Journal für Mobilität und Verkehr

ISSN 2628-4154

www.dvwg.de

Improving port sustainability performance: Cost-benefit and carbon footprint analysis for assessing infrastructure investments

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Abstract

The European Union tightened its climate targets in July 2021. Sectors of the economy - including ports - must contribute by reducing their emissions. This paper strives welfare economics by including externalities such as environmental costs and presents results for evaluating infrastructure investments in ports. By applying a combined cost-benefit and carbon footprint analysis the authors show how decision-makers can assess port investments in infrastructure economically and environmentally. Using European port redevelopment as an example, this article illustrates that including externalities in the cost comparisons of port investment options could lead to new discussion making. Moreover, decarbonizing the economy does not just bring only economic benefits by efficiency increase but can also reduce cost to society. The idea of the triple bottom line (TBL) framework is addressed and discusses the role of the inclusion of social sustainability for port infrastructure investments.

Keywords:
infrastructure, ports, triple-bottom-line framework, cost-benefit-analysis, environmental economics

1. Introduction: The European Union Green Plan and the role of ports in green transition

Roughly 40% of all European exports and 50% of all imports were transported on water in 2020 (Eurostat 2022): These goods are consequently imported or exported through the ports - A port is the door to the world market.

As such, European governments are interested in shaping the development of their ports and ought to provide guidelines for their development (Accario 2015). With its importance continuing to grow, forecasts predict that intra-European shipping will continue to increase until 2050. However, port activities face enormously challenges to meet European climate targets. According to EEA (2021) ports must also contribute to achieving carbon neutrality. At the European level, the maritime sector emits about 13% of CO2e emissions, of which 40% are generated by intra-European maritime transport alone (IMO 2020). Most ships use fossil fuels as energy sources, of which heavy fuel oil (HFO) and marine diesel oil make up the majority because of their low price. They account for about 90% of the energy used in shipping (Fenhann 2017). These fuels, however, are when burned responsible for considerable amounts of pollution and GHG emittance. Besides CO2e emissions, other substances such as sulfur dioxide (SO2), nitrogen oxides (NOX), and particulate matter (PM) are emitted, which have further negative effects on the environment and human health. The price for fuels does not have to reflect their social value (Pindyck and Rubinfeld 2018).

Ports as interface to the shipping and infrastructure provider can contribute to the decarbonization of maritime transport by reduction negative externalities and inefficiency. Ports could serve as catalysts for maritime activities and nodes of industrial and firm activities, can leverage the reduction of emissions aside from just the design of the infrastructure. Decarbonization potentials arise at various levels; the main ones are (i.) the production and provision of renewable energy, (ii.) bunkering of lower-emission fuel alternatives such as LNG, (iii.) the optimization and shortening of handling processes, and (iv.) the replacement of energy-inefficient equipment and technologies (Alamoush et al. 2022). In line with the World Ports Climate Initiative (2010), a decarbonized port should thus seek to reduce the number of

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emissions while increasing the efficiency of the port operation itself.

Cost-Benefit- (CBA) and Carbon-Footprint-Analysis (CFA) can be utilized for the economic and ecological evaluation of these measures. This article discusses the necessity and benefits of a combined CBA/CFA for port investment projects. In course of a European-wide research project on ports, a benefit-cost analysis was developed within a model that combines both analyses and brings up a discussion of port investments according to their financial and environmental performance. Beyond this aspect, the concept of Triple-Bottom-Line is included and discusses if welfare economics can benefit from investments in decarbonization projects. The price of a good need not necessarily present its social value.

The article is structured as follows: The following section introduces the cost-benefit analysis model and explains why the CBA model becomes a fundamental role in the analysis of port investments (Section 2). The theoretical foundations are put into context and elaborate the fundamentals of that model. Section 3 presents a model that combines the CBA and CFA and is applied in a European research project on port development. Section 4 discusses the best-practice results in the context of recent geopolitical and -economic developments and contextualizes them with the triple bottom line (TBL) approach. The article closes with a short conclusion and highlights the limitations of the method and article (Section 5).

2. Methodology: The Approach

Comparing the pros and cons of a potential decision is commonplace. One chooses between food, jobs, transportation, and so on. One chooses between opportunities based on positive or negative classifications and feelings. The cost-benefit analysis attempts to do this in a systematic way based on economic theory (Koopmans and Mouter 2020). However, there is an overall long history of the evaluation of investments. In microeconomics it has its own status and history, and there are even some journals that only look at benefit-cost analysis (e. g. Journal of Benefit-Cost Analysis). The idea of externalities was already part of work by Marshall (1890) and Pigou (1920). They noticed the difference between social and private costs (Pearce et al. 2006). In the 1960s and 1970s, the social cost-benefit analysis started to become a widespread application, and the theory has developed further (Pearce et al. 2006); before it was more a theoretical model in microeconomics.

Cost-benefit analyses (CBAs) enable the economic and the complementary carbon footprint analyses (CFA) for the environmental assessment of investments. Although measuring different variables both analyses aim to better understand their respective financial and ecological performance. This is not new either. But attempts to 'operationalize' a concept of sustainability in assessment methods as cost-benefit for practical decision-making have not always been convincing. Boadway (2006) states the relevance of shadow pricing of market products and inputs to calculate the opportunities of a project. The key concept of shadow prices is to reflect social opportunity costs (European Commission 2015). Barbier et al. (1990) argue, moreover, that this need not be the case when using `shadow' projects – or as in our paper alternatively projects – to ensure a sustainability objective and to calculate the costs and benefits of an investment. In both cases, the resulting optimum differs from the efficient optimum of the traditional and alternative cost-benefit criterion, but the basic cost-benefit model remains in calculation.

With the analysis of investments according to the included metrics offers the possibility to compare investments; ultimately enabling a more efficient use of limited resources through optimization in decision-making (European Commission 2015). Hence, after evaluating an investment on its economic and environmental costs and benefits, different investments can be compared with each other. In this process, objective key figures are used to compare several options for action or investment against self-imposed targets. Besides economic and environmental rates of return, the analyses can also be extended and used to quantify and compare general welfare gains of individual measures. The welfare theory was introduced by Pareto (1896) and discusses the optimum in a state where no one can be made better off without making someone else worse off. The challenge, however, is that, in addition to a general equilibrium determination, this theory is difficult to transfer to quantify `real' (opportunity) costs. In a cost-benefit analysis, the so-called willingness to pay rate is often used to be able to make differences in the modeling (Boadway 2006).

The assessment of economic investments follows existing and widespread cost-analysis methods, which focus mainly on estimates of the cost-benefit ratios. The method calculates the sums of discounted monetary inflows and monetary outflows and then sets them about each other: If the ratio is greater than 1, the project is recommended from an economic perspective (European Investment Bank 2013, 2014; European Commission 2015).

Moreover, there are different methodologies to analyze investments (in ports). Typical in the ex-ante evaluation are Economics Impact Analysis (EIA), but also Computable General Equilibrium Models (CGE) or just a cost-benefit analysis (CBA). All methods have strengths and weaknesses. These common methods have different goals, although there are similarities. A CBA should not be confused with a CGE and an Economic Impact Analysis (EIA). The latter is a widely used tool to assess the economic impact of a political or organizational decisions. Furthermore, an EIA is not based on welfare economics. Effects on private households and externalities are usually not included in EIA, but unemployment and employment are. Methods used in the EIA are often input-output analysis, regional economic models, or also computable general equilibrium models (Forsyth et al. 2021; Koopmans and Mouter 2020, Weisbrod 2008). This is different from CGE models, which are founded on micro- and macroeconomics theory. Prices are crucial in this modelling. The data intensive CGE models can analyze more general aspects of economics within an investment question. On the other hand, a CBA estimates the equivalent monetary value of the costs and benefits to the society of an investment (decision), paying particular attention to externalities with its' negative and positive effects. From this point of view, a CBA is suitable for an environmental economic analysis. As well Forsyth et al. (2021), conclude that the CBA approach and the more recent CGE modeling evaluate investment decisions well, whereby there is a methodological tendency towards CGA model. Under certain conditions et al. a CGE can depict a general equilibrium of an investment decision, whereas a CBA cannot evaluate this, and a CGA can also capture nonlocal externalities. However, for the evaluation there is certain need of data availability, which is not always given (even the port operators, as in this example of the case studies, have perfect data on externalities of the current port activities). This leads to the application of the CBA methodology in the assessment, as recommended by the EIB (2013).

In the context of the `green' transformation of port economies, however, there is a growing demand to extend the comparative assessments of investment decision to include (negative or positive) externalities, beyond the examination of economic firm activities. Emissions, like light, noise, CO2 equivalent emissions, or other elements that are harmful to the environment and health, represent an externality that is not included in classical cost-benefit analysis (Phaneuf and Requate 2016). For example, the US Maritime Administration (MARAD) of the United States Department of Transportation provides the opportunity for Emission Reduction Benefits within the cost-benefit analysis of the Port Infrastructure Development Program Grant. In addition to the reductions in external costs, it states that a benefit is credited for port infrastructure improvements if an emission reduction of fuel consumption is met (MARAD 2020; U.S. Department of Transportation 2022). But why is there a growing need to capture externalities? First, the extension of the emissions trading scheme to more sectors and the expected increase in the carbon price will make energy-inefficient investments less attractive and economically viable (i). Second, with the associated decrease in carbon emissions, other subsequent benefits often follow along e. g., the reduction of noise and light pollution, and an increase in the wellbeing of workers and the community (ii). Third, a potential reduction of energy consumption also reduces overall energy costs, which could lower operating costs making business more profitable (iii) (Phaneuf and Requate 2016; European Commission 2020). The integration of the environmental dimensions of investment decisions is carried out with the help of carbon footprint analyses (CFA). The linchpin of CFA is the `translation' of the impact of an investment on the environment into quantitative, comparable units. To be included in the analysis, the emissions resulting from a measure must be assessed and transformed into a monetary value.

According to micro-economic models, the respective `pricing´ for individual emissions such as CO2, SO2, or NOX can be done with the help of the equilibrium model (see figure 1). Here, increasing social costs $D(E)$, which originate from the emittance of emissions are compared to compensation and abatement cost $I(E)$ of emitters. The goal is to find the efficient emission level $\hat{e}^*$ and the efficient taxation level $\hat{t}^*$, i.e., finding the Pareto optimum that minimizes societal costs as a whole $\min(D(E) + C(E)$. If there is insufficient internalization of societal costs, the emission level would be inefficient, resulting in a market failure (Phaneuf and Requate 2016).

The calculation of the optimal emission level depends on the social costs of greenhouse gas emissions, which are in turn estimates of the expected impacts that climate change brings. The monetary quantification of environmental damages depends on the future development of the climate and the following valuation of said ecosystems and their functions. Socioeconomic and physical climate variables are combined and put into relation to one another (NASEM 2017). Because of the uncertainty of climate models and the monetary valuation of economic systems and ecosystem services, factors are characterized by uncertainty, which can lead to a wide range of social cost estimates. Those estimates also must be discounted. That is due to the assumption that future social costs are lower than the ones in the present.

The discount rate has a normative underlying since a higher discount rate ascribes the present a higher value than the future and thus low discount rates between 0% and 3.5% are suggested (OECD 2018). Depending on the model different damage functions are calculated which influence the optimal emission level and thus the tax (see figure 1); one of the most prominently used models is the Dynamic Integrated model of Climate and Economy (DICE) which has its origins in the works of Nordhaus and Zili (1996). For further consultation of DICE and other damage models, the work of the National Academies of Sciences, Engineering, and Medicines (NASEM 2017: pp. 129-155) provides an extensive overview.

In summary, rational cost-benefit analysis is a method that adds benefits and costs, measured in a unified unit such as the euro. Opportunity costs can be used as an optimization problem to choose the best possible alternative (Acemoglu et al. 2016). The extension to include the environmental effects with a CFA into the CBA makes it possible to evaluate investments based on both economic and social costs and benefits.

choices are made between alternatives. Therefore, the use of CBAs is recommended, which can calculate the economic value of `green´ investments and to compare them with `conventional´ investments.

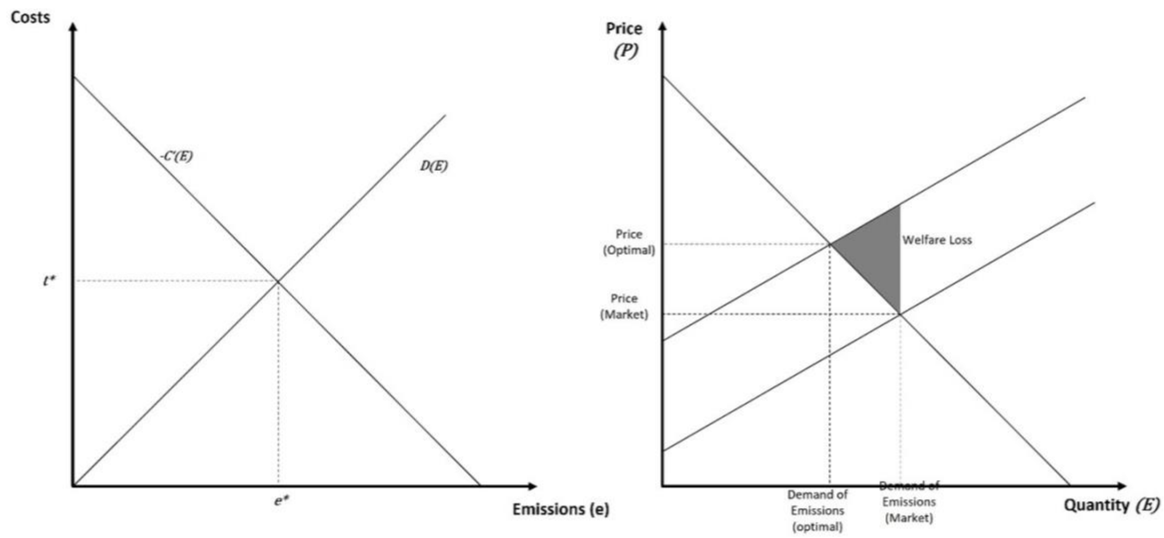

Figure 1: Equilibrium model with an insufficient internali-zation of emissions, Source: Own illustration, orientated at Phaneuf and Requate, 2016.

3. Application: Carbon footprint analyses (CFA) in European port projects

Like all other sectors, ports have only limited financial (and human) resources available. To reduce the external costs of trade, high investment costs are required to avoid these externalities. In the context of port development, cost-benefit analyses (CBA) can be grouped under structuring economic impacts (et al. productivity, efficiency, competitiveness), social and environmental impacts (et al. public safety, improved mobility, reduced emissions), and finally under social and environmental impacts (among others reduced noise, and improved standard of living). Always with the aim of reducing externalities and increasing benefits, respectively decreasing costs (Port of Vancouver 2020). In recent investment decisions, However, regarding the classification of ports' investment decision in a cost-benefit model, it should also be stated that as a first step, the objects of comparison between conventional and 'green' investments must be defined. Usually, business-as-usual is used as the conventional investment option to draw an appropriate comparison (Jahn and Wedemeier 2018, 2021; Nitt-Driesselmann and Wedemeier, 2021). The business-as-usual (or do-nothing) can be used as a so-called counterfactual scenario, a scenario where no action is taken. A `conventional´ investment is insofar an investment that would be realized if no `green´ investment were implemented. `Green´ investment is an investment to avoid social costs of externalities, i. e. emissions. Moreover, in most cases, it is also useful to differentiate between the implementation and operation phases of a project in the analyses and finally evaluate them in the overall view. Thereby, operating costs include all the costs to operate a port service. Cost forecasts can be based on historic data on costs. Although the actual composition is project-specific, typical operation costs include labor costs, materials, or energy costs, including emission taxes (European Commission 2014). For example, when renewing energy-efficient heating systems in ports, investment costs for a `conventional´ heating system may be lower than for the more energy-efficient technology.

However, since the 'green' investment can be operated more cost-effectively and with lower emissions than the `conventional´ system because of its lower energy consumption, the 'green' variant may prove to be the better choice of investment over the total life cycle, considering all economic and social costs. Just as costs vary at different points in the life cycle of an investment, emissions impacts can also vary. Therefore, a distinction ought to be made between implementation and operation periods, and emissions should be recorded and assessed separately (European Commission 2015; Froese et al. 2019). With the prospect of rising CO2 prices and the expansion of port sector that will additionally be covered by emissions trading in close future, including GHG emissions in CBAs, i.e., the addition of CFAs to analyses, becomes increasingly relevant. Currently, the most recently updated Dynamic Integrated model of Climate and Economy (DICE) model suggests a carbon price of around USD 100 per ton of CO2e (Hänsel et al. 2020).

In a European joint-research project, a methodology was developed with which data-based comparisons of the economic and environmental (business) profitability of investments in the context of ports' measures were carried out. In doing so, it is essential to define the observed business units (port area) as relatively small to be able to achieve precise and accurate measures of the related emission externalities. In addition, the definition of the port type – et al. public service port, private service port, landlord port – is important to get information for the treatment of financial flows (Froese et al. 2019; Jahn and Wedemeier 2018). The measures are based on cost-benefit analyses (CBA) and carbon footprint analyses (CFA). The results of the analyses illustrate that ports can develop comparative competitive advantages through the internalization of externalities decarbonization, i.e., the utilization of 'green' instead of 'conventional' investments and processes.

Ports can reduce their externalities in various areas of activities. This can involve the use of alternative materials in the construction or maintenance of port infrastructure, the replacement of existing facilities with more energy-efficient variants, the provision of alternative fuels, the implementation of recent technologies and services, or changes in business or management processes. Depending on the specific project, the necessary information available in each case flows into the analysis. It is, therefore, possible to use this method to evaluate measures for which individual pieces of information are missing or cannot be collected.

The calculation of the economic and environmental performance of the analyzed project(s) occurs through a differentiation of the implementation and operation phases. The implementation phase consists of the planning, construction, and start of the individual investment. As such all capital costs and emissions are required and emitted during the previously mentioned implementation steps (European Commission 2014). The operation phase on the other hand exceeds the implementation and is shaped by the operation and maintenance of the constructed infrastructure and implemented services. Examples of the associated costs can include labor costs, expenditures for required materials, and energy costs. Hence, emissions and costs that come up during that part of the investment are attributed to the investment costs (European Commission 2014.).

The CBAs were carried out within the framework of the European joint-research project. The ports' decision of 'green' and 'conventional' investment includes in the analysis of total investment and operating costs, as well as external effects in the supplementary CFA. The external effects were differentiated according to whether they occurred during the implementation of the measure or during ongoing operation. Indirect externalities were also recorded in the CFA and additionally included in the assessment. The costs of GHG emissions are equal to VGHG*CGHG, where VGHG is the incremental volume of GHG emissions produced by the project, expressed in CO2 equivalents, and CGHG is the damage cost of

CO_2. The detailed differentiation of the various cost aspects and emission levels made it possible to evaluate investment alternatives. The utilization for the analyses of port investments requires various information and data. The analysis is briefly as follows:

(1) Available information of the investment(s). These include among others the sum of required financial resources for the implementation (over the whole implementation period) and the scrap value, i.e., residual value, after the appraisal period or operation period. The scrap value of the investment is considered at the end of the appraisal reference period. The scrap value is calculated based on the residual non-depreciated accounting value (European Commission 2014). The sources of financing are also relevant (e. g. EU grant/co-financing) such as the effective interest rate (p.a.) for the project (no difference between conventional and green investment allowed).

(2) Externalities of the implementation and the operation phase: The input is estimated through the energy consumption, which can directly be attributed to the investment projects. An overall lower energy consumption might reduce the indirect GHG emissions. The GHG emissions reduction can be quantified the reduction through the energy mix and hence might change with a different composition of energy sources (e. g. wind instead of diesel) sources. The energy consumption (kWh) is needed for the calculation – differentiated between energy sources – whereby the national energy mix, including the grid loss/emission factor, must be considered (EIB, 2014; Jahn and Wedemeier 2021).

(3) The specific limit values for the emissions are converted into CO_2e /g/kWh and factors are formed according to specific emissions from energy use (without grid electricity), e.g. marine diesel has a CO_2e g/kWh value of 301.789 and hydropower a limit value of 2.787 (IINAS 2017).

(4) The applied methodology considers the purchased electricity with a country specific grid emission (lost) factor. This factor is converted from t CO_2 into t CO_2/ kWh, adjusted for the national share of green grid electricity (EIB 2014).

(5) A qualitative description of the EU-port project, including background information such as the type of port (e. g. Public Service Port) and port activities and services (e. g. marine terminal operator, ISM, or subcontractor) is retrieved. This serves as an initial classification and allows for a more holistic analysis and a general overview.

For more details, please confer to the applied CBA/CFA tool available at: http://hdl.handle.net/10419/186137)

Seven pilot projects were evaluated for the joint European research project. These seven include all different port investments which are (1) the treatment of contaminated soil directly at the port, (2) the generation of renewable energy on the port site and its use for the provision of district heating, and (3) the use of 'green asphalt' that binds pollutants and is more efficient to produce. Additionally (4) the application of LED lighting systems was tested, (5) the construction of LNG bunkers was considered, and the use of recycled materials for port construction projects was experimented. These projects are EU-wide best practice examples; the results are not directly transferable to other ports. For more information, see Nitt-Driesselmann et al. (2022).

To better illustrate the use of a CBA/CFA for the economic and environmental improvement of a port, a LED pilot for the port of Emden, Germany acts as a prime example. The idea behind the pilot is that the lighting systems of a track field area of the port had to be replaced and two options were available: a `conventional´ lighting system with lower initial investment costs but with higher annual operating costs and a more efficient LED system that had higher investment but lower operating costs. Viewing just the economic dimension, we see a 3% reduction in yearly operating costs and a 3% total cost reduction over an investment span of 20 years. Shifting the focus to the environmental dimension, the calculation of the carbon footprint occurs based on the report by Jahn and Wedemeier (2018). Compared to the conventional investment, LED lighting systems only require around 20% of electricity. Using energy from the German electricity grid emits around 527g CO_2e/kWh (EIB 2014) and hence investing in the LED lighting system results in an 80% reduction of carbon emissions with only 10.83 tons of CO_2e p.a. compared to 54.13 tons of CO_2e p.a. In the model calculation of the presented tool itself, the national electricity grid emits are calculated country wise, since the grid loss according to infrastructure age and systems differs between the EU countries (Jahn and Wedemeier 2018a). With estimated social costs of CO_2 ranging from 33€ in 2018 to 45€ in 2045, choosing the green investment alternative would also cause around 20%

of social costs compared to the conventional investment (Umweltbundesamt 2017).

Compared to conventional investment, CO2 emissions were reduced in the research project with each of the seven 'green' alternatives investigated. In four 'green' pilots, the relative savings potential (in percent) compared to the 'conventional' alternative was rated as very high. In terms of absolute CO2 savings in tons, one project (district heating) proved to be particularly promising. For five projects, the total cost of the green investment was below that of the conventional investment, and for two projects (LNG bunkering) it was above. With one project – the usage of recycled construction materials – the green investment achieved only medium percentage savings in total costs and only small percentage savings in CO2 emissions compared to the conventional method, but the total cost saved per ton of CO2 saved was almost 15,000€. Some decarbonization measures thus proved to be low-hanging fruit, where high emissions savings could be achieved with simple-to-implement measures and low-cost investments (see table 1).

Besides the realization of individual measures, implementing 'green management' in the operation of a port has proven to increase the efficiency. If business processes are incrementally scrutinized, energy-saving and further emission reduction potentials are identified and communicated to management and employees, ports can reduce not only private but also social costs of externalities.

Pilot	Potential for the reduction of total costs	Potential for the reduction of CO_2 emissions	CO_2 savings in tons	Saved or additional total costs (Euro) for each saved ton of CO_2
Local sediment treatment	***	***	615	8.767 €/t CO2
Onsite Renewable Energy production	***	***	72.619	74 €/t CO2
Use of Recycled Construction Materials for Port Construction	**	*	90	14.704 €/t CO2
LED-Lighting	*	***	43	4.041 €/t CO2
Green Asphalt	None	***	6	-1.506 €/t CO2
LNG-Bunkering	None	***	2.811	-1.460 €/t CO2

† Positive numbers are reductions in emissions and costs while negative values are increases in costs and emissions

Total cost reduction (Ports goal: -20 %)	Total CO_2 emissions reduction (Ports goal -10 %)	The ratio of the saved total cost (Euro) and CO_2 emissions (tons)
$None \leq 0$ $* \ > 0 \ and \ < 10\ \%$ $** \ \geq 10\ \% \ and \ < 20\ \%$ $*** \geq 20\ \%$	$* \ \leq 5\ \%$ $** \ > 5\ \% \ and \ \leq 10\ \%$ $*** > 10\ \%$	The absolute value of total costs saved divided by the absolute value of saved tons of CO_2

Table 1: Potential for the reduction of total costs and CO2 emissions with green investment in EU-ports. Source: Own illustration

4. Discussion: Triple bottom line (TBL) framework

The triple bottom line (TBL) framework brings in arguments for the internalization of social costs (and benefits), i. e. costs of externalities by a firm which affect others. Simply defined, it is the idea that firm's success cannot only just be measured by private benefits but also must integrate their externalities as environmental and social (Norman and MacDonald 2004). Even more, it is adequate to speak of social sustainability, i. e. economic welfare and its allocation of resources affecting social welfare. Consistent with environmental and economic sustainability the focus on social costs ought to make sure that resources are managed efficiently, and externalities are marginalized. That could include for example access to public goods such as healthcare, and education (Mohammed et al. 2021). Externalities – and public goods as port infrastructure – are sources of market failures – and insofar relevant for public policy (Pindyck and Rubinfeld 2018). In reference to the presented best-practice examples of ports, it ought to be reflected that the social costs are not fully included. While the overall social costs of carbon emissions are factored, a concrete quantification of the social costs and benefit could not be carried out. The reasoning lies in the complexity of quantifying social costs and, more importantly, in the lack of data (and definitions). This represents a gap that future research ought to fill. To put the results of the European research project into the context of the triple-bottom-line, one can see the simultaneous consideration of economic and environmental performance. Using objective benchmarks or standard indicators, we see that the positive performance of one bottom line is not mutually exclusive with the other one. The increase of firms' efficiency diminishes the externalities on human health because of fewer emitted fine particles, reduced noise, and light emissions.

A port offers a value proposition to its region and hinterland (e.g., port of Oostende, Belgium) such as its country and beyond (e.g., port of Rotterdam, the Netherlands) as it offers economic and social benefits. However, ports are always vulnerable to environmental and economic constraints. Significant increases in port throughput increase the pressure for the further development of new, efficient port infrastructure. The need to react is immense, especially with ports being capital-intensive infrastructures and the ever-increasing demand for sufficient and reliable shipping infrastructure. This becomes particularly clear as port development and world trade are closely interrelated (Notteboom et al. 2022). Highlighting the importance of the social bottom line is the development of the ongoing Russo-Ukrainian war. The current military war between the Russian Federation and Ukraine has brought the dependence of the European Union on Russian energy imports clearly to the attention of politicians and the public. The rising threat of the energy supply to the European market presents the ports as bottlenecks for the import and export of goods. The combination of rising energy insecurity, energy prices resulting in high inflation, and the increase in private costs of energy hit the demand market (Claeys and Guetta-Jeanrenaud 2022; Rees and Rungcharoenkitkul 2021; Wang and Man 2022).

This international crisis highlights the risks of fossil path dependency that can arise for European economies from a lack of energy imports and rising energy prices. Greater self-reliance in energy supply and the loosening of bottlenecks would directly strengthen the resilience of economies and influence the foreign policy position of nations (Dźwigoł et al. 2019; Martišauskas 2018; Miller 2010). If the CBA/CFA is expanded to include previously unconsidered fields of action, such as issues of national security or economic resilience, its informative value expands. Instead of the previously included goals of selecting infrastructure projects that are as cost-efficient and environmentally friendly as possible using a combined CBA/CFA, an expanded canon of goals would then be pursued.

As an example of an extension of the CBA/CFA to include safety aspects, the LNG pilot described above in the EU project already mentioned can be cited. Although the 'green' alternative of LNG bunkering has a high savings potential in CO2- emissions compared to the 'conventional' investment (For more information, see Nitt-Driesselmann et al. 2022), Germany has just changed its policy for LNG terminals, as it has seen so far not need since it was assumed to causes higher overall costs than the `conventional´ alternative. However, if one now also considers the aspect that LNG bunkering in ports will reduce dependence on Russian gas and thus increase the competitiveness of the German economy, a different overall calculation may result. Here, too, the decisive factor for the overall assessment is how the impact of LNG bunkering on the EU's security and competitiveness is evaluated and with what monetary value it is included in the overall cost and benefit calculation. From the point of view of an economy, the new international crises and the looming conflicts between democratic and autocratic states is a rising world of externalities.

To sum up, a study on the infrastructure needs of European seaports (EU-27) balance that ports face a substantial investment need of around 48 €billion (5 €billion annually) for the period until 2027 (ESPO 2018). However, it is necessary not to carry out the port investments exclusively as replacement investments, but on the one hand to make them sustainable, efficient, and progressive to implement them according to the triple bottom line framework: The strategy of European ports underlines the relevance to the further development of cost-benefit analysis (CBA) in order to be able to depict the social costs of projects for the European's added value and gross domestic product (ESPO 2018). This article is a contribution to that discussion. Insofar, the TBL framework brings in arguments for the adoption of social, environmental, and economic externalities.

It is important to critically reflect on the notion that with the internalization of environmental and social costs fundamental challenges such as climate change can be properly addressed. The presented combined CBA/CFA underlies assumptions to simplify the 'real economy' into a micro-economic model (Phaneuf and Requate 2016). However, our model shows that assessments of 'project alternatives` benefit to ensure the sustainability objective of investment. In both cases, the resulting optimum differs from the efficient optimum of the conventional cost-benefit criterion, but the basic cost-benefit model remains intact (Barbier et al 1990). Current developments observe a continuing use of resources and energy, since the 1970s' resource use has tripled. Thus, one ought to not see the combined CBA/CFA analyses as an aid to holistically address environmental and social challenges but to assess the economic and environmental performance of investments (Erb et al. 2014; Haberl et al. 2011).

5. Conclusion

The European Union is pursuing ambitious climate targets of reducing overall greenhouse gas emissions by 55% until 2030. Hence, the need for transformation is high in many areas of the economy. In this context, the sectoral transformation of ports is of particular importance because of the considerable environmental impacts of intra-European and international shipping. Cost-benefit (CBA) and carbon footprint analyses (CFA) can be applied when investments need to be assessed in terms of both economic and environmental costs. It does not matter whether the investments are mandatory or whether they involve the renewal of infrastructure or an expansion of the port service portfolio.

However, the European Sea and Port Organisation (2022) anticipates that the maritime sector will be included in the European Emissions Trading Scheme (EU ETS). That would automatically require the maritime sector incl. ports to internalize externalities in their business operations and make the CBA/CFA even more relevant. Negative externalities encourage port development to remain as usual in the industry.

The limitations of the methodology and the paper at hand are the missing inclusion of social costs with regard to human health or work. While social costs per ton of CO2e are included, a thorough quantification and comparison of social costs and benefits are left out. Consistent with the previous limitation, only pollutant emissions are recorded, but not, for example, light or noise emissions from port activities. It neither considers, for example, property value losses through noise emissions because of the physical proximity of ports nor the benefit of social amenity gains or the increase of human health. The applied methodology itself is a simplification to provide port management with an analysis for more efficient investments. Besides economic and environmental aspects, other perspectives can also be addressed with the combined CBA/CFA. Most critical, the CBA is subject to the usual problems with CBA is (i) the availability of data, (ii) the definition and identification of externalities, (iii) the use of subjective assessment and classification of the data for the effects, and (iv) and the monetization of intangible impacts. While the explained CBA/CFA and the provided methodology can aid in evaluating investments according to their economic and ecological performance, it is important to highlight that the calculation behind underlies typical economic assumptions as neoclassical functions and expectations such as usual inputs factors of the European Investment Bank. The general criticism of CBA in the context of environmental economics often goes so far that cost-benefit analysis is essentially subject to a methodological misconception to this day. The core is almost always the lack of data, which can often only be done in the past (Ackerman et al. 2005).

Consistent with the triple bottom line (TBL) framework, which aims to achieve a lasting balance between economic, ecological, and social sustainability, analysis tools for infrastructure investments such as cost-benefit analyses (CBA), and carbon footprint analyses (CFA) should increasingly take all relevant aspects of sustainability into account. As an example, the importance of LNG bunkering has increased in the wake of the war in Ukraine. In European governments, the realization quickly took hold that reducing demand for fossil energy imports strengthens the resilience of national economies besides ecological aspects and thus significantly expands the scope for public policy. Considering the current inflation of prices, increasing the independence from fossil fuels and building efficient port infrastructure by avoiding negative effect on third parties becomes even more relevant. This can relieve supply chain bottlenecks, the price pressure on firms and relieve the strain on consumers struggling with price increases.

However, at the latest with the publication of Pigous `The Economics of Welfare' (1920) the effects of the market through externalities on environment are known. It is up to the ports to internalize their externalities to continue to be the gateway to the world.

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Acknowledgement:

We would like to thank Dörte Nitt-Driesselmann, Hamburg Institute of International Economics for numerous comments and hints.

Disclosure Statement:

The authors report there are no competing interests to declare. This work was co-funded by the INTERREG North See Region EU-Programme (European Regional Development Fund) 2014-2020 under Grant J-No: 38-2-7-15

Data availability:

The data that support the findings of this study are available from the corresponding author, Jan Wedemeier, upon request. The used tool is available at: http://hdl.handle.net/10419/186137