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Research Article

CEDI-INDEX VALIDATION INCIRCULAR FISHING VESSEL DESIGN PROCESS

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A B S T R A C T

From the first economic crises (80's) to the upcoming climate agreementswithCO2 reduction targets, the Dutch fishery(research)has been working to address sustainability in the fishing vessel design process. For designing complex fishing vessels, the sustainability aspects go beyond substantial Green House Gas emission reductions (GHG). It started with a sustainable crew in sound safety and health environments (SHE, 90's),followed by integrating the People-, Planet and Profit sustainability aspects (Triple-P, Beamer 2000) and in 2015 the launching of a further sustainable pilot-fishing vessel (MDV-1, 30m). However, the shipping sector increasingly needs to adapt to societal-political changes complying with stricter CO2 emission reduction targets, anticipating the zero-carbon shipping by 2050 and emerging Circular Economy principles (CE).In a series of TU Delft PhD papers, the changing Dutch fishing vessel design processes have been described, from a multi-criteria design methodology via a sustainability-integrated design towards the development of Circular Economy Design Indexes (CEDI, part I, II and III)). With the CEDI design approach three crucial CE-factors are holistically combined (decarbonization, recycling, fish processing-automation), leading to a supportive pre-designtool. With which currently known and emerging green technologies can be applied and gradually ranked in a range of four technical sustainable MDV-1 redesign CE-concepts with, for the time being still too high ROI's. Through further integration of the triple-P aspects the ultimate CE-, triple-Z targets are gradually achieved (zero-emission, zero-waste, zero-accidents). In this 4th paper the usefulness of the CEDI-indexes have been validated, redesigning the linear-sustainableMDV-1in a circular-sustainableMDV-1-Circularconcept. Instead of CE-intentions, a pathway is given to anticipate and integrate the new CE-principles in an early design stage with sustainable, technical feasible design solutions.

INTRODUCTION

North Seafisheries in Dutch sustainability transition process

During three decades the Dutch fishing vessel owners and designers have been working to address three major socio-political changes, from traditional beam trawling to a more Safety & Health Environment (SHE), from SHE to Sustainable fishing vessels (triple-P) and today towards Circular Economy value chains (CE). The necessary (re)design modifications grew in magnitude and are respectively appliedin a beamer redesign approach (Beamer 2000), a disruptive new twinrig trawler design (MDV-1, 2015) to foreseeable, future-proof circular designs (CE-concepts). Ad-hoc vessel modifications usually came with unacceptably high transition costs. This severely hampered the ability of individual SME's to invest in mid-life upgrades, let alone in modern sustainable new builds. Under the umbrella of the MDV foundation, with private-public financing, the MDV pilot project started (2010) and a sustainable fishing vessel was launched (MDV-1, 2015). With this innovative MDV pilot vessel the first triple-P fishing vessel design aspects have been fully applied in the Netherlands. In this design process a positive fishery business model was leading, through 80 % energy-savings, a shorter-high quality flatfish cool chain (fish2dish) and selective fishing gears.

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CEDI index, application of climate-friendly technologies in circular fishing vessel design process

In order to remain flexible and adaptive to future political and societal-climate demands, the fishing vessel design process should become more transparent. Such a transparency must start in the conceptual design stage with identification of the design values and business models, rather than only restrictive detailing and quantification of technical performance indicators. Such a starting point facilitates foresight on future use and exploitation of fishing vessels in a more life-cycle approach, independent of political, business and sociotechnical changes on the short and longer term. Meeting the evolving circular economy principles, a helpful and transparent CE-design tool has been developed, the here so-called Circular Economy Design Indexes (CEDI, ref.). The proven Beamer-2000 safety-integrated concept and successful sustainability-integrated MDV-1 design process were excellent starting points.

MDV-1, North Sea flatfish twinrigger, linear-sustainable design, 2015-present

Circular Fishing Vessel Design principles and goals

CE-principles, CE-drivers and CE-design targets

As learned by the successful MDV approach, one must firstly define the ultimate Horizon 2050 targets in an innovative design trajectory (table 4). Originating from these goals a new pre-design can be drafted. For SME's, the most important focus is the financial aspects with realistic return of investments (ROI), but today also increasingly incorporating into account their Corporate Social Responsibilities (licence2fish). With a flexible CE-circular design, the SME's can foreseeablyanticipate new and near future climate-regulations. With eco-friendly materials, products and CE-value chains, a much longer lifetime and retaining value can be realized than today. When full use is made of bio-based materials and recyclable equipment, the SME's will get the most out of their new assets, intrinsic-sustainable fishing vessels in anearly never-ending lifecycle.

Table 1 Circular Economy principles, CE-drivers and CE-design targets

Circular Economy (CE) principles *made to be----->made again*	**CE-drivers 2018** *triple-P*	**CE-targets 2050** *triple-Z*
Energy saving	Planet	0 % CO2
Reducing waste	Profit	0 % waste
Happy people	People	0% accidents
Retaining value	End-of-life value	100 %recycling, re-use
Prolonging lifespan	lifetime	40 yrs.

CEDI index and circular MDV-1design drivers

With the new CEDI indexes the ship designers have a potential decision-supporttool to develop intrinsic-sustainable fishing vessels, anticipating the CE-design targets. With this index the new sustainability requirements can be integrated early in the design process and the degree of sustainability can be ranked with reference to the existing parent vessels (Beamer-2000, MDV-1; table 2). All the Planet & Profit & People aspects, with hard and vague requirement, can be feasibly integrated in four conceptual pre-designs, based on the evolving shift to circular economy value chains (remanufacturing, reconditioning and re-use) with CE-targets.

With the CEDI ranking a pre-design pathway is given to gradually identify and integrate the three CE- holistic design factors. The CEDI rating system has a scale from 1 – 5 towards zero-emission vessels (ZEV). For this, three climate-key design indicators have to be considered at the same time, namely green shipping installations (Planet), green recycling features (Profit) and well-being of the crew (People). These MDV-1 re-design aspects are the main CEDI determining factors:

- the post-2020 marine alternative fuels (technical design aspects (ß),
- the gradually increasing green recycling process (societal and economic design aspects (ɣ),
- a sound safety & health environment (crew design aspects (α).

As proof of the CEDI-concepts, the sustainability-integrated MDV-1 has finally been redesignedina circular economy-integratedMDV-1-Circular concept.

MDV-1 parent vessel towards MDV-1-Circular concept

With respect to the MDV-1 multi eco-design requirements, the launching& fishing practice of this sustainable fishing vessel (2015-2018) was very successfully (ref.). In 2016 the ship was awarded as the most innovative and sustainable Dutch Ship of the Year (KNVTS).The green MDV design goals have been fully realised (positive business model, 80 % CO2 emission reduction, crew comfort). Many MDV innovations have already been taken over by the EU fishery sector and 7 MDV-type new fishing vessels have been ordered.

Table 2 CE MDV-1eco-, climate friendly design drivers

CEDI indexes **MDV-1design drivers**	**CEDI, part I** **Planet**	**CEDI, part II** **Profit**	**CEDI, part III** **People**	**Ran king**
Beamer 2000 reference ship (Diesel-Direct, DD) LBT 30-40m/8-9 m/4-5 m PB 1500 kW/fossil fuel oils	Energy-saving	Cost ↓, Earnings↑	Kindunos accident solution matrices	1
MDV-1-5 twin riggers, diesel-electricparentvessel; 2015 (Diesel-Electric. DE) LBT 30-32 m/8-9 m/4m PB 400 kW /fossilfueloils	Eco-friendly	Positive business model (fish2dish) ROI = 8 yrs.	-fish processing amidships, -gear handling astern -mechanisation/autom. -high comfort level	2
MDV-5-10 twin riggers; post-2020 alternative fuels (LNG/dual-fuel gas engine, hybrid-electric, LNG/BIO-E) LBT 32-35 m/9-10 m/4m PB <400 kW /LNG, bio-fuels,	to-CO2-neutral	Positive business model ROI >20 yrs., depending on emerging fuel price difference	Further automation	3
MDV 10-20 twin riggers; hydrogen ICE engine/fuel cell, 2030(LH2-Cell) LBT 32-35 m/9 -10 m/4m PB <400 kW/hydrogen-cell	GHG-neutral	CE value chains (end-of-life value > 50 %.)	High automation standard fresh fish processing and storage on-board	4
MDV-Circular, twin rigger; all electric powered, 2050, AE) LBT 35 m/8-9 m/4m PB <400 kW /electric	Climate-neutral	Zero Emission,- Waste, Accident Vessel (ZEV)	Automated fresh fish processing and storage	5

As MDV-1 parent vessel and based on the experiences with the disruptive, new MDV-1 design process and the sustainable MDV-1 innovation pillars (IP, table 3), the next sustainability steps can be taken to comply with the CE-principles. To what extent and estimated costs, can the linear-designed MDV-1 be circular-redesigned with the emerging green technologies and can the new CEDI design indexes become a supportive pre-design tool for the fishery sector? So that, early in the decarbonization (re) design processes, cost-effective new technology choices can be made and the integration of the CE-principles become more transparent. However, to fully establish the CE-principles the whole fishery value chain should be taken into consideration (fish2dish), but from the ship design perspective and for the time being, the focus is here limited to the vessel-system boundary. With the MDV -1 as the successful sustainability-integrated parent vessel, which has already achieved the Dutch climate law target of 50 % (2030) and IMO shipping target of 50 % (2050).

with the 2020-sulphur cap for marine fuels and IMO Tier III engines. Advanced renewable fuels, such as bio- and synthetic fuels (ammonia, methanol, hydrogen) will become in 10-20 yrs. attractive low-zero emission solutions, followed by a fully electric future (ref.). The CEDI key approach is the rapidly accelerating shift in hybrid propulsion installations, renewable power demand and the degree of maturity of alternative fuel infrastructures and full electric, renewable energy installations. Therefore, at this stage, the focus is on the most environmentally friendly, effective gas engines and a DC-grid with battery pack for peak shaving. These choices and the MDV-1 diesel-electric, AC/DC power plantare the basis of the four CE- concepts with rapid progress in green fuel propulsion systems, already more or less proven in merchant shipping with class notations under way. In table 4 the decarbonization ranking is given with foreseeable main MDV-1 layout modifications.

Table 3 MDV-1 green designfeatures and main particulars

MDV-1Innovation pillars
Base for MDV-1CE-redesign drivers and circular economy features

IP hull form optimization
For the most efficient hull form and propeller/nozzle/aftbody combination, advanced modelling methods and tools (CAD, CFD) are being used and much emphasis is given to the North Sea performances (energy-saving, comfort). The propeller size is optimized for the best operational efficiency and thrust bearings. Additional hull resistance is gained by application of eco-friendly anti-fouling systems.

IP green energy-propulsion installations
Only green technology equipment are applied with optimal machinery and energy conversion, from an integrated system perspective and complying with IMO Tier III notation. AC/DC grid solutions and sophisticated management technologies are being integrated, such as power- and fuel management, sustainable climate systems (HVAC), waste-heat recovery and low energy led lighting (energy-saving).

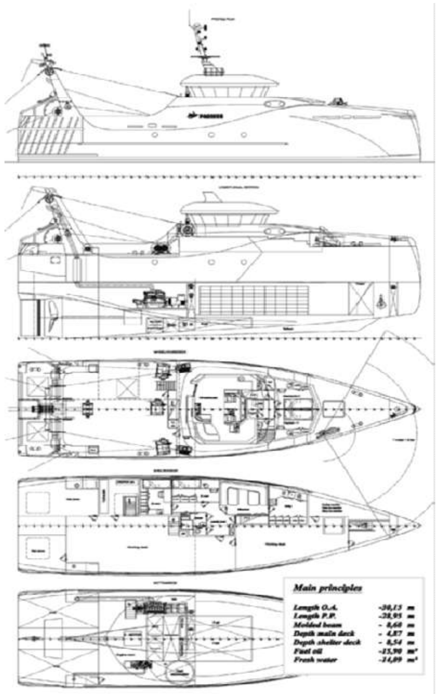
IP hybrid construction materials
Where class applicable, bio-degradable and/or green recycle materials are being used, to start with composite doors and hatches (recycling)

IP (semi-)automated fish processing
A high level of automation is applied, improving the working conditions, work-rest cycles and fish quality (comfort, profit)

IP selective gears
Selective fishing gears and netting are being used with respect to a substantial reduction of fishing impact and fuel consumption (eco-friendly, green deal)

MDV-1main particulars

Length o.a.	30.15 m
Beam o.a.	8.60 m
Draught	3.75 m
Depth to main deck	4.87 m
Depth to shelter deck	8.54 m
E-motor	1 x 400 kW
Generator	1 x 500 ekW
Harbour generator	1 x 117 ekW
Max speed	10.5 knots
Nozzled propeller	3 m



Crew	max. 8
Cabins	4
Fuel tanks	15.9 m³
Fuel consumption	6500 ltr./week fishing
Fishing boxes	850 (34 tons)

CEDI index, part I: degree of marine fuel decarbonization

In the last decade, the shift to marine alternative fuels has already been taken with many appealing pilot vessels. In the alternative marine fuel range, LNG is indicated as a low fossil transition fuel to replace the MDO/HFO diesel oils, complying

In this stage, the first estimated additional costs are also given, based on the MDV-1 building experiences and currentmarine decarbonization studies (ref.).

Table 4 CEDI-index, part I alternative fuel installations, from MDV-1 -->MDV-1-Circular concept

CEDI ranking Part I	**1**	**2**	**3**	**4**	**5**
MDV-1 re-designCE-concepts	Twin-rig beamer (OD 6)	Twin-rig sterntrawler (MDV-1 to 5)	Twin-rig sterntrawler (MDV-5 – 10)	Twinrig stern trawler (MDV 10- 20)	Twinrig stern trawler (MDV- Circular)
Level of marine fuel decarbonisation	benchmark Diesel-direct +gearbox	Diesel-electric / AC/DC motor, thrust bearings	Single/dual fuel LNG/BIO gas engines-hybrid electric.	Liquefied hydrogen-fuel cell-electric	Battery electrification + renewablejettyrecharging
	DD	DE	LNG/BIO-E	LH2-E	AE
Power	Dieselengine	E-motor	Gasengine	Fuel cell	Batteries
Fuel tanks	50 m3	25 m3	60 m3	80 m3	-
Layout/length	30-40 m	30-32 m	32-35 m	35 m	35 m
Fuel/100 hrs.	18.000 lts.	6500 - 7000 ltr	6000 – 6500 lltr	10.000 ltr.	-
ton CO2 per yr	2880	1040	825	-	-
CO2 reduction	-	63 %	70 %	100 %	100 %
Additional CE-Investments:	-		euro	euro	euro
-equipment			400.000	700.000	1.000.000
-storage, safety			500..000	600.000	700.000
-layout adapt.			200.000	300.000	400.000
Percentage		parent vessel	+ 25 %	+36 %	+ 47 %
Estimated new	6 – 8 Meuro	4.5 Meuro	5.6Meuro	6.1Meuro	6.6Meuro

The conventional DD design has a layout, that lacks flexibility for positioning the primary engine room components. The MDV-1 DE layout gives more flexibility in the layout and enables a better loading of the engines by advanced power management systems and use of batteries (LNG-DE hybrid; 100 eKW). It also opens up the possibility of reducing the size of the generator sets (500 eKW to 400 eKW) and further operational and comfort optimization, (peaks having, noise reduction and vessel trimming). An additional benefit for fishing vessels is, that batteries can decrease the fixed ballast. But for class safety- and control reasons, length and layout modifications are required (30 --> 35 m).The MDV-1 experiences demonstrated that with a PM e-propulsion motor the gear box can be reliably replaced by efficient thrust bearings. Then also, the propeller revs. Can besteplessly controlled with a higher propeller efficiency for the variable fishery load profiles. By installing a variable speed generator and DC-bus, the MDV-1 generator always run at very high efficiency with revs. ranging from 800 - 1200 rpm. Together with advanced power- and fuel management systems, the MDV-1 electrical installation has been optimized without too much redundancy. Because the energy-density for the LNG and Hydrogen liquid fuels is far lower than diesel fuels, the tank capacities must be considerably enlarged (50 %) and additional ventilation areas, alarm and fire protection are required, minimizing the flammability risks. Resulting in extra ship length and additional space for the cryogenic high pressure/low temperature tanks. With reference to the MDV-1 parent vessel and current LNG/BIO/LH2 pilot vessel, the estimated modification costs are ca. 20 – 50 %. From a fishery business model perspective, the payback period is at least 3 x higher than of MDV-1 (8 yrs.). It will become only economically viable if the capital costs can be substantially reduced through the current new technology developments, competitive fuel prices and new fuel infrastructures. For coastal/inshore fishing vessels, where on board energy demands are relatively low and bunkering is frequent, LNG and hydrogen can become feasible in the short term. A possibly cheaper alternative is methanol, due to availability, lower production costs and no need for cryogenic tank storage.

On the long term, fully battery electrification with renewable port-side recharging systems can become a feasible zero-carbon fishery alternative. However, this is strongly dependent on substantially reducing the high capital costs, increasing the life span and new green battery (recycling) technologies. With DC based electrical propulsion systems, a functional integration of batteries can effectively be achieved. Class rules are rapidly evolving because of political energy transition and the validation of new technologies on board pilot vessels.

CEDI index, part II: degree of ship recycling, re-use and disassembling

From a ship design perspective, the CE- design must be such that the construction materials and components can be re-used in a straightforward manner. Instead of linear 'made-to-be' vessels it must become circular 'made-again' through value creation (good end-of-life value, extended life-cycle). For the Dutch fishery SME's, a higher end-of-life value is a stimulating target, because for the existing beamers this value is next-to-nothing. Besides, the Dutch governmental ambition is to use 50 % less primary raw materials and being fully circular by 2050. The shipping industry is already working on a more profitable and safe ship recycling processes. Complying with IMO guidelines, the merchant marine is developing a green passport, containing details of all used materials in the ship construction. Such a green passport is delivered with the ship by the shipyard and must be updated with all the constructional changes made to the shipduring its lifetime, a so-called material register with environmental impact details. Recycling and modular designing (disassembling) are key design factors for the CEDI index, part II. In the4 CE-concepts innovative materials are increasingly applied, such as (multi) metallic and non-metallic, glass fiber reinforced plastics and bio-based materials. Then the life cycle performance of new build ships can be considerably increased and a substantial reduction of the environmental foot print will be achieved. In table 5, four gradually increasing recycling CE-concepts are given, from MDV-1 with composite doors& hatches towards a bio-degradable composite MDV-1 Circular concept.

Table 5 CEDI-index, part II recycling, re-use from MDV-1 -->MDV-1 Circular concept

CEDI ranking part II	**1 DD**	**2 DE**	**3 LNG/BIO-E**	**4 LH2-CELL**	**5 AE**
MDV-1 re-design CE-concepts	Twin-rig beamer (OD 6)	Twin-rig sterntrawler (MDV-1 to 5)	Twin-rig sterntrawler (MDV-5 – 10)	Twinrig stern trawler (MDV 10- 20)	Twinrig stern trawler (MDV- Circular)
Level of recycling	Benchmark	SUSTAINABLE design with hybrid construction components	MODULAR design & composite wheelhouse	MODULARdesign with biodegradable construction materials	MODULAR& fully recyclable materials
Recycling, re-use	10 %	30 %	50 %	80 %	100 %
End-of -life value	10 % new value	30%	40 %	50 %	60 %
-Additional costs	-	-	80.000	500.000	1000.000 euro
-Percentage		parent vessel	+ 1.5 %	+ 11 %	+ 22%
Estimated inv.	6- 8 Meuro	4.5 Meuro	4.55 Meuro	5 Meuro	5.5 Meuro

In the MDV-1 building process it was apparent that the current Dutch maritime rules and building regulations (IL&T) do not yet consider the use of innovative materials, such as the intended module for a composite wheelhouse on steel hulls. It appeared to be much too time consuming to start a case-proof study regarding equivalent safety aspects with conventional steel solutions(ref.). Instead, the MDV-1 shipyards designed a much lighter steel hull construction and integration of some composite doors and hatches. In the shipping sector, the commercial application of lightweight and maintenance free biodegradable construction materials are still lagging behind the potential. With CEDI part II, insight is given into the recycling, re-use solutions, gradually achieving the CE-target. With such an approach, the near-future shortages of raw materials can be anticipated and discussed in the pre-design process. The CEDI-part II approach is more a matter of mind set than application of revolutionary design technologies. In the marine sector there are already many good examples (ref.) With the MDV-1 case-study a greater recycling awareness and understanding is achieved from the designer/SME perspective. The (partial) solutions will provide increased flexibility in design, reducing the ship weight, thus fuel demand and also lower maintenance costs. Pre-outfitting and pre-fabrication of larger modules can be foreseen, a win-win case for the SME and environmental, social and economic circular economy challenges.

CEDI index, part III: degree offish processing-automation

For decades and in case of the emerging CE-principles, the human factor is/remains a crucial factor on board fishing vessels. In the first place, a good crew is needed for hands-on fish processing and safe gear-handling and secondly, sound working conditions are required to keep experienced fishermen on board. Partly by the Kindunos approach (accident-, workload analysis with solutions, ref.) and ongoing focus on occupational accidents and working conditions, the Dutch fisheries are certainly aware of on board safety and well-being and the necessary technical measures, which could be taken with various (partial) design solutions (α design drivers).These (re)design requirements have been fully applied in the MDV-1 building specifications with additional fish processing-automation. In the CEDI-part III approach, the degree of automation has been increased in the circular fishing vessel design process with four appealingMDV-1 redesign CE-concepts. A fully autonomous fishing vessel is not out of the realm of possibility but absolutely not yet a main cost driver.

Although the current technological developments are rapidly accelerating, it will be a matter of decennia before a fully remotely controlled fishing platform will be operated safely and commercially viable. With the CEDI-approach the fish-processing automation modifications are given, gradually improving the sustainable working conditions with better work-rest cycles. The focus is only on layout modifications (fish processing amidships, additional automation, higher crew comfort), especially preventing labour-intensive and risky workplaces (fish processing, fish box storage). On board of the MDV-1 the SHE Beamer-2000 shortcomings and technical solutions have been fully integrated (table 6).

Table 6 SHE beamer shortcomings and MDV-1 (partial) solutions

SHE Beamer shortcomings	MDV-1 (partial) solutions
	
Falling and comfort	good sea performance, good noise and workable acceleration levels
Swaying nets, hit by lashing cables	gear handling astern, no fishing lines over deck
Shifting bulks/netting/objects	Retaining devices, deckcranes
Safe working conditions and workload	Mechanization of fish processing, clear deck layout and fish hold

To keep a good and happy crew on board while anticipating the CE-principles, further automation of fish processing is needed. In table 7 the technical possibilities and additional modifications have been given with a rating system from 1- 5 towards more sound SHE environment and next-to-nothing accidents on board.

In the innovative MDV-1 design, the human aspects are fully taken in consideration, preventing hazardous working conditions, higher crew comfort and a start has been made with further fish processing-automation (mechanical flatfish gutting, - sorting, -weighing/filling fish boxes).

Based on these experiences and crew recommendations, the CEDI, part III approach is focusing on the next levels of automation, improving the quality of the landed fish and work-rest cycle system to comply with new EU legislation.

Table 7 CEDI-index, part III fish processing-automation, from MDV-1 --->MDV 1-Circular concept

CEDI ranking part III	1 DD	2 DE	3 LNG/BIO-E	4 LH2-CELL	5 AE
MDV-1 redesign CE-concepts	Twin-rig beamer (OD 6)	Twin-rig sterntrawler (MDV-1 to 5)	Twin-rig sterntrawler (MDV-5 – 10)	Twinrig stern trawler (MDV 10- 20)	Twinrig stern trawler (MDV- Circular)
Level of automation Fishproces sing	Benchmark -fish process. forward -handsorting species -hoppers -transport conveyors -batch washing -pre-cooling	Idem 1) but -fish proc. amidships -mechanical flatfish fish gutting, -mechanical flatfish sorting -mechanical weighing and filling boxes	Idem 2) plus -stunning module -version 2.0 gutter and grader	Idem 3) plus gutter-grader andsemi-autonomous storage fish boxes	Autonomous fish processing and storage
SHE beamer solutions (table 6)	40 %	70 %	80 %	90 %	100 %
degree of automation	10 %	30 %	50 %	75 %	100 %
Investments	-		100.000	300.000	1.000.000
Percentage	-	parent vessel	2 %	6.5 %	22 %
Estimated new	6.5 M euro	4.5 M euro	4.6 M euro	5 M euro	5.5 Meuro

On-board the MDV-1, prototypes of flatfish gutting machines and weight/length graders have been installed and the version 2 modifications are underway. The ultimate CE-goals are nearly autonomous fish processing decks and fish hold-box handling. There are already good handling and storage systems on shore, albeit these systems aren't yet marine proven. Regarding the new build investments, the additional investments are 2 –22 % with realistic payback times (2 – 3 yrs.), once better landed fish prices are achieved due to better quality fish in the emerging CE-fishery value chain (fish2dish). As a result of sustainable working conditions are guaranteed for the crew and SME's, besides making use of the current mandatory interactive risk assessment web tools (OiRA tools). With such an on board tool, an appropriate risk assessment process/awareness takes place constantly, starting with the identification and evaluation of workplace risks and taking preventive actions with transparent monitoring and reporting.

DISCUSSION AND CONCLUSIONS

With the development and validation of the here-called CEDI-indexes, a design shift has been made to integrate the CE-principles and CE-goals in the early stages of fishing vessel design. Instead of the current CE-intentions, pre-design actions with potential sustainable solutions have been drafted, from a ship design and fishery SME perspective. Based on the Beamer-2000 and MDV-1 experiences, four further sustainable MDV-1 concepts are given, combining the three crucial CE-design factors at the same time (decarbonization, recycling, fish processing-automation). By ranking (semi) proven, rapidly emerging green technologies, the linear MDV-1 design process is evolving into a circular MDV-1 Circular concept. However, in this paper the focus is limited to the most crucial factor in the CE-fishery value chain (fish2dish), namely the catching and landing of good quality North Sea fish with a sustainable North Sea working platform. By using this design approach, more awareness and understanding is achieved of the circular economy SME cost drivers, derived fishing vessel re-design requirements and cost-effective application of currently known and/or rapidly emerging green technologies.

These have either already been proven in the merchant marine shipping or already been tested on board various pilot vessels. However, in international shipping (IMO) the goal is only a modest CO2 reduction of 50 %by 2050. Mainly approached with linear ship designs, based on single energy-performance algorithms, such as the EEDI-index (kg. CO2/nautical mile).In the circular economy approach, additional design aspects have to be considered at the same time. Instead of only making vessels sustainable through energy saving, design aspects addressing the degree of recycling and social sustainability must be equally taken in consideration. To comply with these CE-targets, a holistic design approach was developed with further integration of the ultimate triple-P aspects and the triple Z targets (zero emission, zero-waste, zero accidents). Gradually working on these targets, three design factors got key priority, the increasing level of decarbonization (Planet), increasing level of recycling (Profit) and substantially higher levels of automation (People). Especially for small to medium sized fishing vessels (24-40 m), the human and societal factors are crucial CE-design drivers and equally important to substantial energy saving and recycling for future positive business models. With the CEDI approach and four MDV-1 redesign CE concepts, insight is given into the potential sustainable solutions and the fishing vessel CE-design process. For the time being, the application of new technologies for post-2020 marine alternative fuels are still dependent on economic viability and availability (fuel price differences, infrastructures). The recycling possibilities are more a matter of modular designing and application of sustainable materials, so that the vessel can be easily disassembled and individual components can be effectively repaired, re-used or re-purposed. Regarding preventing occupational accidents and sustainable working conditions, this can be achieved by application of the current EU/IMO/ILO and FAO directives and by cost-efficiently increasing of the level of on board automation. Although the fisheries safety and health awareness is high, severe incidences are still occurring (ref.). With the CEDI-index validation tool and through fishery discussions it can be demonstrated that ship designers and SME's will get a supportive pre-design tool. The chosen MDV-1 design process and applied innovation pillars have already proven their practical potential with realistic return of investment (8 yrs.).

But for the next sustainability steps the capital costs and life span of the new green technologies must be improved substantially. Because of the current rapid developments and pilot vessels, the here chosen technologies can be easily replaced by alternatives as long as the ultimate CE-requirements are kept in mind. The CEDI-case study is aiming to change the fishing vessel design process in a circular economy direction rather than giving a blueprint for the application of certain green technologies. As in the MDV-1 design and building process, it is recommended that a multidisciplinary team takes charge of the renewal process. Such a team appeared to be one of the main MDV success factors, having good knowledge of the fishing sector, North Sea operational profiles and commercially viable business models. The Dutch circular economy awareness is starting and the first CEDI pre-design discussions are already taking place in pre-designing a 24 m intrinsic-sustainable, Wadden Sea-shrimp trawler. With this new design the stricter regulations in the World Heritage area can be anticipated, resulting in the first climate-friendly Dutch fishing vessel with of course sound safety and sustainable working conditions.

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