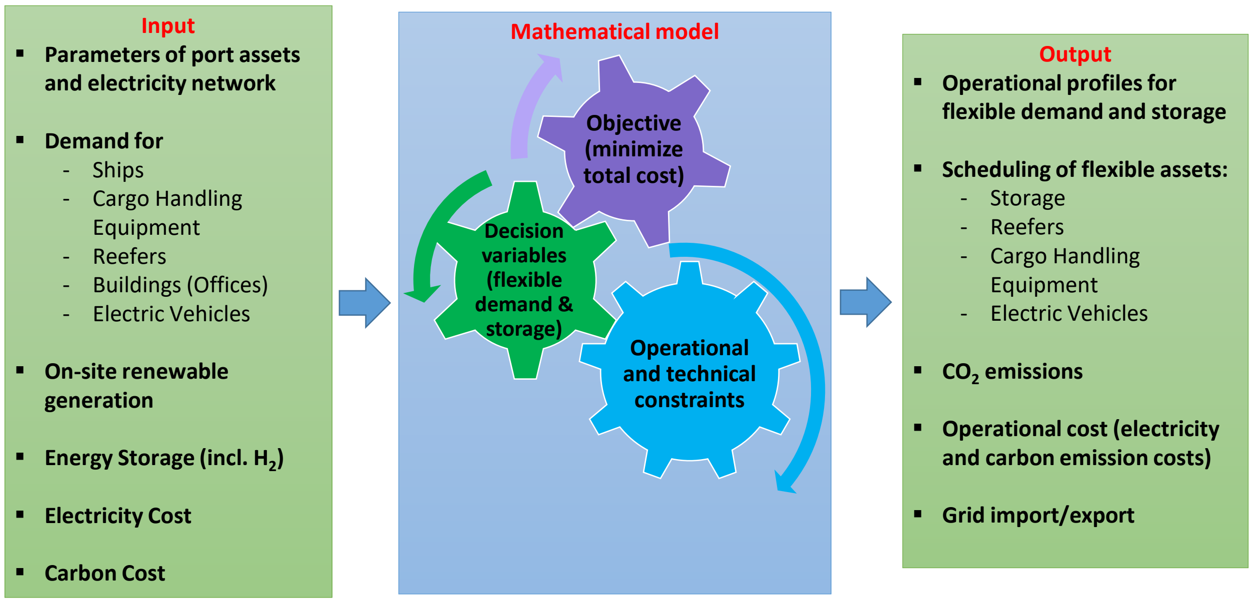

Figure 4. High-level overview of the developed mathematical model.

Objective Function

The objective function is to minimize the total cost, which comprises the energy cost (electricity, MGO, diesel) and the carbon emission cost. Electricity price and grid carbon intensity vary throughout the day, as shown in Figure 5. Therefore, the lower the values of electricity price and carbon intensity are at a specific time step, the more grid electricity usage is encouraged.

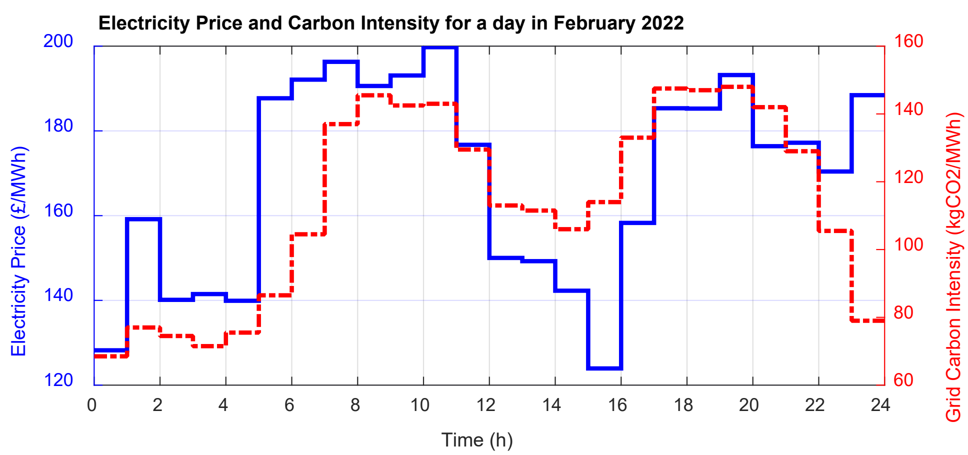

Figure 5. Electricity price and grid carbon intensity for a day in February 2022.

Constraints

We formulate the constraints as mathematical equations. Key constraints represent: 1) the network, 2) mains-connected (e.g., cranes) and battery-powered (e.g., Forklift Trucks) CHE, 3) reefers, 4) energy storage, and 5) electric vehicles. Below, we describe what the constraints express.

1) The equations for the network, which are called power flow equations, account for the topology of the network, the energy losses, as well as the power flow and voltage limits.

2) The main equation for the cranes relates the load of the ship at a specific time step with the load of the ship at the previous time step and the corresponding operating status of the cranes (i.e., operating or idle). Moreover, the ship has an initial load, which should be unloaded by the end of its stay in the port. In terms of battery-powered CHE, number of assets and availability are taken into account, as well as charging and discharging limits.
3) The main equation for the reefers links their internal temperature at a time step with the corresponding temperature at the previous time step, along with the cooling power of the device and the ambient temperature (i.e., thermal model). The demand of reefers is flexible because of their thermal inertia; therefore, we can exploit this characteristic to optimally schedule their consumption when electricity price and carbon intensity are at their lowest values. We have considered a setpoint of -29°C, along with a band of 1°C around the setpoint, within which the reefers maintain their internal temperature.
4) Energy storage equations involve: the relationship of the state of charge with charging/discharging power and efficiency; power limits; and ensuring that the device does not charge and discharge at the same time.
5) Similar equations apply for electric vehicles, except for discharging capability (vehicle-to-grid was not considered), which means that optimal charging was the aim for EVs. EVs were assumed to arrive at the port at 08:00 with 50% state of charge, and leave at 17:00 with 90% state of charge.

Results

Having provided a high-level overview of our mathematical model, this section presents the results, which are divided in three subsections: 1) impact of coordination (optimization); 2) impact of emission reduction technologies (shore power, CHE electrification, onsite renewables, and energy storage); and 3) impact of uncertainty on investment deferral.

Impact of Coordination

We have simulated three scenarios which correspond to a representative day in 2030, 2040, and 2050, respectively. The associated results are presented in the following sections. In each of these scenarios, results are compared with and without coordination/optimization, and some key results are illustrated.

Scenario 2030

Table 3 provides an overview of the simulation results for the 2030 scenario. The impact of coordination is manifested by the savings in terms of carbon emissions and total cost (total cost is cost of energy + cost of carbon emissions). Carbon emission savings are equal to 48 kgCO_2e/day, which accounts for 1% of the ‘2030 no optimization’ case, whilst total cost savings are 2%. Note that only reefers and cranes are optimized in this scenario, and approximately 50% of the assets are considered to have been electrified.

Table 3. Results overview of 2030 scenario.

Case	Carbon Emissions (tCO_2e/day)	Total Cost (£/day)
2022 base case	15.130	8,530
2030 no optimization	5.743	6,878
2030 optimized	5.695	6,767

The ‘no optimization’ case considers two cranes operating all the time during which the ship is at berth at the Bulk Terminal. The ‘optimized’ case considers three cranes available, which not only gives the port (considered as microgrid operator) the opportunity to increase the rate of unloading the ship, but also to stop operation at times when electricity price and/or carbon intensity are high (see Figure 5).

Of the total 48kg saving, 9kg comes from coordination of cranes at TBT, 16kg comes from coordinating reefers, and the remaining 23kg comes from coordinating cranes at RSQE.

Scenario 2040

The results overview for 2040 is shown in Table 4. Impact of coordination is greater here because: i) more asset types are coordinated (cranes, reefers, EVs, and battery-powered CHE), and ii) all assets have been electrified. Carbon emission savings are now 134 $kgCO_2e$/day, which account for 12% of the ‘2040 no optimization’ case. In terms of total cost, the corresponding saving is 16%.

Table 4. Results overview of 2040 scenario.

Case	Carbon Emissions (tCO_2e/day)	Total Cost (£/day)
2030 optimized	5.695	6,767
2040 no optimization	1.079	4,121
2040 optimized	0.945	3,476

Sixty (7 kW / 24 kWh) EVs are charged between 08:00 – 17:00, with the assumption that their initial state of charge is 50%, and the final is 90%. The ‘no optimization’ case assumes uniform charging across the whole time period during which EVs are parked at the port, while the ‘optimized’ case optimizes charging according to variable electricity and carbon emission prices (shown in Figure 5). The resulting carbon emission saving is 2 $kgCO_2e$/day.

Scenario 2050

A results overview for the 2050 scenario is shown in Table 5. Total cost saving is now £916/day, which accounts for 45% of the ‘2050 no optimization’ case. In this scenario, for approximately half of the day, the network exports to the grid, which leads to an operating profit of £371/day. Exporting, due to renewables and storage, could represent an additional revenue for the port.

Table 5. Results overview of 2050 scenario.

Case	Carbon Emissions (tCO_2e/day)	Total Cost (£/day)
2040 optimized	0.945	3,476
2050 no optimization	0	2,051
2050 optimized	0	1,135

Impact of Emission Reduction Technologies

This section briefly describes the impact of ERTs. Shore power and electrification (as well as one PV installation) from 2022-2030 results in 62% reduction from base case emissions. Going all-electric by 2040 further reduces emissions by 93% compared to 2022. This is also due to installation of two 500kW wind turbines, multiple PV installations (2.2 MW in total), and 2.5 MW / 5 MWh of energy storage. Emissions are zero in 2050. The decarbonization of UK electricity supply is the main driver behind this result. More discussion follows in the 'Key Findings and Discussion' Section.

Impact of Uncertainty on Investment Deferral

In order to investigate the impact of uncertainty on investment deferral, we now take the previous 'Future Scenario 2040' as a new base case. Within this scenario, we focus on Tyne Coal 11kV ring, which has a Battery ESS (BESS) of 1.25MW/2.5MWh connected. The simulation of this scenario results in carbon emissions of 1.033tCO_2e/day from the Tyne Coal ring. Without knowledge of historical data, we assume 50% uncertainty of net demand (load minus renewable generation) at each bus of the Tyne Coal network. As an example, the average shore power demand at TCT1 is 1.04MW; assuming 50% uncertainty means that the actual shore power demand profile could range from 0.52 – 1.56MW. Possible profiles are produced using Monte Carlo Simulation, where at each time step, we sample shore power demand from the following interval: $[0.5 \cdot 1.04, 1.5 \cdot 1.04] = [0.52\text{MW}, 1.56\text{MW}]$. In this base case, the probability of exceeding the emissions of 1.033tCO_2e/day is around 50%.

If we now double the size of the BESS to 2.5MW/5MWh and perform the same Monte Carlo simulation (with 50% uncertainty), the resulting probability of exceeding the base case emissions of 1.033tCO_2e/day decreases to 10%. A bigger BESS gives the capability to manage carbon emissions more effectively by taking advantage of the variability of grid carbon intensity; the BESS can charge when grid carbon intensity is low, and discharge when it is high, so that the demand on Tyne Coal is met with lower emission electricity. However, the bigger BESS will come at significantly higher capital cost.

If sufficient historical data for net demand was available, the uncertainty would be significantly reduced. For example, if we assume that sufficient data would reduce the uncertainty of net demand to 10%, more accurate scheduling would be possible, and, therefore, a smaller BESS would be required to achieve the same emissions. By trying different sizes of BESS, we found that this is achieved with a 1.5MW/3MWh battery, which is only 20% bigger than the initial battery, and significantly smaller than the 2.5MW/5MWh battery that would be required in the case of 50% uncertainty of net demand. This in turn would result in a substantial CapEx saving.

Key Findings and Discussion

This section presents the key findings and discusses the results reported above.

Coordination

Figure 6 illustrates the difference coordination can make in 2030, 2040, and 2050. Electrification of assets combined with data collected in a digital platform enables coordination of assets, leading to significant CO_2 and total cost reductions. The impact of coordination increases as more assets are electrified and as more renewables and storage are added. In a fully electrified port, coordination can enable negative CO_2 emissions and power export from onsite renewable energy sources to the grid, generating additional revenue. Table 6 summarizes the results of coordination impact.

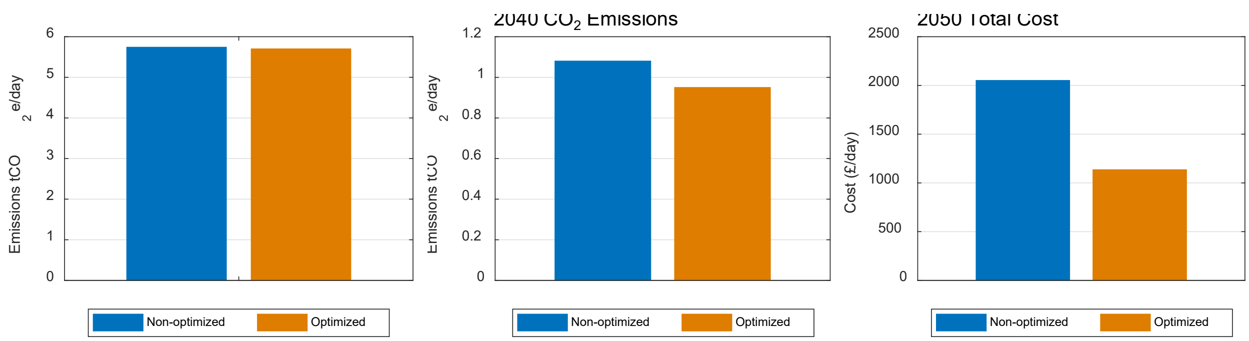

Figure 6. Impact of coordination (operational optimization) on carbon emissions / total cost in 2030, 2040, and 2050.

Table 6. Summary of coordination impact results.

	2030	2040	2050
Emissions reduction due to operational coordination (compared to non-coordinated operation)	1%	12%	N/A
Total Cost reduction due to operational coordination (compared to non-coordinated operation)	2%	16%	45%

Emission Reduction Technologies

Emission reduction technologies (shore power, electrification of CHE, onsite renewables and energy storage) have significant emission reduction impact, as shown in Figure 7. Table 7 presents the CO_2 reduction in 2030, 2040, and 2050 compared to 2022.

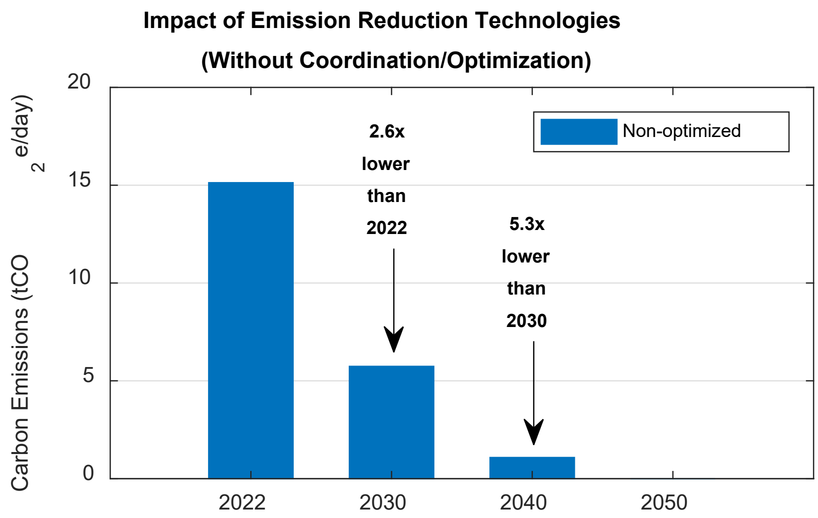

Figure 7. Impact of Emission Reduction Technologies.

Table 7. Impact of emission reduction technologies on carbon emissions.

	2030	2040	2050
Emissions reduction due to technological measures (compared to 2022)	62%	93%	100%

As part of our analysis, we have also considered a pessimistic scenario, where UK electricity supply is not fully decarbonized in 2050. In that case, the carbon intensity level is equal to that of 2040, which is 40% of 2022 level. In this case, there is a remaining 4% CO_2 emissions in 2050 (compared to the 2022 level), which is further decreased to 2% with optimization. What was interesting in this case was that one of the port networks effectively produced negative emissions, which shows that ports (or more generally local energy systems) can help achieve net zero by exporting electricity to the grid when grid carbon intensity is non-zero. Exporting when carbon intensity is zero, would not make any difference, but exporting when there is non-zero carbon intensity, would reduce electricity supply emissions. Coordinating local energy systems at a national scale would then be able to offset any remaining emissions stemming from electricity supply.

Uncertainty and Investment Deferral

To evaluate the impact of uncertainty on investment deferral, we have performed a feasibility study to obtain two BESS solutions that result in the same value of emissions, while each corresponding to a different level of uncertainty. In the first case, without a digital platform, the lack of data results in a high uncertainty of net demand – assumed to be 50%. With this level of uncertainty, a 2.5MW/5MWh BESS is required to achieve emissions of 1.033tCO_2e/day. In the second case, data made available through a digital platform is estimated to reduce uncertainty of net demand to 10%. With this reduced uncertainty, the size of BESS required to achieve the same emissions of 1.033tCO_2e/day is now only 1.5MW/3MWh. This analysis shows that a 40% reduction in data uncertainty results in a 1MW/2MWh reduction of required BESS capacity; based on capital costs of £1.16M/MW and £1.095M/MWh, this results in a CapEx saving of £3.35M. The main conclusion, therefore, is that a 40% reduction of uncertainty through data availability leads to a £3.35M reduction of CapEx for a particular case considering energy storage installed at the port.

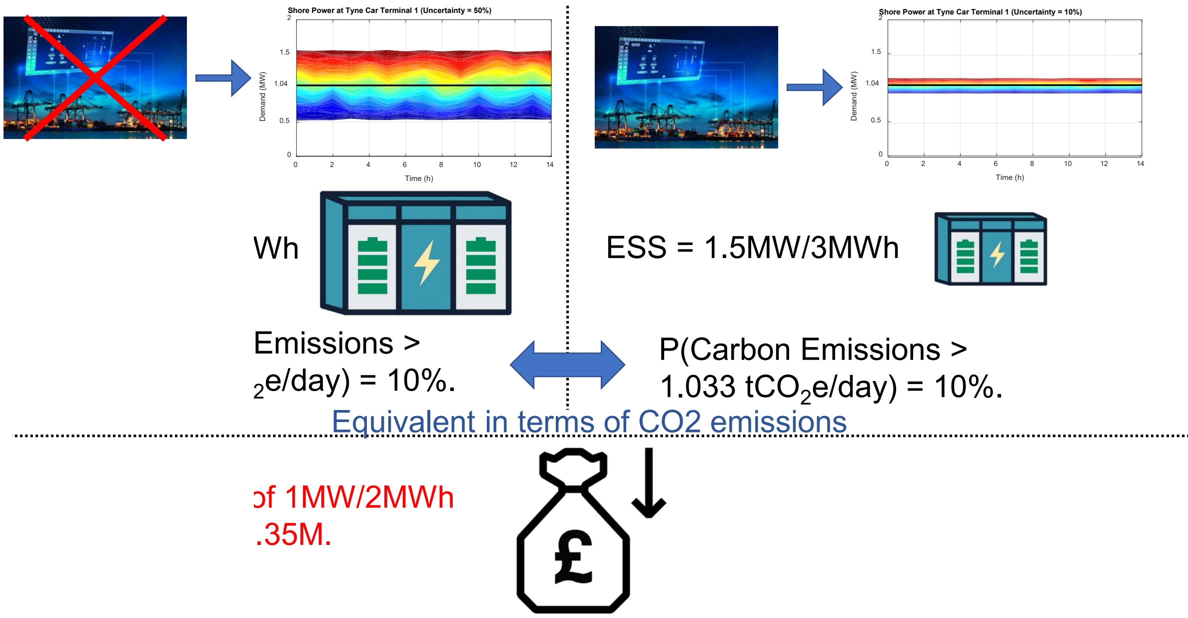

Figure 8. Uncertainty and Investment Deferral Overview. Left: Without Digital Platform/Digitalization. Right: With Digital Platform/Digitalization.

Conclusions

Through this work we have produced a range of results targeted at providing quantifiable evidence around potential contributions digitalization (in the form of a digital platform) can have in the reduction of carbon emissions, as well as operating and infrastructural costs. Our results have been divided in three main categories: impact of emission reduction technologies, impact of coordination, and impact of uncertainty on investment deferral. Under certain credible modelling and data assumptions, and considering mainly energy operational costs and emissions, our key findings are:

1) Shore power, electrification of CHE, onsite renewables, and energy storage can yield significant emissions reductions of up to 93% in year 2040 compared to a present scenario, even if imported power is not 100% zero-carbon.
2) Energy costs related with key operations can be reduced up to 45% in year 2050 compared to a scenario where assets are not coordinated.
3) Confidence in data can yield significant reductions in infrastructural investment costs for key energy assets such as energy storage. We have noted that a 40% reduction of uncertainty (through data that could be made available by a digital platform) led to a £3.35M reduction of CapEx for a particular case considering energy storage installed at the port.

In our modelling, the optimal coordination of CHE such as cranes for energy cost and carbon emissions reduction was achieved through making additional assets available to service ships at berth, which would otherwise not be in use. For example, making a third crane available at the Tyne Bulk Terminal to unload a bulk carrier. As a result, there was no increase in the time taken to unload a ship, and thus no financial penalties incurred by the port for breaching the vessel turnaround time agreed in its contract(s) with the relevant parties.

Future work could consider such penalties into the formulation of the optimization problem in order to explore potential benefits of extending the stay of a vessel at berth on cost, carbon emissions, and network constraints. Optimization can also be beneficial as a tool to better inform negotiations between the port and customers who are willing to accept a longer ship turnaround time, if it results in lower carbon emissions. A shorter handling time would require a more intensive asset utilization, which would be preferred by the customer, but might put a pressure on the port's CHE availability, and also increase emissions, cost, and potentially violate electricity network constraints. This tool could assess each option, and provide the optimal trade-off between duration, CHE utilization, emissions, and cost, while also ensuring all network constraints are satisfied.

For Further Reading

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