TØI report 1461/2015

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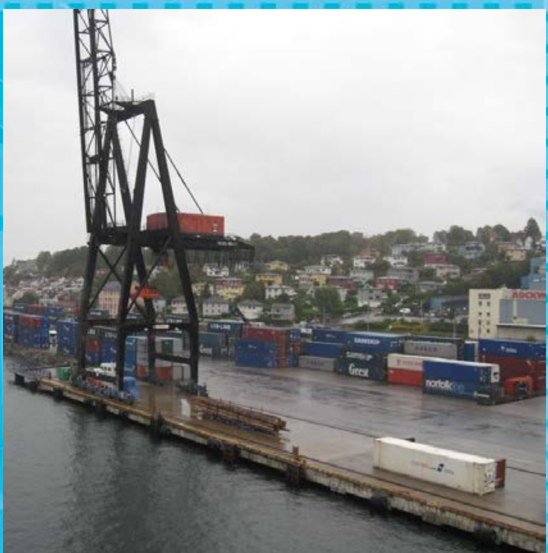
Institute of Transport Economics
Norwegian Centre for Transport Research

# Data availability for traditional and environmental productivity and efficiency analyses of Norwegian ports



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**Title:** Data availability for traditional and environmental productivity and efficiency analyses of Norwegian ports

**Tittel:** Datatilgjengelighet for tradisjonell og miljømessig produktivitets- og effektivitetsanalyse av norske havner

**Author(s):** Kenneth Løvold Rødseth, Paal Brevik Wangsness

**Forfattere:** Kenneth Løvold Rødseth, Paal Brevik Wangsness

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**Summary:**

This report concludes Work Package 1 of the research project entitled EXPORT, which is financed by the Research Council of Norway, the Norwegian Coastal Administration, and KS Bedrift Havn. The report surveys available data sources for ports in Norway, and focuses on their applicability to microeconomic analysis of the social costs of port operation. Moreover, the report provides an overview of data management and the construction of datasets to be used for EXPORT's subsequent empirical analyses.

**Sammendrag:**

Denne rapporten konkluderer arbeidspakke 1 (WP1) i prosjektet EXPORT, som finansieres av Forskningsrådet, Kystverket og KS Bedrift Havn. Rapporten gjennomgår tilgjengelige data om aktiviteten til norske havner og miljøaspekter ved denne. Videre fokuserer den på dataenes anvendelighet for mikroøkonomiske analyser av norske havners produktivitet og effektivitet, både tradisjonell og miljømessig. Rapporten gir også en oversikt over planlagt databehandling og konstruksjon av datasett til EXPORTs empiriske analyser.

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# Preface

This report responds to Tasks 1.2 and 1.3 of Work Package 1 of the research project entitled "Examining the Social Costs of Port Operations", abbreviated "EXPORT". The report summarizes the outputs of Work Package 1, and its publication is one of the key milestones of the project. The project is financed by the Research Council of Norway, the Norwegian Coastal Administration, and KS Bedrift Havn, and will be executed over the period between 2014 and 2018.

The overall objective of the EXPORT project is to examine environmental-economic trade-offs in cargo handling in Norwegian ports. We consider microeconomic production analysis to be an appropriate tool for this purpose, in particular because a series of production models that include externalities have recently been developed. This report summarizes available data on port operations that facilitate undertaking traditional and environmental production analyses of Norwegian ports. It reviews and ranks available data sources, and describes how data have been selected, compiled, and processed to produce two datasets that are essential inputs to EXPORT's subsequent empirical analyses.

EXPORT's project leader Kenneth Løvold Rødseth and Paal Brevik Wangsness (Institute of Transport Economics) have written the report. While they have been in charge of the data collection and management, EXPORT researchers Finn R. Førsund and Inger Beate Hovi have provided important inputs to the data collection process. Halvor Schøyen (Buskerud and Vestfold University College) has been the quality manager. We are grateful to Thorkel C. Askildsen at the Norwegian Coastal Administration for providing helpful comments to the manuscript. Of course, the usual disclaimer applies.

We acknowledge with thanks important inputs from key stakeholders of the Norwegian port sector, in particular Senior Engineer Kristine Mordal Hessen and Chief Engineer Erik Høygaard of the Norwegian Environment Agency, Senior Researcher Susana Lopez-Aparicio of the Norwegian Institute for Air Research, Port Advisor South Carl Johan Hatteland of the Port of Oslo, and Port Director Rune J. Arnøy of the Port of Narvik. Data and assistance from Statistics Norway and the Norwegian Costal Administration is much appreciated. Finally, we thank the 23 Norwegian ports that helped quality ensuring EXPORT's port infrastructure data.

Oslo, desember 2015
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| *Managing director* | *Research Director* |

# Content

Summary:

# Data availability for traditional and environmental productivity and efficiency analyses of Norwegian ports

*TØI Report 1461/2015*
*Author(s): Kenneth Løvold Rødseth and Paal Brevik Wangsness*
*Oslo 2015, 53 pages English language*

*This report reviews and rates 16 relevant data sources on port operations, before describing the selection, compilation, and management of data. The report concludes by presenting an overview of the two datasets that have been constructed for the empirical analyses of the research project entitled "Examining the Social Costs of Port Operations (EXPORT)". This report concludes EXPORT's Work Package 1.*

This report responds to Tasks 1.2 and 1.3 of Work Package 1 of the research project entitled EXPORT. The report summarizes the outputs of Work Package 1, and its publication is one of the key milestones of the project. The report is tailor-made for researchers associated with the EXPORT project, but will also be of interest to stakeholders in the maritime sector in Norway and to the scientific community.

The report summarizes available data on port operations that facilitate undertaking traditional and environmental production analysis of Norwegian ports. It includes i) a description of the data selection process (including information on the project team's communication with Norwegian ports and other key stakeholders), ii) a review and ranking of all relevant data sources, iii) a formal discussion and justification of the selection of ports and data to be analysed, and iv) an overview of how the data has been compiled and arranged for EXPORT's subsequent empirical analyses. The data can broadly be classified into activity data, environmental data, and other data. In total, 16 relevant data sources were reviewed and rated by the project team before compiling and organizing the data.

We have utilized data for 25 ports included in Statistics Norway's quarterly port statistics. The reasons for this is that they are the main ports in Norway and thus play a key role in promoting a mode shift to maritime transport, and because we have access to good data – comprising information about cargo type and throughput, the duration of the cargo handling, and ship type and size for each call taking place at these ports. The port statistics coupled with self-compiled data on port capacity makes up our activity data.

In a preceding EXPORT-report, Rødseth and Wangsness (2015) proposed that i) the dispersion of contaminated sediments, ii) emissions to air from ships at berth, iii) air and noise emissions from land-based port operations, and iv) soil, sediment, and water pollution due to accidental spills are the key externalities associated with port operations. Our compilation of environmental data has therefore been targeted at obtaining information about the occurrences of these four categories of pollutants. We have found that the dispersion of polluted sediments and air pollutant emissions from ships at berth can be estimated using available tools and data. We have further reviewed a database on accidental oil spills to locate events that have taken place at the ports included in Statistics Norway's quarterly port statistics. The information on sediment pollution, ship emissions, and accidental spills can be connected to our port-level activity data. However, high-quality data on noise emissions from port operations are only available for Sjursøya and Ormsund container terminals located within the port of Oslo. Consequently, a separate case study needs to be undertaken to evaluate the relationship between port activities and noise pollution. This means that in total two datasets – one dataset on port-level activity and emissions data and one dataset on noise emissions and container handling activities in Oslo – has been constructed within EXPORT's WP1.

Sammendrag:

# Datatilgjengelighet for tradisjonell og miljømessig produktivitets- og effektivitetsanalyse av norske havner

*TØI rapport 1461/2015*
*Forfatter(e): Kenneth Løvold Rødseth and Paal Brevik Wangsness*
*Oslo 2015 53 sider*

*Denne rapporten gjennomgår og rangerer 16 datakilder om havneoperasjoner, før den beskriver hvordan data er blitt valgt ut, samlet inn og bearbeidet. Rapporten presenterer avslutningsvis en oversikt over de to datasettene som legges til grunn for forskningsprosjektet "Examining the Social Costs of Port Operations (EXPORT)" sine oppfølgende empiriske analyser. Med publiseringen av rapporten er prosjektets Work Package 1 avsluttet.*

Denne rapporten svarer til oppgavene 1.2. og 1.3 under arbeidspakke 1 tilhørende forskningsprosjektet EXPORT. Rapporten oppsummerer arbeidet innenfor arbeidspakke 1, og dens publisering er en av de viktigste milepælene innenfor prosjektet. Rapporten er i stor grad tilpasset forskerne som jobber på EXPORT-prosjektet, men vil også være av interesse for aktører innen den maritime sektoren i Norge og for andre forskere som jobber med havneøkonomi.

Rapporten fokuserer på innhenting av data som kan muliggjøre tradisjonelle og miljømessige produktivitets- og effektivitetsanalyser av norske havner. Den omfatter i) en generell beskrivelse av arbeidet innenfor EXPORTs arbeidspakke 1 (inklusiv informasjon om prosjektgruppens kommunikasjon med norske havner og andre interessenter), ii) en beskrivelse og vurdering av alle relevante datakilder, iii) en formell diskusjon og begrunnelse for seleksjonen av havner og data som vil inngå i EXPORT-prosjektets empiriske analyser, iv) samt en gjennomgang av hvordan dataen har blitt samlet inn og bearbeidet. Dataen kan overordnet klassifiseres som aktivitetsdata, miljødata og annen data. Totalt ble 16 relevante datakilder gjennomgått og vurdert før data ble samlet inn og bearbeidet.

Vi har hovedsakelig samlet inn data for 25 havner som inngår i Statistisk Sentralbyrås kvartalsvise havnestatistikk. Dette skyldes at de er de største havnene i Norge og derfor vil spille en sentral rolle i en overføring av gods til sjø, samt at vi har tilgang til data av god kvalitet for disse havnene. Denne omfatter informasjon om type og mengde gods, godshåndteringens varighet og skipstype og størrelse for hvert enkelt anløp som har funnet sted. Havnestatistikken utgjør sammen med innsamlede tall for havnekapasitet våre viktigste aktivitetsdata.

I en tidligere EXPORT-rapport argumenterte Rødseth og Wangsness (2015) at de viktigste eksterne kostnadene knyttet til havnenes godshåndtering er i) oppvirvling av giftige sedimenter, ii) utslipp til luft fra skip som ligger til kai, iii) utslipp til luft og støy fra landbaserte havneoperasjoner og iv) akutte utslipp til vann og grunn. Vi har derfor fokusert på å finne data om disse eksternalitetene. Vi har funnet ut at oppvirvling av sedimenter og utslipp til luft fra skip som ligger til kai kan estimeres ved bruk av tilgjengelig data og modellverktøyer. Vi har videre undersøkt en database over akutte oljeutslipp langs norskekysten for å etablere omfanget av hendelser som finner sted i de største havnene i Norge. Den foreliggende informasjonen om sedimentforurensning, skipsutslipp og akutt forurensning kan dermed knyttes opp mot våre aktivitetsdata for havnene som inngår i den kvartalsvise havnestatistikken. Derimot finnes det ikke god data om disse havnenes støyemisjoner. Vi er kun kjent med at gode støydata foreligger for kontainerterminalene Sjursøya og Ormsund i Oslo havn. Det er derfor behov for å gjøre en enkeltstående case-studie om kontainerhåndtering i Oslo for å belyse omfanget av støy fra havnevirksomhet. Det betyr at i alt to datasett – ett datasett for 25 havner og ett datasett omhandlende kontainerhåndtering i Oslo – er blitt konstruert innenfor rammen av EXPORTs arbeidspakke 1.

# 1 Introduction

This report responds to Tasks 1.2 and 1.3 of Work Package 1 of the research project entitled “Examining the Social Costs of Port Operations”, abbreviated “EXPORT”. The report summarizes the outputs of Work Package 1, and its publication is one of the key milestones of the project. The report is tailor-made for researchers associated with the EXPORT project, as it provides an overview of the data that is available to the project team’s subsequent empirical analyses of Norwegian ports. By pinpointing available data sources for port sector analysis, the report will also be useful for policy makers, for the public sector, and for other stakeholders in the maritime sector. The report will also benefit researchers in the field of applied port economics, by providing a comprehensive discussion on the availability of data for ports, on different data sources’ pros and cons, and on their applicability to applied productivity and efficiency analysis.

This report is structured as follows: Section 2 provides information about the EXPORT project and summarizes the main findings of the project’s preceding report by Rødseth and Wangsness (2015) entitled “Production analysis in port economics: A critical review of modelling strategies and data management”. Rødseth and Wangsness (2015) responds to Task 1.1 of EXPORT’s Work Package 1. Section 3 provides an overview of the data compilation process, in particular by elaborating on the project’s communication with Norwegian ports and its own compilation of data. Section 4 briefly reviews all available data, while Section 5 summarizes the subset of the data that are considered useful for EXPORT’s empirical analyses by relating them to applied productivity and efficiency modelling. Section 6 deals with data management for the selected data, while section 7 concludes the findings.

# 2 Background

One of the Norwegian government's main strategies for freight-transport, as outlined in its National Transport Plan (NTP), is to ensure that an increasing share of the future growth in long-distance freight transport is captured by maritime- or rail transport. Maritime transport's main advantages compared to e.g. road transport are thought to be i) lower infrastructure requirements, ii) higher energy efficiency, and iii) lower external costs, especially since a large share of the overall transport takes place at sea and, hence, far away from densely populated areas.

Ports are vital components in the maritime logistics chain. International studies have pointed to the importance of ports' cost efficiencies and exploitation of economies of scale and scope for domestic competitiveness and economic growth; cf. Tovar et al. (2007). Comparable assessments for Norway are few (Lea & Lindjord, 1996; Schøyen & Odeck, 2013), and little information about cost reductions by better exploitation of the current port infrastructure – in particular by handling larger and more diversified freight volumes – is available.

While the (private) economic benefits of more efficient cargo handling in ports have been treated by the international literature, less attention has been devoted to the external costs of port operations. TØI did recently complete a pilot project on external costs of maritime transport which concluded that proper estimates of the marginal external costs of port operations are lacking (Rødseth & Killi, 2014).

The overall objective of EXPORT is to examine environmental-economic trade-offs in cargo handling in Norwegian ports. The expected outcomes of the project are:

1. New knowledge about the optimal (efficient) exploitation of the current port infrastructure in Norway, and how it contributes to lowering user costs and increasing the attractiveness of maritime transport.
2. New knowledge about marginal external cost estimation for ports, and how external costs caused by port operations affect the optimal use of the port infrastructure.
3. Policy recommendations for maritime transport in general and the port sector in particular.

The project comprises 6 Work Packages. This reports concludes Work Package 1, which addresses the following tasks:

*Task 1.1*: To provide a literature review on previous research projects on port economics and a mapping of the available data.

*Task 1.2*: Based on Task 1.1 and the scopes of Work Packages 2-5, to identify which variables need to be collected.

*Task 1.3*: On the basis of Task 1.2, to collect the relevant data and to process it, e.g. by calculating emissions

This report responds to Tasks 1.2-1.3, while Task 1.1 has been addressed by the preceding report entitled "Production analysis in port economics: A critical review of modelling strategies and data management". The main findings of the latter report are summarized in the following section.

## 2.1 Production analysis in port economics: A critical review of modelling strategies and data management

Rødseth and Wangsness (2015) start by characterizing port operations. They can be seen as a chain of separable operations (confined to the the quay, the yard, and the gate), and ports can generally be seen as multi-output producers that handle a variety of cargo types (and passengers). Cargo-handling inputs can be separated into cargo-specific inputs and inputs that are common (or quasi-common) to all cargo types.

These characteristics provide guidelines for an ideal model of port operations, e.g., by advising to model ports using network production models in which some inputs are cargo-specific while others are interchangeable among cargo types. However, as the subsequent chapters of this report will show, such analyses are not feasible because of the current lack of data. They are also lacking in the scientific literature[1]. Most of the previous studies on port productivity and efficiency emphasize container terminals using either Data Envelopment Analysis (DEA) of Stochastic Frontier Analysis (SFA) to evaluate technical and scale efficiencies. There is also a different, yet smaller, strand of literature that views ports as a multi-output producers. These studies use financial data on labour, capital, services, and energy to estimate cost functions to evaluate economies of scope from handling multiple cargo-types simultaneously.

The majority of container terminal studies treat stock input data, e.g., they use the number of cranes and reach stackers as input variables. They are, in other words, modelling the terminals' capacities, not their capacity utilization. Rødseth and Wangsness (2015) consider this a shortcoming as i) externalities from port operations depend in particular on the ports' activities[2], and because ii) estimates of returns to scale would refer to the change in outputs by an expansion of capacity (e.g., surface area, quay lengths, and cargo handling equipment such as cranes). In Norway, it may be more important to consider expansions of *capacity utilization,* rather than physical expansions of the port infrastructure. That is, it may be more sensible to evaluate returns to density (Caves, Christensen, & Tretheway, 1984) rather than returns to scale for Norwegian ports.

The (multi-output) cost function studies rely on financial data obtained from port administrations. Such data are also available for Norwegian ports. However, the port administrations constitute only a small fraction of the set of agents that operate in Norwegian ports. Thus, only considering the port administrations' costs will severely underestimate the overall costs of handling cargo.

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[1] Bichou (2011) and Wanke (2013) are examples of network model applications to ports, but they are far simpler that the port characteristics stated above. Data availability prevents Bichou (2011) from modelling the port by its three interlinked operations; the quay, the yard, and the gate. Moreover, his study focuses solely on containers, while the EXPORT project focuses on multiple cargo types.

[2] Thus, using stock input data to model the generation of externalities (e.g., by a production function approach) may provide biased estimates.

While the literature on productivity and efficiency analysis of ports is abundant, Rødseth and Wangsness (2015) were only able to identify five papers that address environmental aspects of port operations. Their focus is on emissions to air and on water pollution, which are among the most important externalities connected to port operations. More precisely, Miola et al. (2009) review externalities due to loading and unloading operations on terminals and find the most important are:

- Local air pollution
- Global air pollution
- Noise and vibration
- Odour
- Water pollution (due to accidental leakage)
- Soil and sediment pollution (due to accidental leakage)

If port expansions are considered, then impacts on the eco-system can also be expected.

Rødseth and Wangness (2015) argue that while the list of potential pollutants is long, the sample sizes for port efficiency analysis are usually quite small. It may therefore be necessary to prioritize which external impacts to consider. On the basis of their review, Rødseth and Wangsness propose to emphasize the following externalities:

- Turbidity (dispersion of contaminated sediments) due to ships' arrival and departures
- Noise and air pollution emissions due to land-based cargo handling operations
- Air pollution (local and global) from ships at berth
- Soil, sediment, and water pollution due to accidental spills

Rødseth and Wangness (2015) point out that while externalities such as noise and air pollution emissions have properties that make them suitable for traditional productivity and efficiency analysis, emissions to sea and soil are stochastic in nature. Thus, alternative models developed by the agricultural economics literature on production risk may be more useful for modelling such externalities.

# 3 On the compilation of data for Norwegian ports

This section elaborates on EXPORT's approach to data collection. The data collection process began at EXPORT's kick-off conference (October 7th, 2014) and concludes with the publication of this report.

The data collection process has involved compiling data from various sources, and to evaluate their qualities and applicability to productivity and efficiency analysis (and perhaps risk analysis) of ports. Section 4 provides an overview of all data that have been considered alongside the project team's evaluation of it. This section summarizes some of the main events of the data compilation process, focusing on EXPORT's communication with the Norwegian port sector and the Norwegian Environment Agency.

## 3.1 Communication with the Norwegian Environment Agency

Prior to its kick-off conference, EXPORT contacted the Norwegian Environment Agency to invite the agency to participate in the conference. The purpose was to inform the project team about the agency's work on mapping the level of contamination of Norwegian ports' surrounding sea beds. One employee of the Norwegian Environment Agency attended the meeting. He informed that the agency considers dispersion of pollution stored at the sea bed, induced by ships arriving and leaving the ports, to be among the main environmental impacts of port activities. After the kick-off meeting, he provided a copy of the agency's manual " Risk assessment of contaminated sediment (in Norwegian)", along with reports on pollution dispersion risk assessments for 10 Norwegian ports.

In order to treat this environmental issue in an economic analysis, it is necessary to obtain a measure of the degree of pollution dispersion taking place (i.e., a bad output[3] jointly produced with the cargo handling). In the kick-off meeting, Norwegian Environmental Agency's representative commented that *turbidity* is a useful measure of pollution dispersion, but later communications with him revealed that consistent and continuous mappings of turbidity are unavailable. In fact, only a few of the reports distributed by the Norwegian Environment Agency contain turbidity mappings. Most reports use mathematical formulas provided by the agency's risk assessment manual to *estimate* pollution dispersion. Unfortunately, the reports only cover a small number of relevant ports for EXPORT's analyses, and the analyses are performed at different points in time. Consequently, these analyses are

[3] In the productivity analysis literature, negative externalities, such as pollutants, are often referred to as bad/undesired outputs.

not useful to EXPORT's productivity and efficiency analyses that require data on all relevant variables for each port and for each time period under consideration. Consequently, if pollution dispersion is to be treated, it must be estimated using the formulas provided by the Norwegian Environment Agency in their risk assessment report.

## 3.2 Meeting with the Port of Oslo

On March 24th, 2015, four of EXPORT's associated researchers met with the port of Oslo to discuss EXPORT's data collection strategy. Prior to the meeting, the port had received the following set of questions to be discussed during the meeting:

**Labour**

- Does the port of Oslo have a complete overview of the number of man-hours associated with cargo handling (including the port administration, operators, and stevedores)?
- Is the number of dock workers highly correlated with the port's capital/equipment stock, or will the amount of cargo to be loaded/unloaded affect the number of employees involved in the ship handling?
- Is there a given number of employees involved in the handling of a given cargo type? For example, illustrations published by the port of Oslo indicate that 6 workers are involved in a container port calls (ship's crew is excluded), while 3 workers are involved in loading and unloading of scrap iron. Will the number of employees be the same for each call, or it will vary with the amount of goods / other factors (cf. the previous question)
- Is it possible to divide the total labor input into operations and administrational resources?

**Capital**

- What proportion of the port's equipment stock is owned by the Port Authority? Are there examples of private operators who own equipment used for cargo handling?
- Is there available information about the operating hours of the equipment, not including crane hours?

**Energy**

- Statistics Norway's detailed KOSTRA accounting data for the port of Oslo includes item 170 entitled "Transportation expenses and operation of owned and leased vehicles". The port administration's expenditures on fuels is one of the main cost components of this item. Is it possible to identify the proportion of item 170 that relates to energy consumption (electricity is a separate item)?

- To which degree does item 170 cover the port's overall expenses for operating cargo handling equipment. Cf. the previous question about whether other agents besides the Port Administration operate their own cargo handling equipment.

**Operating costs**

- If the port leases operators, cargo workers, and equipment, we expect that these costs will appear under "other operating expenses" in the port administration's accounting. In this case, the port of Oslo's total operating expenses will provide a good overview of the resource costs related to the port's overall cargo handling. We are not sure how well this description actually fits for dry bulk and general cargo operators (eg. Unicon and Cemex). We wonder if they rent properties from the port administration, thereby providing revenues, not expenses, to the port administration.

The Port of Oslo's representative confirmed that it is challenging to map all the resources employed to the port's overall activities because there are many agents involved in handling cargo. He felt that the port administration's accounting data (KOSTRA data; operating expenses) would be poor proxies of the overall resource efforts.

He said that the port of Oslo had compiled information about all agents associated with the port, but noted that this had been a demanding task. Personal communication with the port of Narvik[4] revealed that it too had undertaken this task in 2009, but had been unable to update the information because of the task's resource demand. This illustrates that the Norwegian ports would not be equipped with annual data about the overall port activities and facilities – which would be preferable for EXPORT's empirical analyses.

The Port of Oslo's representative argued that it would be possible to extract information about variable inputs such as man-hours using the port's invoicing system. However, as this would be resource demanding, it would only be provided if it also would be beneficial to the port. Given that similar information would also have to be obtained from other Norwegian ports to undertake EXPORT's productivity and efficiency analyses, the information was not considered useful to the project. Our experience with collecting data from Norwegian ports (cf. section 3.4.) suggests that the response rate would have been low, and the resulting data would have been insufficient for the project's empirical analyses.

The representative concluded that appropriate information on the labour, capital, and energy consumption of Norwegian ports would be challenging to obtain. However, he proposed that the essential inputs to cargo handling are quays (quay lengths) and dedicated areas for cargo handling. These variables, he said, could be collected from the ports' web-pages, or by using a web-based map service (gulesider.no) to survey the port areas.

[4] October 19th, 2015, at the Transport and Logistics conference; Gardermoen, Norway

## 3.3 Selecting ports

There are 125 ports in Norway (excluding Svalbard), which cannot be seen as a set of homogenous or comparable decision making units (Rødseth & Wangsness, 2015). Rødseth and Wangsness proposed several potential criteria for selecting comparable units:

- Selection by geographical location
- Selection by cargo type or types
- Selection by port size
- Selection by corporate structure
- Selection by ownership structure
- Selection by appointment (trunk line ports)

We have decided to select ports primarily based on port size, by emphasizing port operations taking place within the 25 largest ports in Norway in terms of annual freight volumes. Most of these ports are also appointed trunk line ports. We prefer our selection i) because the largest ports will play key roles in promoting maritime transport, ii) because we favour analyses of multiple cargo types (and economies of scope) to a single cargo type[5], and iii) because we have access to excellent data on port operations taking place in these 25 ports. These ports are often denoted "quartely ports" (kvatalshavner), referring to that Statistics Norway publishes data for the ports on a quarterly basis. The quarterly ports each handle more than 1,000,000 tons of cargo and/or 200,000 passengers annually. EXPORT has been granted access to the raw data underlying Statistics Norway's quarterly publications.

## 3.4 Communication with Norwegian ports

Based on the outcome of the meeting with the port of Oslo and the port selection, the project team contacted the 25 quarterly ports to obtain information about the ports' i) total quay lengths, ii) areas dedicated to cargo handling, iii) sea depths, and iv) opening hours. The two latter variables were not suggested by the port of Oslo, but do also contribute to determining the overall port capacity. Sea depths play a crucial role in determining the maximum size of the ships calling on the port, as larger ships cannot access ports whose entrances are shallow. The ports' overall capacities for cargo handling is also clearly contingent on their opening hours. Bichou (2011) proposed using this variable for productivity and efficiency analysis of ports.

The project team compiled information about the relevant variables from the ports' web-pages and other sources (e.g., the national freight model system), and thereafter submitted them to the port administrations for quality assessment. Data for the period 2010-2013 were requested, because the project team has access to micro-data

[5] In particular, containers constitute a small share of the overall cargo loaded/unloaded in Norwegian ports. Hence, following the literature by focusing on container operations would provide little insights into the optimal utilisation of the port infrastructure in Norway.

on cargo flows and ship working rates during this time span (see section 4.1.1 for more details). Table 1 provides an example of the Excel file submitted to the port of Oslo:

**Table 1**: *Template for data collection*

| Havn | År | Areal til havneformål (m2) | Totale kailengder (m) | Dimensjonerende havnedybde container/stykkgods (m) | Dimensjonerende havnedybde tørrbulk (m) | Dimensjonerende havnedybde våtbulk (m) | Åpningstid for godshåndtering (timer per døgn) |
|---|---|---|---|---|---|---|---|
| Oslo | 2010 | | | 10,8 | 11 | 11 | |
| | 2011 | | | 10,8 | 11 | 11 | |
| | 2012 | | | 10,8 | 11 | 11 | |
| | 2013 | 1224313 | 9922 | 10,8 | 11 | 11 | 24 |
| Kilder: | | Vista analyse | Havnens hjemmeside | Kystverket | Kystverket | Kystverket | Havnens hjemmesi |
| | | | | / Nasjonal godsmodell | / Nasjonal godsmodell | / Nasjonal godsmodell | |

25 ports – the ports included in the Quarterly Port Statistics by Statistics Norway – received the data template around April/May, 2015. 22 ports returned the Excel file to the project team by June/ July. The remaining ports received a final reminder about the data template in December 2015, upon finalizing this report. During this last call, one additional port returned the Excel file. Thus, we have been able to collect and ensure the quality of capacity data for 23 of 25 "quarterly ports".

Upon the construction of the Excel files (cf. Table 1), the project team also debated whether to request the amount of information about the ports' equipment that would be necessary for a technological classification of the ports that is found in the Norwegian Logistics Model (see section 4.1.4 for details). This would have expanded the Excel-file from table 1 substantially, and the project team was therefore concerned that the response rate would be low[6]. This would be critical to the feasibility of undertaking applied productivity and efficiency analyses, as appropriate performance assessment is contingent on a high ratio of the number of observations to the number of variables to be used in the analysis[7]. EXPORT therefore refrained from requesting such information.

[6] Recall the discussions from section 3.2, which indicate that information about the overall port facilities would not be readily available to the port administrations.

[7] See (Dyson et al., 2001) for an elaboration on this issue.

# 4 An assessment of available data

In the following, we provide an overview of all the data that the project team has compiled and reviewed. The data are briefly described and thereafter given an assessment of its usefulness for EXPORT's empirical analyses. The data is classified into i) activity data, ii) environmental data, and iii) other data.

## 4.1 Activity data

Activity data comprises cargo and passenger throughputs (outputs) and the associated cargo handling inputs. As described by section 2.1, the ideal port model is able to distinguish between inputs and outputs at different stages of port operations, and to distinguish between cargo-specific and allocable inputs. Though desirable, this modelling approach is not compatible with the available data. Given the data constraints, we have formulated the following proposal for data collection:

**Table 2:** *A proposal for data collection*

| Category | Variabels |
|---|---|
| Outputs: | • Cargo types (volume)<br>• Passengers (volume) |
| Inputs: Capacity | • Areas<br>• Quay lengths<br>• Depths<br>• Cargo handling equipment inventory<br>• Buildings/Warehouses |
| Inputs: Capacity utilization | • Hours of operation, cargo handling equipment<br>• Man-hours/Employees<br>• Overall energy consumption |

The definition of outputs is consistent with the literature on port economics, while the definition of inputs is not. This is due to the distinction between capacity determining inputs (e.g., areas and quay lengths) and factors associated with capacity utilization (e.g, hours of operation and energy consumption). In economics, it is common to label such inputs as either (quasi)fixed or variable inputs, respectively, referring to that the inputs are fixed or variable in the short run.

As explained by section 2.1, the literature on productivity and efficiency analysis of ports can broadly be classified into container studies and cost function studies. The former solely accounts for (quasi)fixed inputs, while the latter considers all inputs to be variable. We propose a hybrid model for the following reasons:

i) Our discussions with the port of Oslo indicate that capacity determinants (areas and quay lengths) are essential to port operations,

ii) Failure to account for capacity utilization may lead to biased estimates of environmental efficiency (Rødseth & Wangsness, 2015)

iii) Returns to density (i.e., returns to variable inputs) may be a more useful measure than returns to scale (i.e., also including port infrastructure expansions) when evaluating the productivities of Norwegian ports (Rødseth & Wangsness, 2015).

Note that the following discussion focuses on available data for the 25 selected quarterly ports.

### 4.1.1 The port statistic (micro data)

**Source**: Statistics Norway

**Variables**: Detailed data per port call for years 2010-2014:

- *Throughput (different cargo types and passengers)*
- *The duration of loading/unloading (hours)*
- *Ship characteristics (IMO number, ship classification, and gross tonnage)*

**Assessment**: This data source is essential for modelling port outputs – throughput and handling durations – and for estimating emissions to air from ships at berth. The data can be used for evaluating port logistics efficiency and could perhaps also be used for evaluating congestion using information on ships' time at anchor points.

**Coverage (so far)**: All 25 quarterly ports

### 4.1.2 Port capacity

**Source**: Own compilation by issuing surveys to the relevant ports (see section 3.4)

**Variables**: Data per port for years 2010-2013[8]:

- *Size of port area (m2)*
- *Quay lengths (metres)*
- *Depths (metres)*
- *Opening hours (hours)*

[8] Note that port statistics data for 2014 became available to the project team upon finalizing this report. Because the port capacity data was collected prior to the publication of the 2014 port statistics, and because access to this data was not anticipated by the project team, port capacity data was unfortunately not compiled for 2014. If found necessary, we will update the port capacity database later.

**Assessment**: This data describes essential quasi-fixed inputs. There could be some issues related to the quality of the variable "size of port area", as some ports reported that they found it difficult to determine this variable. Moreover, most ports report 24-hours operations.

**Coverage (so far)**: 23 of 25 relevant ports

### 4.1.3 Container data

**Source**: Halvor Schøyen's survey of selected Norwegian container ports

**Variables**: Data per port for the years 2002-2014:

- *Cargo throughput (TEU/yr)*
- *Berth length (metres)*
- *Terminal area (m2)*
- *Quay cranes (no. of units)*
- *Equipment for container handling within the terminal area (no. of units of each equipment type)*

**Assessment**: These data are relevant if the role of the cargo handling equipment as inputs is important. An in-depth study of container terminal efficiency could be of use to the EXPORT project, but mainly as a supplement to the main studies that deal with the handling of multiple cargo types.

**Coverage (so far)**: Panel data set with up to 8 Norwegian ports with container terminals

### 4.1.4 Technological classifications

**Source**: The Norwegian Logistics Model/ Stein Erik Grønland

**Variables**: 5 categories of port technologies – the Norwegian ports included in the modelling framework fall into categories 1-3

**Assessment**: Data on port characteristics (e.g., the number of cranes) must be compiled if using the classifications for e.g. cluster analysis is found relevant. We currently refrain from compiling the data because of anticipated low response rates, and because of the classifications are currently not considered very useful for the project's empirical analyses. They are very coarse, and build on the perception of time usage and equipment.

**Coverage (so far)**: None of the relevant ports

### 4.1.5 KOSTRA (micro data)

**Source**: Statistics Norway

**Variables**: Data per port for years 2008-2012:

- *Detailed on the port administrations' operating costs (NOK)*

- *Detailed on the port administrations investment costs (NOK)*

**Assessment**: The data are not representative for the overall costs of port operations, as all other agents than the port administration are neglected. The data are useful if the objective of the analysis is to examine the productivities and efficiencies of the ports' central administrations. This is, however, not consistent with EXPORT's objectives.

The KOSTRA item 620 allows identifying the total rent which the port administrations receive by making dedicated areas available to private operators. Assuming economic optimality and the cost share of area in the private agents' cost functions, the overall operating costs of other agents than the port administration could be retrieved. This information may, however, be less useful to EXPORT if the agents' costs cover the provision of other services than cargo handling, e.g., customizing cars to Norwegian car standards.

**Coverage (so far)**: 50 Norwegian ports (24 of them are included in the quarterly port statistics)

### 4.1.6 Stevedores

**Source**: Norsk Transportarbeiderforbund (NTF, The Norwegian Transport Workers' Union)

**Variables**: Data per port as of 2014:

- *Stevedores (number)*

**Assessment**: These data could be used as a proxy for labour inputs, because stevedores have priority over other labour for dedicated cargo handling assignments by negotiated agreement (Implementation of ILO agreement).

**Coverage (so far)**: 28 Norwegian ports (18 of them are quarterly ports)

### 4.1.7 The Central Register of Establishments and Enterprises and Accounting Data (Bof)

**Source**: Statistics Norway / Brønnøysundregisteret

**Variables**: Covering the years 2002-2015, for all establishments (local activity units) and enterprises:

- *Industry (NACE Rev 2/SN2007)*
- *Localisation (address, municipality, sub-municipality unit)*
- *Legal form (foundation, corporation, limited partnership etc.)*
- *Ownership (private, public)*
- *Number of employees*

**Additional variables**: For the years 2002-2014, accounting data for reporting establishments (local activity units) and enterprises are available:

- *Operating expenses*
- *Total income*
- *Operating profit*
- *Wage costs*
- *Fixed assets*

- *Current assets*
- *Debt and equity*

**Assessment**: The EXPORT team has considered various strategies to extract information about <u>the operating costs of other relevant agents than the port administration</u>, e.g. by selecting enterprises based on geographical location (i.e., the ports' premises) and by using the information on the ports' web-sites to select the relevant units. We experience two main issues:

- Selecting the relevant units is challenging. This was made clear during the meeting with the port of Oslo (cf. section 3.2). When a list of selected enterprises was presented, the representative from the port of Oslo felt that the selected units were inconsistent with his knowledge about private operators in the port of Oslo. This problem could be circumvented, as the project team has been informed that the Norwegian Costal Administration is working on mapping all agents operating in Norway's main ports. The EXPORT team has received some information about this work and has been promised access to the final results of the mapping, but at the time of finishing this report the mapping is not complete.
- The private operators' costs cover other activities than cargo handling (which is the main emphasis of EXPORT). For example, in 2014, Møller bilklargjøring as (associated with the port of Oslo) had 69 employees according to the BoF register (Central Register of Establishments and Enterprises and Accounting Data – Bedrifts- og Foretaksregisteret). We expect that cargo handling (in particular loading/unloading cars) would take up a minor share of the company's overall labor efforts, as activities such as technical preparation and fitting of accessories of cars would probably take up the much of the resources. Thus, using the information on the total number of employees in a port productivity and efficiency analysis would underestimate cargo handling efficiency as the resources used for handling cargo are overestimated.

Based on this discussion, we have at this point concluded that the BoF data is not useful to EXPORT's analyses.

**Coverage (so far)**: If found relevant later, data on all relevant ports can be collected.

### 4.1.8 Energy accounting

**Source**: Statistics Norway

**Variables**: Use of energy (electricity; fossil fuels)

**Assessment**: Information from Kristin Aasestad at Statistics Norway revealed that their energy statistics is based on aggregate statistics, and is thus not available on the micro-level (e.g., at the establishment level). The data is thus not useful for the EXPORT project.

**Coverage (so far)**: No ports (irrelevant data).

### 4.1.9 Summary – activity data

We have reviewed several sources of activity data for ports, and have found that:

- The port statistics by Statistics Norway is a key data source by providing information on throughput (cargo and passengers), the duration of cargo

handling, and ship characteristics. The latter is particularly relevant for estimating emissions to air from ships at berth.
- The data on port capacity is essential for describing (quasi)fixed inputs in cargo handling
- Halvor Schøyen's data is relevant for analyses where container handling is emphasized, and when information about the different ports' cargo handling equipment (e.g., cranes and reach stackers) is paramount. The data could be supplemented with information from the port statistics (e.g., the duration of container handling and the characteristics of container ships).
- The number of stevedores could act as a proxy of the overall labour efforts in the various ports. However, we question how representative the variable is, in particular because different ports may operate under different legal agreements to prioritize stevedores.

## 4.2 Environmental data

Rødseth and Wangness (2015) made a thorough assessment of port externalities, and proposed to narrow EXPORT's scope to the following list:

- Turbidity (pollution dispersion) due to ships entering and exiting the port
- Noise and air pollution emissions due to land-based cargo handling operations
- Air pollution (local and global) from ships at berth
- Soil, sediment, and water pollution due to accidental spills

Naturally, the selected categories will receive most attention when we now review available data on externalities.

### 4.2.1 Ship register data (used for estimating emissions to air from ships)

**Source**: The Norwegian Costal Administration

**Variables**: For all registered ships

- *Gross tonnage (tons)*
- *Dead weight tons (tons)*
- *Length overall (metres)*
- *Length between perpendiculars (metres)*
- *Moulded breadth (metres)*
- *Draught (metres)*
- *Total engine power (kW)*
- *Ship type (classification)*

**Assessment**: This data source is essential for calculating ships' emissions to air at berth. This is explained in detail in Section 6.2.

**Coverage (so far)**: Available for all relevant ports (i.e., ships)

### 4.2.2 Noise monitoring

**Source:** The Port of Oslo (Ormsund)/ Risavika

**Variables:** Continuous noise reporting (LAeq, 1hr)

**Assessment:** Excellent data for undertaking a case-study on noise emissions due to container handling. Coupled with the port statistics (see section 4.1.1), the data allows evaluating the impact of i) the container throughput, ii) the cargo handling duration, and iii) ship type/size on noise for each call.

Relevant for micro-studies on noise – linking noise to the individual port call

**Coverage (so far)**: 2 container terminals for 2009-present (Oslo) and 2014-present (Risavika)

### 4.2.3 Noise estimates

**Source**: Reports on noise mappings are available for 9 ports

**Variables**: Noise maps and hours of operation of various equipment. The latter variables are only available from the port of Borg's noise mapping report.

**Assessment**: Inconsistent use of methods and reporting of results – could be applicable for a sub-sample of ports, but the data quality might be questionable. Moreover, the reports provide static noise analyses for a given year, and the year under consideration differs from port to port, which makes the reports less useful for EXPORT's empirical analyses.

**Coverage (so far)**: 9 ports

### 4.2.4 Dispersion of contaminated sediment (Turbidity)

**Source**: The Norwegian Environmental Agency

**Variables**: The Norwegian Environmental Agency has provided the following information on water pollution

- *their handbook "Risk assessment of contaminated sediment (in Norwegian)", which suggest an approach to estimating pollution dispersion as a function of the number of annual calls and port characteristics*
- *10 reports on risk assessments of pollution dispersion at selected ports (some not relevant for EXPORT)*

**Assessment**: The risk assessment reports do only cover a small number of relevant ports for EXPORT's analyses. Moreover, the analyses are performed at different points in time, and are therefore not found useful to EXPORT's productivity and efficiency analyses (see section 3.1). The best way to deal with the pollution dispersion is thus to use the agency's handbook for estimating turbidity based on port call data and port characteristics (e.g. depth).

**Coverage (so far)**: All relevant ports, i.e., the pollution dispersion must be estimated.

### 4.2.5 Accidental oil spills

**Source**: The Norwegian Costal Administration

**Variables**: Databases containing information about accidental oil spills to sea and land for the years 2013-2015, covering both events taking place at sea and on land. Key variables are

- *Verbal description of each event*
- *Location (longitude and latitude)*
- *Fuel types*
- *Total emissions (litres)*

**Assessment**: The data is relevant for mapping oil spills related to cargo handling in ports. Note that the database focuses solely on fossil fuels (oil), and does not take into account the emissions of other substances to sea and soil.

**Coverage (so far)**: All ports (i.e., the databases cover all reported annual oil spills for the entire country).

### 4.2.6 Water and soil quality

**Source:** http://vannmiljo.miljodirektoratet.no/ and http://grunn.klif.no/

**Variables:** A collection of reports on water quality at specific geographical locations (laid out on a map of Norway)

**Assessment:** Must be further reviewed if found relevant. Our preliminary studies revealed that it is difficult to use the databases to find comparable estimates of water and soil quality across ports. Moreover, it might be difficult to relate water and soil qualities to port activities, as water/soil qualities also are influenced by contamination related to other sources.

**Coverage (so far):** No ports: the available data is currently found inadequate for both environmental mapping and productivity analysis of Norwegian ports.

### 4.2.7 Personal injuries

**Source**: Norwegian Maritime Authority/ Norwegian Labor Inspection Authority

**Variables**: Accidents occurring to ship members while in port, or to port crew.

**Assessment**: Not relevant to EXPORT's analyses for the following reason

- *Using the Norwegian Maritime Authority's database, Vista analyse (2015) finds that the number of personal accidents on cargo vessels are almost negligible. In 2014, there were zero fatalities and 4 injuries within Norwegian waters. Consequently, the number of injuries taking place at ports will be zero for all or most of the ports in our sample (the quarterly ports). This information will not be useful to empirical analyses at the port level.*

**Coverage (so far)**: No ports (irrelevant data)

### 4.2.8 Summary – environmental data

Rødseth and Wangsness (2015) proposed assessing the following externalities:

- Turbidity (pollution dispersion) due to ships entering and exiting the port
- Noise and air pollution emissions due to land-based cargo handling operations
- Air pollution (local and global) from ships at berth
- Soil, sediment, and water pollution due to accidental spills

Our review of available data shows that:

- Turbidity (pollution dispersion) can be estimated based on the Norwegian Environmental Agency's handbook, using information on the number of annual calls and on port characteristics (i.e., depth and area).
- Noise emissions due to land-based cargo handling operations can be assessed for container operations in the port of Oslo (and Risavika from 2014), based on data from their continuous emissions monitoring.
- Air pollution (local and global) from ships at berth must be estimated based on i) the duration of loading/unloading (obtained from the port statistics; see section 4.1.1) and ship engine characteristics (obtained from the ship register data; see section 4.2.1)
- Information about soil, sediment, and water pollution due to accidental oil spills can be obtained from the Norwegian Coastal Administration's database on acute emissions.

## 4.3 Other data

In this section, we review data on i) unit prices (damage costs) for externalities and ii) hinterland characteristics.

### 4.3.1 The study on the value of time, safety and environment in Norwegian passenger transport

**Source**: Institute of Transport Economics – Norwegian Centre for Transport Research/SWECO

**Variables**: <u>Unit price estimates</u> for

- *Emissions to air (PM10; $NO_X$; $CO_2$)*
- *Noise*
- *Value of a statistical life*

**Assessment**: The unit prices are highly relevant to EXPORT's analyses. They have recently been updated by Thune-Larsen et al. (2014) due to renewed recommendations for the value of a statistical life. We advise using the most recent unit price estimates.

**Coverage (so far)**: All relevant ports (the price estimates vary among urban and rural areas)

### 4.3.2 The Norwegian road freight survey

**Source**: Statistics Norway

**Variables**: The data is based on a survey of Norwegian freight transport companies. About 1800 surveys, each related to a specific truck, are issued each quarter. The trucks are randomly selected from four different strata, in sum representative for national performance.

**Assessment**: In 2008, a voluntary question about terminal type was implemented in the survey. This information was utilized by Hovi et al. (2014) to identify the hinterland of 15 Norwegian ports (i.e., identifying which municipalities interact with a given port). This information could further be used to identify i) ports with overlapping hinterland (i.e., to identify which ports that can be seen as substitutes from a shipper's perspective) and ii) to identify hinterland characteristics (e.g., accessibility to port, industry structure and hinterland economic development) using publicly available data from Statistics Norway.

**Coverage (so far)**: 15 ports, of which 14 are quarterly ports. Additional information could also be retrieved for all 25 ports if needed, as the road freight survey is available to the project team.

# 5 Applying the selected data to empirical productivity and efficiency analyses

Building on the assessments made in Section 4, Section 5 elaborates on how to use the available data for productivity and efficiency analysis. It is thus timely to review Rødseth and Wangsness' (2015) proposed modelling strategies, and to assess their feasibilities based on the preceding data review. However, before proceeding with their recommendations, it is useful to return to the proposal for data collection in section 4.1, and to discuss how the available data could be used for the empirical analysis.

## 5.1 Establishing the port production model

The purpose of this section is to propose a port production model that can be used for EXPORT's subsequent empirical analyses. In this section, we focus primarily on establishing a model apparatus for traditional technologies (i.e., without considering externalities). The extension of the model to also comprise externalities will be treated in section 5.2.

In section 4.1, we proposed to model ports using a production model comprising three variable categories:

- Outputs: cargo and passenger volumes
- Capacity-determining inputs: port areas; total quay lengths; depths; cargo handling equipment inventory; buildings/warehouses
- Capacity utilization: hours of operation, cargo handling equipment; man-hours; energy consumption

Sections 3 and 4 revealed that, while high-quality data for outputs and some capacity-determining inputs are available, information about the port's cargo handling equipment and its utilization – as well as other data on capacity utilization – is unavailable. On the other hand, data on the duration of ship handling can be obtained from the port statistics.

In this section, we attempt to address the following questions:

- Is time an essential input in cargo handling?
- What are the structural consequences of ignoring cargo handling equipment and its utilization when measuring port efficiency?

Moreover, proxies for variable inputs will be examined.

### 5.1.1 Time as an essential input in cargo handling

There is a vast literature that addresses the potential for ports to reduce their operating costs by technical efficiency improvements and exploitation of scale economies. Tongzon's (2001) paper is rare as it considers both the quantity of cargo handled and the quality of port services (the latter is operationalized by the number of containers moved per working hour per ship). Wang et al. (2005) argue that high-quality ports attract more clients, which ensures a strong positive relationship between the cargo throughput and service quality. Consequently, they propose to include only the throughput variable in port performance assessments. Most of the published papers on port performance measurement follow up on this idea. However, a recent paper by Suárez – Alemán et al. (2014) provides an empirical illustration showing that defining outputs in terms of "throughput per hour" as opposed to "throughput" (without reference to the time dimension) significantly alters the efficiency scores.

Time is a critical factor in maritime transport. On any given voyage, the carriers' costs – and thus the transport users' costs – ultimately depend on the distance travelled and the time it takes to complete the voyage (Cullinane & Khanna, 2000). The time spent in port is unavoidable since cargo must be loaded/unloaded, and thus constitutes an important component of the overall transport costs. Consequently, there is an important trade-off involved in choosing ship size and capacity utilization (i.e., the amount of cargo to be loaded/unloaded), because the positive benefits earned at sea might be outweighed by additional cargo handling time in ports (Jansson & Schneerson, 1987).

From an analytic point of view, an economic model should emphasize factors that are in some sense economically scarce and over which the entrepreneur exercises effective control (Chambers, 1988). The time spent on handling cargo fulfils both criteria. First, as has been established, the time in port has economic implications for carriers. Any form of delay on behalf of the port readily inflicts costs on them, and should in that sense be regarded as an externality. Second, we believe that the ports voluntarily can improve their cargo handling rates by either i) efficiency improvements and/or ii) by increasing its operating costs. Better planning of loading/unloading operations that leads to more efficient loading/unloading is an example of the first measure. Adding and operating a second crane to allow the simultaneous use of two cranes when loading/unloading containers is an example of the latter.

Time could either be seen as an input in port production or as an undesirable output stemming from port production. Both entail modelling time as a freely disposable input in a technical sense, hence we will refer to it as an input in the remainder of the report. By this axiom, i) time is substitutable to other productive inputs for a given amount of cargo loaded/unloaded, and ii) the marginal productivity of time in cargo loading/unloading is non-negative. This allows capturing that time is an essential input in cargo handling, and that the cargo handling rate can be improved by increasing the use of other inputs. The latter means that time reductions are costly for ports, as they imply substituting time with other inputs that incur additional costs (when the potential for technical efficiency improvements has been exhausted). The model is thus economically intuitive.

### 5.1.2 The structural consequences of ignoring cargo handling equipment and its utilization when measuring port efficiency

As described by sections 3 and 4, reliable information on the ports' equipment (e.g., cranes and other handling equipment) as well as their capacity utilization (e.g., man-hours and energy use) is not available. In this case, there are two ways to proceed; i) by ignoring such inputs or ii) by identifying proxies for the missing data. In this section, we examining the structural consequences of ignoring the variables, while the following section examines the use of proxies.

Consider a port that utilizes resources $x \in \Re_+^N$ to handle the throughput of cargo $y \in \Re_+^M$ within a given timespan $b \in \Re_+$. The input vector can be partitioned into observable inputs (superscript O) and non-observable inputs (superscript NO), i.e., $x = \left(x^O, x^{NO}\right)$. The port's cargo handling possibilities is formalized as:

$$T = \left\{\left(x,b,y\right) : \left(x,b\right) \text{ can produce } y\right\} \tag{1}$$

In order to undertake empirical analysis, we need to establish a functional representation for the technology in equation 1. Assume, for simplicity, the minimization of the cargo handling duration, given the throughput of cargo and the port's current consumption of inputs:

$$b\left(x,y\right) = \inf_b \left\{b : \left(x,b,y\right) \in T\right\} \tag{2}$$

However, the overall input vector is not observable to the analyst. Instead the following model is being estimated:

$$b\left(x^O,y\right) = \inf_b \left\{b : \left(x^O,b,y\right) \in T\right\} \tag{3}$$

To understand the implication of estimating equation 3 instead of equation 2 (i.e., the "true" model), note that equation 3 may alternatively be written:

$$\begin{aligned} b\left(x^O,y\right) &= \inf_{x^{NO},b} \left\{b : \left(x^O,x^{NO},b,y\right) \in T\right\} = \inf_{x^{NO}} \left\{b\left(x^O,x^{NO},y\right)\right\} \\ &= b\left(x^O,x^{NO}\left(x^O,y\right),y\right) \end{aligned} \tag{4}$$

Equation 4 tells us that by estimating $b\left(x^{O},y\right)$, we assume that the non-observables readily are allocated to minimize the duration of the cargo handling, i.e., to maximize the productivity of the observable inputs. The downside of this assumption is that i) the port's actual costs related to adjusting $x^{NO}$ (to maximize productivity of observable inputs) are not accounted for by the model and, consequently, ii) that it is not possible to distinguish technical efficiencies (i.e., deviation from best practices) from the allocation of non-observable inputs to maximize the productivity of the observables. To elaborate on this point, we define the following efficiency measure (EM) for the model in 3:

$$EM = \frac{b\left(x^{O},y\right)}{b} \tag{5}$$

which ranges from 0 to 1, where 1 indicates efficiency. Using equation 4 and the result that $b\left(x^{O},x^{NO}\left(x^{O},y\right),y\right) \le b\left(x^{O},x^{NO},y\right)$, we can rewrite equation 5 as:

$$EM = \underbrace{\frac{b\left(x^{O},x^{NO}\left(x^{O},y\right),y\right)}{b\left(x^{O},x^{NO},y\right)}}_{\text{Input adjustment effect}} \times \underbrace{\frac{b\left(x^{O},x^{NO},y\right)}{b}}_{\text{Pure technical efficiency}} \tag{6}$$

Equation 6 shows that EM decomposes as i) an input adjustment effect (i.e., adjustments of non-observables) and ii) a pure technical efficiency effect (i.e., wastage of time because the port is not allocated on the frontier). Since $x^{NO}$ is unknown to the analyst, it is not possible to distinguish the two effects.

What are the implications of this finding for EXPORT's empirical assessments? According to the project description, a key objective is to provide new knowledge about the *optimal* (efficient) exploitation of the current port infrastructure in Norway, and how it contributes to *lowering user costs* and increasing the attractiveness of maritime transport. If we narrow the term "port infrastructure" to capacity determining factors for which we have obtained data (i.e., quay lengths, areas, depths, and opening hours) – factors that ultimately determine the amount of cargo that can be handled by the port – it appears reasonable to use the approach as it, by definition, assumes that (unobserved) inputs are allocated to achieve a maximal exploitation of the current infrastructure.

We note that, by assuming that capacity determining inputs are fixed while variable inputs can freely be determined, the approach outlined in this section corresponds to Färe et al.'s (1989) measure of capacity utilization. This measure builds on Leif Johansen's definition of capacity as the maximal amount that can be produced per unit of time with existing plant and equipment, provided that the availability of variable factors is not restricted.

### 5.1.3 Proxies for variable inputs

In section 5.1.2, we considered the pros and cons of ignoring non-observable inputs in the analysis. In this section, we discuss data that could be utilized as proxies for these inputs.

**Labour**: As previously mentioned, we have no accurate data on labour efforts in cargo handling. We do, on the other hand, have access to accurate data on employment for i) the port administrations and ii) for stevedores. If these variables are highly correlated with the overall employment, it is possible to utilize them as proxies.

Considering that our emphasis is primarily on cargo handling, the data on stevedores appear to be most useful as the port administrations usually do not directly participate in this activity[9]. The argument in favour of using stevedore data is that dockworkers have legal rights to participate in cargo handling activities in selected ports in Norway. However, our data on stevedores is limited to 18 of 23 ports, and we do only hold stevedores data for 2014 while our main dataset covers the period 2010-2014. Moreover, a recent example from the port of Oslo indicate that the stevedore's power is fading, and that they are becoming a less important agent in the cargo handling process. This leads us to conclude that the review of data has not been able to produce relevant data on labour efforts in cargo handling.

**Equipment:** Reviewing the technological classification in section 4.1.4, we find that the number of cranes is considered paramount to determining the duration of cargo handling. Unfortunately, no complete overview of cranes belonging to the quarterly ports exists. However, Caspersen and Hovi (2014) have compiled information of the number of cranes for container handling in the largest ports in Norway. Although this information is not sufficient for entering the economic model as it ignores handling equipment for non-containerized cargo, it could be used to undertake empirical testing, e.g., to examine the correlation coefficient between the number of cranes and the port's efficiency score.

Alternatively, information about the port administrations' incomes from lending of equipment to private agents operating in the port could be obtained from the available accounting data. This information should not be used as a variable in the economic model either, as it ignores any cargo handling equipment that is not owned by the administrative units but by the private agents. The variable could, however, be used for empirical testing.

In conclusion, there are to our knowledge no reliable proxies for variable inputs. We therefore advise estimating the model with capacity determining inputs and information on the duration of cargo handling only, bearing in mind that this implies that "the true" technical efficiencies cannot be separated from the effect of adjusting variable (unobservable) inputs to maximize the productivity of the capacity determining inputs.

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[9] The exception is crane operations, which is frequently undertaken by employees of the port administrations.

## 5.2 On modelling externalities: Rødseth and Wangsness' proposed modelling strategies

As summarized by section 2.1, Rødseth and Wangsness' (2015) report proposed 4 modelling strategies based on the data that they perceived to be available. These were:

- Modelling turbidity as a function of the number of ships leaving and entering the port
- Air pollution emissions from ships as a function of the time spent at berth
- Noise and air pollution emissions from land-based port operations
- A Just-Pope (1978) risk assessment of emissions to sea and soil

Based on the thorough review of available data in Section 4, we are now fully able to evaluate their feasibility.

### 5.2.1 Turbidity

As noted in Section 3.1, *turbidity* is a useful measure of pollution dispersion. However, communication with the Norwegian Environment Agency revealed that consistent and continuous mappings of turbidity are unavailable. Most of the reports on contaminated sediments that have been made available to the EXPORT team use formulas provided by the agency's manual to estimate pollution dispersion.

Traditionally, productivity and efficiency analysis depend on observed data. In the case where a variable is estimated using a specific function, there cannot be inefficiencies with regards to the computed variable. Even so, it might be useful to apply the formula for pollution dispersion, in particular to indicate the implications on pollution dispersion when Norwegian ports adopt economies of scale and scope.

According to the Norwegian Environmental Agency's handbook, the dispersion of contamination depends on the number of ships calling on the port. Consequently, boosting *logistics efficiencies* (operationalized as the amount of cargo loaded/unloaded per call) would imply boosting the eco efficiency of maritime transport as the ratio of economic outcome – or the amount of goods to be loaded/unloaded – would be high relative to the number of calls that contribute to the dispersion of sediment pollutants

A key issue is consequently whether the ports' characteristics (or other characteristics, such as port clusters) influence logistics efficiencies. For example, are more productive ports visited by more productive liners, hence implying that the ratio of cargo handling relative to pollution dispersion is high? Moreover, adopting economies of scale might also be realized through port expansions. Increased quay lengths and depths may facilitate handling larger ships, which in turn hypothetically may promote logistics efficiency improvements, e.g., by reducing the number of calls for a given amount of cargo.

Rødseth (2015) proposed a new approach to logistics efficiency measurement that can be useful for empirically addressing this issue. He assumed the following model, where a given port is the DMU:

T=((cargo, calls, tonnage): (calls, tonnage) can provide the cargo throughput)

The model assumes that the number of calls and ship tonnage (i.e., ships' overall cargo handling capacity, e.g. in dead weight tons) are freely disposable inputs, while the cargo throughput vector consists of freely disposable outputs (i.e., cargo types). Consequently, the model implies substitution possibilities between tonnage and the number of calls required to deliver a given vector of cargo. Moreover, the minimum input requirement to deliver a given bundle of cargo can be identified. Thus, logistics efficiencies can be evaluated by comparing a port's current cargo throughput per call to the estimated minimum calls necessary to deliver that cargo throughput[10]. The model can be extended, e.g., by accounting for that (ship) tonnage is contingent on total quay lengths of the ports.

A simple approach to examine whether port performance affects logistics performance is to consider correlation coefficients, explaining the relationship between the logistics efficiency measure (ton of cargo/call) and the port's efficiency score calculated based on our main dataset.

### 5.2.2 Air pollution emissions from ships at berth

We will estimate air pollution emissions per call for a range of pollutants ($CO_2$, $NO_X$, PM, $SO_X$ etc.). These estimates are based on information about the characteristics of the ships calling on Norwegian ports, as is further elaborated on in section 6.2

The following modelling strategy was provided by Rødseth and Wangsness (2015). They assumed a Frisch (1965) type production model consisting of two production relations:

Time spent on loading/unloading cargo = f(total quay lengths, port area, cargo throughput handled by the port)

Air pollution emissions from ships at berth = g(time spent on loading/unloading cargo, ship energy consumption; ship engine type)

The first production relation relates the time use to the amount of cargo loaded/unloaded and to the ports' use of other (capacity determining) inputs. This is our standard port technology, which can be used to estimate technical and scale efficiencies for ports along the lines of traditional port economics.

The second production relation relates the ships' air pollution emissions at berth to the time spent on loading and unloading cargo and to their characteristics (fuel and engine types).

The essential linkage between the two production relations is the time spent on loading/unloading cargo. That is, port efficiency improvements in the sense of

[10] Factors such as the mix of liner and tramp ships calling on a port, as well as e.g. directional imbalances, do of course play an important role in determining logistics efficiencies. The proposed logistics productivity analysis framework should therefore account for multiple cargo types (to control for the composition of carriers) and contextual variables (e.g., hinterland characteristics) that may influence productivities.

reduced time to handle a given bundle of cargo will simultaneously reduce air pollution emissions from ships at berth[11].

We note that the first production relation, explaining the port's resource utilization, might be extended by treating the ship type as a contextual variable, as it is likely that different ship types and sizes vary in terms of resource requirement for cargo handling.

We can further monetize some of the air pollutants based on official Norwegian unit prices (cf. section 4.3.1), and estimate the external cost reductions of lowering in-port air pollution. Unit prices will be corrected for population density in the port area.

### 5.2.3 Noise and air pollution emissions from land-based port operations

At this point, we have been unable to retrieve data that would allow us to evaluate air pollution emissions due to land-based operations (i.e., due to the operation of equipment). However, according to a detailed air pollution mapping for the port of Oslo[12], only 8 percent of its total $NO_x$ emissions in 2013 stemmed from land-based port operations. This figure includes emissions from road and rail transport (at the port's gate), in addition to the operation of cargo handling equipment. This suggests that the air pollution caused by ships at berth – which was treated in the previous section – are far more important.

Trozzi (2000) identifies three main sources of port noise:

- Passenger car and heavy vehicle road traffic
- Goods movement, deriving from equipment such as quay cranes and pumps
- Rail traffic noise

As noted by Miola et al. (2009), most port activities generate noise. For example, the development of specialized container or bulk handling facilities with their 24-hour high-speed operations produces an increase of noise. Miola et al. further note that the main propulsion and auxiliary engines, the propeller and transverse propulsion unit, and the heating, ventilation, and air conditioning system are the main sources of noise emissions caused by ships at berth. Although noise can be waterborne, airborne, or structure born, the most important port noise emission is airborne noise and particularly the ambient noise in the port area (Miola et al., 2009).

As discussed in section 4, the best data source on noise emissions is the continuous noise monitoring in the port of Oslo, related to the container handling at the Ormsund and Sjursøya terminals, as data on equivalent noise is available per hour. Consequently, since Statistics Norway's port statistics provide information about the time of arrival and departure of ships calling on Ormsund and Sjursøya, it is possible to link the amount of cargo loaded/unloaded, the duration of the loading/unloading operations, and ship characteristics to the results of the noise monitoring. Note that

[11] This relationship is based on the assumption that time in port is costly for ships, and thus that time benefits reaped in ports will be exploited to either slow steam among ports and/or to add on additional port calls in liner shipping. If reduced cargo handling durations merely leads to additional idle time, the emissions reductions from faster cargo handling will be overestimated.

[12] See http://www.oslohavn.no/filestore/Milj/2015Faktaark-LuftutslippfraOslobyogOslohavn.pdf (in Norwegian) See http://www.oslohavn.no/filestore/Milj/2015Faktaark-LuftutslippfraOslobyogOslohavn.pdf (in Norwegian)

data on Ormsund and Sjursøya's equipment is available from Halvor Schøyen's dataset on Norwegian container ports (see section 4.1.3).

### 5.2.4 Risk assessment of emissions to sea and land

We have obtained data on accidental oil spills to sea and land from the Norwegian Coastal Administration for the period 2013-2015. This data contains the logs from the preparedness team against acute pollution. The data consists of all cases of acute pollution between 2012 and 2015 (there exists logs as far back as the mid-90s, but they would require manual processing). There are about 1000 – 1300 acute pollution cases per year in our sample. Less than 10 % of the cases take place in a port area, either on land or at sea.

As explained in Rødseth and Wangsness (2015), in order to model the stochastic nature of accidental spills the Just-Pope (1978) risk assessment technique can be used. Utilizing this idea, we can define a function explaining accidental spills by the port operations technology, and an error term (e) which can be thought of as an manifestation of risk:

Accidental spills = f(cargo handling duration, total quay lengths, port area, cargo throughput; ship type, ship size) + e

The following modelling strategy can be considered:

- Estimate the regression equation and predict the error term, e
- Identify variables that are expected to increase or decrease the probability of accidental spills taking place by a priori reasoning
- Run a regression where the identified variables are used to explain the variations of e (the error term)

The usefulness of the Just-Pope approach depends on the available data. In particular, on whether events do occur in the ports under consideration (i.e., the quarterly ports) or not. If the probability of accidental spills is small or negligible (e.g., that accidental spills are observed only in a few of the relevant ports), the approach is less likely to be fruitful.

## 5.3 On the difference between loading and unloading

We note that the literature on port economics solely considers the throughput of cargo, and does not distinguish loading and unloading (i.e., by viewing the amount of cargo loaded and unloaded as different (heterogeneous) outputs). However, these two operations might differ substantially in terms of the port's resource requirements to undertake them. Fortunately, the port statistic distinguishes between loading and unloading of commodities, which allows us to evaluate whether treating the two differently is fruitful for EXPORT's empirical analyses.

Of particular interest is whether joint loading/unloading of cargo is less time consuming than undertaking the tasks separately. In the economics literature, resource saving due to the joint production of multiple outputs are known as economies of scope. If evidence of economies of scope in loading/unloading commodities is detected, it indicates that a port system that facilities joint loading and unloading at a given port should be promoted.

## 5.4 On modelling contextual factors

To our knowledge, only a few studies on port economics have considered contextual variables that are not under the control by the port, but which might affect its productivity. Wanke (2013) considers the following variable:

- Private administration (dummy variable)

- Hinterland (Sq. Km)

- Number of highway accesses

- Riverine access (dummy variable)

- Railroad access (dummy variable)

- Number of accessing channels

while Yuen et al. (2013) consider:

- Ownership (Chinese and non-Chinese)

- Hinterland population

- Hinterland GDP

- The degree of inter-port competition (the log distance of the seaport where a particular container terminal located from the nearest other seaport)

- The degree of intra-port competition (number of the container port terminal operators in the port city)

- The average wage

Broadly speaking, the reviewed publications emphasize ownership type, hinterland characteristics, and accessibility. Our dataset comprises publicly owned domestic ports. Thus, we turn our attention to hinterland characteristics and accessibility. Moreover, we add to the literature by also considering variations in the types and sizes of ships to be potentially important determinants of port productivity, in particular when the cargo handling duration is taken into account in port productivity and efficiency analyses.

**Hinterland characteristics and accessibility:** Hinterland characteristics dictate the types and amounts of cargo that flows through the port. For example, ports in nearby location to mines or metal ores are likely to be dry bulk intensive. Moreover, the size of the port's hinterland with respect to cargo demand is likely to affect its possibility to adopt the most productive scale size, simply because the cargo throughput in adjacent regions can be seen as exogenously given[13].

[13] This assumption is common when modelling freight transport. For example, the development of Norwegian National Freight Model System (see http://www.ntp.dep.no/Transportanalyser/Transportanalyse+godstransport/_attachment/526626/binary/847833?_ts=14135402fc8http://www.ntp.dep.no/Transportanalyser/Transportanalyse+godstransport/_attachment/526626/binary/847833?_ts=14135402fc8) started with the determination of

From the point of view of productivity and efficiency analysis, the influence of hinterland characteristics on cargo flows can easily be circumvented by adopting an input oriented approach, i.e., to measure productivity and efficiency when treating the output vector (and thus, the influence of hinterland characteristics) as exogenously given. If the purpose of the analysis is merely to address port efficiencies, this approach is sufficient.

However, the EXPORT project intends to provide new knowledge about the optimal (efficient) exploitation of the current port infrastructure in Norway. This promotes evaluating productivity and efficiency given capacity-determining inputs, rather than treating the cargo flows as exogenously given. This output oriented approach might, however, produce results on cargo throughput that are not supported by the current production and consumption patterns of the ports' hinterlands.

Arguing that EXPORT focuses on future growth scenarios, where e.g., extensive political reforms have been implemented in support of maritime transport or by prolonged GDP-growth that promotes growth for all modes, may provide some support for the approach. However, it is unlikely that cargo flows can be viewed as independent from the hinterland characteristics in any distant scenario, as their production capacities must be taken into consideration. For example, there are bounds to the extraction of natural resources, which in turn influences the future flows of bulk cargoes at different locations. The current crises in the petroleum sector is one example of factors that are likely to determine the flow of wet bulk commodities.

Establishing the hinterlands' production capacities goes well beyond the scope of the EXPORT project. Instead, we propose an alternative modelling approach that i) takes into account the impact of hinterland characteristics on port production and ii) does not entail considering cargo flows to be fixed at the port level. This is achieved by assuming that different regions' cargo flows are exogenously given, but that cargo may be transferred between ports with overlapping hinterland. For example, assume that the ports of Borg and Moss both currently receive containerized cargo from Oslo. In this case, the ports have overlapping hinterlands (i.e., Oslo). We might treat the total amount of cargo from Oslo to Borg and Moss as exogenously given, but to consider whether reallocating the cargo among Borg and Moss, relative to the current cargo distribution, could lead to increased productivity i) at the port level and ii) for the port sector (which in our stylized example comprises only Borg and Moss).

As discussed in section 5.3.2, a recent report by Hovi, Grue, and Caspersen (2014) analyse the hinterland of key ports in Norway, using both Statistic Norway's freight truck survey and the Norwegian National Freight Model System. This information is applicable to our analyses, and additional information can be obtained from the road freight survey if found useful at a later stage of the project.

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cargo flows between production zones and consumption zones. Taking these flows as given, the objective is then to determine the least costly way of transporting the cargo between the zones.

**Ship types and sizes:** The handling of different ship types – and consequently – different cargo types requires different resources use by the ports. This is controlled for by modelling ports as multi-output producers (i.e., by handling different types of commodities). However, the ship size also plays a role in determining the input use. For example, Jansson and Schneerson (1987) find that there is a positive relationship between the handling time and the ship size. Fortunately, the port statistics contains information about the sizes of ships calling on the quarterly ports, which thereby would allow us to control for the effect of ship size on port efficiency and productivity. Note that if the sizes of ships calling on a given port is highly correlated with the port capacity (e.g., total quay lengths, the size of the port area, or depths), the ship size variable can be omitted from the model.

# 6 Data management

As explained by section 2, the overall purpose of EXPORT is to evaluate the optimal use of the current port infrastructure when external costs related to port operations also are taken into account. By optimal use of the current port infrastructure, we mean maximizing port productivity by adopting technical efficiency and exploiting scale and scope economies in cargo handling. Our main dataset therefore considers the quarterly ports' annual throughput of various cargo types and passengers, capacity determining inputs, and the total time spent on loading/unloading cargo. Considering the ports as multi-output producers (i.e., by handling different cargo types) allows us to consider economies of scope by the joint handling of different cargo types. Moreover, as our dataset further separates the output vector into the amounts of cargo that are loaded and unloaded, our dataset allows us to evaluate economies of scope in jointly loading and unloading cargo (compared to undertaking the loading and unloading in two separate operations). Our main dataset further contains information about ship types and ship and engine sizes, which i) might be important determinants for port productivity and ii) is crucial for calculating emission to air from ships at berth.

Rødseth and Wangsness (2015) view i) the dispersion of contaminated sediments, ii) emissions to air from ships at berth, iii) noise and air pollutant emissions due to land-based port operations, and iv) accidental spills as being key externalities associated with the port sector.

The dispersion of contaminated sediment was treated in section 5.2.1, where it was argued that the pollution dispersion could be estimated based on the number of annual calls per port. Further, the average cargo throughput per call (i.e., logistics productivity) was perceived to be an important determinant of eco efficiency – viewed as the ratio of economic output to the dispersion of contamination. Our main dataset provides the relevant variables (e.g., the number of annual calls and aggregate ship capacities) in order to analyse pollution dispersion and logistics efficiency.

Air pollution emissions from ships at berth was treated in section 5.2.2. Our main dataset contains information about the ships' engine power, which together with the other available data on ship characteristics allows estimating ship emission to air for each call. This information is, in turn, aggregated to the port level.

Accidental spills to sea and ground were treated in section 5.2.4. The Norwegian Costal Administration has provided a database on all recorded oil spills between 2013 and 2015. Thus, in-port events (i.e., the number of events and their magnitudes) can be extracted and coupled with our main dataset. However, our preliminary results show that very few events occur at the quarterly ports, which means that this data might not be very useful for EXPORT's analyses. This will be further discussed in section 6.4.

Finally, noise and land-based port operations were treated in section 5.2.3. It was concluded that the best data on noise emissions is from the continuous noise monitoring of the container handling in the port of Oslo. This entails that noise emissions cannot be appended to our main dataset covering 25 quarterly ports, but must be examined by undertaking a case study on container handling in Oslo. Thus, we are not able to make comparisons of (noise-related) environmental efficiencies across ports, and cannot examine economies of scope by handling multiple cargo types based on this data. However, the detailed emissions data allow us to pinpoint the determinants of noise emissions and also to assess social noise costs as the noise meter from which the data is retrieved is located in a densely populated area (Ormøya).

So far, this report has dealt with tasks 1.1 and 1.2 of EXPORT's work package 1. This section responds to task 1.3 by presenting how the collected data has been processed in order to make it ready for EXPORT's subsequent empirical analyses. It is important to include a thorough discussion of the data management, both in order to ensure a detailed record of data preparation and to enable researchers and/or other users of the data to review the quality of the data management.

## 6.1 Establishing the main (port-level) dataset

Statistics Norway publish quarterly data on port activity for the ports with most cargo throughput per year. We have been given access to the raw data behind the official statistics for the years 2010 to 2014, subject to signing a confidentiality agreement with Statistics Norway. All results from these raw data will be presented in aggregated form and will be untraceable to individual ports of call. The explanation of variables from this data set has been given in sections 4.1.1 and 4.2.1.

There has been a data management process for taking the raw data and processing it into an applicable port level dataset. We describe the main steps in the following:

1. **Linking datasets on cargo handling with data sets on time spent in port:** Statistics Norway receive raw data in different sets, but each port of call is given a unique identifier so that cargo handling can be linked with time usage. However, before the linking can take place, several observations per port of call needs to be aggregated to one observation. E.g. a port of call may have several observations of loading and unloading different types of cargo, or observations of loading, unloading and repair, i.e. several rows per port of call. These were aggregated to one row per port of call, but with more columns.
2. **Data cleaning:** Of the thousands of observations on ports of call, some observations (approx. 50 per 100 0000) have obviously been filled out inconsistently. This creates duplicate observations of ports of call, or cases where some of the several observations for one port of call cannot be aggregated to one observation due to inconsistent registration (e.g. the same ship could be registered under different ship types for the same port of call). This gives some indication that the data quality is not perfect, but it is still considered acceptable. Ports of call from privately owned ports were also deleted due to confidentiality issues. Data from the following privately owned ports were deleted: Årdal, Hjelmeland, Sokndal, Strand, Vanylven, Suldal, Meløy, Odda, Sveagruva, Årdalstangen, Glomsfjord, Jelsa, Odda, Rekefjord, Tau og Åheim.
3. **Imputing missing (or impossible/improbable) values for time observations:** Approximately 20 % of the ports of call had either missing

(non-registered) observations for time, or negative values (which is impossible, so it's safe to assume registration error) or highly improbable values (e.g. several months spent on "normal" amounts of cargo). These unusable values were replaced by imputed estimated values based on regression analysis in Stata of the ports of call with non-missing, reasonable values. The estimation results for 2011 and 2012 are given in the table below.

**Table 3:** *Ordinary least squares result for imputing missing time observations*

```
  Source |       SS       df       MS              Number of obs =   81013
-------------+------------------------------           F(143, 80869) =  253.65
       Model |  4.3452e+10   143   303860192           Prob > F      =  0.0000
    Residual |  9.6876e+10 80869   1197942.2           R-squared     =  0.3096
-------------+------------------------------           Adj R-squared =  0.3084
       Total |  1.4033e+11 81012   1732192.7           Root MSE      =  1094.5
```

| LL_min | Coef. | Std. Err. | t | P>\|t\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| BT | .0536652 | .0147664 | 3.63 | 0.000 | .0247232 | .0826071 |
| containerskip | -102.097 | 92.26166 | -1.11 | 0.268 | -282.9293 | 78.73518 |
| stykkskip | 98.26216 | 78.89053 | 1.25 | 0.213 | -56.36275 | 252.8871 |
| bulkskip | 52.80877 | 79.44644 | 0.66 | 0.506 | -102.9057 | 208.5233 |
| oljetanker | -32.29178 | 82.18994 | -0.39 | 0.694 | -193.3835 | 128.8 |
| gasskip | 82.5117 | 87.90021 | 0.94 | 0.348 | -89.77213 | 254.7955 |
| offshore_service | 1050.877 | 89.70465 | 11.71 | 0.000 | 875.0562 | 1226.697 |
| fiskeskip | 367.5919 | 83.31836 | 4.41 | 0.000 | 204.2884 | 530.8953 |
| kjemikalie | -27.07578 | 84.39838 | -0.32 | 0.748 | -192.4961 | 138.3445 |
| fryseskip | 361.3618 | 150.0306 | 2.41 | 0.016 | 67.3028 | 655.4208 |
| offshore_supply | 590.0372 | 100.6827 | 5.86 | 0.000 | 392.6998 | 787.3747 |
| passasjerskip | -55.40399 | 84.20373 | -0.66 | 0.511 | -220.4427 | 109.6348 |
| roro | -24.62802 | 89.50023 | -0.28 | 0.783 | -200.0479 | 150.7918 |
| containerskip_BT | -.0309222 | .0169016 | -1.83 | 0.067 | -.0640492 | .0022047 |
| offshore_service_BT | -.1196944 | .0174253 | -6.87 | 0.000 | -.1538479 | -.0855409 |
| bulkskip_BT | -.0409172 | .01484 | -2.76 | 0.006 | -.0700035 | -.0118309 |
| fiskeskip_BT | .1790705 | .0254807 | 7.03 | 0.000 | .1291285 | .2290126 |
| gasskip_BT | -.0446907 | .0148168 | -3.02 | 0.003 | -.0737314 | -.0156499 |
| kjemikalie_BT | -.0004085 | .0153286 | -0.03 | 0.979 | -.0304524 | .0296355 |
| fryseskip_BT | -.1461007 | .0400689 | -3.65 | 0.000 | -.2246354 | -.067566 |
| offshore_supply_BT | -.0656687 | .0167498 | -3.92 | 0.000 | -.0984981 | -.0328393 |
| oljetanker_BT | -.042345 | .0148615 | -2.85 | 0.004 | -.0714734 | -.0132166 |
| passasjerskip_BT | -.0701341 | .0148853 | -4.71 | 0.000 | -.0993091 | -.040959 |
| roro_BT | -.0595188 | .0151951 | -3.92 | 0.000 | -.089301 | -.0297365 |
| stykkskip_BT | -.0625753 | .0148003 | -4.23 | 0.000 | -.0915838 | -.0335669 |
| passasjerer | .0207151 | .0029253 | 7.08 | 0.000 | .0149814 | .0264487 |
| TEU_last | 2.731174 | .3876624 | 7.05 | 0.000 | 1.971359 | 3.49099 |
| TEU_loss | 1.219555 | .3403753 | 3.58 | 0.000 | .5524214 | 1.886688 |
| TEU_last2 | -.0028213 | .0009057 | -3.12 | 0.002 | -.0045965 | -.0010462 |
| TEU_loss2 | -.0012549 | .000621 | -2.02 | 0.043 | -.0024721 | -.0000377 |
| last_stykk_tonn | .4186186 | .0098684 | 42.42 | 0.000 | .3992765 | .4379606 |

| | | | | | | |
|---|---|---|---|---|---|---|
| loss_stykk_tonn | .1641698 | .0064095 | 25.61 | 0.000 | .1516073 | .1767323 |
| last_stykk2 | -4.76e-06 | 1.35e-07 | -35.17 | 0.000 | -5.03e-06 | -4.50e-06 |
| loss_stykk2 | -6.01e-07 | 2.53e-08 | -23.72 | 0.000 | -6.50e-07 | -5.51e-07 |
| last_torr_tonn | .1055918 | .0024691 | 42.77 | 0.000 | .1007524 | .1104311 |
| loss_torr_tonn | .1808564 | .0053438 | 33.84 | 0.000 | .1703825 | .1913303 |
| last_torr2 | -4.43e-07 | 1.22e-08 | -36.34 | 0.000 | -4.67e-07 | -4.19e-07 |
| loss_torr2 | -9.41e-07 | 1.83e-07 | -5.13 | 0.000 | -1.30e-06 | -5.81e-07 |
| last_vaat_tonn | .0129799 | .0014832 | 8.75 | 0.000 | .0100728 | .0158871 |
| loss_vaat_tonn | .0233385 | .0031445 | 7.42 | 0.000 | .0171752 | .0295017 |
| last_vaat2 | -2.54e-08 | 4.06e-09 | -6.25 | 0.000 | -3.33e-08 | -1.74e-08 |
| loss_vaat2 | -1.17e-07 | 2.61e-08 | -4.48 | 0.000 | -1.68e-07 | -6.59e-08 |
| Bergen_TEU1 | 207.0113 | 46.01367 | 4.50 | 0.000 | 116.8249 | 297.1978 |
| Bodø_TEU1 | -18.64356 | 61.1304 | -0.30 | 0.760 | -138.4587 | 101.1716 |
| Borg_TEU1 | 250.3825 | 75.30613 | 3.32 | 0.001 | 102.783 | 397.982 |
| Bremanger_TEU1 | 11.02234 | 73.74928 | 0.15 | 0.881 | -133.5258 | 155.5704 |
| Brønnøy_TEU1 | -493.5759 | 1094.648 | -0.45 | 0.652 | -2639.079 | 1651.927 |
| Drammen_TEU1 | -144.4607 | 116.2897 | -1.24 | 0.214 | -372.3877 | 83.46637 |
| Eigersund_TEU1 | -141.9881 | 92.8131 | -1.53 | 0.126 | -323.9011 | 39.925 |
| Florø_TEU1 | -364.1762 | 66.11444 | -5.51 | 0.000 | -493.7601 | -234.5924 |
| Grenland_TEU1 | -203.0893 | 69.17293 | -2.94 | 0.003 | -338.6677 | -67.51077 |
| Hammerfest_TEU1 | -177.6545 | 123.0115 | -1.44 | 0.149 | -418.7563 | 63.44733 |
| Karmsund_TEU1 | -348.6209 | 49.26399 | -7.08 | 0.000 | -445.178 | -252.0638 |
| Kristiansand_TEU1 | -206.5777 | 50.94602 | -4.05 | 0.000 | -306.4316 | -106.7238 |
| Kristiansund_TEU1 | -255.0571 | 56.67881 | -4.50 | 0.000 | -366.1472 | -143.967 |
| Larvik_TEU1 | 383.4422 | 632.6564 | 0.61 | 0.544 | -856.5602 | 1623.445 |
| Molde_TEU1 | -246.5674 | 128.4062 | -1.92 | 0.055 | -498.2427 | 5.107853 |
| Moss_TEU1 | -301.7825 | 53.50955 | -5.64 | 0.000 | -406.6609 | -196.9041 |
| Måløy_TEU1 | -400.3807 | 53.91872 | -7.43 | 0.000 | -506.061 | -294.7004 |
| Narvik_TEU1 | 89.22613 | 634.0471 | 0.14 | 0.888 | -1153.502 | 1331.954 |
| Oslo_TEU1 | -184.7236 | 58.40823 | -3.16 | 0.002 | -299.2033 | -70.24385 |
| Rana_TEU1 | -499.2838 | 171.7555 | -2.91 | 0.004 | -835.9234 | -162.6443 |
| Stavanger_TEU1 | -337.9111 | 44.19386 | -7.65 | 0.000 | -424.5308 | -251.2914 |
| Tromsø_TEU1 | -253.1503 | 70.8932 | -3.57 | 0.000 | -392.1005 | -114.2001 |
| Trondheim_TEU1 | -150.4751 | 60.39199 | -2.49 | 0.013 | -268.843 | -32.10715 |
| Verdal_TEU1 | 57.2201 | 83.29561 | 0.69 | 0.492 | -106.0387 | 220.4789 |
| Alesund_TEU1 | -59.91388 | 44.45838 | -1.35 | 0.178 | -147.052 | 27.22425 |
| Bergen_stykk1 | -118.566 | 22.51766 | -5.27 | 0.000 | -162.7005 | -74.43157 |
| Bodø_stykk1 | 24.19286 | 35.49797 | 0.68 | 0.496 | -45.38292 | 93.76864 |
| Borg_stykk1 | 691.4454 | 54.34473 | 12.72 | 0.000 | 584.9301 | 797.9607 |
| Bremanger_stykk1 | 328.9111 | 229.7578 | 1.43 | 0.152 | -121.4126 | 779.2348 |
| Brønnøy_stykk1 | -420.4156 | 47.00773 | -8.94 | 0.000 | -512.5505 | -328.2808 |
| Drammen_stykk1 | 167.6445 | 39.71358 | 4.22 | 0.000 | 89.80618 | 245.4829 |
| Eigersund_stykk1 | 748.2499 | 65.27409 | 11.46 | 0.000 | 620.3131 | 876.1867 |
| Florø_stykk1 | -47.83998 | 25.70298 | -1.86 | 0.063 | -98.21765 | 2.537691 |
| Grenland_stykk1 | 202.2531 | 54.15299 | 3.73 | 0.000 | 96.11358 | 308.3926 |
| Hammerfest_stykk1 | -47.72378 | 32.36396 | -1.47 | 0.140 | -111.1569 | 15.70937 |
| Karmsund_stykk1 | 9.135729 | 31.79011 | 0.29 | 0.774 | -53.17267 | 71.44413 |
| Kristiansand_stykk1 | 66.86653 | 38.29898 | 1.75 | 0.081 | -8.199206 | 141.9323 |
| Kristiansund_stykk1 | -59.84202 | 28.4716 | -2.10 | 0.036 | -115.6462 | -4.037874 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Larvik_stykk1 | -302.1732 | 489.797 | -0.62 | 0.537 | -1262.172 | 657.8256 |
| Molde_stykk1 | -170.0714 | 46.22366 | -3.68 | 0.000 | -260.6695 | -79.47335 |
| Moss_stykk1 | 207.9198 | 89.2273 | 2.33 | 0.020 | 33.03489 | 382.8047 |
| Måløy_stykk1 | -7.150871 | 44.99235 | -0.16 | 0.874 | -95.33557 | 81.03383 |
| Narvik_stykk1 | -209.9402 | 78.03775 | -2.69 | 0.007 | -362.8937 | -56.98673 |
| Oslo_stykk1 | 404.1269 | 47.77013 | 8.46 | 0.000 | 310.4978 | 497.7561 |
| Rana_stykk1 | 817.4164 | 41.38705 | 19.75 | 0.000 | 736.298 | 898.5347 |
| Stavanger_stykk1 | 5.680377 | 26.89344 | 0.21 | 0.833 | -47.03058 | 58.39133 |
| Tromsø_stykk1 | 78.94691 | 28.43536 | 2.78 | 0.005 | 23.21378 | 134.68 |
| Trondheim_stykk1 | 51.28828 | 28.24046 | 1.82 | 0.069 | -4.062823 | 106.6394 |
| Tønsberg_stykk1 | 238.7325 | 178.3811 | 1.34 | 0.181 | -110.8932 | 588.3583 |
| Verdal_stykk1 | 422.3349 | 43.60791 | 9.68 | 0.000 | 336.8637 | 507.8061 |
| Alesund_stykk1 | 3.636484 | 26.42562 | 0.14 | 0.891 | -48.15755 | 55.43052 |
| Bergen_torr1 | -348.0811 | 28.67018 | -12.14 | 0.000 | -404.2745 | -291.8877 |
| Bodø_torr1 | 421.2764 | 53.98156 | 7.80 | 0.000 | 315.4729 | 527.0799 |
| Borg_torr1 | 903.8637 | 50.52335 | 17.89 | 0.000 | 804.8383 | 1002.889 |
| Bremanger_torr1 | -52.79019 | 136.2943 | -0.39 | 0.699 | -319.9262 | 214.3458 |
| Brønnøy_torr1 | -1370.286 | 73.34024 | -18.68 | 0.000 | -1514.033 | -1226.54 |
| Drammen_torr1 | 446.2869 | 50.70808 | 8.80 | 0.000 | 346.8994 | 545.6744 |
| Eigersund_torr1 | 222.2882 | 55.13383 | 4.03 | 0.000 | 114.2262 | 330.3501 |
| Florø_torr1 | 394.9973 | 35.70874 | 11.06 | 0.000 | 325.0084 | 464.9862 |
| Grenland_torr1 | 1394.683 | 33.13054 | 42.10 | 0.000 | 1329.748 | 1459.619 |
| Hammerfest_torr1 | 252.0389 | 100.7719 | 2.50 | 0.012 | 54.52659 | 449.5511 |
| Karmsund_torr1 | 61.46645 | 29.86105 | 2.06 | 0.040 | 2.938995 | 119.9939 |
| Kristiansand_torr1 | 601.93 | 62.36908 | 9.65 | 0.000 | 479.687 | 724.1729 |
| Kristiansund_torr1 | 440.7329 | 34.734 | 12.69 | 0.000 | 372.6545 | 508.8113 |
| Larvik_torr1 | 695.9262 | 632.239 | 1.10 | 0.271 | -543.2581 | 1935.11 |
| Molde_torr1 | -311.6309 | 39.84357 | -7.82 | 0.000 | -389.724 | -233.5378 |
| Moss_torr1 | 937.9694 | 123.2774 | 7.61 | 0.000 | 696.3465 | 1179.592 |
| Måløy_torr1 | -49.79001 | 96.78383 | -0.51 | 0.607 | -239.4857 | 139.9057 |
| Narvik_torr1 | -64.62827 | 50.50402 | -1.28 | 0.201 | -163.6158 | 34.35926 |
| Oslo_torr1 | 318.5158 | 32.90293 | 9.68 | 0.000 | 254.0263 | 383.0053 |
| Rana_torr1 | 297.2713 | 40.58427 | 7.32 | 0.000 | 217.7264 | 376.8162 |
| Stavanger_torr1 | 484.9241 | 33.06624 | 14.67 | 0.000 | 420.1145 | 549.7337 |
| Tromsø_torr1 | -281.2381 | 35.07932 | -8.02 | 0.000 | -349.9933 | -212.4829 |
| Trondheim_torr1 | 444.9668 | 39.4309 | 11.28 | 0.000 | 367.6825 | 522.2511 |
| Tønsberg_torr1 | -102.418 | 87.87383 | -1.17 | 0.244 | -274.6501 | 69.81417 |
| Verdal_torr1 | 545.7118 | 44.53363 | 12.25 | 0.000 | 458.4262 | 632.9974 |
| Alesund_torr1 | -10.57831 | 41.66355 | -0.25 | 0.800 | -92.23859 | 71.08198 |
| Bergen_vaat1 | 179.1885 | 27.65625 | 6.48 | 0.000 | 124.9824 | 233.3945 |
| Bodø_vaat1 | -147.6494 | 144.4782 | -1.02 | 0.307 | -430.8256 | 135.5268 |
| Borg_vaat1 | 801.5393 | 54.86552 | 14.61 | 0.000 | 694.0033 | 909.0754 |
| Bremanger_vaat1 | 148.903 | 42.68874 | 3.49 | 0.000 | 65.2334 | 232.5727 |
| Brønnøy_vaat1 | -332.0979 | 127.5214 | -2.60 | 0.009 | -582.039 | -82.15685 |
| Drammen_vaat1 | 395.7473 | 96.89961 | 4.08 | 0.000 | 205.8247 | 585.6699 |
| Eigersund_vaat1 | 24.54015 | 94.5555 | 0.26 | 0.795 | -160.788 | 209.8683 |
| Florø_vaat1 | 1.067847 | 25.97148 | 0.04 | 0.967 | -49.83608 | 51.97178 |
| Grenland_vaat1 | 707.9509 | 39.14899 | 18.08 | 0.000 | 631.2191 | 784.6827 |
| Hammerfest_vaat1 | 456.696 | 56.12232 | 8.14 | 0.000 | 346.6967 | 566.6954 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Karmsund_vaat1 | 214.278 | 41.98724 | 5.10 | 0.000 | 131.9833 | 296.5727 |
| Kristiansand_vaat1 | 334.1624 | 74.24115 | 4.50 | 0.000 | 188.6502 | 479.6745 |
| Kristiansund_vaat1 | 269.4418 | 33.22114 | 8.11 | 0.000 | 204.3285 | 334.555 |
| Molde_vaat1 | 761.3998 | 54.36487 | 14.01 | 0.000 | 654.845 | 867.9546 |
| Måløy_vaat1 | -44.73183 | 44.22007 | -1.01 | 0.312 | -131.4029 | 41.93921 |
| Narvik_vaat1 | -433.8542 | 136.7118 | -3.17 | 0.002 | -701.8083 | -165.9 |
| Rana_vaat1 | -47.41567 | 97.00196 | -0.49 | 0.625 | -237.5389 | 142.7075 |
| Stavanger_vaat1 | 299.7957 | 34.77861 | 8.62 | 0.000 | 231.6299 | 367.9615 |
| Tromsø_vaat1 | 167.9561 | 56.0699 | 3.00 | 0.003 | 58.05945 | 277.8527 |
| Trondheim_vaat1 | 125.5009 | 74.43276 | 1.69 | 0.092 | -20.38681 | 271.3886 |
| Tønsberg_vaat1 | 1236.968 | 41.76348 | 29.62 | 0.000 | 1155.112 | 1318.824 |
| Verdal_vaat1 | 309.9542 | 117.7386 | 2.63 | 0.008 | 79.18729 | 540.721 |
| Alesund_vaat1 | -7.896254 | 55.34202 | -0.14 | 0.887 | -116.3663 | 100.5737 |
| repa | 217.3743 | 48.18252 | 4.51 | 0.000 | 122.9368 | 311.8117 |
| _cons | 480.7369 | 79.72909 | 6.03 | 0.000 | 324.4684 | 637.0054 |

After the imputation of the estimated values where needed, we aggregated the time values, both the original ones that we kept and the replaced ones, for each port per year. This indicates that the quality of the data applied for the productivity analysis on port level will not be perfect, but we chose this strategy in order to match the complete registration of cargo throughput with an estimate of complete time usage. The data quality is still considered to be acceptable, but our strategy will be the source of some uncertainty. We stress that any analysis on a more detailed level than the port, will only be conducted on observations with original, reasonable time values. All steps in the data management and estimation process are documented in Stata do-files.

After completing these steps in the data management process we are left with a data set with complete cargo throughput per port per year, with the associated time spent on loading and unloading the ships at berth.

## 6.2 Estimating emissions to air from ships at berth

We utilize the methodology described by EPA (2009) to estimate emissions to air from ships at berth. The emissions are calculated for each port call (i.e., each ship), and thereafter aggregated to the port level.

Following EPA (2009), the emissions to air per hour of activity (e.g., hoteling; loading/unloading) can formally be written as:

$$E/A = P \times LF \times EF$$

Where E/A denotes emissions of a given air pollutant per hour, P denotes the ship's maximum continuous rating power (kW), LF denotes load factor, and EF denotes emission factor for the air pollutant under consideration. Since we emphasize emissions to air during hoteling, we focus solely on emissions associated with operating the ships' auxiliary engines.

EPA (2009) recommends Entec (2002) emission factors, and presents the following table of emission factors for auxiliary engines, based on the Entec study:

**Table 4:** *Auxiliary engine emission factors in g/kWh (Source: EPA, 2009)*

| Fuel Type | Sulfur | Emission Factors (g/kWh) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | NOx | $PM_{10}$ | $PM_{2.5}$ | HC | CO | SOx | $CO_2$ | BSFC |
| RO | 2.70% | 14.7 | 1.44 | 1.32 | 0.40 | 1.10 | 11.98 | 722.54 | 227 |
| MDO | 1.00% | 13.9 | 0.49 | 0.45 | 0.40 | 1.10 | 4.24 | 690.71 | 217 |
| MGO | 0.50% | 13.9 | 0.32 | 0.29 | 0.40 | 1.10 | 2.12 | 690.71 | 217 |
| MGO | 0.10% | 13.9 | 0.18 | 0.17 | 0.40 | 1.10 | 0.42 | 690.71 | 217 |

Emission factors for different fuel types are provided by the table, i.e., for residual oil (RO), marine diesel oil (MDO), and high-sulphur and low-sulphur marine gas oil (MGO). Unfortunately, we do not have access to data that allow us to identify different ships' fuel types. However, according to the recent SECA[14]-regulation which applies to ships calling on ports in Norway, only the low-sulphur MGO fuel will be applicable in Norwegian waters in the future[15]. We therefore propose to use the emission factors for low-sulphur MGO for our estimations of emissions to air. We asked a senior researcher at the Norwegian Institute for Air Research (NILU) about the reliability of this approach. She responded that "For emission of $SO_2$ yes, it makes sense to assume that all vessels after 2015 are running on 0.1% sulphur. For emissions of NOx it will not depend on the type of fuel, but on the type of engine that each vessel has, therefore on the type of vessel[16]". We interpret her feedback as supporting our choice to only use the emission factor for low-sulphur MGO when estimating emissions.

As pointed out by the NILU researcher, the vessel type is also crucial for determining the emissions to air. This feature is modelled by allowing emissions to air differ with ship types and their maximum power rating and load factors.

The Norwegian Costal Administration provides ship register data (see section 4.2.1), containing information about various characteristics of ships calling on Norwegian ports. This data is sensitive and is only made available to the project team during the project period.

The ship register provides information about the various ships' total engine power. We use the merge function in Stata to connect the information on total engine power to the ships found in our main dataset (i.e., the port statistics) using IMO-numbers as the key variable for merging. Unfortunately, there are some missing values of total engine power after the merging procedure, i.e., we are unable to identify total engine power for all ships in our main dataset. In order to avoid having to reduce the sample size and thereby to deviate from the publicly available port statistic (published at the

[14] Sulphur Emission Control Areas (SECA) are sea areas in which stricter controls were established to minimize airborne emissions (SOx, NOx, ODS, VOC) from ships.

[15] This is not the case if ships comply with the SECA regulation by installing scrubbers that remove sulphur dioxide from flue gases. In this case, the ships would be able to use high-sulphur fuels without violating the regulation.

[16] Personal e-mail communication, February 5th, 2016

port level) in terms of the figures for annual cargo throughput, we impute the missing values. The imputation procedure is as follows:

1. We merge the information about ship types from the port statistics (i.e., our main dataset) to the dataset on ship characteristics after removing IMO-number duplicates from the port statistics. This is done to ensure that the classification of ships is in line with our main dataset.
2. We focus solely on the ships for which we are able to match information on ship type with the data on ship characteristics. This leaves approx. 4500 ships in the sample for imputation.
3. Further examinations reveals that there is an outlier in the data, which is excluded prior to estimation
4. We regress total engine power on i) dummy variables for ship types (according to the port statistics) and ii) ship size. We approximate the ship size by gross tonnage. Note that other indicators of ship size, such as length overall, was also considered, but was found to be inferior to gross tonnage based on the goodness of fit.

We consider different specifications of the regression model (e.g., with and without interaction dummies), and find that the following model provides the best fit to the data ($R^2$ = 0.86):

**Table 5:** *Ordinary least squares result for imputing total engine power*

| Source | SS | df | MS | | |
|---|---|---|---|---|---|
| Model | 1.5845e+11 | 25 | 6.3380e+09 | Number of obs = | 4123 |
| Residual | 2.5516e+10 | 4097 | 6228064.76 | F( 25, 4097) = | 1017.65 |
| Total | 1.8397e+11 | 4122 | 44630347.5 | Prob > F = | 0.0000 |
| | | | | R-squared = | 0.8613 |
| | | | | Adj R-squared = | 0.8605 |
| | | | | Root MSE = | 2495.6 |

| eng_total_kw | Coef. | Std. Err. | t | P>\|t\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| Andreoff | 1099.008 | 585.1383 | 1.88 | 0.060 | -48.18075 | 2246.197 |
| Bulk | 62.59076 | 511.958 | 0.12 | 0.903 | -941.1249 | 1066.306 |
| Fisk | -1390.389 | 549.6276 | -2.53 | 0.011 | -2467.958 | -312.8203 |
| Gass | 938.2973 | 575.1841 | 1.63 | 0.103 | -189.376 | 2065.971 |
| Kjemi | 7.087284 | 541.9225 | 0.01 | 0.990 | -1055.375 | 1069.55 |
| Kjøle | -2072.372 | 1656.014 | -1.25 | 0.211 | -5319.059 | 1174.315 |
| Container | -1248.911 | 604.6996 | -2.07 | 0.039 | -2434.451 | -63.37154 |
| Offshore | 1977.314 | 596.5133 | 3.31 | 0.001 | 807.8241 | 3146.804 |
| Olje | 1730.139 | 525.3052 | 3.29 | 0.001 | 700.2558 | 2760.023 |
| Passasjer | 480.7433 | 551.5658 | 0.87 | 0.383 | -600.6253 | 1562.112 |
| Roro | 1582.885 | 770.3955 | 2.05 | 0.040 | 72.49167 | 3093.279 |
| Stykk | -725.7768 | 525.6227 | -1.38 | 0.167 | -1756.283 | 304.7292 |
| Andreoffint | -.4754089 | .7315565 | -0.65 | 0.516 | -1.909657 | .9588393 |
| Bulkint | -1.60009 | .7289957 | -2.19 | 0.028 | -3.029317 | -.170862 |

```
     Fiskint |  -.3182414   .7460088    -0.43   0.670    -1.780824    1.144341
     Gassint |  -1.533472    .729027    -2.10   0.035    -2.962761   -.1041836
    Kjemiint |  -1.499489   .7291407    -2.06   0.040       -2.929    -.069977
    Kjøleint |  -.9039705   .8269893    -1.09   0.274    -2.525319    .7173776
Containerint |  -1.038425   .7300698    -1.42   0.155    -2.469758    .3929084
 Offshoreint |  -1.411568   .7296672    -1.93   0.053    -2.842112    .0189763
     Oljeint |  -1.610608   .7289984    -2.21   0.027    -3.039841   -.1813752
Passasjerint |  -1.271721   .7290119    -1.74   0.081     -2.70098    .1575385
     Roroint |  -1.439187   .7295432    -1.97   0.049    -2.869488   -.0088857
    Stykkint |  -1.364686   .7292701    -1.87   0.061    -2.794451    .0650796
      gt_grt |   1.787219   .7289907     2.45   0.014     .3580013    3.216437
       _cons |   1892.095   505.1425     3.75   0.000     901.7414    2882.449
------------------------------------------------------------------------------
```

where the 12 first variable names refer to different ship types (using the classification of ships according to Statistic Norway's port statistics), the variable name gt_grt refers to gross tonnage, while the remaining coefficients capture interaction effects between ship types and gross tonnage and, finally, the constant term.

Since our main dataset (i.e., the port statistics) provides information on ship types and gross tonnage, we use the coefficient estimates listed above to predict total engine power for values missing after merging the total engine power variable from the ship register with our dataset.

Having appended (and imputed) the total engine power to our dataset, it must in turn be distributed among the main and auxiliary engines. In order to identify auxiliary engine power, we utilize auxiliary to propulsion ratios (APR) provided by EPA (2009):

**Table 6:** *Auxiliary engine power ratios (Source: EPA, 2009)*

| Ship Type | Average Propulsion Engine (kW) | Average Auxiliary Engines | | | | Auxiliary to Propulsion Ratio |
|---|---|---|---|---|---|---|
| | | Number | Power Each (kW) | Total Power (kW) | Engine Speed | |
| Auto Carrier | 10,700 | 2.9 | 983 | 2,850 | Medium | 0.266 |
| Bulk Carrier | 8,000 | 2.9 | 612 | 1,776 | Medium | 0.222 |
| Container Ship | 30,900 | 3.6 | 1,889 | 6,800 | Medium | 0.220 |
| Cruise Ship[a] | 39,600 | 4.7 | 2,340 | 11,000 | Medium | 0.278 |
| General Cargo | 9,300 | 2.9 | 612 | 1,776 | Medium | 0.191 |
| RORO | 11,000 | 2.9 | 983 | 2,850 | Medium | 0.259 |
| Reefer | 9,600 | 4.0 | 975 | 3,900 | Medium | 0.406 |
| Tanker | 9,400 | 2.7 | 735 | 1,985 | Medium | 0.211 |

[a] Cruise ships typically use a different engine configuration known as diesel-electric. These vessels use large generator sets for both propulsion and ship-board electricity. The figures for cruise ships above are estimates taken from the Starcrest Vessel Boarding Program.

The propulsion power is calculated by (1/(1+APR))×total engine power, and the auxiliary power can thus be identified by subtracting the total engine power from the calculated propulsion power (or simply, by algebraic manipulation, by (APR/(1+APR))×total engine power).

Finally, the load factors for auxiliary engines are obtained from EPA (2009):

**Table 7:** *Auxiliary engine load factors (Source: EPA, 2009)*

| Ship-Type | Cruise | RSZ | Maneuver | Hotel |
|---|---|---|---|---|
| Auto Carrier | 0.15 | 0.30 | 0.45 | 0.26 |
| Bulk Carrier | 0.17 | 0.27 | 0.45 | 0.10 |
| Container Ship | 0.13 | 0.25 | 0.48 | 0.19 |
| Cruise Ship | 0.80 | 0.80 | 0.80 | 0.64 |
| General Cargo | 0.17 | 0.27 | 0.45 | 0.22 |
| Miscellaneous | 0.17 | 0.27 | 0.45 | 0.22 |
| OG Tug | 0.17 | 0.27 | 0.45 | 0.22 |
| RORO | 0.15 | 0.30 | 0.45 | 0.26 |
| Reefer | 0.20 | 0.34 | 0.67 | 0.32 |
| Tanker | 0.24 | 0.28 | 0.33 | 0.26 |

## 6.3 Generating data on noise emissions

As previously explained, data on port noise are scarce. The main exception is data from the port of Oslo, which continuously monitors noise emissions related to its container handling. The port has installed noise meters at two strategic locations in Oslo; at Ormøya and Bekkelagsskråningen. These meters will, of course, pick up noise from other sources than the port, but this bias appears to be more prominent for Bekkelagsskråningen than for Ormøya. Moreover, we expect more people to be affected by the port noise at Ormøya compared to Bekkelagsskråningen. We therefore choose to focus on the results from the noise meter at Ormøya when compiling the data. This meter targets noise events related to container handling at the Ormsund and Sjursøya container terminals.

The port of Oslo publishes the results of their noise measurement (per hour) at their web site. Unfortunately, the results are not available in numeric form, but are only published as weekly line charts, separated between noise during the day, the evening, and at night. The project team has contacted the port of Oslo to obtain the data e.g. in the form of an Excel file, but has been unsuccessful in achieving this task. It was therefore decided to extract the data from the line plots using the web-based tool WebPlotDigitizer[17]. The data were extracted using the following procedure:

[17] See http://connectedresearchers.com/extracting-data-from-plots-images-and-maps-with-webplotdigitizer/ for more information.

i. First we ran the program in automatic mode, using the mask function to identify the line plot
ii. We used the algorithm x-step with interpolation (0% smoothing), using 1 as the x-step (i.e., identifying noise for each hour).
iii. After using the automatic mode, we switched to manual mode in order to improve the extraction of data by i) adding any missing datapoints that had been overlooked by the automatic mode and ii) adjusting the datapoints whenever necessary (e.g., when the automatic mode puts a datapoint slightly above/below the line chart).
iv. Extract the data and copy to Excel

This extraction procedure is very labour intensive. Moreover, the data are separated into day, evening, and night, which means that we must extract three datasets per week – and thereafter combine them – in order to have a complete dataset of hour-per-hour noise. We therefore decided to only extract a quarter of data at this point, with the option of extracting additional data at a later stage of the project. Given that 2014 is the last year for which detailed port statistics are available to the project team, we decided to focus on noise emissions related to container ships arriving in Oslo during the first quarter of 2014. The choice of quarter is motivated by the seasonal variations in noise at Ormøya, as sounds related to gardening, leisure, and birds increasing in intensity during the spring and summer[18].

The following figure illustrates the variation in the outdoor sound level (LAeq, 1hr) at Ormøya over the first quarter of 2014:

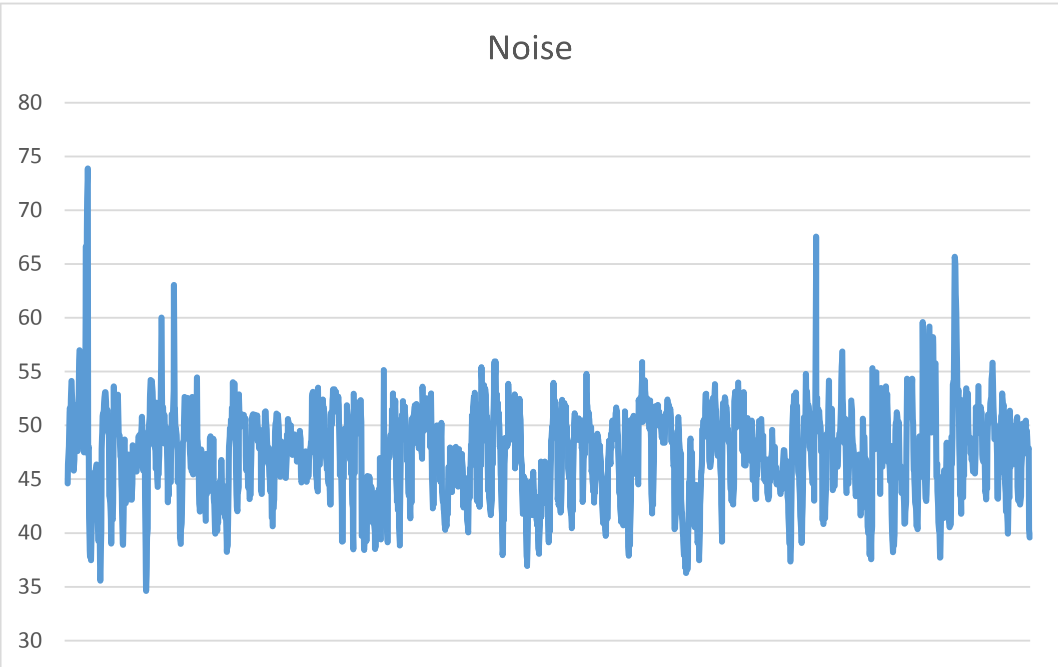


**Figure 1:** *Sound level at Ormøya, 1st quarter of 2014*

Next, we connect the noise emission data to Statistic Norway's port statistics, utilizing its information about the arrival and departure times of each ship calling on

[18] See http://www.akustikk.info/ormoya/http://www.akustikk.info/ormoya/ (in Norwegian)

Sjursøya and Ormsund. In fact, the container port at Sjursøya comprises three quays in use the first quarter of 2014, while the Ormsund terminal comprises two quays in use the first quarter of 2014. The port statistics allows us to pinpoint the quays used for each call, and thereby to distinguish noise emissions related to activities at these 5 different locations. This is illustrated by the following simple regression analysis, where dummy variables that take the value 1 for each hour that a ship is at berth for a given quay is regressed on the hourly outdoor decibel level at Ormøya:

**Table 8:** *Identifying the role of port calls in determining the sound level at Ormøya*

```
      Source |       SS       df       MS              Number of obs =    2170
-------------+------------------------------           F(  5,  2164) =  175.09
       Model |  11285.7522     5  2257.15043           Prob > F      =  0.0000
    Residual |  27896.2652  2164  12.8910652           R-squared     =  0.2880
-------------+------------------------------           Adj R-squared =  0.2864
       Total |  39182.0173  2169  18.0645539           Root MSE      =  3.5904


------------------------------------------------------------------------------
    LAeq,1hr |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     dum8103 |   .8171495   .2036115     4.01   0.000     .4178549    1.216444
     dum8104 |   .7717603   .2821944     2.73   0.006     .2183599    1.325161
     dum8105 |   1.359802    .203537     6.68   0.000     .9606532     1.75895
     dum8802 |   4.331652   .8774827     4.94   0.000     2.610855    6.052449
     dum8803 |   4.256408   .1709066    24.90   0.000      3.92125    4.591566
       _cons |   45.49897    .109391   415.93   0.000     45.28445     45.7135
------------------------------------------------------------------------------
```

where the variable names refer to quay codes[19], with quays 8103-8105 being associated with the Sjursøya terminal and quays 8802-8803 with the Ormsund terminal. This initial analysis illustrate that while noise emissions due to port activities are by far the only contributor to the overall sound level at Ormøya (i.e., the $R^2$ is 0.29), the port activities do significantly impact the overall sound level (i.e., the t-tests indicate that all coefficients are statistically significant from zero). The sizes of the coefficients are also as expected, as calls at Ormsund have a stronger impact on the sound level than calls at Sjursøya. This is because Ormsund is located much closer to Ormøya than Sjursøya. The port of Oslo is therefore aiming at undertaking most of its container operations at Sjursøya in the future.

One of the challenges for future analyses of the noise data is that there are frequently multiple calls taking place at different quays simultaneously. As the sound level at Ormøya will be affected by all simultaneous calls, the overall data may not be readily applicable to environmental production analysis. The reason is that the analysis generally assumes that each unit under evaluation is independent from the other units with regards to the data generating process.

[19] An overview of quay codes and a map of the port area has been provided by the port of Oslo.

For the purpose of undertaking an environmental production analysis, it will sensible to aggregate the data to the call-level in order to compare the environmental and economic performance of the different calls (and thus, ships). However, doing this for all calls in our dataset would ignore the interdependence among simultaneous calls with regards to the sound level, and would thereby lead to biased estimates. There are 67 "stand-alone" calls taking place the first quarter of 2014, which we think is a sufficient sample size for undertaking an environmental production analysis on noise emissions due to container handling. We do, however, advise supplementing the analysis with e.g. regression analysis on the overall dataset in order to also take into account the impact of simultaneous calls on port noise.

## 6.4 Compiling data on emissions to land and sea

The Norwegian Costal Administration provides their database on acute pollution covering the years 2013-2015 to the EXPORT team. This data is sensitive, and is only made available for the project participants within the duration of the project.

The data comprises about 1000 events per year. This includes both events related to maritime transport and to land-based activities such as road transport, housing etc.

Our initial idea is to use the database's geo-references to select events taking place at the quarterly ports. However, the information that the dataset provides on location in the form of decimals-degrees is not complete. We therefore instead attempt a word-search in the Excel-file for 2014, covering the keywords (in Norwegian):

- Havn
- Kai
- Bunkr
- Fylling
- Lekkasje
- Truck
- Kran
- Terminal

During this initial screening, we identify 74 (of 1063) events that are considered potentially relevant to EXPORT[20]. These events do not only concern the quarterly ports. Thus, we undertake a second-stage screening of relevant events, in which we focus on events taking place at quarterly ports. To make sure that an event is taking place within a quarterly port, we use the geo-references to locate the event on the map provided by the Nasjonal Havneoversikt (https://www.barentswatch.no/havner/).

To check the quality of the above procedure to identify relevant events, we undertake a sampling test for the port of Bergen, Bremanger (zero accidents), Hammerfest (zero accidents), Molde and Romsdal (zero accidents), Oslo, and Tønsberg (zero accidents). The ports are selected in particular because Bremanger, Molde and Romsdal, and Tønsberg are found to have zero events, yet they are among the key ports for wet bulk handling in Norway according to Statistics Norway's port statistics.

[20] Note that events related to leisure boats, small craft harbours, and small ferries are not taken into account

The test is only undertaken for events for which we have information about latitudes and longitudes in the form of decimals-degrees. This implies that 112 of 1063 observations (i.e., events) are not taken into account in the sampling test. These events were, however, accounted for in the initial screening.

The sampling test is undertaken in the following way:

- We copy information about events and their latitudes and longitudes to Stata
- We use Nasjonal havneoversikt to obtain information about the location of the 6 ports in terms of latitudes and longitudes
- We review all events taking place within the selected latitudes and longitudes (i.e., the selected ports), and compare them to our initial selection of events based on the word-search approach.

The sampling test based on 6 of 25 ports confirms the results reproduced above, thus indicating that the screening based on the word-search approach is reliable. The results of the second screening based on the word-search approach is summarized by the following table:

**Table 9:** *Accidental oil spills in 2014*

| Port | Number of events |
|---|---|
| Bergen og Omland Havnevesen | 7 |
| Bodø Havn KF | 1 |
| Borg Havn IKS | 0 |
| Bremanger Hamn og Næring KF | 0 |
| Brønnøy Havn KF | 0 |
| Drammenregionens Interkommunale Havnevesen | 1 |
| Eigersund Havnevesen KF | 1 |
| Flora Hamn KF | 2 |
| Grenland Havn IKS | 1 |
| Hammerfest Havn KF | 0 |
| Karmsund Interkommunale Havnevesen IKS | 1 |
| Kristiansand Havn KF | 0 |
| Kristiansund og Nordmøre Havn IKS | 1 |
| Larvik Havn KF | 0 |
| Mo i Rana Havn KF | 0 |
| Molde og Romsdal Havn IKS | 0 |
| Moss Havn KF | 0 |
| Narvik Havn KF | 1 |
| Nordfjord Havn IKS | 0 |

| Port | Number of events |
|---|---|
| Oslo Havn KF | 2 |
| Stavanger Interkommunale Havn IKS | 2 |
| Tromsø Havn KF | 2 |
| Trondheim Havn IKS | 1 |
| Tønsberg Havnevesen | 0 |
| Ålesundregionens Havnevesen | 2 |

We find in total 25 events of accidental oil spills taking place at quarterly ports in 2014. Moreover, 10 of 25 quarterly ports report zero events. This leads us to conclude that accidental oil spills are not among the most important externalities associated with the ports' handling of cargo.

# 7 Summary and conclusions

This report summarizes available data on port operations that facilitate undertaking environmental production analysis of Norwegian ports. The data can broadly be classified into activity data, environmental data, and other data. 16 relevant data sources were reviewed and rated by the project team before compiling and organizing the data.

We have emphasized compiling data for the 25 ports the goes into Statistics Norway's port statistics. The reasons for favouring these ports is that they are the main ports in Norway and thus play a key role in promoting a mode shift to maritime transport, and because we have access to good data – comprising information about cargo type and throughput, the duration of the cargo handling, and ship type and size for each call taking place at these ports. The port statistics coupled with self-compiled data on port capacity makes up our activity data. We aggregate the data to the port level to compare the ports' performances.

In a preceding EXPORT-report, Rødseth and Wangsness (2015) proposed that i) the dispersion of contaminated sediments, ii) emissions to air from ships at berth, iii) air and noise emissions from land-based port operations, and iv) soil, sediment, and water pollution due to accidental spills are the key externalities associated with port operations. Our compilation of environmental data has therefore been targeted at obtaining information about the occurrences of these four categories of pollutants. We have found that the dispersion of polluted sediments and air pollutant emissions from ships at berth can be estimated using available tools and data. We have further reviewed a database on accidental oil spills to locate events that take place at the quarterly ports. The information on sediment pollution, ship emissions, and accidental spills can be connected to our port-level activity data. However, high-quality data on noise emissions from port operations are only available for Sjursøya and Ormsund container terminals located within the port of Oslo. Consequently, a separate case study needs to be undertaken to evaluate the relationship between port activities and noise pollution. This means that in total two datasets – one dataset on port-level activity and emissions data and one dataset on noise emissions and container handling activities in Oslo – has been constructed within EXPORT's WP1. The following table provides an overview of the variables included in the port-level dataset:

**Table 10:** *Variables included in the main dataset (the port statistics)*

| Variable | Description |
|---|---|
| TEU (Lo-lo) | Annual port throughput of containers (measured in TEUs) by lo-lo. Output variable |
| TEU (Ro-ro) | Annual port throughput of containers (measured in TEUs) by ro-ro. Output variable |
| Wet bulk (tons) | Annual port throughput of wet bulk (measured in tons). Output variable. |
| Dry bulk (tons) | Annual port throughput of dry bulk (measured in tons). Output variable. |
| General cargo (tons) | Annual port throughput of general cargo (measured in tons). Output variable. |
| Loading- and unloading time (hours) | Time spent loading and unloading ships at birth per port per year for all types of cargo (measured in hours). Input variable. |
| Passengers | Annual port throughput of passengers (measured in number of persons). Output variable. |
| Area | The ports' total area dedicated to container handling. Input variable. |
| Quay lengths | The sum of the lengths of quays for each port. Input variable. |
| Depths | Dimensioning depth at entrance (determinant of the size classes of ships that are able to call on the port). Input variable. |
| Opening hours | Number of hours daily that the port is open for cargo handling. Input variable. |
| Dispersion of contaminated sediment | The dispersion of contaminated sediment (measured in $mg/m^2/year$) is estimated based on the number of annual calls and on port characteristics. Bad output variable. |
| Emissions to air | Emissions to air from ships at berth (measured in grams) is estimated using data on ship characteristics and the duration of the cargo handling. Bad output variable. |
| Accidental oil spills | The number of annual accidental oil spills (and in some cases, the estimated sizes of the oil spills). Bad output variable. |

The noise emissions data is described by table 11:

**Table 11:** *Variables included in the container handling dataset (noise emissions data)*

| Variable | Description |
|---|---|
| Noise emissions | LAeq, 1hr sound level at Ormøya. Hourly data for the first quarter of 2014. Bad output variable. |
| Container throughput | The throughput of containers/cargo for each call, where the location of the each call is pinpointed (i.e., the calls are distributed among 5 quays within the Ormsund and Sjursøya container terminals). Output variable. |
| The duration of the container handling | The duration of the loading/unloading for each call, where the location of the loading/unloading is identified (i.e., the calls are distributed among 5 quays within the Ormsund and Sjursøya terminals). Input variable. |
| Gross tonnage | The size of the ship is identified for each call[21]. Input variable. |

The noise emissions data can be supplemented with information about the equipment stocks at Sjursøya and Ormsund (see section 4.1.3 for details on container terminal data).

Finally, we have reviewed data on unit prices for pollutants and data that could be useful for establishing the size of the various ports' hinterlands. We will consider identifying ports with overlapping hinterland, to analyse the economic and environmental consequences of moving cargo between such ports (i.e., ports which shippers are likely to view as substitutes).

With this data review, we are comfortable about starting our analysis on productivity and environmental efficiency in Norwegian ports. It shows that we have obtained all of the relevant data that are available, and that the data sources we have available are most likely the ones that will give us insights into the most important aspects of both productivity and environmental efficiency.

[21] All ships calling on Sjursøya and Ormsund are classified as container ships. Consequently, there is no need for a ship-type variable.

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