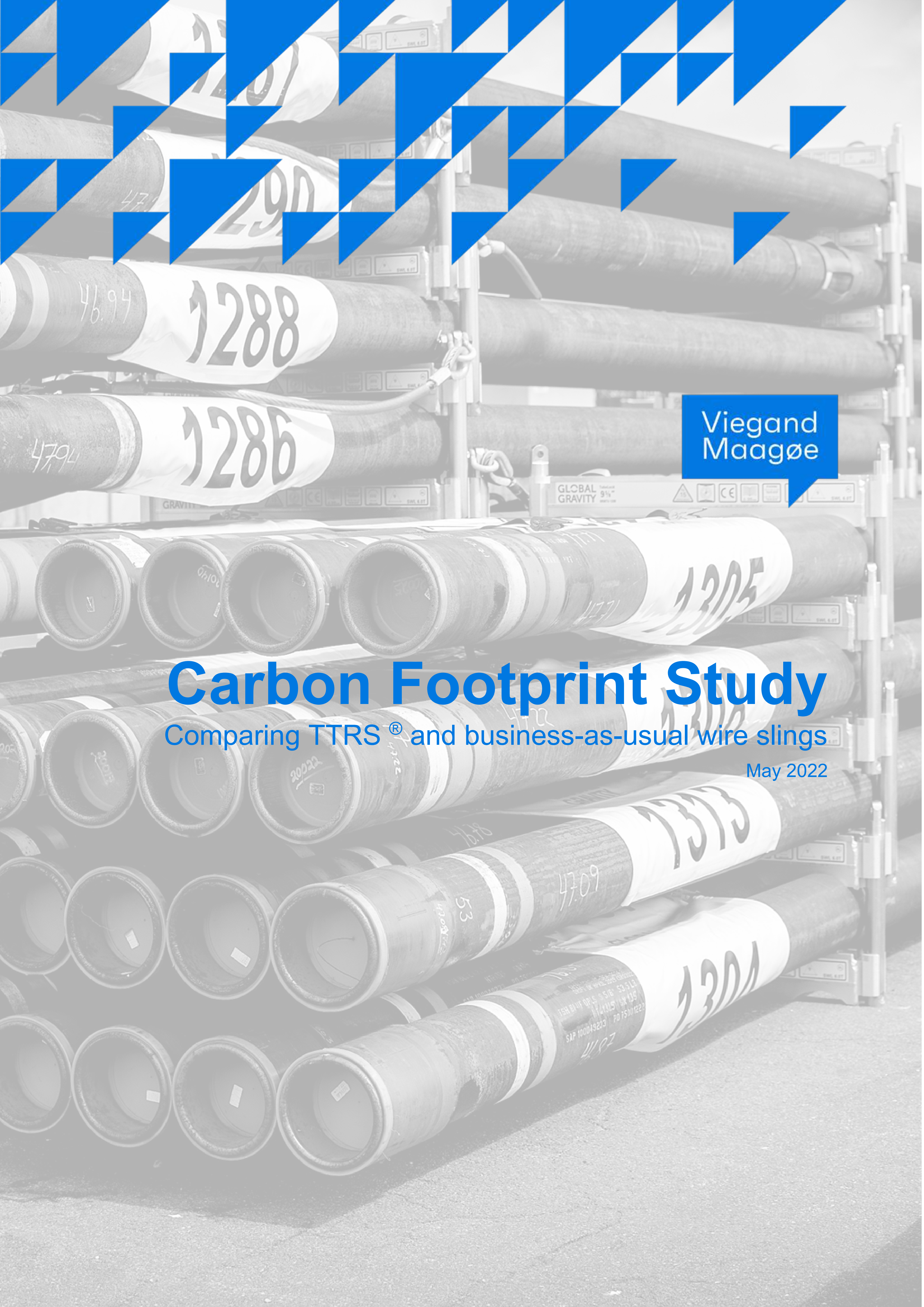

Viegand Maagøe

Carbon Footprint Study

Comparing TTRS ® and business-as-usual wire slings

May 2022

Report: Carbon Footprint Study - Comparing TTRS ® and business-as-usual wire slings

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Content

1 Abbreviations

AoP	Area of Protection
CFP	Carbon footprint of a product
CO_2eq	Carbon dioxide equivalents
EoL	End-of-Life
FU	Functional Unit
GHG	Greenhouse gas
GWP	Global warming potential
IPCC	Intergovernmental Panel on Climate Change
LCA	Life cycle assessment
LCI	Life cycle inventory analysis
LCIA	Life cycle impact assessment
TTRS	Tubular Transport Running System

2 Introduction

Global Gravity is a Danish company that develops and manufactures the Tubular Transport Running System (TTRS) for transportation of tubes and pipes for the offshore oil and gas industry. The company has commissioned this carbon footprint study with the purpose of investigating the climate change impacts for TTRS when comparing to a business-as-usual case using wire-slings for the same purpose. Those wire slings are manufactured and sold by many different companies; thus, a specific model has not been selected for this study. The assessment focuses on a full life cycle perspective from cradle to grave, which includes the extraction of materials, production of the two compared products, transportation along the value chain, the use phase, and final disposal of the products. For the sake of transparency, this carbon footprint study focusses on a particular case, with the client Total and their rig in the North Sea, which is connected via Port of Esbjerg.

Figure 1: Pictures of Global Gravity's Tubular Transport Running System (TTRS) loaded with pipes on a truck and being transported with crane using wire slings unto an oil rig.

Figure 2: Business-as-usual wire sling system[1]. Sometimes also referred to as "bundling" [2]

The TTRS analysis is based on data from Global Gravity's production site, supply chain, and logistics. The baseline case is based on data for generic slings, and database values are used for production processes. Background processes from the LCA-database EcoInvent v3.8 are used to quantify the greenhouse gas emissions and the life cycle impact assessment method IPCC 2021 GWP 100a is used to translate the emissions into possible environmental impacts. To define the use cases, interviews with customers and other relevant stakeholders have been performed by the commissioner of the study.

[1] http://www.hsewebsite.com/rigging-methods-of-slinging-hitches/
[2] http://www.dropsonline.org/downloads/26-02-15/DROPS%20Backload%20Booklet%202%20Feb%202015_hi-res.pdf

3 Methodology and Report Structure

3.1 Report Structure

The report structure follows ISO 14067:2018 “Carbon footprint of products” and the four phases of a Life Cycle Assessment: Goal and scope, inventory analysis, impact assessment, and interpretation, which include the following:

- **Chapter 4: Goal and Scope Definition** defines the overall purpose of the analysis; the functional unit, process flows and system boundaries
- **Chapter 5: Inventory Analysis** involves data collection and specification of all involved processes and the inputs and outputs for each of these processes
- **Chapter 6: Impact Assessment**, where the environmental impacts related to all processes are calculated using database emission factors
- **Chapter 7: Interpretation** of the results is provided including a discussion of sensitivity of the results

Finally, a conclusion to the analysis is provided.

3.2 LCA Methodology

LCA (life cycle assessment) is a strict methodology used to calculate a broad range of possible environmental impacts over the investigated product or system’s entire life cycle, i.e., extraction of raw materials, processing of these (sometimes over multiple steps) into the desired product, use of the product, and finally disposal of the product including possible recycling of materials.
The overall purpose of conducting LCAs is to ensure that humanity can continue to thrive on Earth. For this, the LCA methodology identifies three Areas of Protection (AoP): human health (sick or dead humans do not thrive), planetary ecosystems (which humanity rely on for survival and well-being), and resources (needed for food, health, energy, gadgets, convenience, leisure, etc.). These AoP are rather abstract and complex to quantify and measure, so various “midpoint” impact categories have become the reporting standard. They address a broad range of environmental concerns of which climate change (also called global warming or carbon footprint) is the most well-known – other areas of environmental concern include:

- acid rain damaging on land-based ecosystems,
- depletion of ozone in the upper atmosphere causing a so-called hole in the ozone layer, which allow ultraviolet radiation to reach the Earth’s surface. This causes skin cancer among other effects,
- microscopic particles known as smog in cities causing respiratory problems,
- toxic chemicals released to rivers, seas, air, or soil causing damage to nature and to human health,
- eutrophication in water bodies causing algae to bloom depleting the water of oxygen, which in causes fish to die due to lack of oxygen,
- biodiversity loss and land use change from human activity clearing or disrupting natural ecosystems displacing animals, plants, and other species which shifts the ecosystem balances and species might get extinct because their habitat was destroyed,
- depletion of water reserves or degradation of water quality if used up faster than they refill or regenerate (the same goes for biotic resources, e.g., overfishing or soil exhaustion).

The point of assessing so many different environmental concerns in full LCAs is to avoid or at least be aware of what is called burden-shifting. So, we might be able to reduce carbon emissions of a given product, but we need to outweigh the other environmental issues that might lead to. E.g., electrical vehicles emit less CO_2 and particles compared to fossil vehicles. However, the need for mining of cobalt and disposal of lithium might - in some cases - lead to environmental issues measured in other midpoint categories. It is important to keep in mind, that this study report only quantifies climate change though the measure of CO_2-equivalent emissions. As a result, this study cannot take potential burden shifting into account.

3.3 Carbon Footprint

Many greenhouse gasses (GHG) have a damaging impact on our climate, by increasing the radioactive forces, hence accelerating the rising global temperatures.
Carbon dioxide is the most notable, as it is the one, we emit the biggest volume of. However, the chemical structure other GHGs make them contribute negatively to global warming in a higher degree than CO_2. Each GHG has different potency (its global warming potential, GWP, a measure of how much energy the gas absorbs), lifetime in the atmosphere (typically measured in years), and concentration (typically measured in ppm, parts pr million, of molecules) in the atmosphere. Based on the GWP, all greenhouse gasses are converted into carbon dioxide, to be able to sum and compare them. This converted unit is called CO_2-equivalent or CO_2eq.
Table 1 shows a list of some GHGs and their respective GWP measured in CO_2eq over a time horizon of 100 years. The list if from IPCC, which is the impact assessment methodology applied in this study.

Table 1: Overview of the most abundant GHGs and their GWP in relation to CO_2. [3]

Gas	kg CO_2eq / kg
CO_2	1
CH_4	28
N_2O	265
CFC-11	4,660
CFC-12	10,200
HFC-134a	1,300

[3] https://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf

4 Goal and Scope Definition

4.1 Goal of the CFP Study

The intended application for this study is for Global Gravity to declare the partial CFP of their TTRS product compared with a business-as-usual baseline. The results of the comparison will mainly be used for marketing purposes. The CFPs of the products can furthermore be applied in TTRS users' climate accountings.

The reason for the study to be conducted is due to the assumption that TTRS causes less climate change impacts compared to the baseline. This hypothesis must be assessed before it can be communicated.

The intended audience for the report is Global Gravity's existing and potential clients.

The intended communication of the CFP information includes marketing on website, in slide decks, pamphlets and other relevant marketing channels. This report will be publicly available on Global Gravity's website. In accordance with the ISO 14026, Global Gravity will refer to this report when using information from this CFP study. However, the report has not been reviewed and verified by an independent third party, so it is not in accordance with ISO 14040 on this matter (LCAs to be made public available must be verified before publishing). The study does however follow ISO 14067, which does not dictate a reviewing process.

4.2 Scope of the CFP Study

The system under study includes the raw materials extraction and manufacturing of the two pipe joint transportation alternatives. The use phase includes logistics in harbour, such as fork lifting, crane lifting onto supply vessels and crane offloading onto the oil rig. The end-of-life assumes recycling of all metals, which will be credited for. The system is limited to the client case from Total operating in Port of Esbjerg. In the specific case 1.004 pipe joints for a new well are transported.

4.2.1 Functional Unit of the Investigated System

The functional unit (FU) for the system under study is defined as:

"Safely and securely transport, lift, and offload a total of 1.004 pipe joints each 41 feet long (detailed in columns 1-5 of Table 2) from the Port of Esbjerg to Total's rig in the North Sea in the year 2022."

By "safely and securely" is meant that the pipe joints are at all times under full control, i.e., do not fall from their storage equipment or tumble in an uncontrolled fashion while being transported from one place to another. It is widespread practice to deliver too many joints to the oil rig and then later bring the unused back again.

Table 2: Overview of pipe joints transported, lifted, and offloaded for the functional unit. OD is outer diameter of the pipe in inches, PPF is the density in pounds per foot. All data provided by Global Gravity.

OD [inch]	PPF	Grade	Connection	Joints to rig	TTRS system-ID for joint type	Joints/ TTRS system	TTRS systems needed	Joints/ sling bundle	Slings needed
9,625	53,5	L80	TSH Blue DPLS	128	0958TU-1000-2-F	6	22	3	86
4,5	12,6	L80 1Cr	TSH Blue DPLS	231	0450TU-1200-4-I	24	10	11	42
13,375	68,0	N80Q	TSH ER	134	1338TU-1200-2-I	6	23	3	90
9,625	53,5	L80 1Cr	TSH W523	131	0958TU-1000-2-F	6	22	3	88
4,5	13,5	Q125	TSH W533 DPLS SCP	189	0450TU-1200-4-I	24	8	11	36
7	29,0	L80	TSH 523 DPLS	32	0700TU-1000-3-H	12	3	5	14
7	29,0	L80	TSH Blue DPLS	23	0700TU-1000-3-H	12	2	5	10
5,5	20,0	L80 1Cr	TSH Blue DPLS	4	0550TU-1200-3-F	18	1	9	2
7	29,0	L80 TW523	ACID DISOLVABLE	132	0700TU-1000-3-H	12	11	5	54

To fulfil the functional unit, the two systems – TTRS and slings – have the following reference flows:

- TTRS has various configurations to accommodate different joint sizes. The TTRS vary in the size of the arches (cut-outs) in the H-profiles (the bars securing the joints), the length and number of lifting pipes, and number of bolts and slings needed to fixate the joints. Table 2 column 6-8 detail which TTRS type fits which joint type, the joint capacity of each TTRS type, and the total number of TTRS needed for each joint type. Table 3 gives an overview of the components of each TTRS type and the total number needed of each TTRS type to fulfil the functional unit; this is the reference flow for TTRS.

Table 3: TTRS overview. Note that H-profiles vary in length (1000 or 1200, corresponding to 88 and 106cm) and in the size of the arches (cut-outs), and lifting pipes vary in length (F: 92cm, H: 104cm, I: 110cm). Data from Global Gravity.

System-ID	H-profiles	Lifting pipes	Bolts	Slings	Number needed
0958TU-1000-2-F	6	4	8	2	44
0450TU-1200-4-I	15	6	18	2	18
1338TU-1200-2-I	6	4	8	2	23
0700TU-1000-3-H	8	4	12	2	16
0550TU-1200-3-F	12	6	16	2	1

- Slings are metal wires which at each end are secured around a ferrule with one or more wire clamps. Just one type of wire and one type of clamp are considered in this study. Slings are wrapped around the pipe joints and the diameter of the joints determines how many joints can be carried at a time. Two slings are needed for stability and balance for each joint bundle, one at each end. Table 2 column 9-10 detail how many joints can be carried in one go, and how many slings are needed for each joint type. It is assumed, based on conversation with Global Gravity and Total, that slings are only used once and then discarded. In total **422 slings are needed** to fulfil the functional unit.

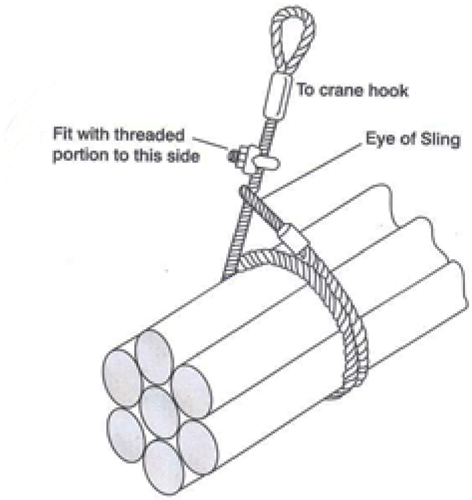


Figure 3: Figure of slings that shows the wire clamp.[4]

4.2.2 System Boundary

The CFP study includes all life cycle stages, however, with the neglection of packaging, galvanizing, and the manual labour work at the quay. The raw material extraction and the processing of those into

[4] http://liftechniques.com/typical_slinging_methods.html

materials include all related upstream transport, logistics and emissions to air. The system boundaries are visualised in Figure 4.

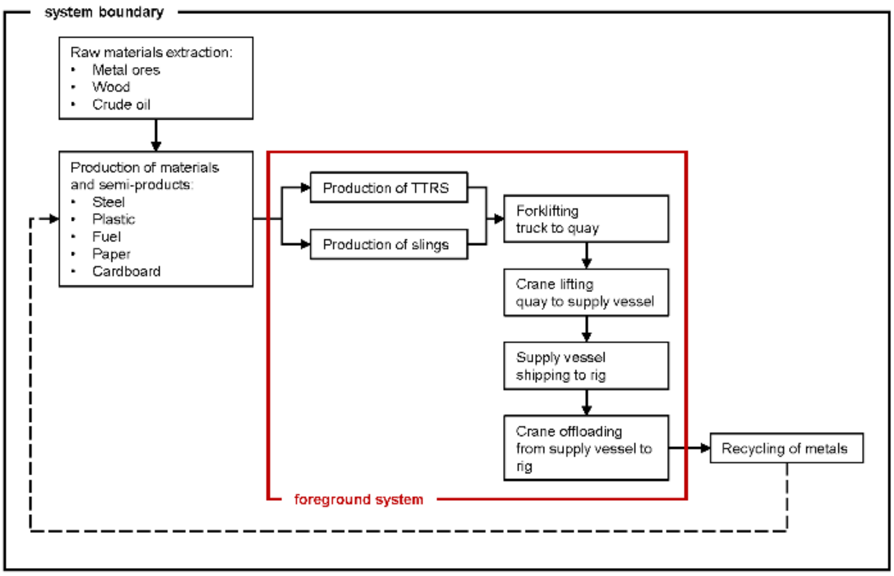


Figure 4: a systems overview of the system under study. It shows foreground systems, background, and the system boundary.

4.2.3 Data and Data Quality

Site-specific data is used where either the commissioner of the study (Global Gravity) or the end-user (Total) have control over the process. This entails, that specific measures are used for the production of TTRS. Specific time measures are conducted for the crane loading and forklifting of the pipe joints. However, the emission factors for the specific machineries are calculated mainly based on database values. Production of slings is based of assumed production processes and generic database emission factors for these processes and materials.

4.2.4 Time Boundary for Data

The results of this CFP study are a snapshot of the case-system under study in 2022. Thus, the report will not invalidate over time, as it refers to the circumstances from 2022. However, for marketing purposes of the results a 5-year validity is advised, given that no significant processes or materials change in the system under study during this time. This is because – despite the report referring to conditions from a specific case in 2022 – the results are nevertheless shown to conclude performances about the current portfolio of products.

4.2.5 Assumptions

4.2.5.1 Assumptions for use phase

- **Information on the user**

The user of the product in the given case is Total in Port of Esbjerg. The user (Total) has confirmed the measures to Global Gravity who has provided the data to the LCA-consultant (Viegand Maagøe) of this study. Estimates are made during the use phase where the product is in Total's custody. The data validity should be documented by the user and can be provided alongside with this report.

- **Use profile**

The use phase in the CFP study includes forklifting, crane lifting and supply vessel docking. Time measures from those operations have been counted and estimated for both scenarios.
The commissioner of the study (Global Gravity) expects these operations to potentially save the Port of Esbjerg or Total a whole forklift or crane unit. However, due to lack of documentation on this, the conductor of the study (VM) has decided to exclude this from the summed CFP results, but the calculations have been made and are supplied in the report in section 6.4 and 6.5.

- **Production and materials**
  - To account for smaller components in the wire slings (such as clamps and screws) additional 15% material has been added to the inventory analysis.
  - Steel is assumed low-alloyed in the inventory analysis for both scenarios.
  - Overhead, such as electricity and heating for administration is not included in either scenario.
  - Transport of goods is assumed to be the same for both scenarios and is therefore excluded.
  - For TTRS the service life is assumed at a minimum of 10 years lifetime and 13 use cycles a year. The TTRS has a 10-year guaranteed life span.
  - Materials that are not metals are not accounted for (handles, stickers, wood).
- **Service life and maintenance**

Global Gravity provides a 10-year warranty with their TTRS, but it is expected that service life is closer to 20 years. The products have not been on the market long enough to have data that document the longer service life; thus, this study has made a conservative assumption that the service life is equal the guaranteed lifetime of 10 years.

The TTRS undergoes inspection for maintenance on a yearly basis. However, since the products are made in steel beams, they are usually not repaired. If they are broken – they are genuinely broken, thus faulty TTRS's are sent to recycling without further repairment. <1% fail the annual inspection. For the CFP study 1% is assumed as losses annually.

For the baseline product, slings, it is assumed that slings are used only once, as per safety procedures in Total and Port of Esbjerg. From expert interviews it is estimated that normal service life is 3-4 uses. Due to the significant difference between the given case and an expected service life, a sensitivity analysis will be conducted on the service life for slings by extending the lifetime to 4 uses to see how it influences the result.

4.2.5.2 Assumptions for end-of-life

For all metal products, both slings and TTRS, metal recycling is assumed. No losses are expected – such as products being dumped at sea or going to incineration. The recycling process will be credited for in the impact assessment.

The 1% losses from TTRS that fail annual inspection is sent to recycling and will be credited for in the impact assessment.

4.2.6 Allocation Procedures

All multifunctional processes in this system are background data from the EcoInvent v. 3.8 database. Values have been extracted in a consequential methodology, meaning that system expansion has been made to account for the multifunctional processes.

System expansion has also been made for the end-of-life treatment of metal. Recycling processes have been used in the system, and the substitution of virgin metals has been credited for in the modelled systems.

4.2.7 This CFP Study Related to ISO Standards

This report follows to some extend the ISO 14067:2018, however it does not comply with the requirement of reporting separately net fossil GHG emissions and removals, biogenic emissions and removals, emissions, and removals from direct land use change, and GHG emissions from air transportation.[5] Here, only the net fossil GHG emissions are reported.

No critical review of this report has been conducted, which is required in accordance with ISO14040 for comparative studies aimed at being disclosed to the public.

4.2.8 Limitations of the CFP Study

It is important to keep in mind, that this study report only quantifies climate change though the measure of CO_2eq emissions. As a result, this study cannot take potential burden shifting into account. For other environmental impact examples and the definition of burden shifting see section 3.2.

[5] ISO14067:2018 section 7.2

5 Inventory Analysis

5.1 Material for Production

5.1.1 H-profile 1000 and H-profile 1200

H-profile 1000 is 88 cm long and used for 2 of the needed systems, and H-profile 1200 is 106 cm long and used for 3 of the needed systems. They both consist of various bigger and smaller parts, which are extruded, cut, milled, and otherwise processed in various ways, before finally being assembled. Figure 5 gives a schematic overview of the manufacture process. Note that transport between the different processing sites has not been included in the figure but is included in the calculations; 22.3 ton-km of transport by truck has been included in the calculations for each H-profile.

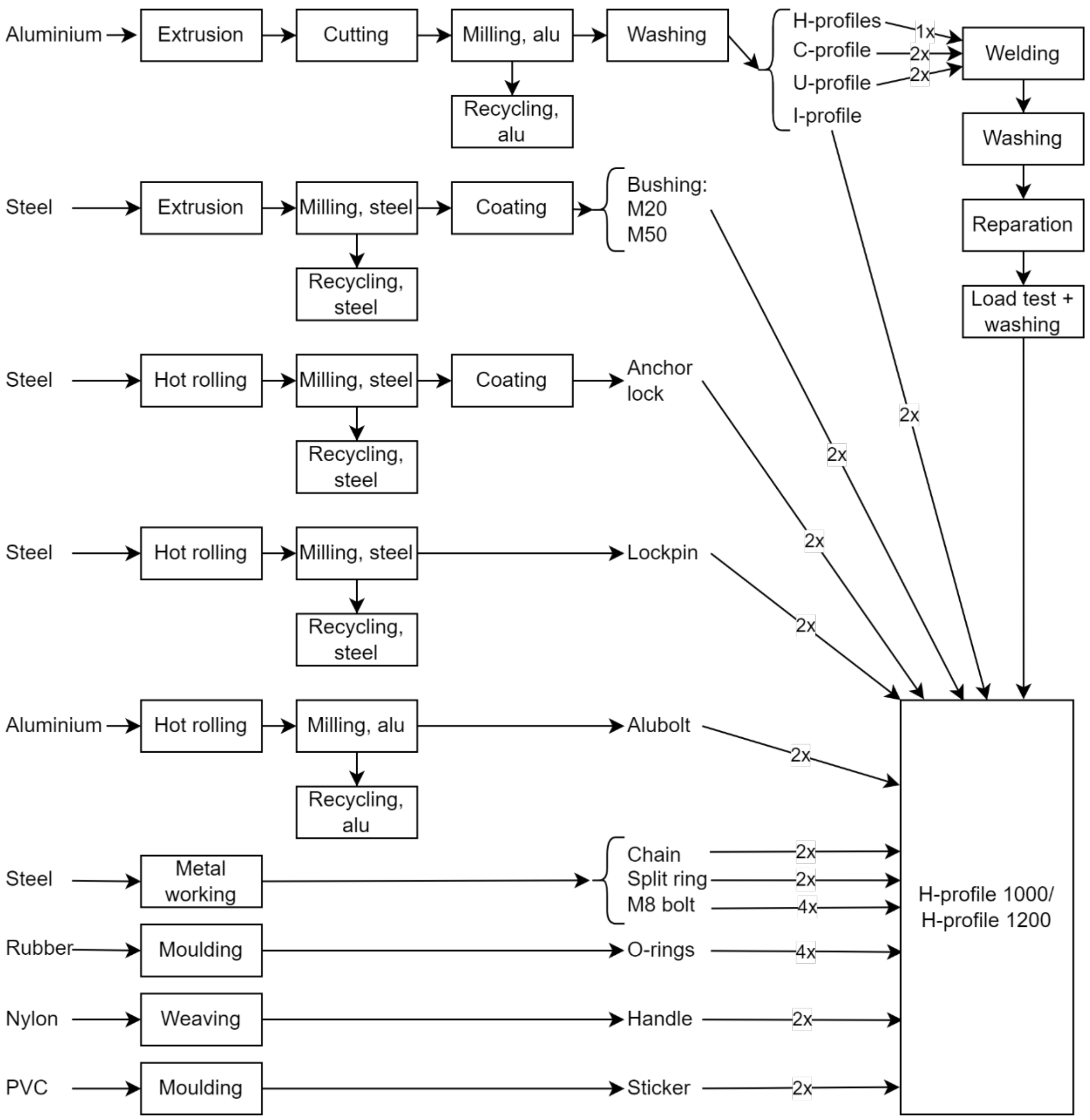


Figure 5: Overview of materials and processes used for manufacturing of H-profile 1000 and H-profile 1200 (the only difference is the amount of material for the sub-component H-profile). See the appendix for modelling details. Note: transport of components between processing sites is not included here.

5.1.2 Lifting pipes F, H, and I

Lifting pipe F is 92 cm long and used in 3 of the needed systems, lifting pipe H is 104 cm and used in 1 of needed systems, and I is 110 cm long and used in 2 of the needed systems. Besides the long pipe, they also consist of 5 smaller components. Figure 6 gives a schematic overview of the manufacture process. Note that transport between the different processing sites has not been included in the figure but is included in the calculations; 2.2 ton-km of transport by truck has been included in the calculations for each lifting pipe.

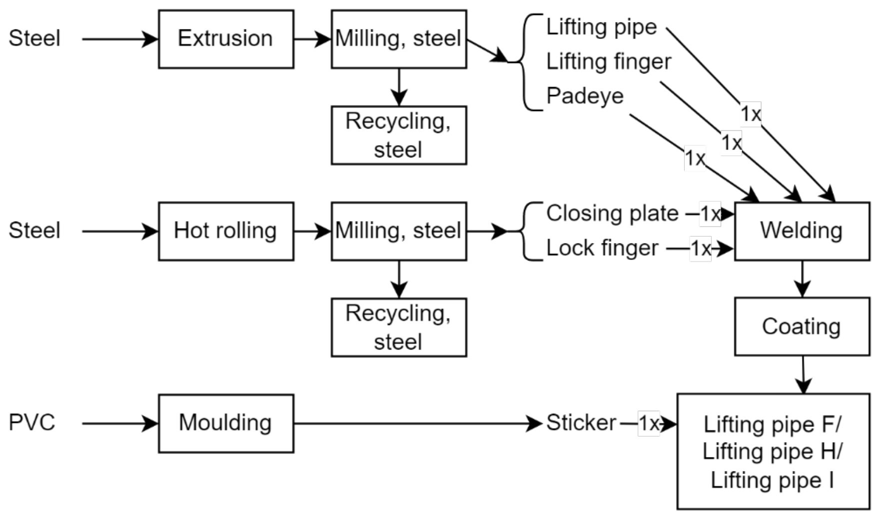


Figure 6: Materials and processes for manufacturing lifting pipes F, H, and I. The difference between the three types is the amount of steel used for the lifting pipe subcomponent. See the appendix for modelling details. NOTE transport of components between processing sites is not included here.

5.1.3 Slings and Bolts

Each TTRS consists of 2 slings and a varying number of bolts besides the H-profiles and lifting tubes. See Figure 7 for details on how these have been modelled. Transport by truck has been included in the calculations: 0.95 ton-km for each sling and 0.24 ton-km for each bolt (but not shown in the figure).

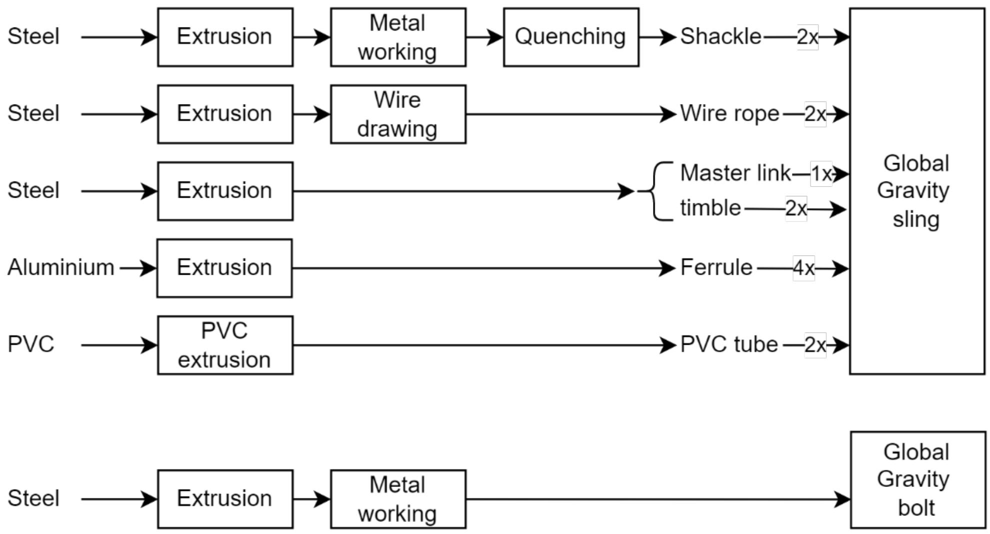


Figure 7: Materials and processes used for manufacturing slings used for TTRS (upper flow chart) and for bolts used for TTRS (lower part). See the appendix for modelling details. NOTE transport of components between processing sites is not included here.

5.1.4 Wire Slings of the Baseline System

Data for the baseline system has been provided by Global Gravity even though they do not manufacture the wire slings. Hence, a lot of assumptions have been made in regard to materials, manufacturing processes, and transport mode and distances, which means that the data quality for this system is not as good as for the systems concerning Global Gravity's own products. See Figure 8 for how it has been modelled. 32 ton-km of transport by truck is included for the system (not shown in the figure).

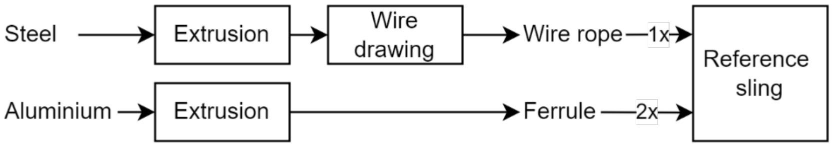


Figure 8: Materials and processes used to model each wire sling of the baseline case with which TTRS is compared. Note that clamps for securing the wire slings have been excluded due to lack of data. See the appendix for modelling details. NOTE transport of components between processing sites is not included in the figure.

5.2 Forklifting

Figure 9: an illustration of the Konecrane SMV 16-1200C[6]

Port of Esbjerg uses forklifts of the brand Konecranes model SMV 16-1200 C. From official data sheets of the machine, the motor is specified to have an engine power at 185 kW which corresponds to 248 mechanical hp. Timing on the operation time of two compared scenarios has been delivered by Global Gravity but made in collaboration with the Port of Esbjerg.

Table 4: Time measures of forklift operation. Data provided by Global Gravity

	Baseline scenario			TTRS scenario		
Operation description	**Low load time (m: ss)**	**High load time (m: ss)**	**Number of handlings**	**Low load time (m: ss)**	**High load time (m: ss)**	**Number of handlings**
Forklift trips for Packing/slinging	6:00	4:00	265	7:00	5:00	169
Forklift to storage TubeLock	4:00	6:00	265	5:00	5:00	130
Forklift to truck	0:00	4:00	265	0:00	4:00	130
Forklift Unloading truck to quay side storage	0:00	4:00	265	0:00	4:00	130
Forklift transport to quay side for loading to ship	0:00	0:00	265	0:00	4:00	130
Total	44.17 hours	79.50 hours		30.55 hours	50.92 hours	

Observations and measures on the time (in minutes) per forklift handling is provided by Global Gravity and Port of Esbjerg and are shown in the table below. However, between the two scenarios there is a significant difference in the number of handlings. These differ compared to the number of pipe joints that are handled.

[6] https://globalportequipment.com/product/konecranes-smv-16-1200-c/

5.3 Crane Lifting

Figure 10: Image of a Liebherr LHM 180[7]

To lift the cargo from dock to supply vessel the Port of Esbjerg uses cranes from Liebherr model LHM 180. This specific crane has an engine power of 400 kW. The total weight is 165 tonnes. Port of Esbjerg and Global Gravity have measured the operation time in standby and lifting, see Table 5.
A study that describes the different processes and best practices for these types of transportation in Best Practice Transport of Tubulars from Statoil (2010) has been used to further understand the stages the tubulars go through.

Table 5: Time measures from crane lifting on and off supply vessel. Data provided by Global Gravity

	Baseline scenario		TTRS scenario	
Operation description	**High load time (m: ss)**	**Number of handlings**	**High load time (m: ss)**	**Number of handlings**
Crane for wire handling	0:00	265	5:00	0
Crane lifts to ship	5:00	265	5:00	130
Crane unloading ship to rig-storage site	12:00	217	10:00	105
Crane lay out pipe on cantilevers deck	0:00	217	10:00	0
Crane Backload bundling	0:00	48	17:00	0
Crane backload bundling to storage	0:00	48	9:00	0
Crane backload bundling to ship	12:00	48	12:00	25
Total	75.08 hours		33.33 hours	

5.4 Supply Vessel Operation

As for the forklifts and cranes in the Port of Esbjerg, it is also assumed that TTRS will benefit the docking time of the supply vessel, when it is unloading the pipe joints to the rig.
The case client Total has estimated the time that a crane on the rig is offloading the supply vessel. While the crane is offloading, the supply vessel must have its engines running to stabilise its position while it is docked out at sea. The vessels that are used from Port of Esbjerg are Esvagt Heidi and Esvagt Leah.

[7] https://www.liebherr.com/en/int/products/maritime-cranes/port-equipment/mobile-harbour-crane/details/lhm180.html

Figure 11: (left) picture of Esvagt Heidi[8]. (right) Picture of Esvagt Leah[9]

They are both 84 metres (277 feet) in length. The typical deadweight can be between 1.000 tons and 6.500 tons, but the maximum is much higher. The deadweight is set to 4242 tons.
While the supply vessel is docked at the offshore rig, the engine is still running to keep the vessel in balance and to generate electricity. Meanwhile, a crane at the rig is offloading the cargo (pipes). Time savings in this process will eventually lead to less engine time for the vessel.
Measures of the rig crane efficiency are given below in Table 6.

Table 6: Time measures from when the supply vessel is docked at the rig. Data from Global Gravity.

	Baseline scenario		TTRS scenario	
Operation description	**High load time (m:ss)**	**Number of handlings**	**High load time (m:ss)**	**Number of handlings**
Crane unloading ship to rig-storage site	12:00	217	10:00	105
Crane lay out pipe on cantilevers deck	0:00	217	10:00	0
Crane Backload bundling	0:00	48	17:00	0
Crane backload bundling to storage	0:00	48	9:00	0
Crane backload bundling to ship	12:00	48	12:00	25
Total	53.0 hours		22.5 hours	

The time savings are 30.5 hours when using the TTRS.

5.5 End of Life recycling

Metals (steel and aluminium) are assumed to be recycled at end of service life and also processing cut offs (as indicated in the figures above). A recycling rate of 90% is used for both cases. The recycling credits the impacts avoided from production of virgin metals to these system and therefore results from recycling show up as "negative impacts".

[8] https://www.mynewsdesk.com/dk/esvagt/pressreleases/vi-har-faaet-to-fremragende-skibe-3153899
[9] https://www.vesselfinder.com/vessels/ESVAGT-LEAH-IMO-9613692-MMSI-219029726

6 Impact Assessment

The following chapter presents the climate impact of this CFP study. Emission factors for materials and processes have been extracted from the LCA-database EcoInvent v.3.8 (see the full list of datapoints in Appendix A). Using SimaPro v.9.3 software some of these datapoints have been adapted to the case, including changing the energy grid mix to a Danish average, removing overhead data from datasets or changing material input. The inventory of the LCA is calculated into CO_2eq with LCIA-method IPCC 2021 GWP100 as shown in Table 1 on page 6.

6.1 Materials for Production

Modelling results for carbon footprints for components and the considered full TTRS are shown in Table 7 and Table 8, respectively.

Table 7: Cradle-to-gate carbon footprints (CFP) for each Global Gravity component.

Component	Cradle-to-gate CFP [kg CO_2eq]
H-profile 1000	255
H-profile 1200	294
Lifting pipe F	47
Lifting pipe H	51
Lifting pipe I	53
Sling	83
Bolt	4.4

Table 8: Cradle-to-gate carbon footprint (CFP) for each of the TTRS needed to fulfil the functional unit.

System-ID	H-profiles	Lifting pipes	Bolts	Slings	CFP [ton CO_2eq]
0958TU-1000-2-F	6	4	8	2	1.9
0450TU-1200-4-I	15	6	18	2	5.0
1338TU-1200-2-I	6	4	8	2	2.2
0700TU-1000-3-H	8	4	12	2	2.5
0550TU-1200-3-F	12	6	16	2	4.0

The total CFP for producing all the TTRSs needed to fulfil the functional unit is 347 ton CO_2eq (see Table 3 for the needed number of each system). It is assumed that the lifetime of each TTRS is 10 years and that they are used 13 times each year, which means that only a 130th part of the CFP from production of the TTRS is ascribed to the functional unit in this study. This brings the production CFP for the functional unit down to 2,7 ton CO_2eq.

For wire slings in the baseline system the carbon footprint for producing 1 sling is shown in Table 9.

Table 9: Cradle-to-gate carbon footprint for producing 1 sling.

Component	Cradle-to-gate CFP [kg CO_2eq]
Wire sling	104

It is assumed that each sling is only used once before it is discarded due to safety procedures. This means that for the 422 slings needed to fulfil the functional unit the total production CFP is 44 ton CO_2eq.

6.2 Forklift Operation

In the EcoInvent 3.8 lifecycle inventory database, average emissions for diesel operated machines are provided measured on an emissions per hour basis. These are measured in a high load and low load operation states and provided for >=74.57 kW (100 hp) engines. The operation includes infrastructure, lubricating oil, fuel consumption, air emissions and waste.
Using the emission factors from above and the time measures from section 5.2, the CO_2eq-emissions from the operation can be calculated for the two scenarios.

Baseline scenario forklifting operation:

$$LowLoadHours\ x\ LowLoadEF + HighLoadHours\ x\ HighLoadEF = total\ emission$$

$$44.17\ \text{hours} \times 24.16\ {}^{\text{kg CO}_2\text{eq}}/_{\text{hour}} + 79.50\ \text{hours} \times 152.53\ {}^{\text{kg CO}_2\text{eq}}/_{\text{hour}} = 13{,}193\ \text{kg CO}_2\text{eq}$$

TTRS scenario forklifting operation:

$$30.55\ \text{hours} \times 24.16\ {}^{\text{kg CO}_2\text{eq}}/_{\text{hour}} + 50.92\ \text{hours} \times 152.53\ {}^{\text{kg CO}_2\text{eq}}/_{\text{hour}} = 8{,}505\ \text{kg CO}_2\text{eq}$$

The difference between the two scenarios is $4{,}688\ \text{kg CO}_2\text{eq}$ alone in the saved operation time of the forklifts when using TTRS.

6.3 Crane Operation

In the EcoInvent 3.8 lifecycle inventory database, average emissions for diesel operated machines are provided measured on an emissions-per-hour basis. These are measured in a high load and low load operation states and provided for >=74.57 kW (100 hp) engines. The operation includes infrastructure, lubricating oil, fuel consumption, air emissions and waste. It is assumed that the same or a similar crane is used at the rigs to unload the supply vessel.
Using the emission factors from above and the time measures from section 5.3, the CO_2eq-emissions from the crane operation can be calculated for the two scenarios.

Baseline scenario crane operation:

$$HighLoadHours\ x\ HighLoadEF = total\ emission$$

$$75.08\ \text{hours} \times 152.53\ {}^{\text{kg CO}_2\text{eq}}/_{\text{hour}} = 11{,}452\ \text{kg CO}_2\text{eq}$$

TTRS scenario crane operation:

$$33.33 \text{ hours } \times 152.53 \,{}^{\text{kg CO}_2\text{eq}}/_{\text{hour}} = 5.084 \text{ kg CO}_2\text{eq}$$

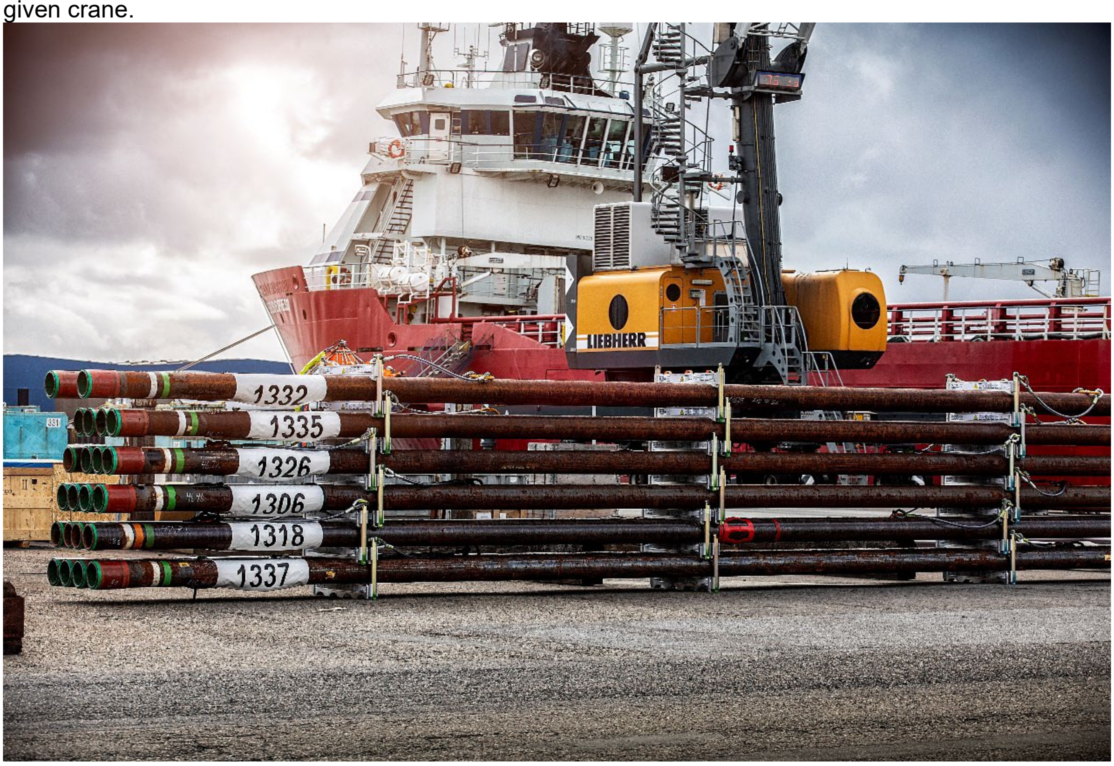
The difference between the two scenarios is $6{,}368 \text{ kg CO}_2\text{eq}$ alone in the saved operation time of the crane when using TTRS.

6.4 A Forklift

In some cases, the efficiency of using TTRS for pipe logistics could lead to a whole machine unit becoming redundant. If a port were to reduce their machine fleet by one forklift, this study wants to provide an estimate of the total CO_2eq-savings this could lead to, e.g., for use in climate accountings. Using the EcoInvent v. 3.8 database, emission factors are found for 1 average unit of mobile infrastructure that is made of 100% steel. The value is based on an average of building machines, which have a service life of 10.000 hours and a lifetime of 20 years. The cradle to gate emission for such machine is 51.4 tons of CO_2eq.

6.5 A Crane

Port of Esbjerg is using the crane Liebherr LHM 180 for the loading of cargo onto their supply vessels. The engine has an effect of 400 kW and the crane itself has a total weight of 165 tonnes. It is assumed that in some cases, the TubeLock system could potentially save the purchase of one whole crane. To put this into a climate perspective, we want to calculate the full CO_2eq-cost of the production of this given crane.



Data from the EcoInvent lifecycle inventory database 3.8 is used to find information on an average industrial heavy machine that is immobile with an estimated lifetime of 25 years. The infrastructure represents a rock crusher made with a lifetime of 25 years. The process includes input materials but excludes the energy for assembling on site. The total emissions for the production and transport (cradle to gate values) for a 160 tons crane is calculated to be 662 tons CO_2eq.

6.6 Supply Vessel Operation

The carbon emissions for this supply vessel docking process are calculated using the DESMO calculator[10] that has been developed by Danish Maritime Fund, the Technological University of Denmark (DTU) and the University of Southern Denmark.
The specific vessel is in the DESMO calculator called a bulk carrier and the specific data from the used vessel can be applied.

Emission factor for fuel is $\mathbf{3206}\ \frac{\mathrm{g\,CO_2eq}}{\mathrm{kg\,fuel}}$

The CO_2eq-emissions are, based on the specification of Esvagt Heidi and Esvagt Leah, given by:
$\mathbf{0.103}\,\frac{\boldsymbol{ton\,CO_2eq}}{\boldsymbol{hour}} \Rightarrow \mathbf{1.72}\ \frac{\boldsymbol{kg\,CO_2eq}}{\boldsymbol{min}}$

Different dead-weights and their relative CO_2eq-emissions are plotted below. The relation is assumed linear, despite the graph showing a minor variation as shown in Figure 12.

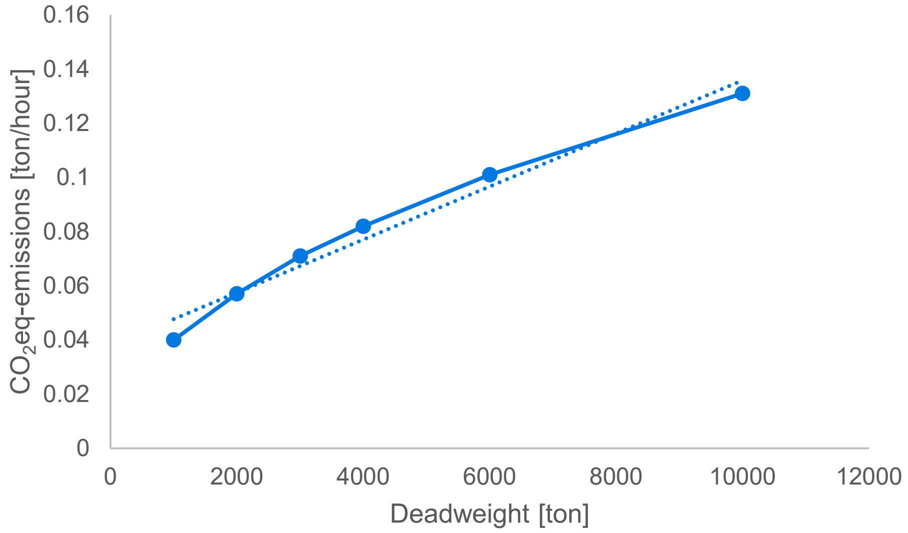


Figure 12: A graph showing the relation between deadweight of a supply vessel for the given specification and their relative emissions.

Assuming the linear correlation between deadweight and emissions per hour, then emissions are given by $0.00001\frac{\frac{ton\,CO_2}{hour}}{ton\,deadweight}$, which can be used for other cases.

For the baseline scenario 43,4 hours are spent on unloading the pipes from the vessel onto the rig and additional 9,6 hours on backloading the bundling systems back onto the vessel.

$$\mathbf{0.103}\frac{\boldsymbol{ton\,CO_2eq}}{\boldsymbol{h}} \cdot \mathbf{53.0}\ \boldsymbol{h} = \underline{\mathbf{5.46}\ \boldsymbol{ton\,CO_2eq}}$$

In the TTRS scenario, 17,5 hours are spent on unloading the pipes onto the rig and 5,0 hours on backloading the empty TTRS onto the vessel.

$$\mathbf{0.103}\frac{\boldsymbol{ton\,CO_2eq}}{\boldsymbol{h}} \cdot \mathbf{22.5}\ \boldsymbol{h} = \underline{\mathbf{2.32}\ \boldsymbol{ton\,CO_2eq}}$$

Thus, by using the TTRS, 30,5 hours operation time is saved, leading to less emissions from the supply vessel engine running in neutral. Using the results from above, the total savings are 3.14 tons CO_2eq.

[10] https://www.danishshipping.dk/en/policy/klimapolitik/beregningsvaerktoejer/

6.7 End of Life Recycling of Metals

It is assumed that 90% of the steel and the aluminium used in all metal components of both TTRS and the slings of the baseline system are recycled after ended service life. When the entire TTRS modelled here is recycled, it is credited 257 ton CO_2eq which corresponds to 1.97 ton CO_2eq per functional unit. For slings in the baseline system, the number is 22.7 ton CO_2eq per functional unit.

7 Interpretation

The climate impact calculations consist of 5 parameters that add up to the total life cycle results in this comparative CFP study. The 5 parameters are:

1. Material flow
2. Forklifting
3. Crane lifting
4. Supply vessel operation
5. EoL (recycling, credited in material flow)

For overview reasons of the results, recycling is shown as a separate parameter here, instead of incorporated into the material flow results.

A critical assumption for this study is the lifetime (times of use) for the slings in the baseline scenario. For security reasons, Total only use them once. However, according to expert interviews slings are often used up to 4 times in other cases. Because of this assumption, a sensitivity analysis has been conducted where the slings are reused 4 times.

7.1 Sum of Results

Figure 13 shows the overall results of the CFP study. The trends that are shown in the results are:

- Due to the reusable design of TTRS, there is relatively minor climate change impact in the material flow phase.
- Forklifting, crane lifting, and supply vessel operation has a relatively lower impact for TTRS compared to slings. This is due to more efficient processes and reduced number of lifts.
- For slings, material flow is relatively high. This is due to the end users' single-use safety protocol of wire slings. However, EoL crediting is also high due to the greater mass of metals for recycling.

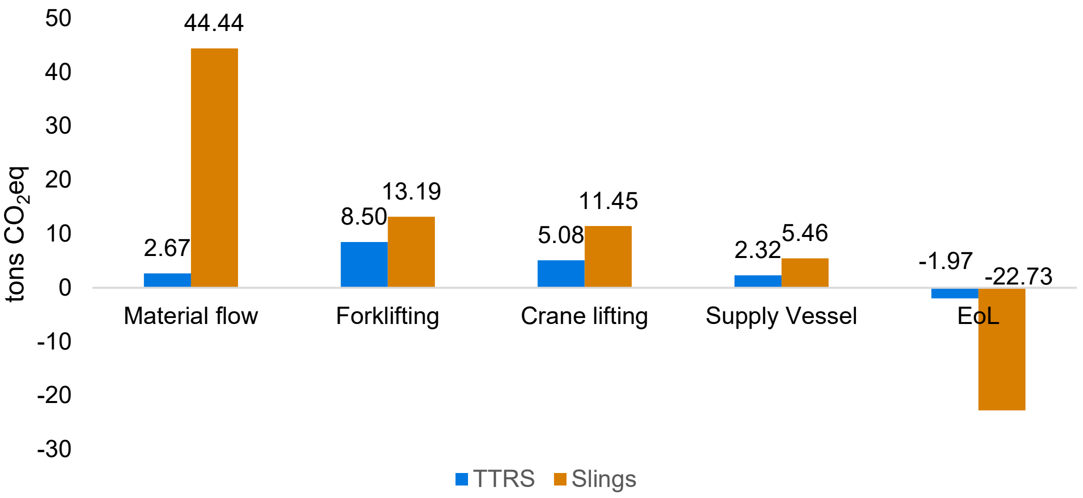


Figure 13: Results of the CFP study divided in the 5 stages

A sum of the five phases is shown in Figure 14 for the two scenarios. For this CFP study and the given case under investigation, wire slings are 3 times more GHG intensive in the given parameters that are studied. **The climate change impact savings correspond to 35 tons CO_2eq for the functional unit.**

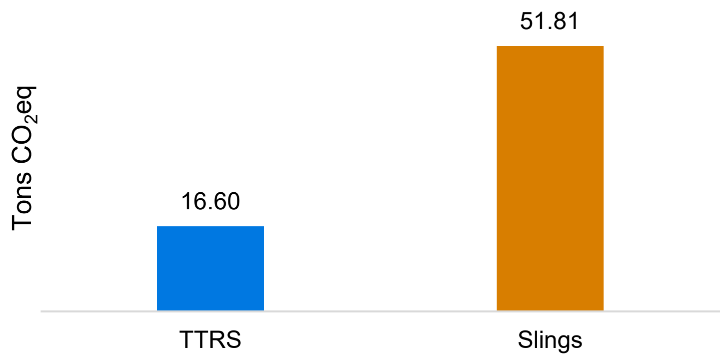


Figure 14: Sum of climate impact for TTRS and Slings

7.2 Sensitivity Analysis of Wire Slings' Service Life

As described in section 4.2.5, a sensitivity analysis will be conducted for expected lifetime of slings. Therefore, the lifetime is changed to be reused 4 times before disposal. Figure 15 shows a comparison in material flow, where Slings Worst Case is under the assumption of only 1 use case per sling. Best Case assumes 4 times reusing. The calculation takes crediting from recycling into account.

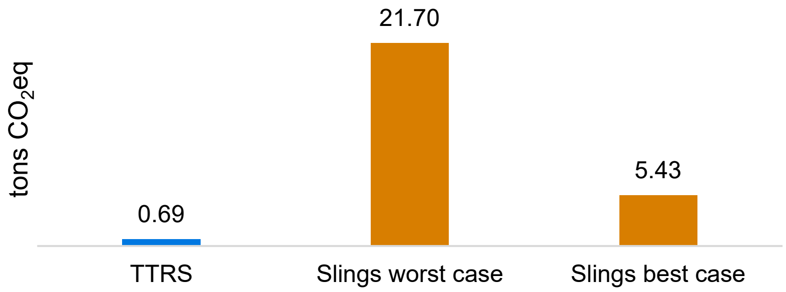


Figure 15: graph showing the CO_2eq for material flow (recycling is credited for).

Figure 16 shows the total results after extending the service life of slings by a factor 4. This reduces the overall life cycle impact results by 31% compared to the case where slings are only used once (see Figure 14). This is important to keep in mind if the results of this CFP study are used as indicators for other use cases by other clients than Total.

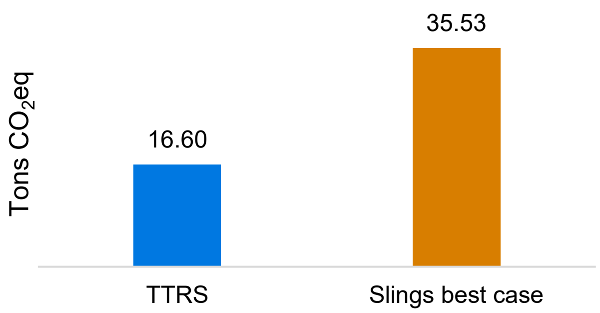


Figure 16: Full life cycle results in a best-case-scenario, where slings are reused 4 times.

Another assumption is the usage and lifetime of TTRS. The original assumption is that each TTRS is used 13 times a year for 10 years, or that only 1% are damaged before the full lifetime.

7.3 Reflection on Results

The study has shown that TTRS reduces GHG-emissions by 35.21 tons CO_2eq for the given use case. To put this into perspective the GHG-emissions are converted into the unit “trips around the world in a car.” It is assumed that an average European car emits 122 grams CO_2eq per km[11], and that the earth circumference is 40075 km.

$$\frac{\frac{35210\ \mathrm{kg\ CO_2eq}}{0.122\ \mathrm{kg\ CO_2eq/km}}}{40075\ \mathrm{km}} = 7.2\ \text{tips around the world}$$

The 35.21 tons CO_2eq savings correspond to 7.2 trips around the world.

[11] https://www.eea.europa.eu/ims/co2-performance-of-new-passenger

8 Conclusions

- A CFP study has investigated and compared Global Gravity's TTRS with a business-as-usual sling in the case of the user Total in their rig in the North Sea. The study includes material flow, forklifting, crane lifting and supply vessel docking along with end-of-life of the products.
- TTRS is assumed to be reused 13 times per year in a lifetime of 10 years. This lifetime is equal to the warranty period of TTRS. This assumption is relatively conservative, as TTRS are expected to live significant longer than their warranty period.
- Slings are typically expected to be reused 4 times before disposal. However, for this given case, Total (the user) follows a safety protocol that dictates only 1 time use for the slings. This limitation is considerable for the results; thus, a sensitivity analysis has also investigated a 4 times reuse case.
- For both TTRS and slings, recycling is assumed as end-of-life treatment. The calculation is based on average treatment process for metal, which includes average losses from the system.
- The cradle-to-gate emissions for this system under study includes raw materials extraction, material production and processing of materials into products. The emissions for the material flow are:
  - TTRS: 2.67 tons CO_2eq to fulfil the FU
  - TTRS recycling credit: -1.97 tons CO_2eq
  - Slings: 44.44 tons CO_2eq to fulfil the FU
  - Slings recycling credit: -22.73 tons CO_2eq
- Time savings during fork lifting, crane lifting, and supply vessel operation has been measured and estimated and are supplied in this document. This data has been delivered by the commissioner of the study, Global Gravity.
- The time savings for forklifting when using TTRS corresponds to 4.7 tons CO_2eq due to less fuel and lubrication for the forklifts in the port. Average database values have been applied for the fuel and lubrication consumption of an average forklift of the specified engine power in Port of Esbjerg.
- The time savings for crane lifting when using TTRS corresponds to 6.4 tons CO_2eq due to less fuel and lubrication for the crane in the port. Average database values have been applied for the fuel and lubrication consumption of an average crane of the specified engine power in Port of Esbjerg.
- The time savings for docking a supply vessel when using TTRS corresponds to 3.1 tons CO_2eq due to less fuel for the vessel while docking. The DESMO calculator has been used to calculate fuel consumption of the two specified vessels: Esvagt Heidi and Esvagt Leah from Port of Esbjerg.
- The total GHG-emissions for the system under study are
  - TTRS: 16.60 tons CO_2eq
  - Slings: 51.81 tons CO_2eq
- **The CFP study shows a total GHG-savings of 35.21 tons CO_2eq when using TTRS compared to business-as-usual slings.**
- A sensitivity analysis that considered 4 times reuse of slings, still favours TTRS. The savings in this scenario are 18.93 tons CO_2eq.
- The GHG-saving of 35.21 tons corresponds to 7.2 trips around the world in an average European car.
- If TTRS efficiency leads to making a forklift redundant and the port would buy one less forklift, this would save the environment around 51.4 tons CO_2eq.
- If TTRS efficiency leads to making a crane redundant and the port would buy one less crane, this would save the environment around 662 tons CO_2eq.

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Appendix A

Table 10: Processes from EcoInvent. Short names in the first column are used in Figure 5. Process names in second column are from EcoInvent v3.8 (2021). Third column contains information on how the process has been modified to better fit this study.

Name in this report	Process from EcoInvent	Comment
Aluminium	Aluminium, wrought alloy {GLO}| market for | Conseq, U	
Steel	Steel, low-alloyed {GLO}| market for | Conseq, U	
Extrusion	Section bar extrusion, aluminium {RER}| processing | Conseq, U	Also used for steel processes
Hot rolling	Hot rolling, steel {RoW}| processing | Conseq, U	
Cutting		Modelled at electricity only
Milling, alu	Aluminium removed by milling, average {RER}| cast iron milling, average | Conseq, U	Amount of electricity has been updated with measurements by Global Gravity
Milling, steel	Cast iron removed by milling, average {RER}| cast iron milling, average | Conseq, U	Amount of electricity has been updated with measurements by Global Gravity
Washing		Modelled at electricity only
Welding	Welding, arc, steel {RER}| processing | Conseq, U	Amount of electricity has been updated with measurements by Global Gravity
Coating	Powder coat, steel {RoW}| powder coating, steel | Conseq, U	
Metal working	Metal working, average for aluminium product manufacturing {RER}| processing | Conseq, U	Input of aluminium has been removed
Quenching	Impact extrusion of steel, hot, tempering {GLO}| market for | Conseq, U	Quenching and tempering
Wire drawing	Wire drawing, steel {GLO}| market for | Conseq, U	
Nylon	Nylon 6: Nylon 6 {RoW}| market for nylon 6 | Conseq, U	
Weaving	Weaving, synthetic fibre {GLO}| weaving of synthetic fibre, for industrial use | Conseq, U	
Rubber	Synthetic rubber {GLO}| market for | Conseq, U	
Moulding	Injection moulding {GLO}| market for | Conseq, U	
PVC	Polyvinylidenchloride, granulate {RER}| market for polyvinylidenchloride, granulate | Conseq, U	
PVC-extrusion	Extrusion, plastic film {GLO}| market for | Conseq, U	
Electricity	Electricity, low voltage {DK}| market for | Conseq, U	
Recycling, alu	Aluminium, in mixed metal scrap {RoW}| market for aluminium, in mixed metal scrap | Conseq, U	Recycling rate of 90% is assumed
Recycling, steel	Ferrous metal, in mixed metal scrap {RoW}| treatment of metal scrap, mixed, for recycling, unsorted, sorting | Conseq, U	Recycling rate of 90% is assumed
Truck	Transport, freight, lorry 16-32 metric ton, EURO5 {RoW}| transport, freight, lorry 16-32 metric ton, EURO5 | Conseq, U	Used for all transport for all components in all systems