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Autonomous Shipping Initiative for European Waters

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LIST OF CONTENTS

1. LIST OF ABBREVIATIONS AND DEFINITIONS

Abbreviation	**Definition**
B/C Ratio	Benefits/Costs Ratio
CBA	Cost Benefit Abalysis
DoA	Description of Action
DR	Discount Rate
DSS	Decision Support System
EC	European Commission
ENPV	Economic Net Present Value
ERR	Economic Rate of Return
EU	European Union
FDR	Financial Discount Rate
FNPV	Financial Net Present Value
FRR	Financial Rate of Return
GHG	Green House Gas
H2020	Horizon 2020
IRR	Internal Rate of Return
IWW	Inland Waterways
NPV	Net Present Value
O&M	Operation & Maintenance
PV	Present Value
RCC	Remote Control Center
ROC	Remote Operation Center
SDR	Social Discount Rate
SSS	Short Sea Shipping
TEU	Twenty-foot Equivalent Unit

Short name	Name
PNO	Ciaotech Srl / EGEN BV
KOGCM	Kongsberg Maritime CM AS
KOGM	Kongsberg Maritime AS
KOGD	Kongsberg Digital AS
KOGN	Kongsberg Nordcontrol AS
STF	Sintef Ocean AS
USTRAT	University of Strathclyde
BLL	Blue Line Logistics
BV	Bureau Veritas Marine & Offshore
DVW	De Vlaamse Waterweg
EAS	Eidsvaag AS
ZA	Zulu Associates

2. EXECUTIVE SUMMARY

Autonomous shipping can become a crucial component of the digitalization of transport infrastructure and logistics. As technology and legislation advance, the impact will be felt across the entire value chain.

The deliverable presents the results of cost-benefit analyses conducted on two use cases - short sea shipping (SSS) and inland waterway (IWW) transport - within the AUTOSHIP project.

The results also offer insights into how the required investment, supported by both infrastructure owners and ship owners, can be justified through improved business cases and societal benefits. Adopting autonomous technology and designing ships that are fully synchronized with clean powertrains and environmentally-friendly designs will transform the logistics model, further strengthening the case for investment.

Short Sea Shipping analysis

The SSS use-case analyses an autonomous ship providing fish feed to fish farms along the Norwegian coast, compared to a conventional ship (Exhibit 1, Exhibit 2). The autonomous configuration design results in increased cargo capacity and less fuel consumption, bringing both financial advantages to the ship-owner and economic benefits to society.

Although the investment costs for a similar autonomous ship are higher than for a conventional ship (ca. +10%), the financial analysis for the Pioner use-case results in a high FNPV(C), between € 28,157,866 € and € 10,777,863, depending on whether the additional cargo capacity enabled by the autonomy is utilised, and if the amount of transported cargo stays equal to the reference scenario.

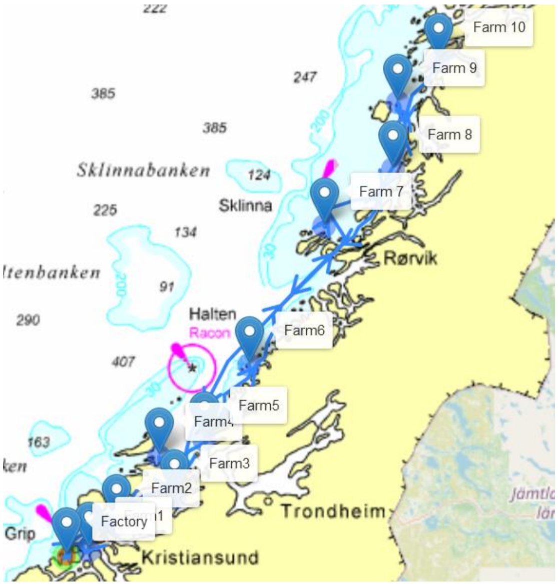

Exhibit 1: Use case route: representative route for one year of operation.

	Reference scenario	Project scenario
Cargo capacity	1,888 ton	2,230 ton
Average sailing speed	13 knots	13 knots
Auxiliary power consumption	130 kW	100 kW
Transported cargo (annual)	182,950 ton	203,376 ton
Voyages	102	96
Fuel type	LNG	LNG

	Reference scenario	Project scenario
Fuel consumption (annual in kgs)	1,437,340	1,303,955
Operating time	90%	90%
Max. load when leaving factory	95%	95%
Economic lifetime	30 years	30 years

Exhibit 1: SSS use-case, comparison project and reference scenario.

Behind these numbers, the Pioner use-case shows a significant decrease of the ship's O&M costs compared to the conventional operations in the chosen reference period of 25 years (evaluated € 15,326,082, NPV, FDR = 4.0%). **This is** a result of the wages cost reduction, **although they will be negatively affected by increased maintenance (at least initially) and by the expenditures for making use of the RCC's service. Fuel consumption, and therefore fuel costs and emissions are then likely to be mitigated due to** more efficient operations of the ship and the engines, reduced ship weight, and less air resistance as a result of **the new design**. On top of that, **GHG and other pollutants reductions provide socio-economic benefits for the society (resulting in an ENPV of € 12,701,421 and an ERR of 21.1%).** This highlights the significant advantages beyond the ship-owner's balance sheet.

Inland Waterways analysis

The IWW use-case shows a newbuild autonomous, battery-electric ship, transporting containers between Zeebrugge and Antwerp (Belgium) compared to a conventional diesel-powered ship.

Exhibit 2: IWW use-case route between Antwerp and Zeebrugge

This case deviates from the Zulu Barge used as a demonstrator in the project (a retrofit case), to look at the next step envisaged by Zulu as a more complete and functional business case: namely the X-Barge design. Based on the same autonomous package, the X-Barge is taken as an example of how autonomy can be synergetic to (and enable) new -green - modular barge designs, by leveraging on the absence of the crew quarters.

	Reference scenario	**Project scenario**
Fuel type	Diesel	Battery electric
Fuel consumption	145.48 l/hour	300 kWh
Cargo capacity	80 TEU	90 TEU
Operational hours (annual)	4,608	6,912
Length of average trip (in km)	138	138
Duration of average trip (hours)	12.5	12.5
Cargo capacity utilisation	100%	100%
Mooring	Manually	Autonomously

Exhibit 3: IWW use-case, comparison overview project and reference scenario

Firstly, exploring the benefits of autonomy, the new design and capabilities lead to both increased cargo capacity and operational hours, resulting in higher competitiveness against truck transportation. For this analysis, it is thus considered that when additional demand can be satisfied, this is obtained by a modal shift from road to inland waterway transport.

In contrast to the short sea shipping case, the inland waterway transport use case revealed minimal (negligeable) incremental investment costs between the project and reference scenarios. However, overall operations and maintenance costs tend to rise, driven by the requirement for electrification, which incurs high power costs, as well as the costs associated with the RCC[1]. It is to be noted that although the Remote Control Center (RCC) service costs result in an increase in operational costs, it is believed that these costs can be lowered if more autonomous ships adopt these services (Exhibit 4).

	Absolute value (sum over project lifetime)	**Present value (FDR = 4%)**
Crew wages	- € 3,456,000	-
Maintenance costs	- € 120,000	-
Remote Control Centre	€ 5,806,080	-
Fuel costs	- € 12,019,139	-
Electricity costs	€ 15,552,000	
Total O&M costs	**€ 5,762,941**	**€ 3,661,140**

Exhibit 4: Incremental O&M costs for the IWW case

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[1] It should be noted that the adopted business model for the usage and installation of the battery powertrain is “servitisation”, limiting CAPEX but increasing OPEX.

The results of the autonomous operations show the potential for substantial revenue growth compared to conventional operations for this type of vessel. The increased operational hours available to the autonomous ship offer a significant competitive advantage in this business. **All in all, the IWW case has a high NPV** (Exhibit 5), **yet strongly depending on critical assumptions and variables, such as the fuel and power prices and the unit price per TEU** (€/TEU).

Price per TEU	FNPV (@FDR 4%) over 25 years project lifetime
20 €	2,520,566 €
50€	11,795,623 €
100€	27,252,384 €
150€	42,709,145 €
200€	58,165,907
221€	64,555,732

Exhibit 5: IWW case comparison between transport tariffs and calculated FNPV or the ship-owner

Looking at societal benefits, by transitioning from a diesel-powered conventional ship to a battery-electric autonomous ship, air pollution and GHG emissions will decrease. Additional benefits appear when considering the modal shift too: the simulated case between Zeebrugge and Antwerp demonstrates the possibility to replace truck transport for a demand equivalent to more than 20k TEU, equal to ca. 984,361 km/year, which results in economic benefits of €6,609,825 (NPV, SDR = 3.0%).

	Reference scenario	Project scenario
Capacity (TEUs)	80	90
Operational hours	4,608	6,912
Number of trips	369	553
Number of kilometres	51,069	76,603
TEUs transported	29,491	49,766

Exhibit 6: Operational comparison between project and reference scenario

Key points and recommendations:

The need for value-chain support: Despite the positive results of the projects, investment costs are required from third parties to install auto-mooring equipment and sensors. These costs can reach millions of euros and depend on the extent of the infrastructure involved (e.g., €3.5 million for 5 locks and 2 ports in the IWW case and approximately €1 million at the fish factory in the SSS case). Currently, these costs cannot be fully recovered and may require additional funding, creating potential barriers to wider adoption. However, it’s important to consider that the equipment will be used by multiple autonomous ships in the future, reducing investment costs per autonomous ship.

To fully utilize the increased operational capacity and potential additional revenues, **a thorough market analysis is needed** to determine market demand and prices. This is particularly crucial as it will also impact external factors such as reduced greenhouse gas emissions.

For future CBAs, it's recommended to adopt a holistic approach based on fleets and related infrastructure, to gain a better understanding of the impacts of autonomy in specific areas and deliver more comprehensive results, with more parts of the value-chain to be involved.

3. INTRODUCTION AND METHODOLOGY

3.1. SCOPE AND CONTENT

The scope of this deliverable is providing the reader with a holistic analysis of the two AUTOSHIP's use cases business and the societal perspectives, in one framework analysis.

Cost Benefit Analysis (CBA) methodologies are commonly adopted and required by the European Commission for investment analysis and public funding applications, such as Connecting Europe Facilities (CEF Transport) and Projects of Common Interest (PCI). **This work represents the first structured effort to apply a well-established CBA methodology to the field of autonomous shipping and specifically addresses the AUTOSHIP's two use cases**. This approach allows for the creation of a financial perspective that complements the socio-economic framework of autonomous shipping and provides an overview of the key externalities that the technology brings to the shipping business. It effectively aligns and complements the work done in WP2, WP7 and WP8.

Additionally, the considerations outlined will enhance the future exploitation of the project, since this document presents background economic information, enabling informed speculation about where funding needs are likely to be needed in the future and the impact of incorporating autonomous technology into infrastructure and digitalization development programs. Finally, this report will contribute to the expansion of the database established within the project's DSS, as outlined in D8.3 and uses it to perform logistics modelling as well as GHG calculations (only for the SSS case).

The work can thus be valuable for experts and entrepreneurs, willing to explore the potential of autonomous shipping, as well as for all maritime stakeholders and policymakers, who need to have a bird's eye view of the changes in the value-chain, the associated costs and the benefits. The approach to the 2 use-cases is quite different. The SSS use case compares an autonomous fish feed vessel (EAS's Pioner) to a non-autonomous counterpart, while the IWW scenario compares an electrified autonomous barge to a non-autonomous counterpart, as well as to road transportation, therefore delivering a wider overview of autonomy externalities. The corresponding approach to data collection has therefore been very different, mixing data elaborated by the D8.3 DSS as well as secondary sources.

CONTENT GUIDE

- **This CHAPTER 3** illustrates the general CBA methodology.
- **CHAPTER 4** describes the SSS use case scenario and reference scenario, corresponding cost and benefits (including main assumptions and considerations), and the results of the financial, economic and sensitivity analysis.

- **CHAPTER 5** describes the IWW use case scenario and reference scenario, corresponding cost and benefits (including main assumptions and considerations), and the results of the financial, economic and sensitivity analysis.

3.2. METHODOLOGY

3.2.1. Overall Work Approach

This task was completed by an iterative workflow composed of:

- Set-up of the framework of the analysis by PNO, STF and USTRAT
- Structured interviews with the two use-case owners (EAS and ZA), run by STF and PNO
- Desktop search and integration of results by PNO

The DSS described in AUTOSHIP's *D8.3DSS decision support system (software and documentation)* was used for:

- SSS case: logistics scenario and GHG emissions calculation
- IWW case: logistics scenario

3.2.2. Approach to costs and benefits: Step-by-step plan

Cost-Benefit Analysis (CBA) is an analytical tool to appraise the economic advantages and disadvantages of an investment decision. By assessing all relevant costs and benefits, this analysis provides insight into the welfare changes attributable to the investment decision.

An estimation of the project effects and impacts is conducted by means of an incremental analysis, through calculation of the difference between the (expected) situation after the implementation of the investment decision (project case) and the situation without the investment decision (reference case). A CBA is conducted with an incorporated view of society as a whole, including the total costs and benefits from the perspective of all stakeholders that are positively or negatively affected by the investment decision.

In this respect, CBA differs from financial analyses, wherein generally only financial costs and benefits that accrue to the owner of the project are considered. The costs and benefits of the AUTOSHIP project have been estimated using the methodology provided in the EC CBA guidelines.[2]

This CBA consists of seven steps: which will be described in the subsequent sections of this chapter (and in chapter 5 and 6 for use case specific steps, i.e. definition of project/reference case and demand analysis):

1. Definition of the project and reference cases for the (incremental) analysis.
2. Analysis of future development of demand in the project and reference case (Demand analysis).

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[2] DG REGIO (2015). Guide to Cost-Benefit Analysis of Investment Projects.

3. Identification and quantification of the project's financial costs and benefits (Financial Analysis)
4. Identification of the project's economic costs and benefits (Economic Analysis)
5. Quantification and monetisation of these costs and benefits with respect to reference case (Economic Analysis)
6. Project evaluation through balancing the monetised costs and benefits (Economic Analysis)
7. Sensitivity analysis (assessing the robustness of the results of the analysis based on a set of alternative variables)

The financial, economic and sensitivity analyses will be described in the subsequent sections of this chapter.

3.2.3. Financial, economic and sensitivity analyses

3.2.3.1. Financial analysis

It is essential to include a financial analysis as part of the Cost-Benefit Analysis (CBA) in order to calculate the project's financial performance indicators. This financial analysis is performed to identify the cash inflows and outflows and determine the profitability and sustainability of the project, using an incremental analysis to compare the project case and the reference case[3].

The main financial **project costs** that need to be taken into account comprise the following:

- Investment costs
- Operating and maintenance costs

Investment costs (capital costs) refer to all capital costs of fixed assets (e.g. land purchase, buildings, constructions, machinery, equipment, etc.) and of non-fixed assets (e.g. planning & design fees, technical assistance, publicity, project supervision) including replacements. Being a cashflow-based analysis, depreciation costs are not included in the investment costs. Additionally, residual values of fixed investments are included when the economic life is not yet completely exhausted. In calculating the investments costs, VAT is excluded when recoverable, since these transfer payments do not affect national income.

Operating and maintenance costs accrue due to the day-to-day operation of the project and maintaining of the systems and services. This encompasses all expenses related to the ownership and operation of the transportation service. For autonomous shipping, these costs can be categorized into[4]:

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[3] Article 101 (Information necessary for the approval of a major project) of Regulation (EU) No 1303/2023.

[4] Nordahl et al. (2022). *Autonomous ship concept evaluation – Quantification of competitiveness and societal impact*. Journal of Physics: Conference Series 2311 012020.

- *Operating costs*, which constitute the expenses involved in the day-to-day running of the ship – essentially costs such as remote-control center, insurance, and maintenance by boarding crews. These costs will be incurred whatever trade the ship is engaged in.
- *Periodic maintenance costs*, incurred when the ship is dry-docked for major repairs, usually at the time of its special survey.
- *Voyage costs*, namely variable costs associated with a specific voyage and include such items as Automated Facility Services (AFS), fuel, port charges and canal dues.
- *Cargo-handling costs* represent the expense of loading, stowing, and discharging cargo. They are particularly important in linear trades.

The **project revenues** are defined as the '*cash in-flows directly paid by users for the goods or services provided by the operation, such as charges borne directly by users for the use of infrastructure, sale or rent of land or buildings, or payments for services*'[5]. These revenues will be determined by the quantity forecasts of goods/services provided through the demand analysis and by their prices. Equity transfers or subsidies (e.g. transfers from state or regional budgets), as well as other financial income (e.g. interests from bank deposits) are not included within the operating revenues for the calculations of financial profitability, because they are not directly attributable to the project operations[6]. On the contrary, they are computed to determine the financial sustainability of the project.

The **Present Value (PV)** is the value of an expected income or cost determined as of the date of valuation. This means that calculation of the present value requires discounting of future costs and benefits, which is done through the **Financial Discount Rate (FDR)** as is visualized in Figure 1[7]. To calculate the present value of the future cash flows, an appropriate FDR is adopted which reflects the opportunity cost of capital. According to Article 19 (Discounting of cash flows) of Commission Delegated Regulation (EU) No 480/2014, the European Commission recommends that a 4% discount rate in real terms is considered as the reference parameter for the real opportunity cost of capital in the long term.

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[5] Article 61 (Operations generating net revenue after completion) of (EU) Regulation 1303/2013.

[6] Article 16 (Determination of revenues) of Commission Delegated Regulation (EU) No 480/2014.

[7] A similar approach is used to calculate the net present value of economic costs and benefits through the social discount rate.

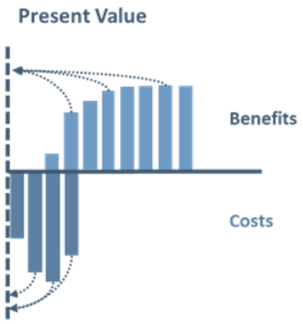

Figure 1: Discounting effects to present value

Project profitability is measured by means of the **Financial Net Present Value** and the **Financial Rate of Return** on investment (FNPV(C) and FRR(C) respectively). FNPV(C) and FRR(C) compare investment costs to net revenues and measure the extent to which the project net revenues can repay the investment, regardless of the sources or methods of financing. FNPV(C) is defined as the sum over the difference between: (1) the discounted investment and operating costs of the project and (2) the discounted value of the expected revenues. This is calculated with the following equation:

$$\text{FNPV(C)} = \sum_{t=0}^{n} a_t S_t = \frac{S_0}{(1+i)^0} + \frac{S_1}{(1+i)^1} + \ldots + \frac{S_n}{(1+i)^n}$$

Where:

FNVP(C)= Financial Net Present Value on investment

S_t = balance of cash flow at time *t*

a_t = FDR factor chosen for discounting at time *t*

i = financial discount rate

Subsequently, The FRR(C) is defined as the discount rate that produces a zero FNPV(C) and is given by the solution of the following equation:

$$0 = \sum \frac{St}{(1+FRR)^t}$$

Where:
S_t = balance of cash flow at time *t*
FRR = Financial Rate of Return on investment

The FNPV(C) is expressed in monetary terms (EUR) and must be related to the scale of the project[8].

The FRR(C) is a pure number and is scale-invariant.

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[8] The present value is always less than or equal to the future value because of the so-called “time value of money”: the principle that money available at the present time is worth more than the same amount in the future due to its potential earning capacity.

3.2.3.2. Economic analysis

Once the financial analysis is completed, an economic analysis must be carried out as part of the CBA, to appraise the project's contribution to welfare through incremental analysis of the economic effects of the project in comparison to the reference case[9]. The key concept in the economic analysis is the use of shadow prices for reflecting social opportunity cost and benefits of goods and services, instead of prices observed in the market that may be distorted.

Starting from the Return On Investment calculation, the following adjustments are needed to move from a financial to economic analysis.:

- Fiscal corrections;
- Switch from market to shadow prices;
- Evaluation of non-market impacts and corrections for externalities.

After market price adjustment and non-market impacts estimation, costs and benefits occurring at different times must be discounted to calculate the present value. The discount rate in the economic analysis, the **Social Discount Rate (SDR)**, reflects the socio-economic perspective on how future benefits and costs should be valued against present ones (which can also be explained by Figure 1). The European Commission suggests two benchmarks for Social Discount Rates (SDR): 5% for the Cohesion countries and 3% for the others[10]. As stated in the CBA Economic Appraisal Vademecum 2021-2027[11], as a matter of simplification, in the absence of national values, 3% SDR can be taken as a reference point for EU-funded projects in 2021–2027.

Once all project cost and benefits have been quantified and valued in monetary terms, it is possible to measure the economic performance of the project by calculating the following indicators:

- **Economic Net Present Value** (ENPV): the overall difference between the discounted social benefits and costs leading to the project effect (see Figure 2);
- **Economic Rate of Return** (ERR): the rate that produces a zero value for the ENPV;
- **B/C Ratio**: the ratio between discounted economic benefits and costs.

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[9] Article 101 (Information necessary for the approval of a major project) of Regulation (EU) No 1303/2013.

[10] Guide to Cost-benefit Analysis of Investment Projects: Economic appraisal tool for Cohesion Policy 2014-2020 (DG REGIO, 2014).

[11] Economic Appraisal Vademecum 2021-2027. DG REGIO (2021).

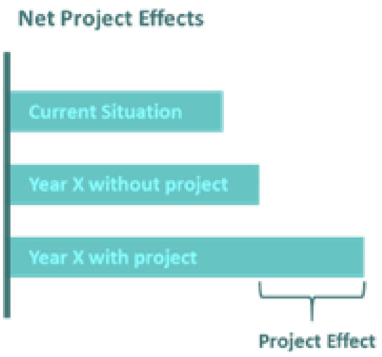

Figure 2: Effects in socio-economic CBA

3.2.3.3. Sensitivity Analysis

Eventually, a full CBA includes a sensitivity analysis. The sensitivity analysis indicates the robustness of the proposed project to changes in underlying assumptions (Harris and Roach, 2018) and enables the identification of ‘critical’ variables of the project. The analysis is carried out by varying one variable at a time and determining the effect of that change on the NPV.[12] As a guiding criterion, the recommendation is to consider ‘critical’ to those variables for which a variation of 1% of the value adopted in the base case gives rise to a variation of more than 1% in the value of the NPV.

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[12] DG REGIO (2015). Guide to Cost-Benefit Analysis of Investment Projects

4. SHORT SEA SHIPPING CBA

4.1. SHORT SEA SHIPPING (SSS) – USE-CASE DESCRIPTION

4.1.1. Scenario description

This chapter outlines the SSS use-case, which involves the transportation of fish feed from factories (suppliers) to fish farms (customers) by ships. Since fish farms are situated at sea, ships are the only means of supplying them. The demand for feed fluctuates throughout the year, dividing it into a high season (June 1st to mid-December) and a low season (mid-December to June 1st). This change in demand affects the number of farms a ship can service on one voyage, the number of voyages a ship completes in a week, and the routes the ship travels throughout the year.

The Eidsvaag Pioner (Autoship's SSS demonstrator vessel) transports feed from a factory located in mid-Norway to fish farms scattered along the Norwegian coast. The ship operates on different routes throughout the year, however a representative route for a typical voyage is given in Figure 3. **The typical voyage starts at the feed factory by loading the ship to 95% of its' carrying capacity, continues with delivery to 10 fish farms in sequential order, and ends by returning to the factory. The ship will complete 2-3 voyages along this representative route per week in high season, and 1-2 voyages in low season**. Assuming an average of 2 voyages per week, the ship will complete an estimated 104 voyages yearly.

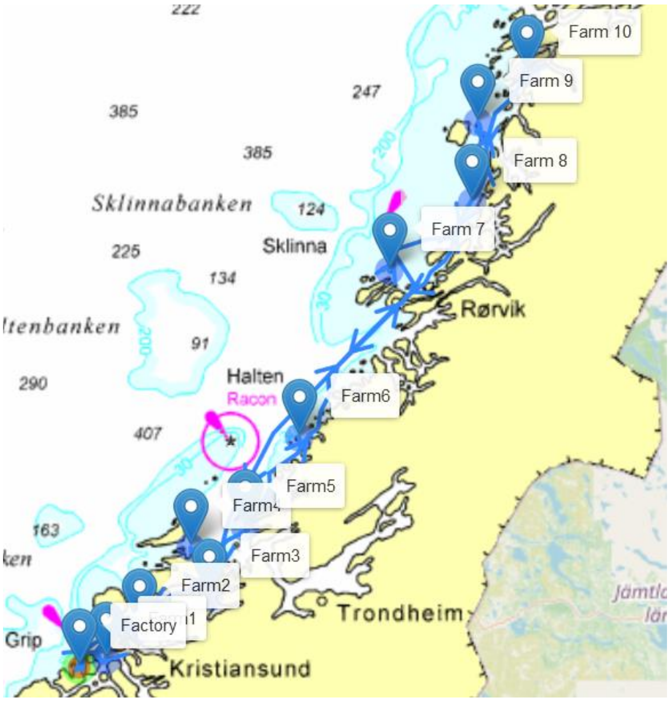

Figure 3: Use case route: representative route for one year of operation

The fish farms have contracts directly with the factories, and these are normally of two types: 1) Integrated feed and transport contract and 2) separate feed and transport contract. In both cases**, the shipowner will have a fixed price agreement for the transportation of the feed. The profit margin of the ship owner will therefore depend on their ability to optimize their operational economy and subsequently operate the ship(s) as efficient as possible.** The most important performance indicator is on-time delivery because the most basic requirement to the service is that no fish farm shall run out of feed. This puts an important limiting factor to the shipowners' freedom to optimize the ship operations; **they must deliver the feed that the fish farms order within certain time windows. This in turn limits the choice of sailing speed and frequency of voyages.**

4.1.2. Project and reference scenario

As described in Chapter 4, the CBA compares the project scenario (autonomous vessel) to the reference scenario (conventional vessel). For this comparison it is assumed that a new ship has to be built for both use cases. In addition, **due to the optimalisation of the vessel design (since the crew related facilities can be removed) the maximum cargo capacity of the vessel will increase from 1,880 tonnes to 2,230 tonnes (+18.6%).** A comparison between the reference and project scenario and corresponding main assumptions is given below.

Table 1: Comparison project and reference scenario

	Reference scenario	**Project scenario**
Cargo capacity	1,888 ton	2,230 ton
Average sailing speed	13 knots	13 knots
Auxiliary power consumption	130 kW	100 kW
Transported cargo (annual)	182,950 ton	203,376 ton
Voyages	102	96
Fuel type	LNG	LNG
Fuel consumption (annual in kgs)	1,437,340	1,303,955
Operating time	90%	90%
Max. load when leaving factory	95%	95%
Economic lifetime	30 years	30 years

As can be seen from Table 1, the main differences are related to the additional cargo capacity. **Assuming that in both the reference scenario and the project scenario the ships are using 95% of their maximum cargo capacity the number of voyages per year will be lower for the autonomous ship. The annual amount of cargo transported to the fish farms will increase and also leads to additional revenues. In addition, economic effects are expected due to the more efficient operation which leads to a reduction in fuel consumption.**

The following paragraph outlines the three key distinctions between the project scenario, where autonomous operation is implemented, and the reference scenario. These differences are presented in greater detail below:

- **Communication -** the baseline scenario involves communication between fish farms and incoming vessels through phone or VHF communication, with alerts being sent just in time for arrival. The process for opening and closing the silo hatches on the feed barge from the ship is also manual. *In the project scenario, Eidsvaag will provide the fish farms with new instrumentation, enabling the ship to assess local weather conditions prior to approach*. This additional information reduces sailing and waiting time by allowing the ship to **avoid delays due to unfavorable weather conditions.**
- **Crew & control of the ship -** In the reference scenario loading and controlling of the cranes is done manually. *In the project scenario, the loading of the ship at the fish feed factories is done automatically, once specific equipment has been installed*. The expected result of this update is **increased safety and loading speed** – the latter will result in **decreased voyage time which is translated into reduced mooring time**. Increased safety will lead to a reduction in external costs. In the reference scenario, a conventional crewed ship is used with manual offloading at fish farms, while *in the project scenario, the ship will employ both transit and remote-control offloading*. This results in a **reduced crew needed, increased efficiency as the ship can operate for longer periods, and additional cargo space**. If both ships utilize 95% of their cargo capacity, this will lead to a 20.426-ton increase in capacity, reducing the number of required voyages and having a positive impact on GHG emissions.

4.2. SSS CASE: IDENTIFICATION OF COSTS & BENEFITS

Below, an overview of the economic and financial effects considered is displayed. For each effect, the expected change with respect to the reference case will be shortly discussed.

4.2.1. Financial Effects

This section describes and lists the financial effects resulting from the implementation of the project. As described in the methodology section, for the economic analysis the CBA calculates with a FDR of 4.0% (as prescribed by the Guide to Cost-Benefit Analysis of Investment Projects).

(1) **Investment costs**: the implementation of the autonomous SSS case will lead to additional investment costs as opposed to the reference case:

Increased vessel construction costs. Investment costs for the autonomous ship are assumed to be 10% higher compared to a similar conventional ship. **The investment costs for building a conventional ship used for the type of operations as described in the use case description are € 33 M. Based on the**

above description, it is assumed that the investment costs for building an autonomous ship will be € 36.3 M.[13]

The absolute value of the (incremental) direct investment costs included in this CBA is thus € 3,300,000 (absolute value excl. VAT). An overview of the absolute value and the NPV (4%) of the project investment costs can be seen in Table 2 (assuming 2 years for the construction period).

Table 2: Direct investment costs

	Absolute value (sum over project lifetime)	**Present value (FDR = 4%)**
Investment costs	€ 3,300,000	€ 3,236,538

More in detail, this increase results from material and immaterial factors, such as:

- **Hull structure (-)**: removal of the deckhouse plus removal of seafarers' accommodation lowers the investments costs for the project case. The actual cost reduction is dependent on the ship size and the design due to the reduction in steel costs.
- **Main and Auxiliary engine (+)**; an increase in investment costs due to the necessity to use of more reliable equipment/system or added redundancy. The actual costs increase is dependent on the engine room/power and the use of energy storage devices.
- **Certification costs (+)**: the certification costs are dependent on the type of vessel. However, the certification of new systems and equipment and the re-evaluation of the operation will lead to additional costs (at first). These costs will likely reduce over time.
- **Electronics (+):** additional equipment (cameras, sensors, communication equipment) is needed for the autonomous operation compared to the reference scenario.

It is remarkably important to note that there will be additional investment costs for the installation of auto-mooring and local sensors/equipment at the fish feed factory. However, as these costs will be incurred by the factory and not the vessel owner, they are classified under economic impacts.

(2) **Residual value of investments and replacement costs**: these elements are affected by the additional investment for the autonomous ship and by its estimated lifetime.

- **Residual Value -** The final project year within the 25-years reference period for this CBA is 2047. Assuming a construction duration of two years and using an estimated economic life for the

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[13] This value has been analysed with direct interviews to EAS management and gave similar results as proposed by available literature: Kretschmann et al. (2017). Analyzing the economic benefit of unmanned autonomous ships: an exploratory cost-comparison between an autonomous and a conventional bulk carrier.

autonomous ship of 25-30 years, **the residual value of the investment at the end of the reference period will be about 20% of the initial investment costs**.

- **Replacement costs:** since the useful life of the autonomous ship is longer than the reference period used in this CBA, replacement costs for the autonomous ship are not included in the CBA.

The absolute value and the NPV (4%) of the residual value can be seen in Table 3.

Table 3: Residual value

	Absolute value (sum over project lifetime)	**Present value (FDR = 4%)**
Residual value	€ 770,000	€ 300,394

(3) **Operating costs**: These costs can be divided into general operational costs and voyage related operational costs. The latter are variable costs, associated with a particular voyage and includes fuel cost, cargo handling and port calls costs (Ziajka-Poznanska& Montewka, 2021).

The **general O&M costs** affected by the switch from a conventional to an autonomous vessel are:

- **Crew wages (-)**: crew wages will be reduced since no on-board crew is needed for the autonomous ship. For a conventional ship, crew wages amount to € 1,200,000 per year.
- **Remote Control Centre (RCC) (+):** in order to have the autonomous ship in operation, additional expenditures for using the service of a RCC will be incurred. These RCC expenditures have been estimated to amount to € 145,000 per year.
- **Maintenance (ship) (+):** the maintenance costs for the autonomous ship are expected to be higher than for a conventional ship (due to additional equipment needed for the autonomous operation). The additional maintenance costs for the autonomous ship have been estimated to amount to € 155,000 per year.
- **Operational Insurance (+/-):** insurance costs for an autonomous ship are assumed to be equal to a conventional ship. Normally the insurance fees are calculated based on the investment costs (which will be higher for the autonomous ship). However, increased safety because of the autonomous operation is expected to result in a decrease in insurance costs. For this reason, insurance costs in the project scenario are set equal to the insurance costs in the reference scenario.

The **voyage related O&M costs** affected by the switch from a conventional to an autonomous ship are:

- **Fuel costs (-):** fuel consumption for the autonomous ship differs from the conventional ship due to a more efficient operation of the ship and the engines, reduced ship weight, and less air resistance as a result of the new design (which is only possible when crew facilities are absent).

This will result in a yearly fuel cost reduction of € 60,000. For this analysis, fuel consumption profiles for both the project and the reference scenario have been calculated with SINTEF's model as presented in D8.3.[14]

- **Port/quay dues (+/-):** incremental port and quay dues are assumed to be insignificant. For a conventional ship, the annual port and quay dues amount to about € 60,000 per year. Since these costs will not increase significantly for an autonomous ship, the incremental port and quay dues are assumed to be zero.

The total absolute value of the (incremental) O&M costs reduction included in this CBA is € 22,080,000 (absolute value excl. of VAT). An overview of the absolute value and the NPV (4%) of the O&M costs can be seen in Table 4.

Table 4: Incremental O&M costs

	Absolute value (sum over project lifetime)	**Present value (FDR = 4%)**
Crew wages	- € 27,600,000	-
Maintenance costs	€ 3,565,000	-
Remote Control Centre	€ 3,335,000	-
Fuel costs	- € 1,380,000	-
Total O&M costs	**- € 22,080,000**	**- € 13,714,008**

(4) **Revenues and market gains:** revenues are "*cash in-flows directly paid by users for the goods or services provided by the operation […]*".[15] Incremental revenues may come from increases in quantities sold, in the level of prices, or both. Due to the business characteristics, in this case the gain comes from an increased capacity and the capability to optimise the yearly delivery.

When comparing the autonomous ship to a conventional ship, the following effect on revenues is expected:

- **Increased capacity (+):** as a result of the new ship design without crew facilities, the autonomous ship has a maximum cargo capacity of 2,230 tonnes compared to 1,888 tonnes for the conventional ship. Therefore, assuming an equal utilisation rate (95%) of the maximum cargo capacity for both the project and reference case, **the autonomous ship will transport an additional 325 tonnes of fish feed per voyage**. This will lead to an annual increase of the amount of cargo transported

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[14] Nordahl et al. (2022). *Autonomous ship concept evaluation – Quantification of competitiveness and societal impact*. J. Phys.: Conf. Ser. 2311 012020.

[15] DG REGIO (2015). Guide to Cost-Benefit Analysis of Investment Projects.

of 20,426 tonnes. Referring to the year 2021, revenues per tonne transported can be estimated € 59,56. Based on this figure, it is assumed that **an additional 20,426 tonnes transported will result in an increase in annual revenues of € 1,216,625**.

The total absolute value of the (incremental) revenues included in this CBA is € 27,982,372 (absolute value excl. of VAT). An overview of the absolute value and the NPV (4%) of the incremental revenues can be seen in Table 5.

Table 5: Incremental revenues

	Absolute value (sum over project lifetime)	**Present value (FDR = 4%)**
Revenues	€ 27,982,372	€ 17,380,003

4.2.2. Economic effects

This section lists the economic effects resulting from the implementation of the project. As described in the methodology section, the economic analysis relies on a SDR of 3.0% (as prescribed by the Guide to Cost-Benefit Analysis of Investment Projects).

(1) **Investment costs incurred by third parties:** investment costs incurred by third parties to be able to operate the autonomous ship. Since the financial analysis only covers the costs (and revenues) from the point of view of the service owner (in this case Eidsvaag as the ship owner), these additional investment costs are listed among the economic effects and are included in the economic analysis, instead of the financial analysis.

For the SSS use case, the investment costs incurred by third parties are the costs for auto-mooring equipment and local sensors at the fish feed plant. These costs will be covered by the fish feed plant owner and are assumed to be € 1,000,000 in total (absolute value excl. of VAT). An overview of the absolute value and the NPV (3%) of these costs can be seen in Table 6.

Table 6: Investment costs incurred by third parties

	Absolute value (sum over project lifetime)	**Present value (SDR = 3%)**
Investment costs incurred by third parties	€ 1,000,000	€ 985,437

(2) **Externalities:** externalities are defined in this CBA as impacts that fall upon uncompensated third parties – and thus not on the project or the direct users of the project services. As defined by the Guide to Cost-Benefit Analysis of Investment Projects, an externality is any cost or benefit that

spills over from the project towards other parties without monetary compensation. Two types of externalities are identified and monetised for this project: 1) greenhouse gas emissions, and; 2) air pollution. In addition, effects on safety, working conditions and unexpected disruptions are described in a qualitative way.

- **Greenhouse gas emissions -** A reduction in CO_2 emissions is expected for the project scenario compared to the reference scenario as a result of the new vessel design. Based on SINTEF's model,[16] an annual reduction of CO_2 emissions of 360 tonne is expected. In order to monetize this value in the CBA, the CO_2 avoidance is multiplied by the climate change costs per tonne of CO_2 equivalent as described in the Handbook on the External Costs of Transport 2019 (see Table 7).[17] Since the costs of climate change as a result of CO_2 equivalent emissions are given for the short-and-medium run (up to 2030) and long run (from 2040 to 2060), a linear growth of external costs has been assumed for the period between 2029 and 2040.

Table 7: External costs of climate change per tonne CO2 equivalent

	2029 (and before)	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040 (and after)
Climate change costs per tonne CO_2-equivalent (in €)[18]	**109,74**	**126,60**	**143,46**	**160,32**	**177,18**	**194,04**	**210,90**	**227,76**	**244,62**	**261,48**	**278,34**	**295,20**

An overview of the total external costs of avoided CO_2 emissions can be seen in Table 8. The reduction of fuel consumption and corresponding avoidance of **CO_2 emissions will result in an overall cost reduction of € 1,791,824 (absolute value excl. of VAT) for the total reference period of 25 years.**

Table 8: External costs of climate change

	Reduction in CO_2 equivalent emissions (in tonne)	**Absolute value (sum over project lifetime)**	**Present Value (SDR = 3.0%)**
Greenhouse gas avoidance	8,280	€ 1,791,824	€ 1,157,181

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[16] Nordahl et al. (2022). *Autonomous ship concept evaluation – Quantification of competitiveness and societal impact*. J. Phys.: Conf. Ser. 2311 012020.

[17] CE Delft (2019). Handbook on the External Costs of Transport 2019.

[18] The climate change costs per tonne CO_2-equivalent have been adjusted to the price level in 2021. Since annual inflation rates for 2022 are not yet available, the 2021 price level has been used.

- **Air pollution -** In addition, a reduction in air pollutant emissions is expected for the project scenario compared to the reference scenario as a result of the new vessel design. For calculating the external costs of air pollution reduction for this project, the following types of emissions have been taken into account in this CBA: NO_x, $PM_{2.5}$, and PM_{10}.

  The expected reduction in air pollutant emissions is based on SINTEF's model and can be seen in Table 9. The total avoidance of air pollutants is multiplied by the external costs of air pollution (per kg) as described in the Handbook on the External Costs of Transport 2019 (see Table 10).[19] This includes health effects, crop loss, biodiversity loss and material damage. Since the air pollution costs are not specified for the Norwegian Sea, air pollution costs for the North Sea (nearest sea for which this is specified) are used for the calculation.

Table 9: Air pollution avoidance

	NO_x (in kg)	**$PM_{2.5}$ (in kg)**	**PM_{10} (in kg)**
Reduction in air pollutant emissions	25,300	179.4	179.4

Table 10: External costs of air pollution

	NO_x	**$PM_{2.5}$**	**PM_{10}**
External costs (in €/kg)[20]	4.28	8.12	4.62

An overview of the total external costs of avoided air pollution can be seen in Table 11. The reduction of fuel consumption and corresponding **avoidance of air pollution will result in an overall external cost reduction of € 110,570 (absolute value excl. of VAT) for the total reference period of 25 years**.

Table 11: External costs of avoided air pollution

Air pollution avoidance	**Absolute value (sum over project lifetime)**	**Present value (SDR = 3%)**
NO_x	€ 108,284	€ 75,162
$PM_{2.5}$	€ 1,457	€ 1,011
PM_{10}	€ 829	€ 575
Total	**€ 110,570**	**€ 76,748**

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[19] CE Delft (2019). Handbook on the External Costs of Transport 2019.

[20] The climate change costs per tonne CO_2-equivalent have been adjusted to the price level in 2021. Since annual inflation rates for 2022 are not yet available, the 2021 price level has been used.

(3) **Increased safety and resilience:** safety can be affected in several ways as a result of this project.

An extensive discussion about autonomy impacts on jobs and the corresponding training requirements is developed in Task 7.3 of the AUTOSHIP project and described in *“AUTOSHIP deliverable D7.2: Autonomous ships: Training Framework for crew, operators and designers*”, by Jeon, Lee, Theotokatos, et al.

The general concept behind is that substantial changes are brought into the picture of working conditions and definitions, as a consequence of ships operating uncrewed or with reduced crew onboard. Several Key Enabling Technologies (KETs) - *such as situation awareness (SA), autonomous navigation system (ANS), Intelligent Machinery System (IMS), Connectivity and Cyber-security System (Con/CyS) and Remote Operations Centre (ROC), which may include a Remote Control Centre (RCC)* – are involved. These KETs are described in D4.3 of the AUTOSHIP D4.3 - KET Executive Summary (Ruud et al., 2021).

All in all, although advanced technologies reduce human interventions in autonomous ships (and cargo operations potentially), human operators are still present in the ROC/RCC, regardless of the autonomy level. For example, in order to enabling autonomous operations, a Digital Master and a Digital Chief will be employed onboard, whereas Remote Navigation Operators and Remote Engineer Operators with physical workstations will be present at the RCC.

These changes will most likely positively impact safety on board and onshore and the overall value-chain resilience.

- **Enhancements in safety and improved onshore working conditions.** The integration of automation and AI technology will result in reduced fatigue for both ship crews and shore personnel, depending on the level of automation and the responsibilities assigned to the ship’s AI control. Additionally, crew safety is improved as they are no longer required to work in hazardous conditions at sea. Thirdly, the risk of human error, which is responsible for 75% to 96% of all maritime accidents, is significantly reduced.
  It should be however noted that, since there are large uncertainties with regard to the type of accidents that will be prevented as a result of autonomous shipping, this effect cannot be quantified in this CBA. However, this will be a positive effect as the number of incidents will be reduced in the project scenario compared to the reference scenario.

- **Increased Resilience and Reduced Disruptions:** The switch to autonomous shipping is expected to lead to a reduction in the impact of unexpected disruptions. For instance, disruptions caused by crew illness, such as during the COVID-19 pandemic, can significantly impact transport movements. However, the absence of an on-board crew in the project scenario eliminates the impact of crew-related disruptions. It must be considered that AUTOSHIP deals with normal operations and emergency response, other ship operations, such as cargo operations at port are out of scope and are not included. **Since these unexpected disruptions can be caused by several other reasons and given the complexity of the total supply chain, the specific effect due to the absence of crew cannot be determined and this effect is not quantified for this CBA**. In any case, it can be argued that this will be a positive effect as the number of (crew-related) unexpected disruptions will be inherently reduced.

4.3. SSS USE CASE – FINANCIAL ANALYSIS

The financial analysis is performed using a 25-year period by defining the Net Present Value (NPV) of the generated cashflows. The financial (and economic) analysis uses constant prices. This means that all calculations of costs and valuation of impacts are done in prices referring to the same year (i.e. the base year). Subsequently, only real price increases (above inflation) are taken into account. All external costs for this study are adjusted to the price level of 2021.[21] A 4.0 % discount rate in real terms is used in the financial calculations in line with the EU wide benchmark set by the European Commission. VAT is excluded from this analysis since this is recoverable.

Table 12: Return on investment

Return on investment	NPV calculated at 4.0%
Project investment cost	- € 3,236,538
Replacement cost	-
Project O&M cost	€ 13,714,008
Total revenues	€ 17,380,003
Residual value of investment	€ 300,394
FNPV(C)	**€ 28,157,866**
FRR(C)	**52.3%**

The financial analysis gives a positive result: the discounted incremental revenues, incremental savings on O&M costs, and the residual value of the investment are higher than the incremental investment costs. This results in a positive FNPV(C) of € 28,157,866. The FRR(C) is 52.3%. This means that the additional investment costs for an autonomous ship compared to a conventional ship will be paid off by increased revenues and a decrease in O&M costs.

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[21] The external costs have been adjusted to the price level in 2021. Since annual inflation rates for 2022 are not yet available, the 2021 price level has been used.

The main driver for this positive result is the increased cargo capacity of the autonomous ship compared to a conventional ship and the corresponding incremental revenues. It is worth noting that for this CBA, it is assumed that this additional cargo capacity will be (almost) fully used.[22] **If the amount of cargo transported stays the same compared to the reference scenario, the FNPV(C) is lower but still positive**: € 10,777,863. For this scenario, the FRR(C) is 25.7%. The results for the financial analysis without additional revenues (assuming that the amount of cargo transported is equal for both the reference and project scenario) are shown in Table 13.

Table 13: Return on investment (without additional revenues)

Return on investment	**NPV calculated at 4.0%**
Project investment cost	- € 3,236,538
Replacement cost	-
Project O&M cost	€ 13,714,008
Total revenues	-
Residual value of investment	€ 300,394
FNPV(C)	**€ 10,777,863**
FRR(C)	**25.7%**

4.4. SSS CASE: ECONOMIC ANALYSIS

The economic analysis provides insight into the project's contribution to the welfare of society. The main assumptions for this analysis overlap partly with the financial analysis, i.e. the reference period is also 25 years (2023-2047). On the other hand, the social discount rate used for the economic analysis is set on 3.0%. Results are presented in Table X, including:

- Economic Net Present Value (ENPV), which is the difference between the discounted total economic benefits and costs over the reference period.
- Economic Rate of Return (ERR), defining the rate that produces a zero value for the ENPV.
- B/C Ratio, i.e. the ratio between discounted economic benefits and costs.

Table 14: Economic analysis overview

	NPV calculated at 3.0%
Project investment cost	- € 3,251,942

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[22] As described before, it is assumed that the utilization rate will be equal for both scenarios (95% of maximum cargo capacity).

	NPV calculated at 3.0%
Replacement cost	-
Project O&M cost	€ 15,326,082
Residual value of investment	€ 378,789
Total economic costs	**€ 12,452,929**
Reduction in $PM_{2.5}$ emissions	€ 1,011
Reduction in PM_{10} emissions	€ 575
Reduction in NO_x emissions	€ 75,162
Reduction in CO_2 emissions	€ 1,157,181
Investment costs incurred by third parties	€ 985,437
Total economic benefits	**€ 248,493**
ENVP / Net benefits	**€ 12,701,421**
ERR	**21.1%**
B/C Ratio	**-0.02 → 0.09 (excluding operational benefits)**

In addition to the financial analysis, the economic analysis gives a positive result too; showing that the project has societal benefits that are substantially higher than the corresponding societal costs. The net benefits (ENPV) are estimated at € 12,701,421. In addition, the positive results are reflected in an ERR of 21.1%. However, as can be seen in Table 14 the B/C Ratio is -0.02. This is the result of large savings on operational costs, which results in a positive number for the economic costs (which is normally a negative number when investment costs are higher than the operational cost savings).[23] If the effect on the operational costs is removed from the calculation, the project results in a positive B/C Ratio of 0.09.

4.5. SSS CASE: SENSITIVITY ANALYSIS

A full CBA includes a sensitivity analysis. The sensitivity analysis indicates the robustness of the proposed project to changes in underlying assumptions (Harris and Roach, 2018) and enables the identification of ‘critical’ variables of the project. The analysis is carried out by varying one variable at a time and determining the effect of that change on the NPV.[24] As a guiding criterion, the recommendation is to consider ‘critical’ to those variables for which a variation of 1% of the value adopted in the base case gives

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[23] The methodology used for the CBA is a two-step process, starting with the financial analysis and after that, when the result is a negative FNPV, the economic analysis. Since the outcome of the financial analysis is positive (FNPV > 0), the calculation for the B/C Ratio is affected by the savings on operational costs.

[24] DG REGIO (2015). Guide to Cost-Benefit Analysis of Investment Projects

rise to a variation of more than 1% in the value of the NPV. The results of the sensitivity analysis can be seen in Table 15.

Table 15: Sensitivity analysis

	Variation of the FNPV due to a 1% variation	**Criticality judgement**	**Variation of the ENPV due to a 1% variation**	**Criticality judgement**
Project investment cost	0.1%	Not critical	0.3%	Not critical
Residual value of investment	0.0%	Not critical	0.0%	Not critical
Crew wages	0.6%	Not critical	1.5%	Critical
Maintenance costs	0.0%	Not critical	0.2%	Not critical
RCC costs	0.0%	Not critical	0.2%	Not critical
Fuel costs	0.0%	Not critical	0.0%	Not critical
Additional revenues	0.6%	Not critical	-	-
Reduction in $PM_{2.5}$ emissions	-	-	0.0%	Not critical
Reduction in PM_{10} emissions	-	-	0.0%	Not critical
Reduction in NO_x emissions	-	-	0.0%	Not critical
Reduction in CO_2 emissions	-	-	0.0%	Not critical
Investment costs incurred by third parties	-	-	0.0%	Not critical

The outcomes of the sensitivity analysis show that the only identified critical variable is crew wages (worth noting that fuel prices were those from 2021). Since the aim of the project is to switch from a conventional manned ship to an autonomous ship without crew **it is not surprising that a variation in the operating cost reduction as a result of the absence of crew wages will result in significant changes in the ENPV. However, attention should be paid to this variable since this CBA is focused on a specific use case** (with corresponding specific crew wages) and the results of this analysis can differ for similar projects with lower crew wages in the reference situation.

4.6. EVALUATION & CONCLUSION

The outcome of the CBA for the SSS use case shows that turning to autonomy is favourable for a shipowner under the made assumptions and analysis framework– from both a financial as well as an economic perspective. The financial benefits outweigh the increase in investment costs and the economic benefits outweigh the external costs for society.

For this specific use case, a switch from a conventional ship to an autonomous ship shows significant benefits:

- The autonomous operation shows a significant decrease in O&M costs compared to the conventional operation. This is a result of the absence of crew resulting in a large reduction of crew wages. In addition, fuel consumption can be reduced compared to the reference scenario. With the available information, although O&M costs will be affected in a negative way by increased maintenance and the expenditures for making use of the RCC's service, the total operating costs will be reduced by € 15,326,082 (NPV, FDR = 4.0%) for the total reference period of 25 years.
- Due to a reduction in fuel consumption, the air pollution and GHG emissions will be reduced alike. This translates into an economic benefit of € 76,748 (NPV of air pollution emission reduction, SDR = 3.0%) and € 1,157,181 (NPV of GHG emissions reduction, SDR = 3.0%).

Although the investment costs for an autonomous ship are higher than for a conventional ship, the financial analysis results in a FNPV(C) of € 28,157,866. Even if the additional cargo capacity will not be utilised and the amount of transported cargo stays equal to the reference scenario, the FNPV(C) is positive (€ 10,777,863).

The economic analysis results in an ENPV of € 12,701,421 and an ERR of 21.1%. This underlines also from an economic perspective that the switch from a conventional ship to an autonomous ship has significant benefits and that not only the ship owner benefits from the project, but also society.

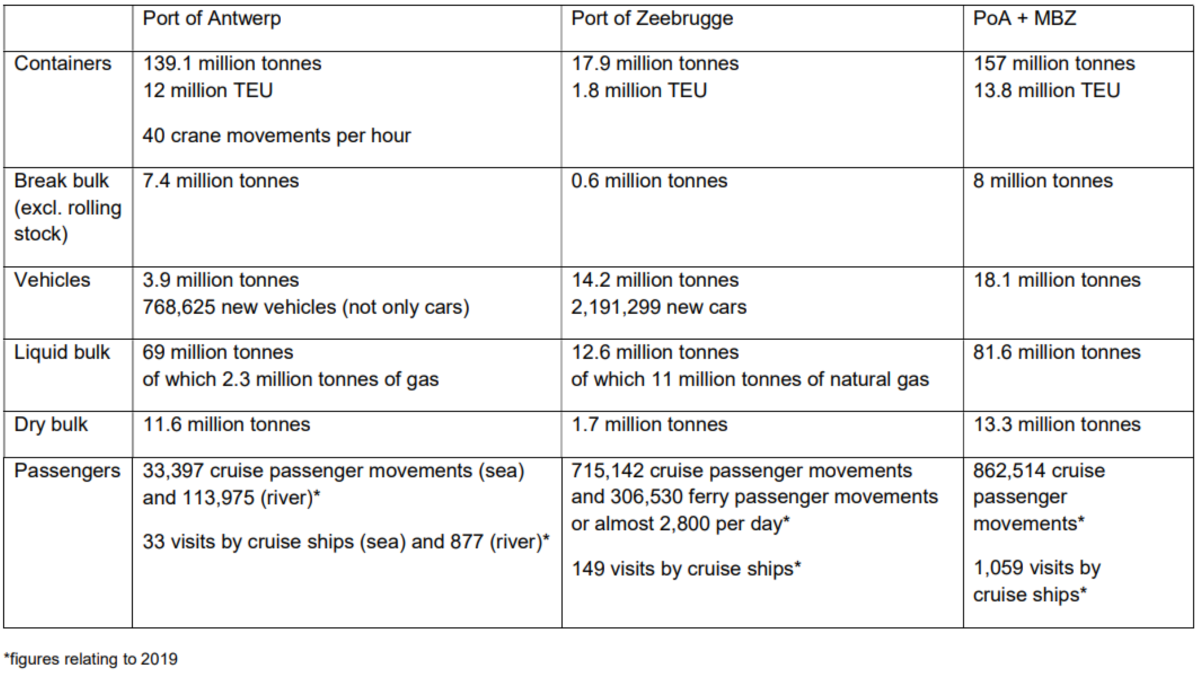
The sensitivity analysis shows only one critical variable: crew wages. Since this analysis is carried out for a specific use case with corresponding specific crew wages, it is not expected that the values for this variable will change. However, when applying the results of this analysis for a similar project it is important to be able to accurately estimate this critical variable since a small change in crew wages can significantly affect the results of the economic analysis.

5. INLAND WATER WAYS (IWW) USE-CASE: PALLET BARGE

5.1. INLAND WATER WAYS (IWW) - USE-CASE DESCRIPTION

5.1.1. Scenario description

This use-case consists of implementing an autonomous ship for inland waterways, between the port of Antwerp and the port of Zeebrugge. The ports of Antwerp and Zeebrugge merged in 2021 to become the Port of Antwerp-Bruges and they are historically complementary: the main volumes for Zeebrugge are ro-ro[25], containers and transshipment of LNG, whereas Antwerp focus on transport and storage of containers, goods (breakbulk) and chemicals (see also Figure 4).



	Port of Antwerp	Port of Zeebrugge	PoA + MBZ
Containers	139.1 million tonnes 12 million TEU 40 crane movements per hour	17.9 million tonnes 1.8 million TEU	157 million tonnes 13.8 million TEU
Break bulk (excl. rolling stock)	7.4 million tonnes	0.6 million tonnes	8 million tonnes
Vehicles	3.9 million tonnes 768,625 new vehicles (not only cars)	14.2 million tonnes 2,191,299 new cars	18.1 million tonnes
Liquid bulk	69 million tonnes of which 2.3 million tonnes of gas	12.6 million tonnes of which 11 million tonnes of natural gas	81.6 million tonnes
Dry bulk	11.6 million tonnes	1.7 million tonnes	13.3 million tonnes
Passengers	33,397 cruise passenger movements (sea) and 113,975 (river)* 33 visits by cruise ships (sea) and 877 (river)*	715,142 cruise passenger movements and 306,530 ferry passenger movements or almost 2,800 per day* 149 visits by cruise ships*	862,514 cruise passenger movements* 1,059 visits by cruise ships*

*figures relating to 2019

Figure 4: Overview and statistics of Port of Antwerp and Port of Zeebrugge[26]

A CEMT class IV container ship (*Conférence Européenne des Ministres des Transports*[27]) is considered. The ship is supposed to transport containers loaded and offloaded both in Antwerp and in Zeebrugge. In the financial analysis, the study will compare a conventional CEMT class IV container ship to the X-barge

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[25] Roll-on roll-of – cargo that is rolled on an off the ship instead of being lifted.

[26] https://www.itln.in/antwerp-zeebrugge-ports-to-merge-will-have-278-mn-tonnes-capacity-shipping

[27] The Classification of European Inland Waterways by CEMT is a set of standards for interoperability of large navigable waterways forming part of the Trans-European Inland Waterway network within Continental Europe and Russia

autonomous CEMT class IV container ship, and then, in the economic analysis, it will account for the externalities related to goods modal shift, comparing the X-barge to an equivalent truck transportation.

The inland waterways route is given in Figure 2, and is approximately 138 km, involves 5 lock passages, and a host of bridges. The estimated duration by *Visuris* is 12 hours and 28 minutes. The corresponding truck route is given in Figure 6 and is approximately 98 km long, with an estimated duration about 1 hour and 20 minutes.

Figure 5: IWW use-case route between Antwerp and Zeebrugge

Figure 6: IWW use-case road transportation alternative

5.1.2. Project and reference scenario

As described in Chapter 4, the CBA compares the project scenario (autonomous vessel) to the reference scenario (conventional vessel). For this case, it is assumed that transport through autonomous vessels will replace a conventional vessel and the additional capacity will replace traditional trucks transport.

Below, the baseline and project scenarios are described, highlighting the difference between the autonomous and the conventional vessel. The complete re-design of the hull allows the X-barge to have a modular design and to switch to an electric powertrain. Besides, the lack of crew quarters increases the cargo capacity by 10 TEU.

Table 16: Comparison overview project and reference scenario

	Reference scenario	Project scenario
Fuel type	Diesel	Battery electric
Fuel consumption	145.48 l/hour	300 kWh
Cargo capacity	80 TEU	90 TEU
Operational hours (annual)	4,608	6,912
Length of average trip (in km)	138	138
Duration of average trip (hours)	12.5	12.5
Cargo capacity utilisation	100%	100%
Mooring	Manually	Autonomously

5.2. IWW CASE: IDENTIFICATION OF COSTS & BENEFITS

An overview of the economic and financial effects considered is detailed in the following. For each effect, the expected change with respect to the reference case will be shortly discussed.

5.2.1 Financial Effects

This section lists the financial effects as a result of implementation of the project. As described in the methodology, for the financial analysis the CBA adopts an FDR equal to 4.0% (as prescribed by the Guide to Cost-Benefit Analysis of Investment Projects).

(1) **Investment costs**: capital costs are all the fixed assets (e.g. vessel, equipment, etc.) and non-fixed assets related to the execution of the project. The Implementation of the IWW use case will lead to changed investment costs as opposed to the reference case. However, with a newbuild cost of ca. some million Euro, **the overall balance between increased and decreased cost components has been considered close to zero and thus negligeable**. Therefore, it is assumed that there are no incremental investment costs with respect to the reference scenario. The affected investment costs at component level are described below:

- ↓ **Hull structure (-):** removal of the deckhouse plus removal of seafarers accommodation. The actual cost reduction is dependent on the ship size and the design due to the reduction in steel costs.

- ↑ **Main and Auxiliary engine (+)**; The actual costs increase is dependent on the engine room/power and the use of energy storage devices. Besides, increased investment costs are due to the necessity to use more reliable equipment/system for added redundancy.
- ↑ **Certification costs (+)**: the certification costs are dependent on the type of vessel. Therefore, he certification of new systems and equipment and the re-evaluation of the operation will lead to additional costs (at first). However, these costs will most likely reduce over time.
- ↑ **Electronics (+):** additional equipment (cameras, sensors, communication equipment) is needed for the autonomous operation compared to the reference scenario.

It must be noted that additional investment costs will be needed for auto-mooring and local sensors/equipment to be installed at locks and ports. However, since the shipowner will not incur these costs but the operator of the waterway/quay/lock instead, these costs are listed as economic effects.

(2) **Residual value of investments and replacement costs**: As described above for the SSS case, the useful life of the autonomous ship is equal to the reference period used in this CBA, so replacement costs for the autonomous ship are not included. There is also no residual value at the end of the reference period since the ship's economic lifetime is similar to the reference period.

(3) **Operation and maintenance (O&M) costs**: These costs can be divided into general operational costs and voyage-related operational costs. The latter are variable costs associated with a particular voyage and includes fuel cost, cargo handling and port call costs (Ziajka-Poznanska& Montewka, 2021).

The **general O&M costs** affected by the switch from a conventional ship to an autonomous ship are:

- ↓ **Crew wages (-):** crew wages will be reduced since less crew is needed for the operation of the autonomous ship. For a conventional ship, crew wages amount to € 216,000 per year. For the autonomous ship the crew wage costs are expected to be € 72,000 per year. This results in a yearly cost reduction of € 144,000.
- ↓ **Maintenance (ship)** (-): the maintenance costs for the fully electrical autonomous ship are expected to be lower than for a conventional ship (except for hull maintenance) and they are assumed to be 65% of the maintenance costs for a conventional ship. This results in a yearly maintenance cost reduction of € 5,000.
- ↓ **Remote Control Centre (RCC) (+):** in order to have the autonomous ship in operation, additional expenditures for using the service of a RCC will be incurred. These RCC expenditures are assumed to be € 35 per operational hour. Since the autonomous ship will be

in operation for 6,912 hours per year, an operational cost increase of € 241,920 per year is expected.

○ **Operational Insurance (+/-):** insurance costs for an autonomous ship are assumed to be equal to a conventional ship. Normally the insurance fees are calculated based on the investment costs. For this reason, insurance costs in the project scenario are set equal to the insurance costs in the reference scenario. However, increased safety as a result of the autonomous operation may result in decreased insurance costs in the future.

The **voyage related O&M costs** affected by the switch from a conventional ship to an autonomous ship are:

↓ **Fuel costs (-):** fuel costs will be null since the considered autonomous ship is designed as a fully electrical vessel. Assuming a diesel consumption of about 146 litre per (operational) hour and a diesel price of € 0.90 per litre for the (diesel powered) reference scenario, this leads to a reduction in fuel costs of € 500,797 per year.

↑ **Electricity costs (+):** electricity costs will increase since the autonomous ship is designed as a fully electrical autonomous ship. Assuming an electricity consumption of 375 kWh per (operational) hour and an electricity price of € 0.25 per kW for the project scenario, this leads to an increase in electricity costs of € 648,000 per year.

○ **Port/quay dues (+/-)**: incremental port and quay dues are assumed to be negligible. Although it is expected that these costs will increase for an autonomous ship, due to additional maintenance costs for quay owners.

Summing up, although several O&M costs will be reduced, the total O&M costs will increase because of the additional operational hours: **the total absolute value of the (incremental) O&M costs increase included in this CBA is € 5,762,941.** An overview of the absolute value and the PV (@4% discount rate) can be seen in Table 17.

Table 17: Incremental O&M costs

	Absolute value (sum over project lifetime)	**Present value (FDR = 4%)**
Crew wages	- € 3,456,000	-
Maintenance costs	- € 120,000	-
Remote Control Centre	€ 5,806,080	-
Fuel costs	- € 12,019,139	-
Electricity costs	€ 15,552,000	
Total O&M costs	€ 5,762,941	€ 3,661,140

	Absolute value (sum over project lifetime)	**Present value (FDR = 4%)**
Crew wages	- € 27,600,000	-
Maintenance costs	€ 3,565,000	-
Remote Control Centre	€ 3,335,000	-
Fuel costs	- € 1,380,000	-
Total O&M costs	**- € 22,080,000**	**- € 13,714,008**

(5) **Revenues and market gains**: revenues can be defined as the "*cash in-flows directly paid by users for the goods or services provided by the operation, such as charges borne directly by users for the use of infrastructure, sale or rent of land or buildings, or payments for services*".[28] Incremental revenues may come from increases in quantities sold, in the level of prices, or both. When comparing the autonomous ship to a conventional ship, the following effect on revenues is expected:

- As a result of the absence of on-board crew the ship **can be operational 24/7 compared to 16 hours per day.** It is assumed that the ship will be in operation for 6 days a week and 48 weeks per year. This results in a yearly **increase in operational hours from 4,608 to 6,912 operational hours (+ 2,304).**
- As a result of the new ship design without crew facilities, **the autonomous ship has a maximum cargo capacity of 90 TEU instead of 80 TEU** (conventional ship). Given the growth in cargo capacity as well as the increase in operational hours, an increase in the number of TEUs transported per year from 29,491 to 49,766 TEU is expected (+ 20,275 TEU).
- Revenues per TEU are assumed to be € 220.67.[29] Based on this number, it is assumed that an additional 20,275 TEUs transported (per year) will result in an **increase in annual revenues of € 4,474,128.**

The total absolute value of the (incremental) revenues included in this CBA is € 107,379,081 (absolute value excl. of VAT). An overview of the absolute value and the PV (@4% discount rate) of the incremental revenues can be seen in Table 18.

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[28] DG REGIO (2015). Guide to Cost-Benefit Analysis of Investment Projects.

[29] https://www.bureauvoorlichtingbinnenvaart.nl/vervoer/logistieke-keten/kosten/. This number is based on figures available for other routes (Rotterdam-Duisburg/ Rotterdam-Tilburg), converted to the length of the use case route and adjusted to the current price level.

Table 18: Incremental revenues

	Absolute value (sum over project lifetime)	Present value (FDR = 4%)
Revenues	€ 107,379,081	€ 68,216,871

5.2.2. Economic effects

This section lists the economic effects as a result of implementation of the project. As described in the methodology, the CBA uses an SDR equal to 3.0%, as prescribed by the Guide to Cost-Benefit Analysis of Investment Projects.

(1) **Investment costs incurred by third parties to be able to operate the autonomous ship.**

For the IWW use case, these are the costs for auto-mooring equipment and local sensors at quays and locks. These costs are considered to occur in the first year of the reference period and will be covered by the quay/lock owner/operator. They are assumed to be € 3,500,000 in total (this number is based on the route described for the use case, including 5 locks and 2 ports). An overview of the absolute value and the PV (@3% SDR) of these costs can be seen in Table 19.

Table 19: Investment costs incurred by third parties

	Absolute value (sum over project lifetime)	Present value (SDR = 3%)
Investment costs incurred by third parties	€ 3,500,000	€ 3,500,000

(2) **Externalities are defined in this CBA as impacts that fall upon uncompensated third parties – and thus not on the project or the direct users of the project services**.

Five types of externalities are identified and monetised for this project: 1) greenhouse gas emissions; 2) air pollution; 3) accidents; 4) noise, and 5) congestion. In addition, effects on safety, working conditions and unexpected disruptions are described in a qualitative way.

These effects are a **result of both the electrification of the ship (compared to the diesel ship in the reference scenario) as well as of the facilitated modal shift from road to inland waterways, which is achieved by increasing the number of operational hours and TEU capacity**. More in detail according to Table 20, the project scenario autonomous barge enables additional 20,275 TEU to be moved with respect to the reference case. It is assumed that the additional TEUs transported as a result of the increase in operational hours would be otherwise transported by trucks on their alternative route (ca. 98 km per trip) between the Antwerp and

Zeebrugge ports. With an average capacity of 2 TEUs per truck, this corresponds to 984,361 km/year on the road.

Table 20: Operational comparison between project and reference scenario

	Reference scenario	Project scenario
Capacity (TEUs)	80	90
Operational hours	4,608	6,912
Number of trips	369	553
Number of kilometres	51,069	76,603
TEUs transported	29,491	49,766

For the five types of externalities in the list above, the unit costs per vehicle-kilometre (vkm) are presented in Table 21 for a diesel-powered inland vessel, a battery-electric inland vessel and for road transportation by trucks[30] and are then adjusted to the 2021 price level.

Table 21: Unit costs per vehicle kilometre and modality

	Inland vessel (diesel)	Inland vessel (battery)	Road (HGV)
Climate change costs (vkm)	€ 4.21	€ 0	€ 0.07
Air pollution costs (vkm)	€ 0.02	€ 0	€ 0.10
Accident costs (vkm)	€ 0.95	€ 0.95	€ 0.17
Noise costs (vkm)	€ 0	€ 0	€ 0.07
Congestion costs (vkm)	€ 0	€ 0	€ 0.01

The monetization is calculated in two steps: step 1 concerns the initial demand, namely considers only the electrification of the autonomous barge with respect to the reference one, while step 2 considers the additional demand, namely that derived from the modal shift.

Step 1 - Electrification effect: the external costs are calculated assuming that the total initial demand is transported by the battery-electric autonomous ship instead of a conventional ship. The comparison and the corresponding external costs can be seen in Table 22.

Table 22: External costs of initial demand

	Inland vessel (diesel)	Inland vessel (battery)	Difference
Climate change costs	€ 214,753.44	€ 0	- € 214,753.44
Air pollution costs	€ 1,047.70	€ 0	- € 1,047.70

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[30] DG Move (2019). Handbook on the external costs of transport 2019.

	Inland vessel (diesel)	Inland vessel (battery)	Difference
Accident costs	€ 48,376.98	€ 48,376.98	€ 0
Noise costs	€ 0	€ 0	€ 0
Congestion costs	€ 0	€ 0	€ 0

Step 2 – Modal Shift and additional demand: For the additional demand (additional number of TEUs that can be transported by inland waterway transportation as a result of the increased number of operational hours) the external costs are calculated assuming that the total additional demand will be transported by the battery-electric autonomous ship instead of road transportation. The comparison between these two transports modes and the corresponding external costs can be seen in Table 23.

Table 23: External costs of additional demand

	Road transportation	Inland vessel (battery)	Difference
Climate change costs	€ 70,016.70	€ 0	- € 70,016.70
Air pollution costs	€ 101,351.34	€ 0	- € 101,351.34
Accident costs	€ 167,478.23	€ 24,188.49	- € 143,289.74
Noise costs	€ 70,232.81	€ 0	- € 70,232.81
Congestion costs	€ 5,402.52	€ 0	- € 5.402,52

Finally, the overview of the total external costs of externalities can be seen in Table 24. This shows **an overall external cost reduction of € 14,546,263 (absolute value excl. of VAT) for the total reference period of 25 years.**

Table 24: total external costs of externalities

	Absolute value (sum over project lifetime)	Present value (SDR = 3.0%)
Climate change costs	€ 6,834,484	€ 4,822,737
Air pollution costs	€ 2,457,577	€ 1,734,183
Accident costs	€ 3,438,954	€ 2,426,689
Noise costs	€ 1,685,587	€ 1,189,431
Congestion costs	€ 129,661	€ 91,495

(3) **Increased safety, better working conditions and resilience can be generated by an autonomous vessel. The reader can refer to Section 5.2.2 of this document. Like for the SSS case,** this effect cannot be quantified in this CBA.

5.3. IWW FINANCIAL ANALYSIS

The financial analysis is performed using a 25-year period and uses constant prices. This means that all calculations of costs and valuation of impacts are done in prices of the same year (i.e. the base year). Subsequently, only real price increases (above inflation) are taken into account. All external costs for this study are adjusted to the price level of 2021.[31] A 4.0 % discount rate in real terms is used in the financial calculations in line with the EU wide benchmark set by the European Commission. VAT is excluded from this analysis since this is recoverable.

Table 25: Return on investment

Return on investment	**NPV calculated at 4.0%**
Project investment cost	-
Replacement cost	-
Project O&M cost	- € 3,661,140
Total revenues	€ 68,216,871
Residual value of investment	-
FNPV(C)	**€ 64,555,731**
FRR(C)	-N.A.

The financial analysis gives a very positive result: the discounted incremental revenues are higher than the discounted incremental O&M costs, while investment costs are expected to be equal. This results in a positive FNPV(C) of € 64,555,731. Since there are no incremental investment costs, the FRR cannot be calculated. However, **the payback period for the investment costs will be shortened as a result of the autonomous operation and corresponding additional revenues**.

The main driver for the positive result is the increase in operational hours for the autonomous ship compared to the conventional ship. This results in a significant increase in the total number of TEUs transported per year. If this additional operational capacity will not be fully utilised, the positive financial result will decrease.

5.4. IWW ECONOMIC ANALYSIS

The economic analysis provides insight into the project’s contribution to the welfare of society. The main assumptions for this analysis overlap partly with the financial analysis, i.e. the reference period is also 25

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[31] The external costs have been adjusted to the price level in 2021. Since annual inflation rates for 2022 are not yet available, the 2021 price level has been used.

years (2023-2047). The social discount rate used for the economic analysis is set on 3.0%. Results are presented in Table 26, including:

- Economic Net Present Value (ENPV), which is the difference between the discounted total economic benefits and costs over the reference period.
- Economic Rate of Return (ERR), defining the rate that produces a zero value for the ENPV.
- B/C Ratio, i.e. the ratio between discounted economic benefits and costs.

Table 26: Economic analysis overview

	NPV calculated at 3.0%
Project investment cost	€ 0
Replacement cost	€ 0
Project O&M cost	- € 4,066,606
Residual value of investment	€ 0
Total economic costs	**- € 4,066,606**
Climate change costs (initial demand)	€ 3,636,966
Air pollution costs (initial demand)	€ 17,743
Investment costs third parties	€ 3,500,000
Climate change costs (additional demand)	€ 1,185,771
Air pollution costs (additional demand)	€ 1,716,440
Accident costs (additional demand)	€ 2,426,689
Noise costs (additional demand)	€ 1,189,431
Congestion costs (additional demand)	€ 91,495
Total economic benefits	**€ 6,764,535**
ENVP / Net benefits	**€ 2,697,929**
ERR	**9.2%**
B/C Ratio	**1.66**

In addition to the financial analysis, the economic analysis also gives a positive result; showing that the project has societal benefits that are substantially higher than the corresponding societal costs. The net benefits (ENPV) are estimated at € 2.697.929. The ERR is 9.2%. The B/C Ratio is 1.66. This means that the economic benefits of the project are more than 1.5 times higher as the economic costs of the project, showing the positive societal impact of the project.

5.5. IWW SENSITIVITY ANALYSIS

A full CBA includes a sensitivity analysis. The sensitivity analysis indicates the robustness of the proposed project to changes in underlying assumptions (Harris and Roach, 2018) and enables the identification of 'critical' variables of the project. The analysis is carried out by varying one variable at a time and determining the effect of that change on the NPV.[32] As a guiding criterion, the recommendation is to consider 'critical' to those variables for which a variation of 1% of the value adopted in the base case gives rise to a variation of more than 1% in the value of the NPV. The results of the sensitivity analysis can be seen in Table 27.

Table 27: Sensitivity analysis

	Variation of the FNPV due to a 1% variation	**Criticality judgement**	**Variation of the ENPV due to a 1% variation**	**Criticality judgement**
Project investment cost	-	-	-	-
Residual value of investment	-	-	-	-
Additional revenues	1.1%	Critical	-	-
Crew wages	0.0%	Not critical	0.9%	Critical
Maintenance costs	0.0%	Not critical	0.0%	Not critical
RCC costs	0.0%	Not critical	1.5%	Critical
Fuel costs	0.1%	Not critical	3.1%	Critical
Electricity costs	1.5%	Critical	4.1%	Critical
Climate change costs (initial demand)	-	-	1.3%	Critical
Air pollution costs (initial demand)	-	-	0.0%	Not critical
Investment costs third parties	-	-	1.3%	Critical
Climate change costs (additional demand)	-	-	0.4%	Not critical
Air pollution costs (additional demand)	-	-	0.6%	Not critical
Accident costs (additional demand)	-	-	0.9%	Not critical
Noise costs (additional demand)	-	-	0.4%	Not critical
Congestion costs (additional demand)	-	-	0.0%	Not critical

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[32] DG REGIO (2015). Guide to Cost-Benefit Analysis of Investment Projects

The results of the sensitivity analysis highlight several key variables that impact both the financial and economic analysis of the project. As one of the main benefits of the project is the increase in operational hours, it's not surprising that changes to the estimated additional revenue have a significant effect on the financial net present value (FNPV). However, it is important to pay attention to the assumptions made in calculating these additional revenues. The same holds true for the variables that are critical to the economic analysis, where assumptions were used to estimate the external costs. This highlights the importance of conducting a thorough market analysis, to determine if the additional operational capacity will be fully utilized, as this is closely related to other external effects such as reduced greenhouse gas emissions. On the other hand, for the critical variable related to investment costs incurred by third parties, it can be assumed that the equipment will be utilized by multiple autonomous ships in the future, meaning these costs only need to be incurred once instead of for each additional autonomous ship, resulting in lower investment costs per autonomous ship.

5.6. EVALUATION & CONCLUSION

The outcome of the CBA for the IWW use case shows that the project is favourable from both a financial as well as an economic perspective. However, for this specific use case, a switch from a conventional (diesel-powered) ship to an autonomous (battery-electric) ship shows significant benefits, which are substantial to keep positive economic benefits. As a summary:

5.6.1. Autonomous Operations:

- The results of the autonomous operations demonstrate a considerable boost in revenues compared to conventional operations. This increase is due to the rise in operational hours for the autonomous ship.
- Furthermore, diesel fuel costs will be substituted by electricity costs, leading to reduced operational costs per TEU transported.
- Although the Remote Control Center (RCC) service costs result in an increase in operational costs, it is believed that these costs can be lowered if more autonomous ships adopt these services.

5.6.2. Externalities Impact:

- By transitioning from a diesel-powered conventional ship to a battery-electric autonomous ship, air pollution and GHG emissions will decrease. However, the carbon footprint of electricity generation should not be overlooked, and here it is assumed that the grid will have a net-zero 2050 EU grid assumption with zero CO_2 contribution. This leads to a total economic benefit of €3,654,709 (NPV, SDR = 3.0%).
- Additionally, the increase in operational hours enables a shift from road to inland waterway transportation. If the total additional operational capacity is utilized as a replacement for road transportation, it will result in economic benefits of €6,609,825 (NPV, SDR = 3.0%).

The financial analysis results in a FNPV(C) of € 64,555,731. The FRR cannot be calculated since the investment costs for the autonomous ship are equal to a conventional ship.

This value is strongly dependent on the expected unit price [€/TEU]. For the sake of completeness, a variation of FNPV with respect to it is reported below.

Table 28: IWW case comparison between transport tariffs and calculated FNPV or the ship-owner

Price per TEU	FNPV (@FDR 4%)
20 €	2,520,566 €
50€	11,795,623 €
100€	27,252,384 €
150€	42,709,145 €
200€	58,165,907
221€	64,555,732

It is assumed that the investment costs for the auto mooring equipment and sensors along the inland waterway and at quays will be incurred by third parties. For these investments it is likely that there remains a funding gap since these third parties will do not fully recover these investment costs by additional port fees or other revenues. In the current situation, this can form a bottleneck for implementing autonomous shipping on a larger scale. Public funding for these investments could be a way to overcome this and accelerate the implementation of autonomous shipping.

The economic analysis results in an ENPV of € 2,697,929. The ERR is 9.2%. The positive ENPV underlines also from an economic perspective that the switch from a (diesel-powered) conventional ship to a (battery-electric) autonomous ship has significant benefits and that not only the ship owner benefits from the project, but also society. The B/C ratio of 1.66 indicates that the economic benefits of implementing the project are more than 1.5 times higher than corresponding economic costs.

The sensitivity analysis shows that there are multiple critical variables. Since this analysis is carried out for a specific use case with corresponding specific input, it is not expected that the values for these variables will change. However, it is important to verify if the assumptions used are reliable before implementing these types of projects since a small change in the input variables can significantly affect the results of both the financial and economic analysis.

6. CONCLUSION AND FURTHER CONSIDERATIONS

This work has completed the socio-economic analysis of AUTOSHIP's use-cases by applying an established CBA methodology. The key conclusions are:

- Both SSS and IWW cases and investments in autonomous technology are justified and have shown positive business cases, especially if merged with more sustainable ships designs, which in turn autonomy can foster and stimulate.
- However, it must be noted that further expenditures by third parties are needed to realise them, which could become a barrier to the adoption and development of the autonomous shipping, since there seems to be no direct benefits for the owners of the infrastructure who should invest (no significant new income). Specific business models along the value-chain and/or public support are thus needed to overcome this financial obstacle.
- On the other hand, a socio-economic payback exists that can back up such investments, in terms of climate change mitigation as well as higher safety and security, shifting traffic from road to water.
- It also appears evident that many variables can be critical to duly evaluate costs and benefits. The need of thorough market analyses to justify the additional revenues is acknowledged.
- A more extended CBA, including more steps of the value-chain and the societal effects of fleets of ships is advised as a next step.

The information acquired on the use-cases financial end economic perspectives, will be further used to extend the CBA and to deliver the project business plan.