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Malte Jahn, Jan Wedemeier

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Authors:

Dr. Malte Jahn
Hamburg Institute of International Economics (HWWI)
Oberhafenstrasse 1 | 20097 Hamburg | Germany
Phone: +49 (0)40 340576-351 | Fax: +49 (0)40 340576-150
jahn@hwwi.org

Dr. Jan Wedemeier
Hamburg Institute of International Economics (HWWI)
Fahrenheitstr. 1 | 28359 Bremen | Germany
Phone: +49 (0)421 2208-243 | Fax: +49 (0)40 340576-150
wedemeier@hwwi.org

HWWI Policy Paper
Hamburg Institute of International Economics (HWWI)
Oberhafenstrasse 1 | 20097 Hamburg | Germany
Phone: +49 (0)40 340576-0 | Fax: +49 (0)40 340576-150
info@hwwi.org | www.hwwi.org
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Content

1 | Introduction

Cost benefit analysis (CBA) is a systematic approach to compare the costs and benefits of alternatives, e.g. a decision between the construction or non-construction of a traffic light, in order to assess the welfare change. The purpose of a CBA is to facilitate a more efficient allocation of resources, mainly in terms of investments decisions.

Technically, costs and benefits do not need to be assessed in monetary terms, but a monetary approach is usually the most relevant for a private or public investor because most goods and services are based on **monetary values**. Monetary CBA analyses consider the benefit-cost ratio or similar figures as the main indicator. However, some costs or benefits cannot be expressed directly as monetary values because the underlying activities/goods are not traded on markets, such as environmental impacts or human health. Usually, these costs/benefits are still given a monetary value in order to integrate them into the monetary CBA framework. Furthermore, the scope of a CBA has to be defined with regard to whose costs and whose benefits are considered. An investor is most likely interested in the internal costs and benefits associated with a certain investment project. For the society or a public planner, also **external costs and benefits** might matter, so they would be added to the internal costs and benefits.

The DUAL Ports project aims to decarbonize regional ports´ resources through innovative port investments that help minimizing the ecological footprint (see Box 1). Stimulating eco-innovation, carbon emission reduction and sustainable use of resources is a widespread priority for the European Commission nowadays. Regional ports are often multi-functional in the sense that logistic, manufacturing and energy-related activities are carried out in the port area. Therefore, it is important that they contribute to a sustainable development by making these activities "greener". As they also need to be economically competitive, innovative measures have to be developed allowing the port to be ecologically and economically successful at the same time.

In order to assess the performance of the low carbon port development investments funded within the DUAL ports project, CBA can be applied. As the carbon emissions constitute external effects from the investor's perspective, they have to be monetized and integrated into the internal CBA in order to capture the associated costs for the society. The CBA spreadsheet tool developed by the HWWI as part of the DUAL ports project measures if the actual green investment projects reach the target of 20% operational cost reduction, of 20% total cost reduction, and 10% emission reduction. These targets are externally given by the INTERREG North Sea Region Programme of the European Union (in the framework of the European Regional Development Fund).

Box 1

> **DUAL Ports - Developing Low carbon Utilities, Abilities and potential of regional entrepreneurial Ports**
>
> The DUAL Ports project aims to decarbonize Regional Entrepreneurial Ports (REPs)´ resources through a shared eco-innovation port program that minimizes their environmental footprint.
>
> The objective is to specifically develop sustainable utilities and abilities of REPs. This will be achieved by collaboratively piloting and managing technologies and processes that tackle targeted measurable direct/indirect emission/pollution sources.
>
> The project will ultimately enhance ports' organizational/operational (energy) efficiency and performance, facilitating decarbonization at reduced cost and with added value. As demonstrated by last years´ offshore wind energy developments in the EU and beyond, ports can be key centers of innovation, testing and uptake of emerging technologies, leveraging participation and multiplier effects, e.g. by triggering value-for-money clustered activities that generate employment and benefit the environment.
>
> A transnational approach will be adopted to allow the DUAL small & medium size ports to capitalize on this potential, overcoming their individual limited staff, funding and capability to identify the most effective solutions on their own. Only few measures have been selected due to the limited project duration and size of the partnership, but they are expected to have a considerable impact on the way ports can act as facilitators between enterprises, research centers and public authorities to enable user-driven eco-innovation in the North Sea area. The total budget of the project is 5,204,050 €, the ERDF contribution is 2,602,025 € (DUAL Ports 2018).

In the second section of this paper, the cost benefit and carbon footprint analyses are introduced, emphasizing the relevance for the framework of decision making with regard to (infrastructure) projects. Section 2.2 discusses the requirements for CBA in the DUAL ports project, Section 2.3 presents the employed method to integrate the carbon footprint analysis into the CBA. Section 3 shows the role of the developed cost benefit and carbon footprint analyses in the EU-funded project DUAL Ports. The two exemplary cases are Emden (located in the northwest of Germany) and Vordingborg (located in the south of the island of Zealand, Denmark). The last section concludes.

2 | Cost benefit & carbon footprint analyses

2.1 | Cost benefit analyses

As mentioned in the introduction, the purpose of a CBA is to facilitate a more efficient allocation of resources, in particular in terms of investment decisions. The analytical framework of CBA underlies mainly the following concepts (EC 2014):

- Opportunity costs: The opportunity costs associated with an investment are defined as the foregone income from not investing one's resources in an alternative investment.
- Long term perspective: Since most CBA are used for investment decisions in infrastructure projects, a long-term perspective is adopted. This can be in a range between a minimum of 10 and above 30 years. The forecast of future costs (and benefits), but also that of future discount rates can be difficult in practice. Moreover, project risks are also uncertain.
- Economic performance expressed in monetary values: The calculation in monetary terms is linked to the risk of over- or underestimation of non-financial values.
- Micro-economic approach: A CBA is typically a microeconomic approach in assessing the impact of a project. While direct employment and income effects or external environmental effects are often addressed in CBA, indirect effects are often excluded.
- Incremental approach: CBA apply comparable scenarios, mainly a scenario with the project and a counterfactual scenario without the project.

A CBA should ideally display the monetary values of all **positive (benefits) and negative (costs) welfare effects** associated with an alternative. These welfare effects technically include external effects. An externality arises when a person engages in an activity that influences the well-being of somebody else who neither pays (positive influence) nor receives (negative influence) any compensation for the effect on him/her. An example is that of an industrial production process, such as a (coal-fired) power plant. There are certain internal costs which the operator of the power plant has to pay to produce one unit of electric energy. The (carbon) emissions created in the production process constitute an external cost because they affect the future well-being of others negatively due to expected climate damages. As the private actor does not consider social (external) costs in his emission decision, the produced quantity of emissions regularly extends the socially optimal amount. This is referred to as a 'market failure'. Public regulations that seek to internalize the social costs make use of different instruments. In this concrete case, one solution could be to subsidize emission-avoiding technologies.

However, a cost benefit analysis – as described above – is explicitly required for decision making on the co-financing of major projects in EU programs as the European Regional Development Fund (ERDF) or the Cohesion Fund.[1] However, it is not common to apply it in EU INTERREG projects such as DUAL Ports. In the end, investments in ports

[1] The legal basis for CBA in major projects is well explained in a paper issued by the European Commission paper on the cost-benefit analysis of investment projects (EC 2014).

will impact the climate in terms of **greenhouse gas (GHG)** emissions. In general, there is a need for more projects, which correct for **negative environmental** impacts and inclusion in the investment costs.

2.2 | Requirements for CBA in the DUAL Ports project

The nature of the DUAL Ports project has some consequences for the CBA. First, it must be **simple** enough to be understood and used by actual decisions makers. In the case of the DUAL Ports project, the decisions-makers are from (small) port administrations or communities and thus, complicated numeric economic models would not be very helpful tools to them. There is an ongoing dialogue with project partners, decision-makers and other experts from inside and outside the project to address their demands. Consequently, a **spreadsheet tool** was developed which allows these decision-makers to evaluate the economic and environmental impact of (carbon-footprint reducing) investments in and around ports rather conveniently.[2]

A systematic approach is still required in order to cover the variety of heterogeneous investment projects within the DUAL Ports project. The common feature of all projects is that they aim at reducing the environmental, in particular carbon footprint of a (port-related) economic activity. We distinguish **three types of investment projects**. The first type (type I) considers the general situation where the implementation as well as the operation period related to the new investment is considered. In type II projects, only the initial implementation phase but not the operation phase is considered. Correspondingly, type III projects are only concerned with the operation and not with the implementation. Note that this distinction is made primarily to address the different situations regarding data availability.

Another important aspect is the fact that the environmental dimension should be included in the CBA. Regarding the economic perspective of the investor, environmental impacts such as carbon emissions constitute an externality. As mentioned earlier, this means that the investor would usually not include these impacts in his calculations because the environmental costs (future damages from climate change) are not his costs, but carried by society. Therefore, in addition to the classical benefit-cost ratio, an **extended benefit-cost ratio** is defined which includes environmental costs.

The most important aspect in a CBA is the definition of the object of comparison. The actual DUAL ports projects are innovative low carbon ("green") investments in and around ports. One possible choice for the object of comparison could be that no project

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[2] The spreadsheet tool is available at: http://www.hwwi.org/fileadmin/hwwi/Publikationen/Policy/Cost-Benefit-Analysis-Tool_rev.3.5.xlsm

is done. However, some of the projects consider the expansion of existing facilities or the replacement of facilities. Since the non-replacement or non-expansion does not constitute a feasible option in most cases, the environmental benefit of the green investment has to be identified by a comparison to a **conventional alternative** instead of "no-project". In other words, the conventional alternative defines the business-as-usual (BAU) scenario.

The final aspect which is important for the considered DUAL Ports projects is time. The temporal dimension is especially important for type I projects because, in this setting, the investor's main concern is whether the anticipated revenues from future operation exceed the (present) investment costs. Discounting is a common way to compare future financial flows with present financial flows and it generally means that future financial flows are attributed a lower value compared to present financial flows. There are two main reasons why discounting would be used. The first one is opportunity costs of capital, which are relevant if there is the realistic option to invest the financial resources in the some (riskless) asset instead of the actual project. As opportunity cost of the conventional investment, the foregone funding for the green investment has to be taken into account. A second reason is time preferences, i.e. the preference for the present. One underlying theory is that the future is uncertain in the sense that, at any point in time, a natural catastrophe or some other (unforeseen) economic or political event could eliminate (part of) the revenue. This is another reason why an investor could value earlier revenues higher than later revenues. In the employed CBA framework, an annual discount rate can be specified in the project based spreadsheet tool[3].

2.3 | Integrating the carbon footprint into the CBA

As the main goal of the DUAL Ports project is to develop low carbon (port) facilities, this has to be reflected in the CBA. The term "low carbon" precisely refers to the **carbon-equivalent emissions** from energy use, including the production process of the technology. Carbon-equivalents are calculated per kWh of energy from a certain (fossil) energy carrier (Table 1) and include the global warming effect of all greenhouse gases being created in the process. The unit is g CO2e.

Regarding CO2, the European Commission (EC) assumes different paths of environmental costs of one unit, depending on different scenarios for the global emission. We

[3] In the later examples, the calculations will be done with a discount rate of zero, which corresponds to no discounting. This is mainly done for sake of simplicity because, with a rate of zero, monetary flows always have the same value independent of the point in time they occur.

use the **central scenario** of the following scheme, based the guidelines of the European Commission (Table 2).

Table 1: Specific emissions for different energy carriers

Energy carrier	g CO2e/kWh
(truck) diesel	301.789
marine diesel	301.789
gasoline	307.364
heating oil	319.430
natural gas	249.981
liquid gas	276.728
lignite	678.952
stone coal (brikets)	678.952
stone coal (koks)	441.348
wood (peaces)	18.891
wood (pellets)	26.589
hydropower	2.787
geothermal	95.498
wind (onshore)	9.335
solar	54.695

Source: IINAS (2017)

Table 2: Environmental costs of carbon

	Value 2010 (€/t CO2e)	Annual adders 2011-2030 (€)
High	40	2
Central	**25**	**1**
Low	10	0.5

Source: European Commission (2014).

Furthermore, nitrogen and sulphur emissions are also considered in the CBA. Note that the climate damages associated with nitrogen and sulphur emissions are already included in the carbon equivalent emissions (Table 1). In addition, nitrogen- and sulphur-compounds may also cause local (health) damages which would not be included in the carbon equivalents. However, the extent of these local health damages is very situation-specific and it is impossible to justify a universal monetary value similar to Table 2.

In fact, the amount of nitrogen and sulphur emissions per kg fuel alone depends on many factors. Whereas the sulphur content in gasoline is very low by law, much higher values are allowed for marine diesel. Regarding nitrogen, it will usually be emitted in the form of either NO or NO2, where the ratio between these molecules and thus, the environmental effects, also depends on specific factors. Subsequently, the CBA includes approximate nitrogen and sulphur contents of the energy carriers considered in Table 1, but they are not monetized and do not enter the extended benefit-cost ratio.

The specific nitrogen and sulphur content per kWh of the considered energy carriers is shown in Table 3.

Table 3: Approximate nitrogen and sulphur content for different energy carriers

Energy carrier	**g S/kWh**	**g N/kWh**
(truck) diesel	0.001	0.050
marine diesel	0.100	2.000
Gasoline	0.001	0.005
heating oil	0.005	0.120
natural gas	0.001	0.080
liquid gas	0.000	0.080
Lignite	2.000	1.000
stone coal (brikets)	1.000	1.400
stone coal (koks)	0.800	1.400
wood (peaces)	0.000	0.300
wood (pellets)	0.000	0.300
hydropower	0.000	0.000
geothermal	0.000	0.000
wind (onshore)	0.000	0.000
Solar	0.000	0.000

Source: own calculations

Grid electricity as an additional source of energy is treated separately. Since the emissions related to grid electricity are determined by the types of power plants, it makes sense to use nation-specific averages for the emission intensity (Table 4).

In case that a facility is supplied with electricity from renewable sources, this will be recognized in the CBA. A lower limit of 25 g CO2e/kWh is assumed for any grid electricity. Possible nitrogen and sulphur emissions related to the production of grid electricity do not enter the CBA.

Table 4: Emissions from grid electricity

Country	g CO2e/kWh
Belgium	237
Denmark	401
Germany	527
Netherlands	462
Sweden	274
United Kingdom	504
EU27	328

Source: EIB (2014)

The final category of environmental impact which is considered in the CBA is waste treatment. This aspect was introduced because the use of recycled materials for port construction is the main environmental benefit of one of the projects. If an investment project uses waste materials that would have otherwise gone to a landfill, the saved environmental costs constitute a benefit. These benefits are monetized and also enter the extended benefit-cost ratio.

3 | Testing of the CBA tool: The cases Emden and Vordingborg

In this section, we want to demonstrate the capabilities of the developed CBA framework. We consider two investments realized in the framework of the DUAL Ports project, one in the Port of Emden and one in the Port of Vordingborg.

3.1 | Port of Emden

The first is the installation of a **LED lighting system** for a track field at the Port of Emden. According to the classification of projects (section 2), the investment in Emden is a type I project, meaning that installation and operation period are both considered. The alternative to the LED system would be a conventional lighting system. A direct comparison of the two alternatives is shown in Table 5. The numbers refer to whole relevant business unit, i.e. the track field (operation).

The numbers from Table 5 are also the relevant input data for the CBA tool. The tool calculates the classical, private benefit-cost ratio as well as the extended benefit-cost ratio which includes externalities from energy use. The results of the CBA tool which corresponds to the result sheet in the CBA tool are shown in Table 6.

Table 5: Emden: Comparison of LED ("green") and conventional track field lighting

	green	conventional
Investment volume	1,500,000.00 €	1,470,000.00 €
Appraisal period	20 years	20 years
Operating revenue (annual avg.)	233,308.00 €	233,308.00 €
Operating cost (annual avg.)	278,124.86 €	288,124.86 €
Energy use (annual avg.)	20,000 kWh	100,000 kWh

Source: own calculations.

Table 6: Emden: Results of CBA

	green	conventional
present value of financial inflows	6,166,160.00 €	6,136,160.00 €
present value of financial outflows	6,811,997.29 €	6,987,007.29 €
net present value (private)	-645,837.29 €	-850,847.29 €
present value of environmental costs	444.91 €	2,224.54 €
Benefit Cost Ratio	0.905	0.878
Social Benefit-Cost Ratio	0.905	0.878
Operating cost (€/a)	278,124.86 €	288,124.86 €
Target 1a: 20% operating cost reduction	-3.47%	-
Total cost (€)	6,811,997.29 €	6,987,007.29 €
Target 1b: 20% total cost reduction (€)	-2.50%	-
Carbon emissions (t CO2e)	10.825	54.125
Target 2: 10% carbon emission reduction (t CO2e)	-80%	-
sulphur emissions [kg]	-	-
nitrogen emissions [kg]	-	-
net waste production [t]	-	-

Source: own calculations.

It can be concluded from the negative net present value that the operation of the track field is not profitable. This is also reflected by benefit-cost ratios below 1. Furthermore, the Port of Emden receives 100% of its electricity from renewable sources. Note that sulphur and nitrogen emissions are not calculated for grid electricity. The carbon emissions for both alternatives are so small that the associated environmental costs are only a few hundred Euros. The same aspect becomes also apparent in the fact that the extended benefit cost ratio virtually coincides with the (classical) benefit-cost ratio.

Regarding the targets, the reduction of operating and total costs is around 3%. The reduction of energy use is 80% which is well above the target of 10%.

3.2 | Port of Vordingborg

The investment project is the expansion of the existing port through the creation of additional quays. The "green" aspect of the project is that waste/recycled materials are used (especially for filling) which would normally go to a landfill. This is beneficial for the investor because he is payed for receiving the waste instead of paying for conventional materials. Secondly, there is an environmental benefit for the society because less material goes to a landfill. Furthermore, a port expansion with conventional materials would require a lot of sand, which has to be dredged from the seabed in a rather energy-intensive process.

The energy use for bringing the construction material to the site as well as the energy use on the site are part of the CBA. The environmental costs associated with the dredging are not calculated but could give another argument for the use of waste/recycled materials for port construction/expansion. The project is type II in our classification because the operation period of the expanded port is still uncertain. In fact, even the details of the construction in the final phases of the expansion are unknown.

It can be seen from Table 7 that the appraisal period and operating cost/revenue are unknown because the project is a type II project. Regarding the total energy use, the intended green construction saves about 300,000 kWh of energy, mainly related to the extraction and transport of the materials. The recycled materials are obtained from nearby facilities and include fly ash which replaces sand, slag (incineration residue) which replaces fine gravel and recycled concrete/clinker which replaces coarse gravel. The results of the CBA as such are shown in Table 8.

Table 7: Vordingborg: Comparison of green and conventional port expansion

	green	**conventional**
Investment volume	12,021,518.07 €	13,316,932.47 €
Appraisal period	-	-
Operating revenue (annual avg.)	-	-
Operating cost (annual avg.)	-	-
Energy use	7,675,970 kWh	7,975,453 kWh

Source: own calculations.

Table 8: Vordingborg: Results of CBA

	green	conventional
present value of financial inflows	12,021,518.07 €	13,316,932.47 €
present value of financial outflows	12,334,077.54 €	13,663,172.72 €
net present value (private)	-312,559.47 €	-346,240.24 €
present value of environmental costs	-1,808,712.74 €	81,840.21 €
Benefit Cost Ratio	0.975	0.975
Social Benefit-Cost Ratio	1.142	0.969
Operating cost (€/a)	0.00 €	0.00 €
Target 1a: 20% operating cost reduction	-	-
Total cost (€)	12,334,077.54 €	13,663,172.72 €
Target 1b: 20% total cost reduction	-9.73%	-
Carbon emissions (t CO2e)	2316.684	2407.065
Target 2: 10% carbon emission reduction (t CO2e)	-3.75%	-
sulphur emissions [kg]	14.172	27.893
nitrogen emissions [kg]	511.573	790.897
net waste production [t]	-107000.000	-

Source: own calculations, HWWI.

Regarding the financial flows, an interest rate of 2.6% was provided by the port administration. In combination with a discount rate of zero and the unknown operation period (no revenues enter the calculation), it is obvious that the net present value must be negative due to the capital costs. Furthermore, the unavailability of estimated figures for the operation period impedes the monetization of another relevant advantage. The recycled materials need less time to settle meaning that the actual construction of facilities can start and finish earlier than would be possible with conventional materials. In other words, revenue can be earned sooner.

The innovative green aspect of the project is the negative environmental costs which can be interpreted as a benefit. These are related to the 107,000 tons of recycled material. In order to monetize these saved landfill costs, we refer to Dijkgraaf and Vollebergh (2004) who estimate environmental costs associated with burning or burying waste materials. We use their landfill costs of 17.64€ per ton which only comprises the pure cost of the land use. Costs relating to a potential contamination of the environment with pollutive substances are not included. Furthermore, we do not account for inflation since 2004, so that the value of 17.64€ can be considered conservative.

The targets are not quite achieved, the carbon emissions are around 4% lower for the green investment and the costs are about 10% lower. Regarding the relatively large scale of the project, these savings are still quite large in absolute terms.

A final interesting remark concerns the sulphur emissions. It can be seen that these are twice as high for the conventional alternative although the overall energy use is just a few percent higher. The reason is that the CBA distinguishes between different fuels, namely marine diesel and truck diesel in this case. The sand which would be used in a conventional construction is dredged and transported by marine vessels which are assumed to be more emission-intensive than trucks.

4 | Conclusion

The CBA tool presented in this paper focuses on the integration of a carbon footprint analysis in order to internalize the corresponding external environmental costs. The special requirements in the DUAL Ports project were that the tool should be: (i) simple and transparent, (ii) capable of being transferred to other projects, and (iii) comply with existent and upcoming EC-standards.

The most important output figure is the social benefit-cost-ratio which corresponds to the private benefit-cost-ratio with environmental costs added to the private costs (environmental benefits would be included as a negative cost).

Of course, the CBA is subject to the usual problems with CBA tools, which are: (i) the reliance on data from other sources; (ii) the use of subjective impressions in assessment; (iii) and the monetization of intangible impacts.

Concluding, the CBA tool explained in this paper allows decision-makers to assess two alternative investments regarding their economic and environmental impacts. The focus of the ecologic impact assessment is on the carbon emissions from energy use. Thus, it is a helpful tool for planning sustainable measures and a sustainable development of businesses and the economy in general.

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Hamburg Institute of International Economics (HWWI)

Oberhafenstrasse 1 | 20097 Hamburg | Germany
Phone: +49 (0)40 340576-0 | Fax: +49 (0)40 340576-150
info@hwwi.org | www.hwwi.org