CHALMERS

Utilizing wave power at anchor

As a complement for marine vessels

Bachelor thesis for Marine Engineering Program

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DEPARTMENT OF MECHANICS AND MARITIME SCIENCES

CHALMERS UNIVERSITY OF TECHNOLOGY
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PREFACE

We applied for a thesis posted by Göteborgs Hamn that included how much CO2 emission ships at anchor produce. Unfortunately, we did not qualify, but it gave birth to this idea.

The authors would like to send a special thanks to Mats Isaksson, a significant contributor to the idea and a guiding star along the way.

Liza Nordfeldt at Chalmers library for her help and contributions regarding references and method expertise.

A big thanks to Yang et al. and Sun et al. and their work regarding the FABWEC-test and Ikegami et al. for the equations regarding irregular waves.

We would also like to thank Jonas Kamf at waves4power that was kind enough to answer questions in an early stage of the thesis.

Also, a special thanks to Thomas Sundman at HYDSUPPLY for cost estimations regarding hydraulics.

Chalmers, Marine Engineering program, 15hp

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SAMMANDRAG (IN SWEDISH)

När fartyg som M / T Ramona inte är i tjänst och ligger ankrade så måste vitala komponenter ombord fortfarande vara i drift. En produkt av detta blir att fartyget producerar CO2 som bidrar till växthusgaser. När ett fartyg ligger ankrat och väntar på en ny order eller på att komma in i en hamn, förser hjälpmotorerna fartyget med elektricitet.
Hjälpmotorerna går på diesel som är ett fossilt bränsle som bidrar till den globala uppvärmningen.
En lösning är att använda en vågenergiomvandlare som är monterad på skrovet för att producera avgasfri energi.

Flera cylindriska bojar är fästa på fartyget med en arm som pumpar ett hydrauloljetryck när bojen går upp och ner. Hydrauloljetrycket samlas i en ackumulatortank som driver en turbin som i sin tur driver en generator.

Med hjälp av SMHI’s väderboj utanför Brofjorden har vågamplitud och frekvens använts för att beräkna hur mycket potentiell kraft vågenergikonverteraren kan producera. Resultatet kan förändra hur fartyg vid ankar producerar energi och nya tillvägagångssätt för miljömässiga hållbara transporter till sjöss.
Denna rapport är baserad på specifikationerna för M / T Ramona och FABWEC-systemet som nyligen testades av Yang et al. (2019) och en bra kandidat för ett sådant system. Denna artikel täcker endast testets teoretiska sida och inget verkligt test utfördes. Resultaten tyder på att tillräckligt med energi kan omvandlas för att försörja ett fartyg av samma storlek som M / T Ramona.

Nyckelord: vågenergikonverterare, vågenergi, FABWEC, M/T Ramona, Brofjorden

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ABSTRACT

When not being in service and at anchor, vessels such as M/T Ramona produces greenhouse emissions when powering vital components on the vessel. When a vessel is anchored and waiting for a new order or to enters a port, the auxiliary engines provide the vessel with electrical power.

The auxiliary engines run on diesel that costs money, and being a fossil fuel, it contributes to global warming.

One solution is to use a wave energy converter attached to the hull to produce zero-emission energy.

Several cylindrical buoys are attached to the vessel through an arm and pump a hydraulic oil pressure when the buoy goes up and down. The hydraulic oil pressure accumulates in an accumulator tank and drives the turbine that drives a generator. With the help of SMHI's weather buoys outside Brofjorden, wave amplitude and frequency have been used to calculate how much potential power the wave energy converter can produce. The result can define how vessels at anchor produce energy and new applications for environmentally sustainable transports at sea.

This report is based on the specifics of M/T Ramona and the FABWEC system that recently was tested by Yang et al. (2019) as a good candidate for such a system. This article only covers the theoretical side of the test, and no real-life test was conducted. Nevertheless, the findings suggest that enough energy can be converted to supply a vessel the same size as M/T Ramona.

Keywords: wave energy converter, wave energy, FABWEC, Brofjorden, M/T Ramona

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF EQUATIONS

ACRONYMS AND TERMINOLOGY

BDC	Bottom dead center
BSFC	Break specific fuel consumption
FABWEC	Floating array-buoy wave energy converter
PTO	Power take-off
SMHI	Swedish Meteorological and Hydrological Institute
TDC	Top dead center
WEC	Wave energy converter
WR	Weather radar

ACRONYMS AND TERMINOLOGY USED IN EQUATIONS

A_{bw} = Buoy Area (m^2)

b = buoy width (m)

D = Diameter (m)

E_i = Total energy input (kJ)

E_{KZ} = Kinetic energy of a buoy (kJ)

E_t = Total energy captured by buoy (kJ)

E_{PZ} = The potential energy of a buoy (kJ)

g = acceleration of gravity (m/s^2)

h = Buoy amplitude (m)

H_s = Wave amplitude (m)

L = angel included wavelength (m)

l = wavelength (m)

m = Buoy mass (kg)

m_a= Added mass (kg)

mt= metric tonnes

n = Number of elements calculated

v^2 = Buoy Velocity (m/s)

$\overline{P_{mean}}$ = Mean power absorbed from a wave

$\overline{P_{wave}}$ = Mean potential wave power

ρ = Seawater density (kg/m^3)

η = surface wave formation function

β = Angel of wave (°)

1. INTRODUCTION

Of all product transports around the world, shipping stands for 90 % and contributes to 2,6 % of all CO_2 emissions worldwide. The total CO2 emission year 2012 was 35 650 million tonnes, shipping stands for 938 million tonnes, and by the year 2050 the emission can increase up to 250 % (Smith et al., 2014). To avoid the significant increase, the United Nations adapted 17 sustainable development goals as environmental actions for the planet. Goal 13, "Climate action" is about increasing and improving education, awareness, and institutional capacity to reduce climate change but also decreasing emissions. Goal 14 Life below water, is about reducing marine pollution from land-based activities, including marine debris before the year 2025 (Ferri, 2010). The United Nations adopted the Paris agreement in 2015, and the goal is to decrease global warming compared to pre-industrial levels to 1,5 degrees Celsius (Erickson et al., 2019).

CO2 from vessels is formed during the combustion of diesel when carbon monoxide oxides (Heywood, 2019, p.623-624). When the vessel lays at anchor the auxiliary engines consume diesel fuels and produce CO2 emissions.

It is imperative to look at new solutions instead of carbon-based fuel. A part of the solution for ships at anchor can be a wave converter.
The wave energy designs date back to the 1800s, but it was not until the 1970s that research leaped forward with new funds and an impending energy crisis. As a result, the industry surrounding wave energy could see the tremendous untapped resource that wave energy represents (Kofoed, J. P. 2017, pp. 22-23).

The potential energy from waves is enormous and estimated at an order of magnitude larger ($\sim 10^{13}$ W) comparable to today's worldwide energy consumption. Using a wave energy converter (WEC) is one way to harvest that energy. Wave converters are a step closer to receiving clean energy and reducing greenhouse gas emissions. Converting energy from waves is considered as clean energy and an energy resource for the future. Wave energy is a part of the solution when it comes to global warming.

> *"Wave energy is more persistent than wind energy"* (Falnes, 2007).

Extracting energy from a wave converter has its advantages when comparing it to wind or solar power. A WEC can potentially convert energy 90 % of the time compared to solar and wind converters, which only can produce 20-30 % of the time (López et al., 2013).

> *"The current wave energy technology is not economically competitive when compared to other renewable energy technologies such as wind and solar energy technologies"* (Nguyen et al., 2020).

Waves are high-density renewable energy carriers and change with the season, therefore, meeting seasonal demands. A wave can travel a long way and lose a small amount of power (Drew et al., 2009). The challenge with wave conversion is to manage the direction and frequency of the waves. The wave with all its force may come in different sizes and converting a high power low frequent force is challenging. Another parameter to consider is the harsh weather climate that materials face at sea (Leijon et al., 2006). The wave amplitude and frequency put a lot of pressure on the power take-off (PTO) -system and its compatibility with modern electrical generators.

The PTO-system needs a steady stream of energy to maximize the production of electricity. Therefore, the wavelength and frequency are essential to maximizing output (Shadman et al., 2021).
Floating array buoy wave energy converter (FABWEC)-system shows that a wave converter can be fitted and optimized on a vessel, this is demonstrated by Sun et al. (2021) and shows the possibility for vessels to adopt new ways to harvest green energy.

1.1 Aim of the study

The aim is to investigate if a wave energy converter can be fitted on a vessel to produce some or all of the power needed and accomplish the goal of reducing emissions from the vessel.
Ships at anchor require power to maintain fully functional and produce CO2 when running on auxiliary engines for power supply.
Is it possible to use a wave energy converter WEC as a power supply when vessels are at anchor to produce all or some of the power needed, is this possible when considering cost and environmental gains?

1.2 Research questions

How much electrical power can a wave energy converter produce when it is fitted on M/T Ramona in Brofjorden?
When does the system turn a profit, considering CO2 and the cost of the system?

1.3 Delimitations

- The closest measuring data about the height of waves to the Brofjorden anchor station is (Swedish Meteorological and Hydrological Institute [SMHI], 2021) SMHI's Brofjorden WR buoy. We expected that the wave amplitude is equal to the amplitude at anchoring spot Brofjorden. The data is from January 2018- December 2018.
- In this report, calculations on floating array buoys energy wave energy converters FABWEC and M/T Ramona are being investigated for potential power production.
- The added weight of the vessel and how it performs at sea after remodeling is not considered in this article.
- Friction and fluid losses in the hydraulic system were not considered.
- Water shading between buoys is not calculated.
- Losses in generator and power grid onboard are not considered.
- Wind and currents and harsh weather conditions on the vessel are not considered while calculating potential power and function of buoys.
- AVD (average deviation) is calculated T_e /5 for all power calculations.
- The calculations of wave energy the following assumptions were made:

  "(1) The fluid is an ideal fluid that is non-viscous, homogeneous and incompressible.
  (2) The mass force on the fluid is only gravity.
  (3) The pressure on the free water surface is uniform and constant.
  (4) Water flow motion is an irrotational planar motion." (Sun et al., 2021)

2 ENERGY THEORY

This chapter explains the background of CO2 emissions from vessels at anchor. The technical aspect of a wave energy converter and the arrangement of buoys on a vessel.

The PTO -system and hydraulic system with accumulators. From hydraulic pressure to electricity through a hydraulic turbine and how steady stream tackles the problem regarding frequency.

With the help of SMHI's weather recording buoy outside Brofjorden, waves amplitude and frequency have been used in equations to calculate how much electrical power one buoy can produce. The general data of M/T Ramona and how much power is needed.

Equations used are explained and presented. The theory behind the FABWEC, data from the FABWEC-test, and where it was tested, are also described in this chapter.

2.1 Wave energy converter

The wave energy converter consists of a cylindrical buoy that is attached to an arm, and the principle of the buoy is to capture the motion of a wave by being forced upwards and downwards, generating power.

The arms are 1,7 m, the buoy has a radius of 1,2 m and a width of 1,8 m, as shown in fig.1. With a weight of 200 kg and 250 liters of water added with an approximated weight of

250 kg. The water is filled through a hatch on top of the buoy, as demonstrated in fig.1.

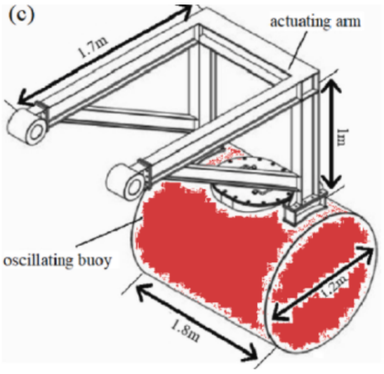
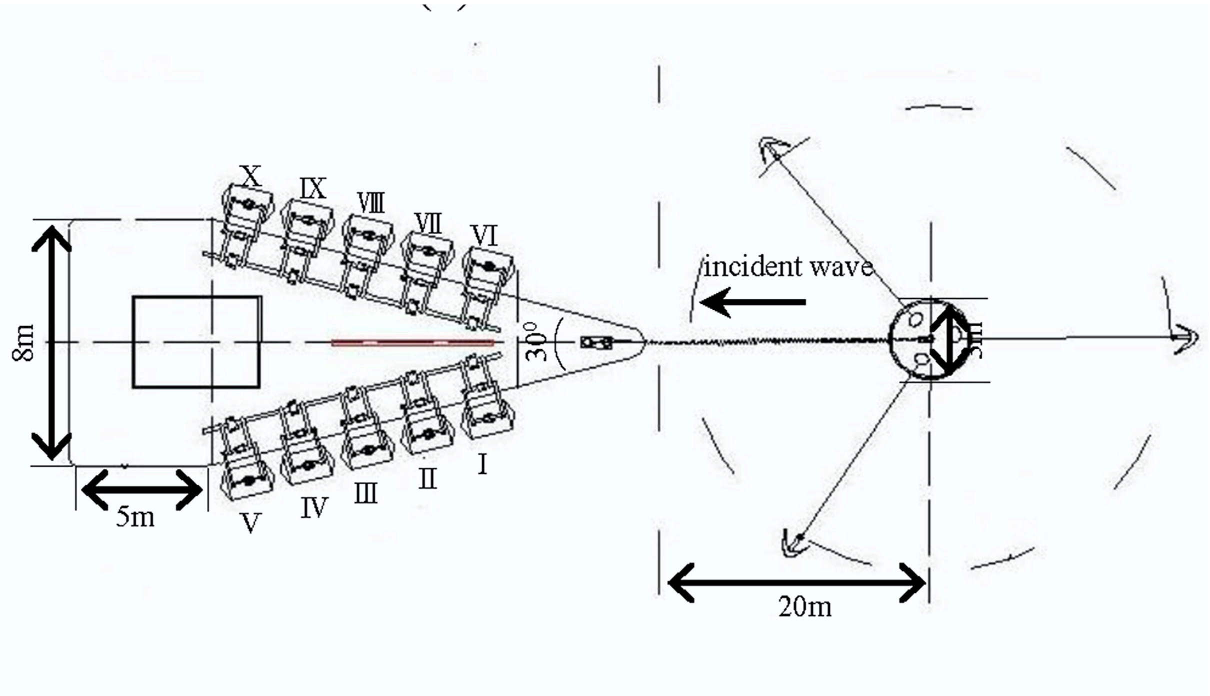


Figure 1: A view over the cylindrical buoy (source (Sun et al., 2021) used with permission 2021-02-10)

2.1.1 System buoy layout

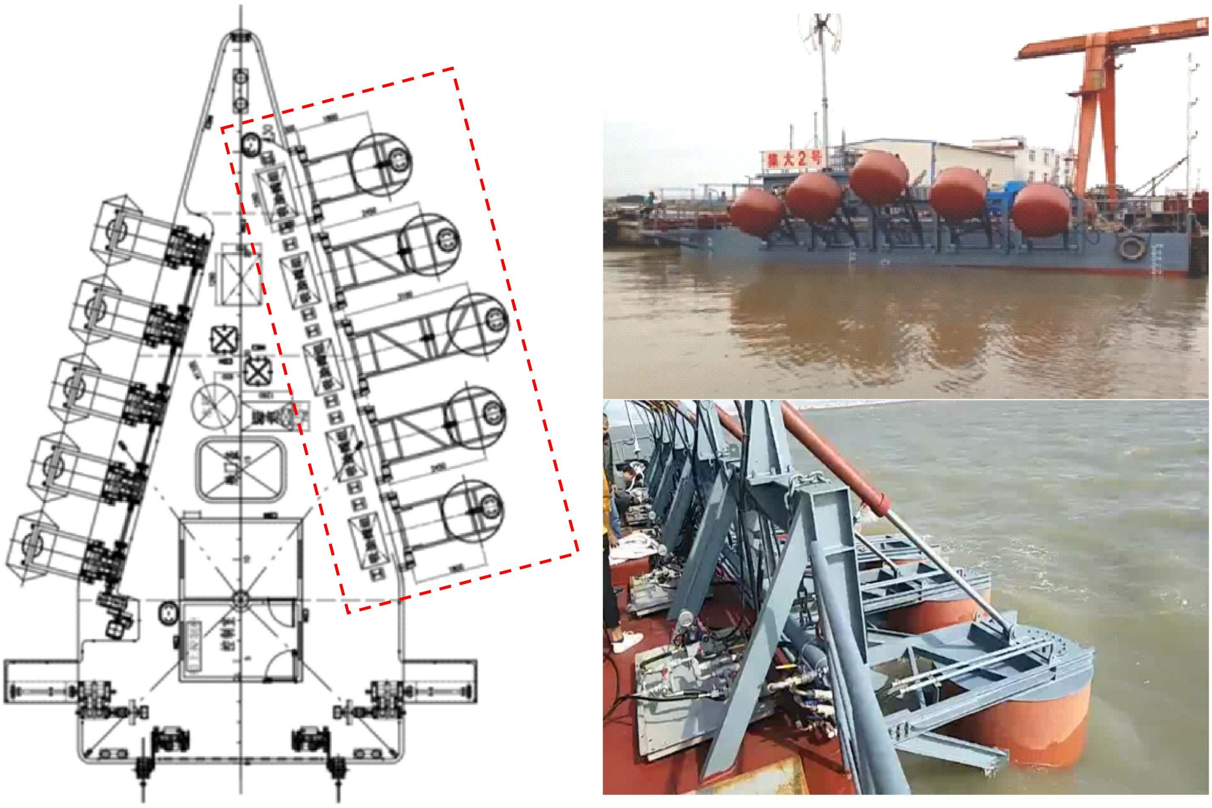
The buoys are lined up on the peak of the vessel buoys on each side, as shown in fig.2. The moving parts are all above the waterline. The buoys' alignment can be optimized, as Sun et al. (2021) demonstrated, where the buoys are aligned in a staggered formation to avoid draught between buoys, and displayed in fig.3 a & b.

Ramona is a larger vessel than used in the FABWEC test and therefore can fit more buoys.



(c) Top view

Figure 2: Arrangement of buoys (source (Yang et al., 2019) used with permission 2021-03-04)



(a) Schematic diagram (b) Prototype

Figure 3 a & b: After optimization of buoys shows (a) schematic and (b) shows the finished prototype, by Sun et al. (2021) (source (Sun et al., 2021) used with permission 2021-03-19)

If the buoys are designed too close to one another they produce a "water shade," the shading effect makes power absorption less efficient. When a wave forces the ship and buoy to oscillate, the horizontal difference between the main deck and buoy varies it also varies between each buoy (Sun et al., 2021). The buoy is connected to the shaft, and when rotating, the shaft picks up energy from the buoy and transfers it to a hydraulic pump, as can be seen in fig.4. The hydraulic pump pressurizes the fluid and pumps it to a bladder accumulator.

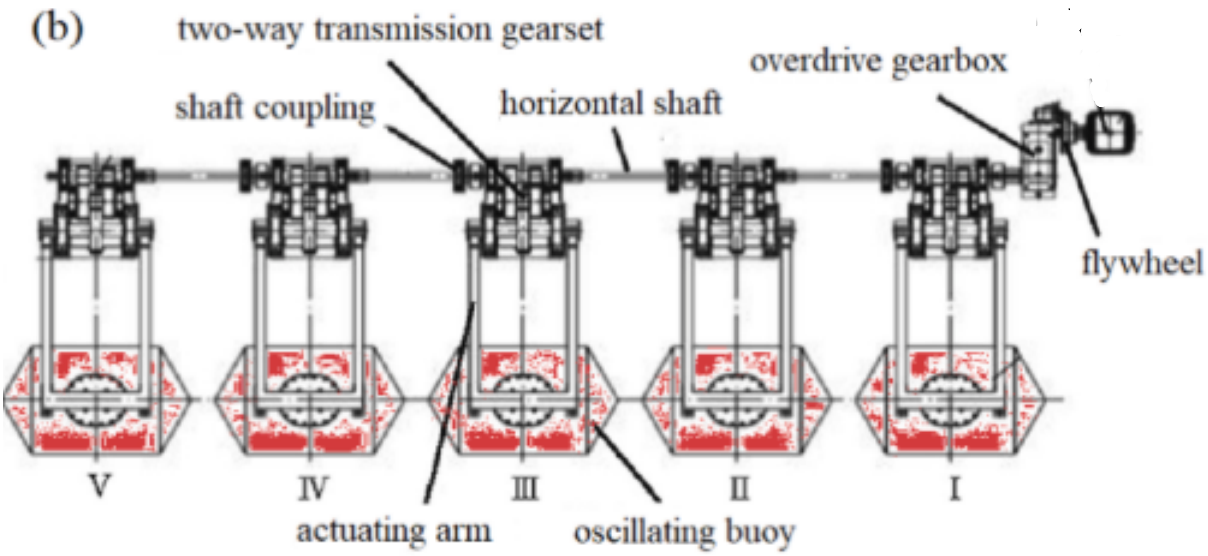


Figure 4: Arrangement of buoys (source (Sun et al., 2021) used with permission 2021-02-10)

2.1.2 Power take-off

The motion of the wave will create a force on the buoy, which is, through a shaft, connected to the power take-off (PTO) (Liu et al., 2016). The shaft connects to a gearbox and flywheel. The flywheel is connected to a hydraulic pump, as shown in fig.4. The hydraulic fluid is pumped to a hydraulic accumulator and stores the energy for a smooth transmission for a turbine. A motor in fig.5 represents the turbine.
The fluid is pumped to the hydraulic bladder accumulator as shown in fig.5.

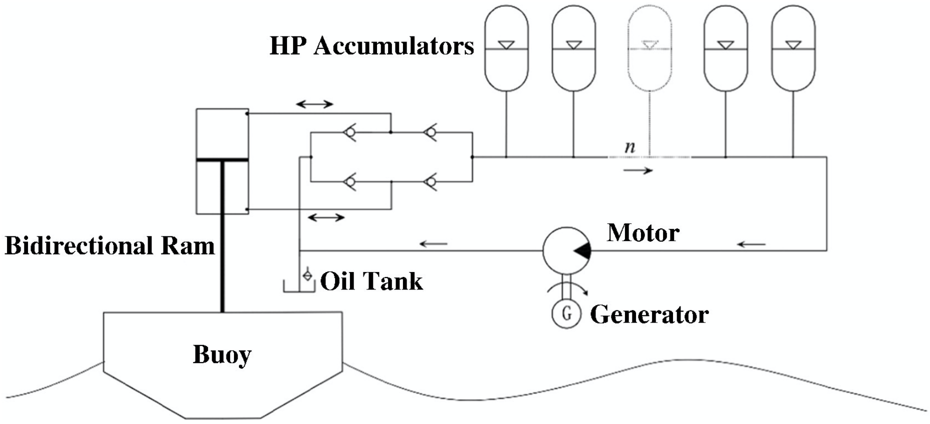


Figure 5: A hydraulic system with bladder accumulators (source (Liu et al., 2016) used with permission 2021-02-19)

2.1.3 Hydraulic system

A method of converting a low-frequency oscillating force is to accumulate the power with a bladder accumulator shown in fig.6. The hydraulic system is suitable for a high force, low-frequency wave that varies in motion (Henderson, 2006).

The hydraulic system is connected to the shaft and therefore receives an oscillating motion from waves forcing the buoy to oscillate. The hydraulic is compressed into a bladder accumulator at high pressure. Using this system with a short-term storage system gives the generator a smooth and constant flow of energy in the form of hydraulic pressure despite the frequency and magnitude of the wave.

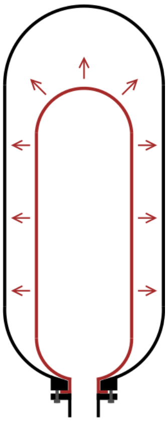


Figure 6: A bladder accumulator tank (MasterTriangle12, 2020).

The power output will smoothen when the system can accumulate power for a short period of time. The hydraulic system was tested and evaluated by Henderson (2006). As can be seen in fig.7a that the input energy from the wave is converted to output energy in fig.7b.

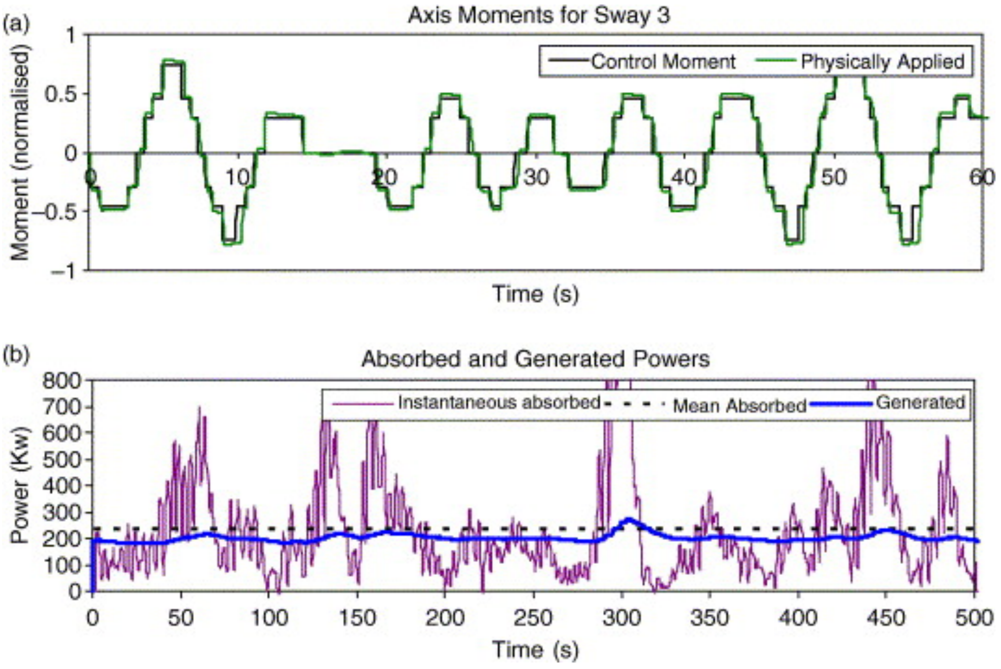


Figure 7a, b shows the moment of a wave, mean absorbed power and generated power (source (Henderson, 2006) used with permission 2021-04-13)

2.1.4 Approximated cost for the hydraulic system

The economy surrounding the system was provided by HYDSUPPLY, Thomas Sundman. For the central part such as generator, motor, piston, and couplings following data, as can be seen in table 1 and mail correspond in (appendix B, 1-2(9)). In addition, the cost from HYDSUPPLY was collected to give an approximation of what the system would cost.

Table 1. Specified cost in SEK (Swedish kronor) for the hydraulic system from HYDSUPPLY (Appendix B, 1-2(9))

Unit	Cost Swedish kronor (SEK)
Accumulator 10 Liters	15 000 SEK
Generator	90 000 SEK
Hydraulic cylinder and piston	70 000 SEK
Motor	30 000 SEK
Couplings	12 000 SEK

2.1.5 Equations

Equations 1 through 9 explain the mathematical path from the energy within a wave to how a WEC-system potentially absorbs power from the wave, given by Sun et al. (2021).

Equation 1 The equation for the total energy of wave within a wavelength:

$$E = E_P + E_k = \frac{1}{8}\ \rho g H^2 L \tag{1}$$

Equation 2 The equation for the wave energy input within the buoy width:

$$E_i = \rho g H^2 L\mathrm{b} \tag{2}$$

Equation 3 The equation for potential energy of one buoy:

$$E_{PZ} = \frac{1}{8}\rho g A_{bw}\, h^2 \tag{3}$$

Equation 4 The equation for the kinetic energy:

$$E_{KZ} = \frac{1}{2}(m + m_a)v^2 \tag{4}$$

Equation 5 The equation for cylindrical buoys which are placed horizontally on the surface of water:

$$A_{bw} = 2l\sqrt{2a * R - a^2} \tag{5}$$

Equation 6 The equation for the actual draught of buoy:

$$a = R - (h - \eta) \tag{6}$$

Equation 7 The equation for cylindrical buoys which are placed vertically on the surface of water:

$$A_{bw} = \frac{\pi D^2}{4} \qquad \textbf{(7)}$$

Equation 8 The equation for the total energy capture by buoy includes the kinetic energy and potential energy:

$$E_t = E_{KZ} + E_{PZ} = \frac{1}{2}(m + m_a)v^2 + \frac{1}{8}\rho g A_{bw}\, h^2 \qquad \textbf{(8)}$$

Equation 9 The equation for efficiency E of wave energy captured within the area of the buoy:

$$E = (E_t/E_i) = (4(m + m_a)v^2 + \frac{1}{8}\rho g A_{bw}\, h^2)/(\rho g H^2 Lb)) \qquad \textbf{(9)}$$

Equations 10, 11 and 12 are lifted from a study made by Ikegami et al. (2018), Yang et al. (2019) and explain the function of irregular wind-power during a wind-power generation. This is used to mathematical be able to approximate wave power converters and the amount of energy in a wave. However, the AVD (average deviation) is not calculated due to a lack of information from the buoy outside Brofjorden. Instead, the waves measured point, as given by SMHI (2021), was used for every half an hour with a mean AVD T_e /5, as shown in (appendix A, 3-4(6)), by Ikegami et al. (2018) and Yang et al. (2019).

Equation 10 The equation for the energy conversion efficiency (Yang et al., 2019):

$$\eta = \frac{\overline{P_{mean}}}{\overline{P_{wave}}} \qquad \textbf{(10)}$$

Equation 11 The equation for the average wave power in deep water (Yang et al., 2019) (Ikegami et al., 2018):

$$\overline{P_{wave}} = \frac{\rho g^2}{64_\pi} H_s^2 T_e L \qquad \textbf{(11)}$$

Equation 12 The equation for the valid width along the direction of the incident wave (Yang et al., 2019):

$$L = nl\, sin\frac{\beta}{2} \qquad \textbf{(12)}$$

2.1.6 Waves outside Brofjorden

The mean wave amplitude measured over a year was 0,943 meters and,
as shown in fig. 8 and fig. 9
according to SMHI (2021). Amplitude and frequency were supplied from SMHI (2021) every 30 minutes for the whole year 2018.
This shows the average for each month and pillar 13 is the average for the whole year.
The same calculation was done for the waves' frequency, as shown in fig.9 with pillar 13 the average for the whole year calculated with MatLab (appendix A, 2-3(6)). Investigated interval 2018-01-01 to 2018-12-31.

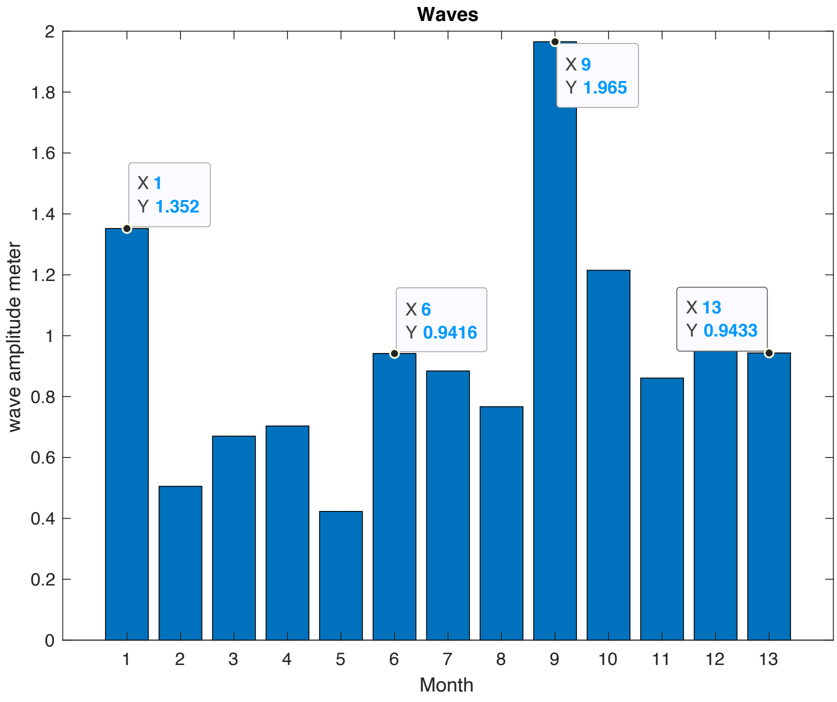


Figure 8: Mean wave amplitude in meters and months outside Brofjorden (SMHI, 2021).

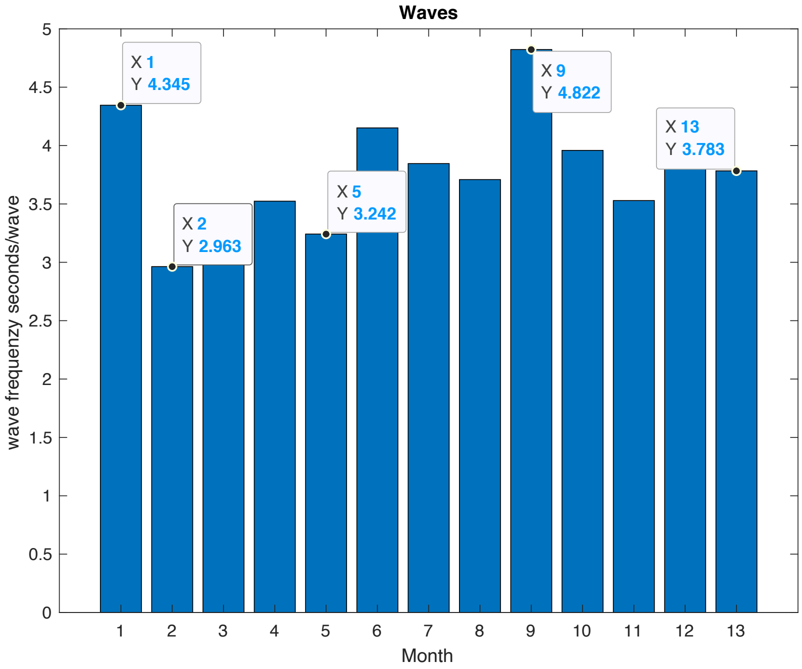


Figure 9: Wave frequency outside Brofjorden (SMHI, 2021).

The mean wave amplitude measured over a year was 0,943 meters and with a mean frequency of 3,783 seconds per wave.

2.2 CO2 emissions from the auxiliary engine

Carbon monoxide emissions is a product of air/fuel (A/F) ratio in the cylinder during combustion. For a CI (compression ignition) diesel engine the air/fuel ratio is (20≤ A/F ≤80) (Heywood, 2019, p.67). This depends on the type of fuel mixture and the fuel composition. A rich mixture is when fuel/air ratio is greater than one, and the emissions contain a lot of unburnt fuel. However, marine diesel engines run on a lean mixture where the fuel/air ratio is smaller than one. Carbon monoxide is a reaction of the combustion with steps (Heywood, 2019, pp.623-624).

$$\mathrm{RH}\rightarrow\mathrm{R}\rightarrow\mathrm{RO2}\rightarrow\mathrm{RCHO}\rightarrow\mathrm{RCO}\rightarrow\mathrm{CO}$$

Where the hydrocarbon radical equals R, H equals hydrogen, carbon equals C and O is oxide. When CO is formed in this process, and the oxidized product is CO2.

$$\mathrm{CO+OH=CO2+H+H}$$

The composition of a specific fuel and the proportion between fuel/air is needed to calculate CO2 mass. As previously mentioned, if sufficient oxygen is added, CO oxidizes to CO2, and hydrogen oxidizes to H2O. Shown by equation 13 the composition of a specific fuel:

$$H_y + aO_2 = bCO_2 + cH_2O \qquad \textbf{(13)}$$

The equation above does not indicate the chemical mechanism that proceeds in the combustion. When air has a low temperature, the nitrogen in the air is not affected. But in the combustion, when air is mixt with a hydrocarbon fuel, as shown with equation 14 an average molecular composition Ca Hb, the equation is: (Heywood, 2019, p.88)

$$C_aH_b + \left(a + \frac{b}{4}\right)(O_2 + 3.773N_2) = aCO_2 + \frac{b}{2}H_2O + 3.773\left(a + \frac{b}{4}\right)N_2 \quad \textbf{(14)}$$

The molecular weight is necessary to calculate what percent of the fuel becomes CO2 after combustion. Oxygen molecular weight is 32 g/mole, Nitrogen 28,01 g/mole, and carbon dioxide 44,01g/mole (Heywood, 2019, p.996)

2.3 M/T Ramona

M/T Ramon is an oil/chemical tanker built in 2004 and sailing under the flag of Sweden. Port of register is Donsö and the registered owner is Rederi AB Älvtank.

M/T Ramona is a larger vessel than the one used in the FABWEC test, by Yang et al. (2019). With a larger vessel, more buoys can be fitted.
Table 2 under shows the data to get to know the vessel. To calculate how much CO2 is produced during the combustion, it is necessary to know which model the auxiliary is and the output. The data is taken from Älvtanks webpage (*Ramona | Rederi AB Älvtank*, 2021).

Table 2: The general data, regarding the size and equipment, of M/T Ramona (Ramona | Rederi AB Älvtank, 2021)

Name of vessel	M/T Ramona
Call sign	SFGZ
Length over all	144 m
Breadth	21,5 m
Draft summer	9,75 m
Dead weigh summer	17 592 t
Gross tonnage	11 548 t
Net tonnage	5 553 t
Ballast capacity	7 032 m^3
Bunker capacity HFO	694 m^3
Bunker capacity GO	116 m^3
Main engine make	MAK
Main engine type	7M43
Main engine output	6 190 kW
Auxiliary engines make	2 x Volvo Penta
Auxiliary engine type	D34 A MT
Auxiliary engine output	828 kW

Ramona consumes between 100 kW – 200 kW when anchoring. It is depending on how many of the systems onboard they are using. Some of the largest consumers are air conditioners, pumps for seawater and fuel, start/service compressors, and the boiler. To meet the power requirement, one auxiliary engine needs to run at 15- 25 %.

The auxiliary engines run on distillate marine fuel (DMA), also called marine gas oil (MGO), with a density of 0,9 kg/l at 15 degrees (Chevron, 2015). The price for bunkering on the 16 of March was 545 USD/ mt (Ship & Bunker, 2021).

2.4 FABWEC-system test

FABWEC was tested by Yang et al. (2019) in between Xiaodeng Island and Xiaojinmen Island of Taiwan Strait, South China Sea.
Specifications of the platform, as shown in table 3.

Table 3: Specifics of the FABWEC platform (Yang et al., 2019)

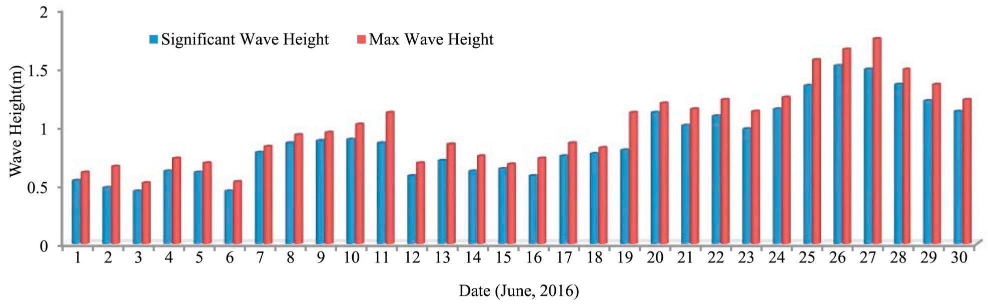
Unit	Specifications
Length	18 m
Width	8 m
Depth	2,4 m
Draught	1,3 m
Displacement	90 517 kg
Hight of gravity	1,23 m
Bowl angel	30°
Maximum righting lever	1,12°
Angel of maximum righting lever	33,8°

The buoy structure was arranged with ten buoys and as specified as the buoy in 2.1.1.
They also considered using a hydraulic system but recognized the potential danger of using a toxic fluid and its impact on the marine environment. The PTO-system was instead designed with a two-way transmission gear set (1:25) to capture energy rotating both forward and backward. The buoys were arranged linearly, with five on each side and in total ten buoys.
The conclusion of the test was that energy could be harvested from waves to a floating body using the relative motion between the vessel's body and the motion of the wave (Yang et al., 2019). The amplitude and frequency were measured by the mooring buoy, as shown in fig.2.

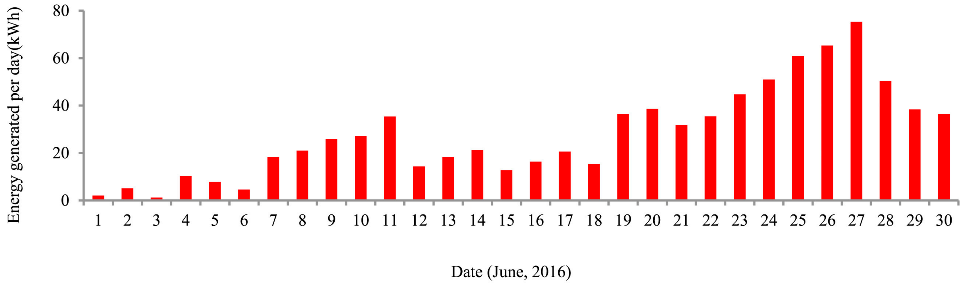
2.4.1 FABWEC results

The FABWEC-system was tested at near conditions to Brofjorden. The test in the south China sea by Yang et al. (2019) with a deployed FABWEC-system reached 9,03 kW/ 30 minutes per buoy, with a max conversion efficiency of 26.65 %. However, the average energy generated per 24 hours was 28,09 kW, and during a 30-day trial, the amount of electrical energy created was 842,7 kW (Yang et al., 2019). The conversion efficiency ranged from 2,5-26 %, with 2,5 % with frequency lower than 2,5 seconds.
The FABWEC system test was performed in the south Chinas sea and tested for 2500 h with wave conditions (0,3 – 1,2 m in height and 3,0 – 4,5 s in frequency) approximately close to the ones outside Brofjorden. The peak amplitude and frequency were 1,75 m and 5,25 seconds (Yang et al., 2019).
Figure 10 a, b, c & d represents a testing period outside South China made by Yang et al. (2019).

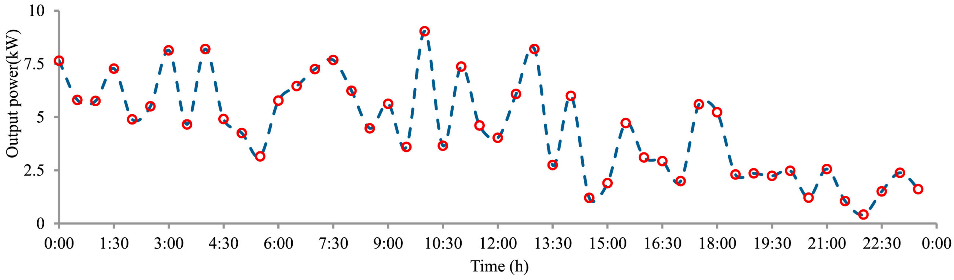
a) The average and highest wave height each day in June.
b) A permanently magnetized generator generates electricity.
c) kW every 30 minutes on the 27th of June 2016.
d) The relationship between half-hour measurements of significant wave height and power output.



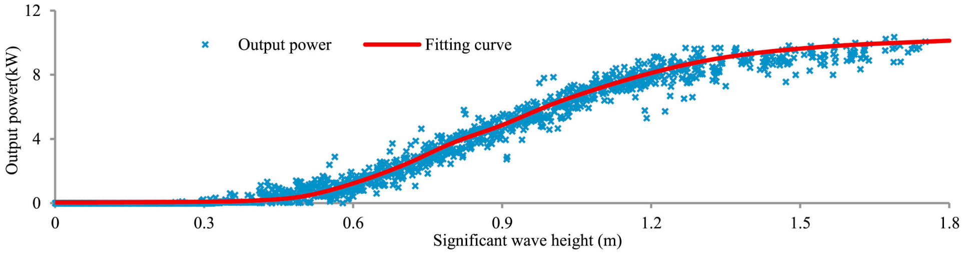
(a) Mean and maximum wave heights per day



(b) Electricity generation per day in June, 2016



(c) Half-hour mean output power on June 27th, 2016



(d) The relationship between half-hour mean output power and significant wave height

Figure 10 a, b, c & d: Measurements on the FABWEC- system, south China source ((Yang et al., 2019) used with permission 2021-03-04)

3. METHODS

This chapter motivates the use of a case study as a qualitative study. This study will make use of existing chosen numerical and calculations to show investigated units potential. The preferred method takes the particular unit into consideration instead of the whole spectra.

This chapter also explains the method regarding equations, literature, and economics that are central to the wave energy converter.

3.1 Case study

The method case studies strong point is that it allows the researcher to use a series of references and data (Denscombe, 2009, pp.59-61).

The choice case study fits well due to the ability to research a specific subject. When the researcher does not have control over the subject's outcome in hand case study is an appropriate method. The method case study is most vulnerable against credibility generalizations regarding the result of the study.

Qualitative methods are a general term for all the methods regarding analyzing text, statistic data, and numerical data that are not generated for a quantitative study (Ahrne & Svensson, 2015 p.9).

Empirical data, research question, and method is the foundation in designing the project. Therefore, to proceed from the research question and work through the document is a good starting point (Svensson & Ahrne, 2015 p.29).

Qualitative does not strive to measure how much or how many but to paint a picture of how the process works, the meaning of the study, and qualities (Renstam & Wästerfors, 2015 p.13).

The case M/T Ramona and FABWEC-system is specific but did not limit us to one theory. Therefore, the possibility to look at different systems and equations for wave power was not limited in the case study.

M/T Ramona is not an uncommon vessel type and does not limit the use of the system in broader spectra.

A case study is considered a qualitative method due to its gathering of numerical data from a narrow perspective and relations between theories (Bryman, 2011, pp.150-151).

3.2 Literature regarding the subject

Articles that were researched contained the technique regarding wave converters and the PTO -system. In addition, Sun et al. (2021) also covered how waves work and the weakness of a WEC-system. This was researched to get an overview of the weaknesses and future development history of WEC-systems.

Sun et al. (2021) provided information on how the WEC-system needs to be designed and the arrangement of a floating body also the optimization of when arranging the FABWEC-system. Drew (2009) Shows a module a WEC-hydraulic circuit for the PTO and shows the benefits of an accumulating system to provide the generator with a steady flow of energy.

Regarding engine, carbon development, and performance, both Heywood (2019) and Kuiken (2012) described the system layout of the engine and chemistry behind CO2 production.

Information regarding wave amplitude and frequency SMHI is provided on their home page (Swedish Meteorological and Hydrological Institute [SMHI], 2021).

Testing the FABWEC-system, the sea trial was conducted by Yang et al. (2019) and provided a real-life test result. The optimization of buoys regarding the FABWEC –system was conducted by Sun et al. (2021)

Heywood (2019) provided information about combustion regarding diesel engines and the process of CO2 emissions. An explanation by Kuiken (2012) contributed with more graphic descriptions of the four-stroke diesel engine.
Hendersson (2006) highlights the potential efficiency gains from using a hydraulic system with a steady stream of fluid.

3.3 Literature regarding equations

Equations regarding the WEC were given by Sun et al. (2021), Ikegam et al. (2018), and Yang et al. (2019).
Sun et al. (2021) provided us with relevant data on designing the buoy in different formations and shapes gives the system a better working efficiency.
Ikegam et al. (2018) explain the calculation of irregular wave patterns and how to convert the numbers in equations.
Yang et al. (2019), the real-life test produces real numbers and gives the use of equations something to compare the reliability with.

3.4 Wave data from SMHI

SMHI (Swedish Meteorological and Hydrological Institute [SMHI], 2021)is an organization that works under the Swedish environmental department. Their primary purpose is to serve companies, organizations, and people with data and information regarding the weather. SMHI provides data from a buoy outside Brofjorden that measures amplitude and frequency.

3.5 Economics

Economics regarding the fuel is retrieved from (Ship & Bunker, 2021) in March 2021 to get the current price in USD at that time. Therefore, the fuel price varies and is not calculated as an average price over time but from the price given at that moment.

Pricing regarding the hydraulic system comes from HYDSUPPLY as part of a mail correspondence with the company, as shown in (appendix B, 1-2(9)).
The pricing for hydraulics was presented by the company but not investigated future, and no other companies provided any cost estimates regarding hydraulics.

4. RESULTS

In this chapter, each month's potential energy outside Brofjorden is presented and more in-depth how the possible energy changes during a day. Accounting for how much CO2 the vessel will produce from the auxiliary engines and fuel price.

4.1 Potential power from waves outside Brofjorden

The power from a wave can be calculated, within the buoy length month by month 2018, using equation (11), by Yang et al. (2019), the unrefined wave energy and amplitude and frequency from SMHI (2021). The values are calculated from a mean value for frequency and amplitude each month and are displayed as shown in fig.11

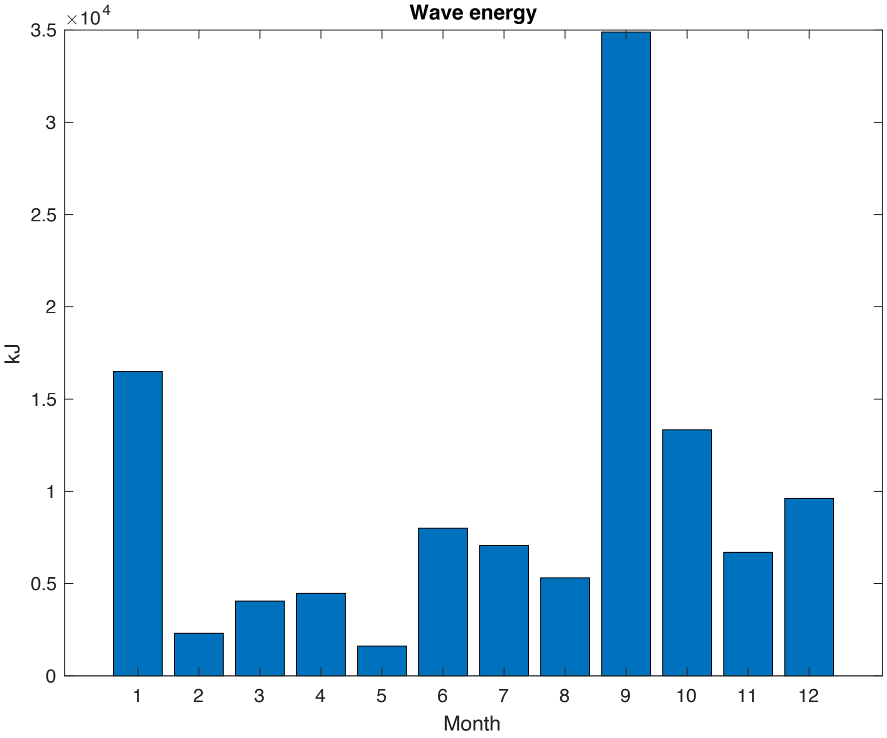


Figure 11: The potential energy from a wave for each month outside Brofjorden (Yang et al., 2019) (SMHI, 2021).

4.2 Potential power from buoys outside Brofjorden

Calculating the mean frequency and amplitude of waves using equations (10), (11), and (12) with an efficiency of 12 % by Ikegami et al. (2018), a computer-based simulation using MatLab (appendix A, 3(6)). The buoy specifications as presented. Added mass of water (ma) is added to submerge the buoy in the water and provide extra weight, as shown by Yang et al. (2019). The efficiency is approximated at 12 % and is based on calculated numbers from Yang et al. (2019). Approximately 250 kg of water is added to each buoy. Mean frequency, time, wave height, wave number, the amplitude of heaving displacement, and measured parameters are calculated from wave frequency, efficiency, and amplitude. The efficiency is calculated from potential wave power to obtained power. When calculating the power following numbers were used, as table 4 shows.

Table 4: Wave amplitude and frequency from SMHI (2021) and presented buoy specification by Sun et al. (2021)

Unit	Numbers
D, diameter	1,8 m
m, mass	200 kg
ma, the mass of water	250 kg
l, length of the buoy	1,8 m
b, buoy width	1,8 m
R, radius of the buoy	0,6 m
H, wave height	Mean value from SMHI (2021) in meters
h, the amplitude of heaving displacement	mean wave amplitude in meters
g, acceleration gravity	9,81 m/s^2
E, efficiency	12 %
raw, seawater density	1 023 kg/m^3

The diagram in fig.12 demonstrates power-input during 2018 outside Brofjorden. The bar represents a mean potential power-input from the mean amplitude and frequency each month with September as the highest power production with a mean value of 37,96 kW and a mean value throughout 2018 at approximately 6,86 kW, as demonstrated in MatLab (appendix A, 3(6)).

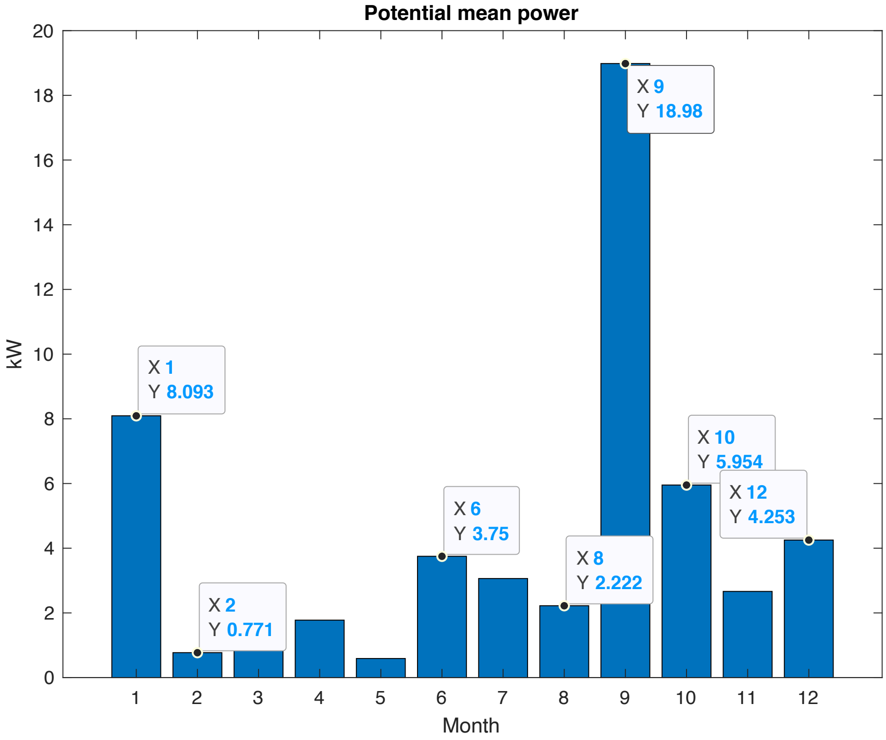


Figure 12: Potential mean power for 30 minutes for each month in 2018 (Yang et al., 2019) (SMHI, 2021).

4.3 June

In this chapter, June 2018 is demonstrated in 720 plotted values in MatLab (appendix A, 4(6)). The line in fig.13 and fig.15 represents a minimum amplitude requirement at 0,45 meters. Waves less than 0,45 meters are considered useless due to very low conversion efficiency, according to Sun et al. (2021). The amplitude can be seen in fig.13. Fig.14 represents the frequency of waves in June 2018 measured each hour for the whole month. Finally, the potential power production is plotted in fig.15 with an approximated line for waves less than 0,45 meters and a mean frequency for the month.

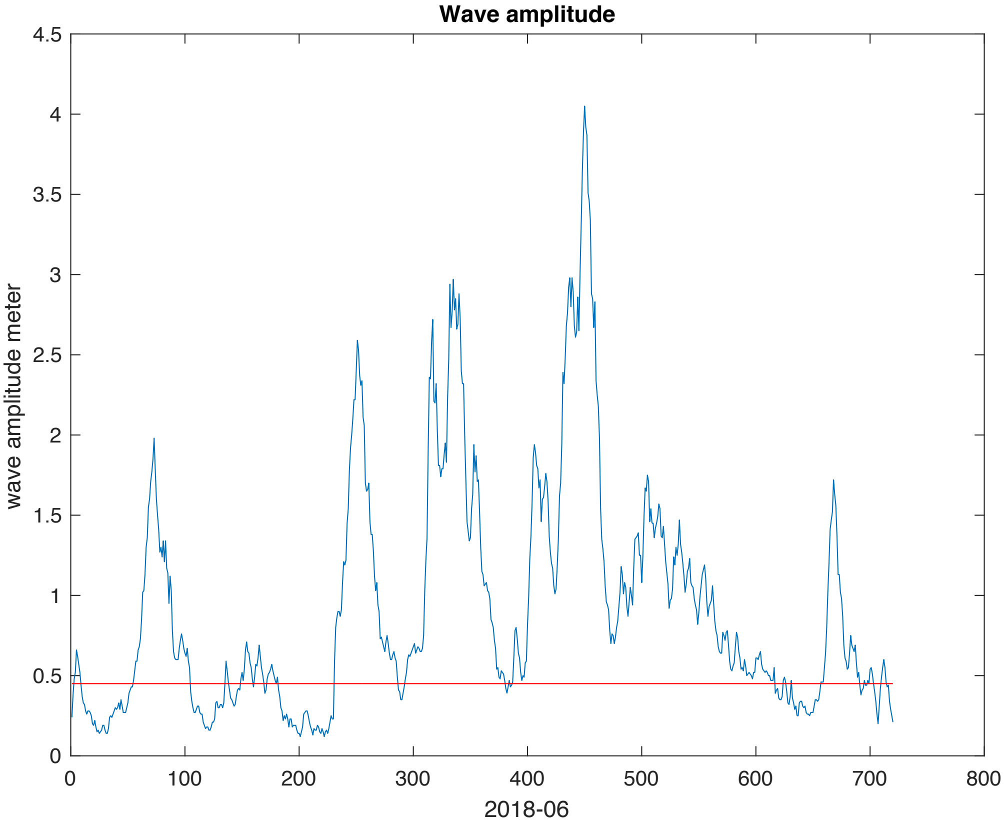


Figure 13: Displays the wave amplitude for June displayed for each hour (Yang et al., 2019) (SMHI, 2021).

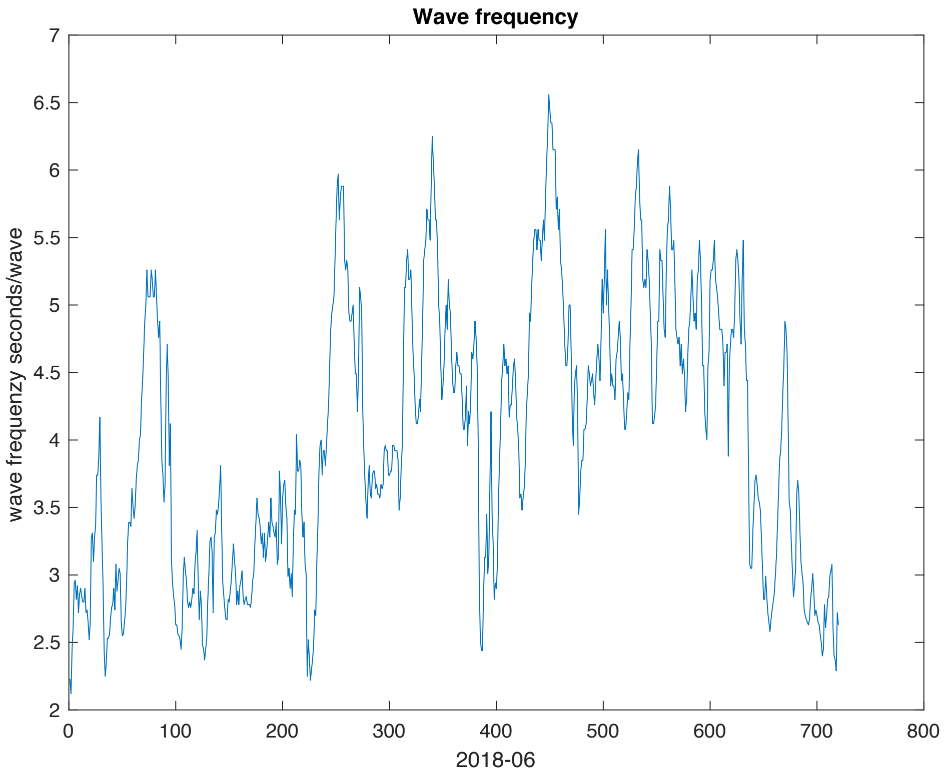


Figure 14: The wave frequency for June 2018 displayed for each hour (Yang et al., 2019) (SMHI, 2021).

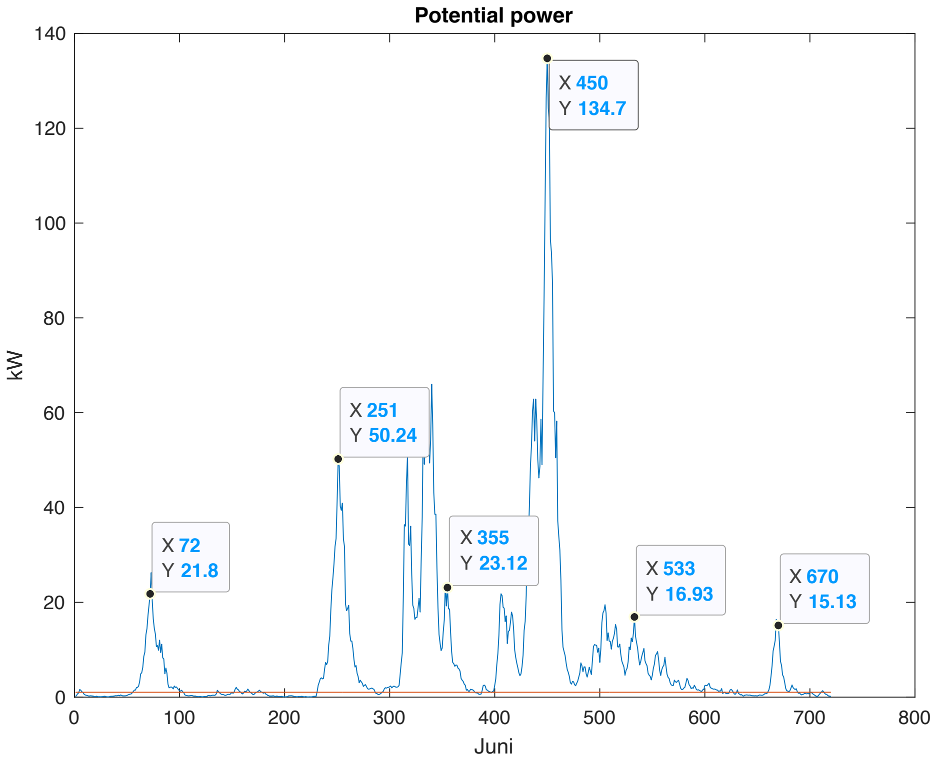


Figure 15: The potential power production for June 2018 (Yang et al., 2019) (SMHI, 2021).

The calculated probability regarding wave amplitude is displayed and validates the mean amplitude over a period.

> "*Normplot superimposes a reference line to assess the linearity of the plot. The line goes through the first and third quartiles of the data*" (MathWorks, 2021).

The probability seen over a month with amplitude in focus is plotted in MatLab (appendix A, 6(6)) and displayed in fig.16.

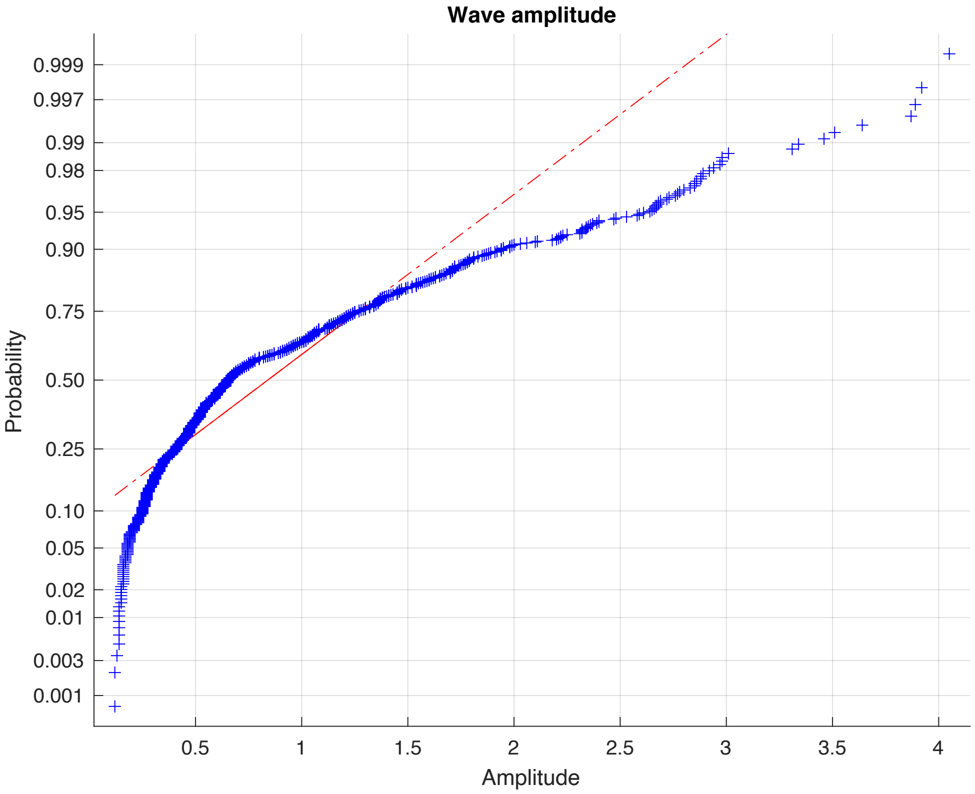


Figure 16: A normal probability plot over waves in June 2018 (Yang et al., 2019) (SMHI, 2021).

4.4 CO2

Using the MGO chemical formula $C_{10}H_{22}$ in equation (14), after combustion, the burnt fuel becomes 10 CO_2, 11 H_20, and 58,48N_2. By first multiplying the molecular weight and then dividing the C02 weight by the total molecular weight. The answer is that the exhaust gas consists of 19 % CO2.

The auxiliary engines on Ramona run at 1500 Rpm to achieve the correct Hz. According to the specific fuel consumption map for Volvo Penta D34A MT (Volvo Penta, 2004), brake specific fuel consumption (BSFC) is 215 g/kWh. To supply the vessel, which needs around 120 kW per hour, the vessel consumes 25,80 kg of fuel per hour, which gives an emission of 4,9 kg CO2 per hour. Therefore, the fuel cost to run the auxiliary engines for one hour will be 14 USD.

4.5 Result for approximated cost

When the WEC -system is designed with 20 buoys, and each buoy needs its own hydraulic cylinder and piston, the generator and motor can be shared. With nine accumulators, the cost will be 1,731 million Swedish kronor (SEK). As mentioned in method discussion chapters 5.5 and 5.4, this cost is not considered reliable but a good measuring point for the report.

The WEC -system needs to run for approximately 14 500 hours to make up for costs before turning a profit when comparing it to fuel cost.

5. DISCUSSION

This chapter discusses the result, method, surrounding hydraulics, WEC economics, environmental, application, and how the method regarding numbers and literature were used.

5.1 Result discussion

With processed data from two different articles regarding energy productions using the FABWEC system and calculating the numbers both from wave amplitude and frequency from SMHI (2021) and based on mathematical formulas from Sun et al. (2021), Ikegami et al. (2018), and Yang et al. (2019) the system seems to be able to produce a reasonable amount of potential energy a wave can contain. Although, calculations regarding September do not add up to a reasonable amount of energy. The value in September is ruled as an uncertain amount.
The calculation made in this article can give an approximated and potential amount of energy that a WEC can convert mounted on M/T Ramona. However, the system will create some losses and/or factors that can gain more energy that cannot be calculated. For example, the AVD is calculated at a fixed point of T_e /5. Therefore, these amounts will be discarded as it does not seem to be significant.

The hydraulic system cost is only approximated by HYDSUPPLY and only used to compare to the environmental gains. Therefore, more than one supplier should look at the order to get a proper cost estimate.
If a shipping company installs a WEC-system onboard, they will potentially receive a lot of attention and commercial benefits. This shows that the shipping company is progressive and takes global warming seriously. In addition, because Ramona transports oil, it will be more attractive for these kinds of solutions. Therefore, it will look better for the oil companies to choose a greener alternative for marine trafficking.

Since the WEC-system is a relatively simple system and the components are less expensive, this will not be a costly system to install. The buoys are made of metal, and a hydraulic system is easy to install. The estimation for the hydraulic cost ended up at 1,731 million SEK, which only covers the hydraulics and not the buoy itself. The price for the hydraulic system seems high and can, by all means, be lower. M/T Ramona will probably have some of the components needed for this type of installation such as transformers, a fully equipped electrical grid, and generators.

The WEC has a mean potential power production at approximately 6,86 kW every hour, all year around. Although if broken up month by month, the WEC can only produce enough during January, September, and October. Those monthly average amplitude and frequency could supply the vessel with enough power. About 80 kW are produced in June and December, about 66 percent of what is required. While in February and May, the WEC-system can produce 14 kW, which corresponds to approximately 11 percent. These numbers considered the WEC fitted on M/T Ramona has a low power conversion and might be problematic for shipping companies as they need a 100% of power demand at all times.

5.2 Hydraulic discussion

The hydraulic fluid that we use in this model was a problem for Yang et al. (2019) doing the FABWEC-test because of the toxicity in hydraulic fluid and the use of a barge as a test platform. This would not be a problem for M/T Ramona since it is a chemical tanker and knowledge about toxic fluids is their job. However, M/T Ramona is a larger vessel than what was used in the FABWEC-test and therefore can hold more buoys and perhaps bigger ones than the platform that was used in the FABWEC-test and in this article. In addition, the crew and company are used to systems surrounding hydraulics and dealing with hazardous chemicals such as hydraulic oil. This has potentially a positive effect on the efficiency of the WEC-system.

5.3 WEC discussion

As shown by Yang et al. (2019), there is a possibility for power-production regarding the wave size and frequency outside Brofjorden as it is comparable to amplitude and frequency during the FABWEC-test.

The equations do not consider the fact that there is an upper limit on how high the waves can produce more power. If they are too high, the waves will wash over the buoys. In September, the mean wave amplitude was almost 2 m which gives 120 kW according to the equations, and we do not consider this to be reasonable. This is because we used the same type of system as in the FABWEC test. The upper limit in the FABWEC test, as shown by Yang et al. (2019), was approximately 2 meters. The upper limit can be pushed because M/T Ramona is a larger vessel, but wave height in September may be too high. To know exactly where the limit is, a sea trail test needs to be conducted.

Calculating the potential energy that can be harvested the mean amplitude and frequency for a whole year, will sum up approximately 17,49 buoys.
If the vessel runs on a WEC-system instead of the auxiliary engines, it does not need the same amount of electrical power. The auxiliary engine room has no need for air conditioning, and the auxiliary engine cooling, fuel, and lube oil pumps do not need to run. Exactly how much less electrical power is difficult to predict due to weather conditions and cargo. The vessel needs approximately 120 kW from the auxiliary engines. When the WEC-system produces the same amount of energy, there is a margin for when several other systems start simultaneously.

5.4 Economical, environmental and application discussion

Fitting this many buoys to a vessel the size of Ramona will be demanding but not impossible. This will create some losses in propulsion and add weight to the vessel, but this is not taken into consideration in this article.

If the vessel runs on the WEC-system and the waves decrease and becomes too small to produce enough power to run the vessel, the auxiliary engines will be on standby and take over the vessel's supply.
When BSFC is calculated on the auxiliary engines and the optimal point of fuel consumption is used. In reality, the fuel consumption will be slightly higher due to the difference in load and power output. Therefore, the WEC system will potentially save 14 USD per hour in fuel cost. Nevertheless, running hours will be less on the auxiliary engines and therefore not require as much maintenance, and potentially saving money for the company.

When seeing the result and knowing that vessels need to take responsibility for their CO2 emissions, the project needs more testing in a real-life model mounted on a vessel.
Goal 14 Life below water states that "30 percent of CO2 produced by humans ends up in the water" (Ferri, 2010). Thus, the ocean is a big part of the ecosystem, and if the FABWEC-system can help reduce CO2 emission, this will have a positive impact on developing a sustainable future.

The shipping industry is growing, and more transports are made using larger marine vessels, according to (Cao et al., 2021). Therefore, the greenhouse emissions increase with a more extensive fleet and heading in the wrong direction considering emissions. The WEC can be a step in the right direction for modern shipping.
Marine traffic needs to be a part of the solution instead of creating new solutions for future generations.
This brings us back to the cost for the system and comparing it to the environmental and economic costs of MGO. The WEC-system is clearly a greener way to produce energy compared to the combustion of MGO. CO2 emissions from a WEC are zero.

Since the WEC-system is a relatively simple system and the components are not considered expensive, this will not be a high-cost system to install. The buoys are made of metal, and a hydraulic system is easy to install. The most expensive part to install is the generator, but onboard system may cover that need and the possibility to integrate it into another system.

5.5 Method discussion

The case study revolves around gathering qualitative data and selecting the relevant research to the subject (Boreus, 2015 pp.184-185). The case study allows us to research a wave energy converter fitted on M/T Ramona and study the potential power production from a theoretical perspective. The vessel is of a common size and type, and hopefully, the application of the FABWEC can be used on a larger scale for vessels of the same size.
However, on the downside, we only studied waves outside Brofjorden and were specific in our choice of WEC and vessel. The case study has its weakness in the amount of data gathered, which is true in this study. The study only gathered data on M/T Ramona and FABWEC-system. However, in the early stages of the study, the authors looked at different types of wave energy converts and selected one that had, according to the authors, a higher chance of working. The authors also had mail correspondence with Wave4Power discussing several different ways of converting energy (see appendix B, 3-6(9)).

The earlier test was made by Yang et al. (2019) and gave us numbers to validate the reliability of the study. Nevertheless, the result in this study is based on numbers and not a real-life test and therefore has lower credibility than a real-life test.

The aim is to research the possibility of a WEC attached to M/T Ramona and its potential to produce energy for the vessel when at anchor.
The hope for the study was to prove how much energy the WEC could produce and supply the vessel with when it was at anchor. However, researching the WEC -system on M/T Ramona shows that it is a generalization for all vessels of the same size, shape, and function.

Building and applying the system on the vessel to demonstrate what costs will occur is considered redundant for this study. The cost is calculated for hydraulics and machinery is only an approximation of the system's total cost. This makes the researched cost not thoroughly investigated. The calculations regarding emissions of CO2 are theoretically calculated through the formulas given by Heywood (2019) and gives us the tools to approximate CO2 from M/T Ramona's auxiliary engines. This approximation is considered near actual emission production and a reliable source.

When researching the potential energy production of a WEC, we looked at a number of functions, such as WEC power stations at sea. However, we found out that the main problem was the vessel's ability to anchor without assistance. Therefore, the FABWEC system developed by Yang et al. (2021) looked like the most likely solution than the examples given in the handbook for WEC (Pecher & Kofoed, 2017).

When calculating potential energy production with the help of equations provided by Ikegami et al. (2018) but also looked at Sun et al. (2021) on efficiency, WEC shape, and construction to evaluate the best solution for M/T Ramona.
The calculations can be validated as shown in chapter 2.5.1 with the real-life FABWEC test by Yang et al. (2019) and shown in (appendix B, 1-6 (6)).

6. CONCLUSIONS

- The potential amount of electrical power a wave energy converter can produce when fitted on M/T Ramona outside Brofjorden.

M/T Ramona needs to install 20 buoys to reach the point of when it can produce enough power to supply the whole vessel, as shown with the calculated 2018 yearly average amplitude and frequency of the waves. This will give the vessel approximately 6,86 kW every hour per buoy all year around. This is calculated for each buoy, and if buoys are added, the power production is potentially more. However, as shown in the result, the system is only fully functional for three months every year.

- When does the system turn a profit, considering CO2 and the cost of the system?

If a vessel is at anchor and runs on the WEC-system for a whole day, it will reduce the CO2 emission by 118 kg. However, the vessel will potentially save 619 kg of fuel and 336 USD.

When reaching approximately one meter in wave amplitude and frequency greater than three seconds, the system produces enough to validate a sea trial. The potential power production is significant enough during these conditions to support a vessel the size of M/T Ramona.

The calculated cost that is given by HYDSUPPLY and ended up at 1,731 million SEK for the hydraulic system and generator.
This cost assessment came from one company and only to gives us an idea of what to expect.
Although it is a lot of money comparing it to environmental gain, it is a low cost.
Considering this, the system is not profitable when environmental gains are not included because it does not turn a profit until after 14 500 hours. However, when environmental gains are included, the system still does not turn a profit, but it will produce zero emission and provide for a sustainable future.

6.1 Recommendations for further research

The added weight to a vessel and how M/T Ramona will perform in water after an installation. The power produced can be converted in a number of ways, and efficiency may be improved.

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APPENDIX

This chapter contains the various code and table structures appendix A and the mail correspondence with HYSUPPLY and Wave4Power in appendix B.

Appendix A

The MatLab code and variables that were used when calculating results and theory.

Mean wave amplitude and buoy energy

```
%% Boj energi
medel2 = [v1 v2 v3 v4 v5 v6 v7 v8 v9 v10 v11 v12]; % significant
medelf2 = [f1 f2 f3 f4 f5 f6 f7 f8 f9 f10 f11 f12];

D = 1.2;
m = 200;
ma = 250;
l = 1.8;
b = 1.8;
L = 8;
R = 0.6;
t = 3600;
T = sum(medelf2)/12;
x = 900;
H = medel2;
k = (2*pi)./L;
w = (2*pi)./T;
v = medel2./medelf2;
h = abs(sum(medel2)/12);
raw = 1023;
g = 9.81;

n = (1/16).*raw.*g.*H.^2.*L.*b;
%(H/2)*(cos(k*x-w*t));
a = abs(R-(h-n));
%Abw = (pi.*D.^2)/4;
%Abw = 2.16;
Abw = abs(2*l*(sqrt(2*a*R-(a.^2))));
%(pi*D.^2)/4;

Ek = ((1/2).*((m+ma).*v.^2)+(1/8).*raw.*g.*Abw.*h.^2).*10.^-5;
Ei = (1/8).*raw.*g.*H.^2.*L.*b;
E = 0.25;
PEk = round(Ek.*E);
PEK10 = round(Ek.*E).*10;
figure
bar(PEk)
title('Power projected 2018')
ylabel('kWh')
xlabel('Months')


b = (12260-3944)/12;
% 1
y1 = hojd(3944:4637);
v1 = (sum(y1))/b;
% 2
y2 = hojd(4637:5330);
v2 = sum(y2)/b;
```

```
% 3
y3 = hojd(5330:6023);
v3 = sum(y3)/b;
% 4
y4 = hojd(6023:6716);
v4 = sum(y4)/b;
% 5
y5 = hojd(6716:7409);
v5 = sum(y5)/b;
% 6
y6 = hojd(7409:8102);
v6 = sum(y6)/b;
% 7
y7 = hojd(8102:8795);
v7 = sum(y7)/b;
% 8
y8 = hojd(8795:9488);
v8 = sum(y8)/b;
% 9
y9 = hojd(9488:10181);
v9 = sum(y9)/b;
% 10
y10 = hojd(10181:10874);
v10 = sum(y10)/b;
% 11
y11 = hojd(10874:11567);
v11 = sum(y11)/b;
% 12
y12 = hojd(11567:12260);
v12 = sum(y12)/b;

% medel
medel = (v1+v2+v3+v4+v5+v6+v7+v8+v9+v10+v11+v12)/12;

v = [v1 v2 v3 v4 v5 v6 v7 v8 v9 v10 v11 v12 medel];
x = [1 2 3 4 5 6 7 8 9 10 11 12 13];

%removeExtraNanSeparators(x,v)
figure
bar(x,v)
title('Waves')
xlabel('Month')
ylabel('wave amplitude meter')
```

Mean wave frequency

```
b = (12260-3944)/12;
% 1
x1 = frek(3944:(3944+b));
f1 = sum(x1)/b;
% 2
x2 = frek((3944+b):5330);
f2 = sum(x2)/b;
% 3
x3 = frek(5330:6023);
f3 = sum(x3)/b;
% 4
x4 = frek(6023:6716);
f4 = sum(x4)/b;
% 5
x5 = frek(6716:7409);
```

```
f5 = sum(x5)/b;
% 6
x6 = frek(7409:8102);
f6 = sum(x6)/b;
% 7
x7 = frek(8102:8795);
f7 = sum(x7)/b;
% 8
x8 = frek(8795:9488);
f8 = sum(x8)/b;
% 9
x9 = frek(9488:10181);
f9 = sum(x9)/b;
% 10
x10 = frek(10181:10874);
f10 = sum(x10)/b;
% 11
x11 = frek(10874:11567);
f11 = sum(x11)/b;
% 12
x12 = frek(11567:12260);
f12 = sum(x12)/b;

% medel
medelf = (f1+f2+f3+f4+f5+f6+f7+f8+f9+f10+f11+f12)/12
% v = [2 3 3 4 3 5 6 6 4 5 6 3];
vf = [f1 f2 f3 f4 f5 f6 f7 f8 f9 f10 f11 f12 medelf];
x = [1 2 3 4 5 6 7 8 9 10 11 12 13];

%removeExtraNanSeparators(x,v)

bar(x,vf)
title('Waves')
xlabel('Month')
ylabel('wave frequenzy seconds/wave')
```

Potential mean wave power

```
medel2 = [v1 v2 v3 v4 v5 v6 v7 v8 v9 v10 v11 v12]; % significant
medelf2 = [f1 f2 f3 f4 f5 f6 f7 f8 f9 f10 f11 f12];

H = medel2;
T = medelf2;
b = 30;
l = 1.8;
n = 1;
L = n.*l.*sin(b/2);
E = 0.12;
Pwave = ((raw.*g.^2)/(864.*pi)).*H.^2.*T.*L;
Pwave2 = (Pwave.*E)/5;

figure
bar(Pwave2)
title('Potential mean power')
xlabel('Month')
ylabel('kW')

figure
bar(Pwave)
title('Figure')
xlabel('Month')
ylabel('kW')
```

Potential mean power June

```
%% juni
A=datetime(2018,06,01);
B=duration(0,60,1);
jv=Juniv(1:720);
jf=Junif(1:720);
x=linspace(1,720,720);
y=linspace(0.45,0.45,720);
figure
normplot(jv)
title('Wave amplitude')
xlabel('Amplitude')
figure
plot(x,jv)
title('Wave amplitude')
xlabel('2018-06')
ylabel('wave amplitude meter')
hold on
plot(x,y,'r')
figure
plot(x,jf)
title('Wave frequency')
xlabel('2018-06')
ylabel('wave frequenzy seconds/wave')

medel = jv; % significant
medelf = jf;
t=sum(jf)/720;
x=linspace(1,720,720);
H = medel;
h=0.45;
T = medelf;
b = 30;
l = 1.8;
n = 1;
L = n.*l.*sin(b/2);
E = 0.15;
P= ((raw.*g.^2)/(864*pi)).*h.^2.*t.*L;
P2 = P*E/5;
PwaveS = ((raw.*g.^2)/(864*pi)).*H.^2.*T.*L;
Pwave2S = PwaveS*E/5;
P21=linspace(P2,P2,720);

figure
plot(x,Pwave2S)
title('Potential power')
xlabel('Juni')
ylabel('kW')
hold on
plot(x,P21)
```

Potential mean power per day

```
v=Dagv(1:24);
f=Dagf(1:24);

A=duration(24,0,0);
B=duration(0,60,1);
x=linspace(A,B,24);
y=linspace(0.45,0.45,24);
figure
plot(x,v)
title('Wave amplitude')
xlabel('2018-09-06')
ylabel('wave amplitude meter')
hold on
plot(x,y,'r')
figure
plot(x,f)
title('Wave frequency')
xlabel('2018-09-06')
ylabel('wave frequenzy seconds/wave')
v=Dagv(1:24);
f=Dagf(1:24);
```

Normplot of wave amplitude

```
A=datetime(2018,06,01);
B=duration(0,60,1);
jv=Juniv(1:720);
jf=Junif(1:720);
x=linspace(1,720,720);
y=linspace(0.45,0.45,720);
figure
normplot(jv)
title('Wave amplitude')
xlabel('Amplitude')
figure
plot(x,jv)
title('Wave amplitude')
xlabel('2018-06')
ylabel('wave amplitude meter')
hold on
plot(x,y,'r')
figure
plot(x,jf)
title('Wave frequency')
xlabel('2018-06')
ylabel('wave frequenzy seconds/wave')

medel = jv; % significant
medelf = jf;
t=sum(jf)/720;
x=linspace(1,720,720);
H = medel;
h=0.45;
T = medelf;
b = 30;
l = 1.8;
n = 1;
L = n.*l.*sin(b/2);
E = 0.15;
P= ((raw.*g.^2)/(864*pi)).*h.^2.*t.*L;
P2 = P*E/5;
PwaveS = ((raw.*g.^2)/(864*pi)).*H.^2.*T.*L;
Pwave2S = PwaveS*E/5;
P21=linspace(P2,P2,720);

figure
plot(x,Pwave2S)
title('Potential power')
xlabel('Juni')
ylabel('kW')
hold on
plot(x,P21)
```

Appendix B
Mail Correspondence with HYDSUPPLY, Johan Sundman

Viktor Bohman:

Hej! Vi är två killar på Chalmers som skriver vårt ex-jobb om wave Energy converters. Vi har modellerat rent teoretiskt ett system som driv med hjälp av hydraulik ackumulatorer och undrar om det finns någon möjlighet om vi skulle kunna få ett ca pris på vad en anläggning med ca 5 ackumulatorer ca 300 bar, hydraulik driven turbin samt en generator. Skulle vara till stor hjälp för oss.

Priset behöver bara vara så att vi får ett hum om ungefär vilka kostnader ett sån system kommer att ha.

Johan Sundman:

Hej,

Roligt att ni gör ett ex-jobb som inkluderar hydraulik,
För att kunna offerera behöver vi lite mer uppgifter,
Vilken volym behöver ni?
Vad har ni för anslutningar?
Vilken typ av ackumulatorer är det ni räknat på?
Har ni ett hydraul schema att skicka över så kan vi se om vi kan hjälpa er.

Med vänlig hälsning/ Kind regards

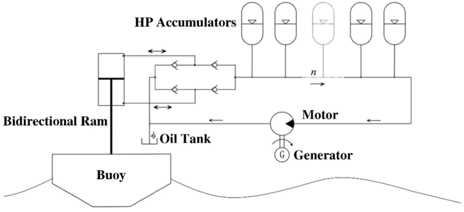
Ronald Modde Blomgren
Platschef/ Site manager
Tel +46 (0)31 745 88 10 | ronald.blomgren@hydsupply.se

Hydsupply AB
Ruskvädersgatan 6, SE-418 34 Göteborg, Sweden
www.hydsupply.se | a part of Volito Automation AB

Viktro Bohamn:

Tack för snabbt svar.

Denna del av vårt arbete är tyvärr inte så grundligt utfört men en grovskiss kommer att se ut såhär.



Kopplingar kommer nog förmodligen att bli av modellen snabbkoppling 1”
Volymen är jag dock lite osäker på. Detta system kommer att vara monterat på ett fartyg och på så sätt så kan volymen vara stor. Men som sagt inte gått in på djupet i det.

Hade gärna skickat arbetet men filen blir lite för stor att skicka digitalt.

Med vänlig hälsning, viktor

Johan Sundman:

Hej Victor
Kul examensarbete ni siktat in er på…
Här, ett kostnadsspann att förhålla sig till, mellan tumme och pekfinger.
Förväntat pris (exklusive moms) för:
-Kolvackumulator 10 liter a´ ca 15000 sek/styck
-Generator 7KVA a` ca 90000 sek.
-Cylinder Sy kolvstång a` ca 70000 sek
-Motor a` ca 30000 sek
-Ledningskomponenter a` ca 12000 Sek

Tillkommer: Övrigt
Avgår: Enligt överenskomna priser efter eventuella rabatter å annat.

Hoppas detta kan vara till nytta för ert arbete.
Lycka till

Thomas Sundman
Servicetekniker
Tel +46 (0)31 745 88 12 | thomas.sundman@hydsupply.se

Hydsupply AB
Ruskvädersgatan 6, SE-418 34 Göteborg, Sweden
www.hydsupply.se | *a part of Volito Automation AB*

Mail correspondence with Wave4Power, Jonas Kamf CEO

Viktor & Jonas:

Hej!

Vi är två killar som studerar på Chalmers och ska skriva vårt examensarbete i vår.
Vi har tänkt att undersöka möjligheten att bära med sig en av era enheter ombord på fartyg för att kunna alstra el när man ligger ankrad.
Vi undrar med detta om det finns någon möjlighet att göra studiebesök hos er eller kanske få ta del av material. Med rådande omständigheter så är kanske ett zoom-möte mer aktuellt.

Med vänlig hälsning, Viktor Bohman & Jonas Daglund (Sjöingenjör, Chalmers)

Jonas Kamf:

Hej Viktor

Tack för intressant förfrågan.
Vår enhet är lite stor att bära med sig. Systemet som testades ute vid Runde i Norge är relativt litet i havet men ändå ganska stort. Bojen är 8 meter i diameter och accelerationsröret är ca 35 meter långt med en diameter på 3,5 meter. Vikten på en WaveEL 4.0 boj är ca 45 ton. Alltså ingenting man bär med sig. Däremot kan man tänka sig att lägga vågkraftsbojar på ankringsplatser för fartyg som ligger och väntar på redden. Ett bra sätt att säkra strömförsörjningen. Men då talar vi om permanenta "tankningsstationer för el".
Så innan jag kan säga om detta är intressant eller inte för oss så skulle jag vilja höra mer om hur ni har tänkt er projektet och vad ni har för mål med arbetet.
Kostnaden för ett system är ca 5 MSEK så det är ingenting vi har liggande på lager.

Med vänlig hälsning

Jonas Kamf
CEO

W4P Waves4Power AB
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433 23 Partille
Sweden

Phone: +46 31 757 04 01
Mobile: +46 70 664 36 25
E-mail: jonas.kamf@waves4power.com
LinkedIn: http://www.linkedin.com/in/jonaskamf
www.waves4power.com

Viktor & Jonas:

Tack för snabbt svar och riktigt bra info.

Den var som du säger alldeles för stor för att ta med sig. Finns det mindre modeller, hur mycket alstrar denna typen(på ett ungefär).
Så en frågeställning kanske skulle vara om det går att ta fram en modell som passar för fartyg. Hur stor måste den vara, för att försörja fartyget eller delar av driften ombord?
Hur mycket skulle detta spara fartygen i form av bränsle och CO2 utsläpp samt kostnad.

Ja det är också ett altrenativ vi tänkt på. Att man använder den mer som en ladd-station. Men då kommer frågan upp hur man skulle koppla sig till bojen.

Här kommer också vår frågeställning att kretsa kring fördelarna för fartyg och man kan driva fartyg grönare, hur mycket mindre CO2 som tex släpps ut i Göteborgs hamn. Vad kommer det kostnadsmässigt betyda för redare.

Med vänlig hälsning, Viktor Bohman & Jonas Daglund

Jonas Kamf:

Hej Viktor

Det är inte så enkelt att ta fram en mindre modell som gör jobbet.
Storleken på den kraftgenererande bojen är anpassad efter det rådande vågklimatet på den plats där den ska ligga. Dvs diametern ska vara anpassad till våglängden så att bojen vare sig är för stor eller för liten. Är den för stor så gungar den inte på rätt sätt och är den för liten så innebär det att fler vågor bara sköljer över utan att göra sitt jobb.

När jag ser en elstation för fartyg så är det en WaveEL park som klarar av att försörja flera fartyg på en gång. Varje boj är kopplad till en central hub och från hubben går det kopplingar dit fartygen kan koppla in sig. Dynamiska kablar som klarar rörelserna i havet (finns redan som patent från NKT). När inga fartyg är på plats eller få fartyg så dirigeras strömmen om till annan användning, allt för att utnyttja strömproduktionen maximalt.

Hur mycket ström talar vi om för ett fartyg som ligger på vänt?

Jonas Kamf:

CEO

W4P Waves4Power AB
Laxfiskevägen 8
Box 166
433 23 Partille
Sweden

Phone: +46 31 757 04 01
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E-mail: jonas.kamf@waves4power.com
LinkedIn: http://www.linkedin.com/in/jonaskamf
www.waves4power.com

Hej igen

En sak till. En WaveEL boj med en installerad effekt av 250 kW producerar ca 500 MWh per år (8 meters boj).
Målet är, att när volymerna ökar, komma ner i en LCOE (levelized cost of electricity) som ligger i paritet med eller under landbaserad vind.

Jonas Kamf:

CEO

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LinkedIn: http://www.linkedin.com/in/jonaskamf
www.waves4power.com

Viktor & Jonas:
Vill bara tacka att du tar dig tid och svara på frågor.

Det störst containerfartygen behöver effekter på ca 6 MW. Medans färjor ligger runt 4 MW.

Idén med ladd-station är riktigt intressant. Vår frågeställningar för tillfället är,

Hur mycket CO2 skulle vi kunna minska? Vad skulle den totala kostnaden bli? Hur skulle tekniken funka?

Skulle vara väldigt bra om vi kan bolla fler frågor med dig under tidens gång.

Med vänlig hälsning, Viktor Bohman & jonas Daglund

Jonas Kamf:

Hej Viktor

En boj med en installerad effekt av 250 kW producerar ca 500 MWh av elektricitet per år. Detta innebär en besparing på mellan 400 – 500 ton av CO_2 utsläpp per år jämfört med att bränna diesel eller olja. En WaveEL park med en installerad effekt på ca 10 MW motsvarar 40 st WaveEL bojar. Som det ser ut idag. Antalet bojar avgörs naturligtvis av hur vågklimatet ser ut på platsen.

Viktor & Jonas:
Okej, det låter ju riktigt bra! Vi ska ta ett snack med vår handledare och kolla hur han vill att frågeställningen ska se ut.

Med vänlig hälsning, Viktor Bohman & Jonas Daglund

Jonas Kamf:

Hej

En WaveEL boj har en beräknad ekonomisk livslängd på minst 25 år.
Vi räknar med att den fasta kostnaden utgör 75% av totalkostnaden och service, underhåll och borttagning står för 25%. Priset per boj kommer signifikant att minska när produktionsvolymen ökar – economy of scale.

Exempel:
En boj kostar installerad 5.000.000 SEK
Service och underhåll etc. ca 1.600.000 SEK

Totalkostnad: 6 600 000 SEK
Obs att detta bara är ett räkneexempel.

Beroende på vågklimat så kan en boj spara upp till 500 ton CO_2utsläpp per år jämfört med att bränna diesel eller olja.

Kind regards/Med vänlig hälsning

Viktor & Jonas:

Hej igen!

Nu har vi spånat lite kring detta! Och detta har vi skickat till vår handledare.
Vad tror du att våra problem kommer att vara? Vad är beräknad livslängd och underhållskostnad för en boj. Mellan tumme pekfinger.

Ja men precis, Hur mycket kan vågkraft reducera koldioxidutsläpp för ankar-liggande fartyg?

Samt vad i kronor detta kommer att kosta per dag per kWh.

Jag tror att vi är något på spåret här Mats. Att det bir mer generellt.

Kan undersökningen vara att OM vi kan koppla till en boj så här mycket kan vi reducera?

Eller till en hub där energin från flera bojar samlas?

Men i alla fall. Där har vi en hel del att undersöka. Dels vad det skulle kosta att får igång anläggningen. Hur mycket två eller tre fartygstyper förbränner/utsläpp när de ligger ankrade. Hur mycket bojar kan producera. Vad kostnaden för en livslängd på en boj. Och om vi har plats vilka väderförhållanden krävs.

Med vänlig hälsning, Viktor Bohamn & Jonas Daglund

Jonas Kamf:

Hej Viktor

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Skulle vara väldigt bra om vi kan bolla fler frågor med dig under tidens gång.

Med vänlig hälsning, Viktor Bohman & jonas Daglund

Jonas Kamf:

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När jag ser en elstation för fartyg så är det en WaveEL park som klarar av att försörja flera fartyg på en gång. Varje boj är kopplad till en central hub och från hubben går det kopplingar dit fartygen kan koppla in sig. Dynamiska kablar som klarar rörelserna i havet (finns redan som patent från NKT). När inga fartyg är på plats eller få fartyg så dirigeras strömmen om till annan användning, allt för att utnyttja strömproduktionen maximalt.

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Viktor & Jonas:

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Den var som du säger alldeles för stor för att ta med sig. Finns det mindre modeller, hur mycket alstrar denna typen(på ett ungefär).
Så en frågeställning kanske skulle vara om det går att ta fram en modell som passar för fartyg. Hur stor måste den vara, för att försörja fartyget eller delar av driften ombord?
Hur mycket skulle detta spara fartygen i form av bränsle och CO2 utsläpp samt kostnad.

Ja det är också ett altrenativ vi tänkt på. Att man använder den mer som en ladd-station. Men då kommer frågan upp hur man skulle koppla sig till bojen.

Här kommer också vår frågeställning att kretsa kring fördelarna för fartyg och man kan driva fartyg grönare, hur mycket mindre CO2 som tex släpps ut i Göteborgs hamn. Vad kommer det kostnadsmässigt betyda för redare.

Med vänlig hälsning, Viktor Bohman & Jonas Daglund

Jonas Kamf:

Hej Viktor

Tack för intressant förfrågan.
Vår enhet är lite stor att bära med sig. Systemet som testades ute vid Runde i Norge är relativt litet i havet men ändå ganska stort. Bojen är 8 meter i diameter och accelerationsröret är ca 35 meter långt med en diameter på 3,5 meter. Vikten på en WaveEL 4.0 boj är ca 45 ton. Alltså ingenting man bär med sig. Däremot kan man tänka sig att lägga vågkraftsbojar på ankringsplatser för fartyg som ligger och väntar på redden. Ett bra sätt att säkra strömförsörjningen. Men då talar vi om permanenta "tankningsstationer för el".
Så innan jag kan säga om detta är intressant eller inte för oss så skulle jag vilja höra mer om hur ni har tänkt er projektet och vad ni har för mål med arbetet.
Kostnaden för ett system är ca 5 MSEK så det är ingenting vi har liggande på lager.

Viktor & Jonas:

Hej!

Vi är två killar som studerar på Chalmers och ska skriva vårt examensarbete i vår.
Vi har tänkt att undersöka möjligheten att bära med sig en av era enheter ombord på fartyg för att kunna alstra el när man ligger ankrad.
Vi undrar med detta om det finns någon möjlighet att göra studiebesök hos er eller kanske få ta del av material. Med rådande omständigheter så är kanske ett zoom-möte mer aktuellt.

Med vänlig hälsning, Viktor Bohman & Jonas Daglund (Sjöingenjör, Chalmers)

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