Feasibility study and cost-benefit analysis of the DUAL Ports Heat project.

- Feasibility of wave energy convertor at the Port of Hvide Sande

Conducted on behalf of the Port of Hvide Sande by GEMBA Seafood Consulting as a part of the Interreg North Sea Region project, DUAL Ports.

2021

Interreg North Sea Region DUAL Ports
European Regional Development Fund
EUROPEAN UNION

HVIDE SANDE HAVN

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1. Executive summary and recommendations

The table below summarize the findings of the feasibility study.

Summary

- Average annual wave power is rather low (at <10 kW/m) compared to other areas in Europe.

- The sea area near Hvide Sande is highly suitable for Weptos WEC units.

- The study shows that electricity produced from a WEC unit (Weptos in this study) is not economically viable compared to a land or sea wind turbine. It is currently more expensive than wind energy.

- The cost of producing 1 MWh with four WEC units is estimated to 173 €/MWh.

- A reduction of the energy production cost with a WEC unit may be reached through:
    - Increased commercialisation of WEC units
    - Increase in the energy output of a WEC unit.
    - Get subsidies (to CAPEX and/or OPEX) through national energy programmes, similar to aid structure that wind turbines had between 1980-2019.

- It is expected that, as the technology matures and economies of scale are achieved, the economic feasibility of the technology is improved, making it more competitive due to reduced costs.

- With significant national aid (subsidies) to a WEC's CAPEX and OPEX, the cost of producing electricity can be reduced to 108 €/MWh

Recommendation

- It is not recommended to invest in the any wave energy converter, as the analysis has shown that costs of wave energy production is too high and cannot compete with other renewable energy such as wind and solar energy

2. Introduction and structure of the feasibility study

The reasoning behind the assessment of new energy concepts is anchored in the green transition of the town of Hvide Sande and lead by the port and district heating (Hvide Sande Havn and Hvide Sande Fjernvarme A.m.b.A).

Hvide Sande has for many years moved towards a green transition and introduced wind turbines and a solar park to reduce their reliance on non-renewable energy, mainly natural gas.

In 2018 three wind turbines were added to the district heating administration in addition to the solar heating, which enabled the heat production to reduce its dependence on natural gas by 83 %. In 2020 a heat pump has been installed that reduces the dependency on fossil energy even further.

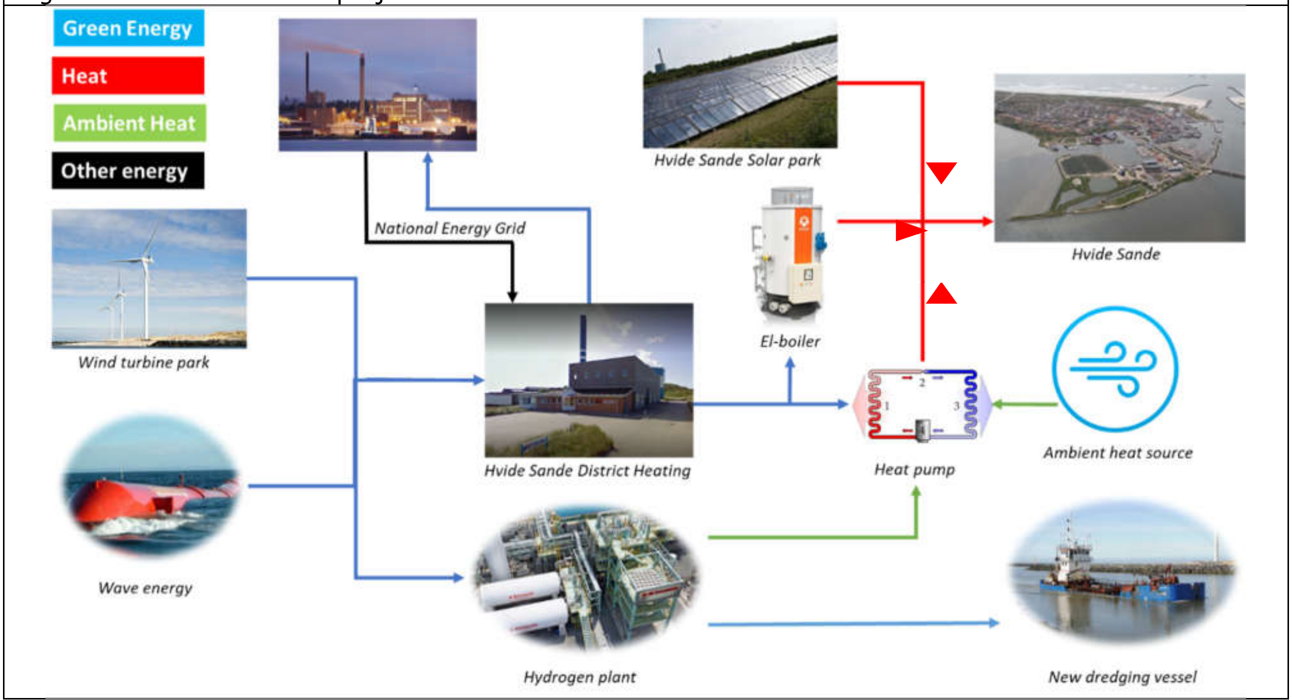
The next step of the green transition for Hvide Sande district heating is to explore the feasibility and integration of a wave energy component in order to create a greater independency from the national energy grid and rely 100% on renewable energy.

In addition to the wave energy component, the integration of a small-scale hydrogen plant will be examined in another report. The small-scale hydrogen plant will supply hydrogen to a new dredging vessel that dredge material from the port entrance of the Port of Hvide Sande.

The heat from the hydrogen production will be channelled to the heat pump and increase the output of the heat production and potentially reducing the cost of supplying district heating for the inhabitants of Hvide Sande.

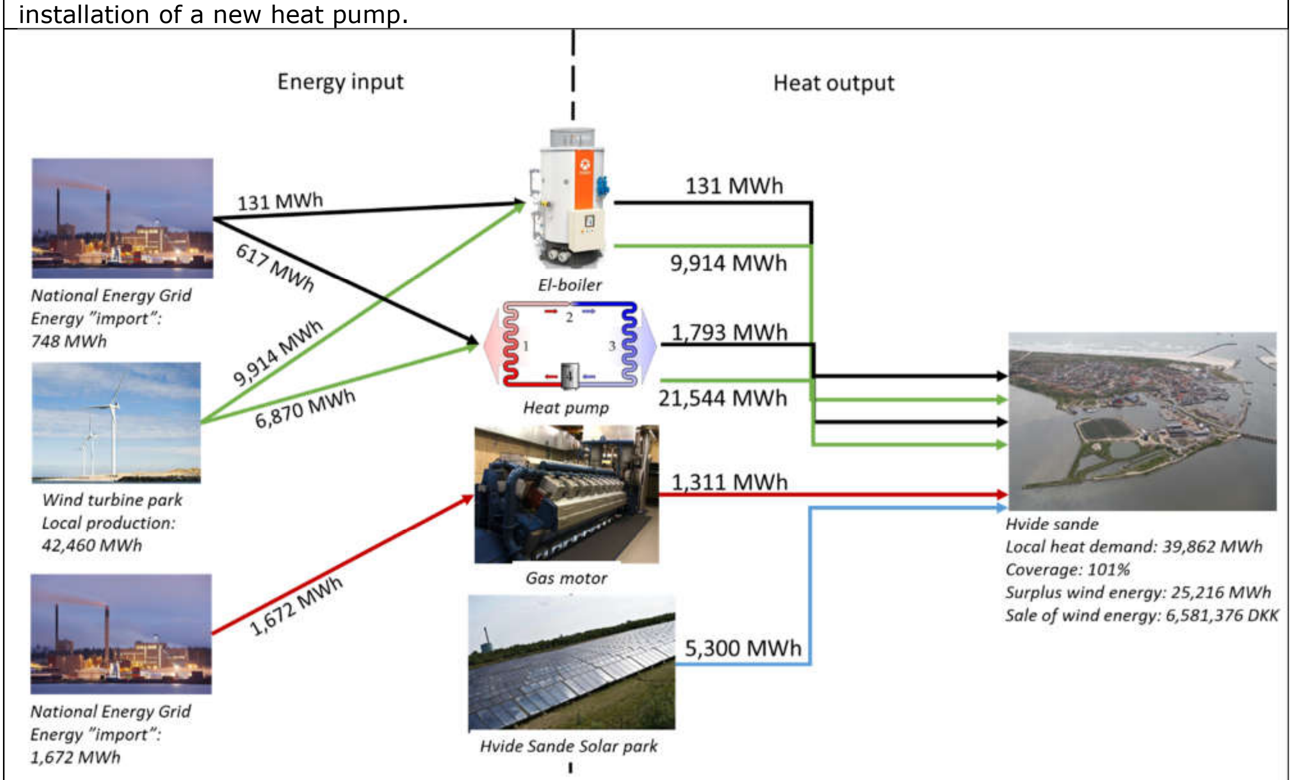
Figure 1 illustrates the green transition vision of Hvide Sande with energy inputs from renewable energy in the form of both electricity and heat, i.e., wind turbines, solar panels, wave energy, hydrogen production and heat pump. Most of these elements are already in place and this report delivers an analysis of the wave component and assessment of the potential for establishing a local hydrogen production for a potential hydrogen vessel (in another report).

Figure 1: Overview of the project in Hvide Sande



Hvide Sande District Heating supply heat to most of the town of Hvide Sande and delivers heat to approx. 1,600 households. This leads to a total heat demand in Hvide Sande of 39,860 MWh per year on average. The amount of energy from different energy sources generated by Hvide Sande Central Heating District is shown in figure 2.

Figure 2: Overview of the energy to heat setup in Hvide Sande Central Heating District after the installation of a new heat pump.



The current energy mix in Hvide Sande cover the city's heating needs and reduce the dependency of fossil fuels leading to a CO_2 reduction of 85% compared to a traditional natural gas consumption. In addition, the new heat pump will reduce the need for wind energy and create a surplus of green energy of 25,216 MWh.

This surplus energy can be sold to the Danish national grid and presents a value of approx. 885,674 € per year (in 2020). However, it is expected that this source of revenue for the central heating district will be omitted as new regulations and price adjustments are introduced to the Danish energy market for wind energy.

Because of the potential reduction in revenue from sales of wind turbine energy a search for a 'more profitable' application of the energy is initiated. This has led to the evaluation of whether hydrogen production is a suitable solution to store energy for when there is very small profit opportunity for selling the energy to the grid.

To ensure operational stability in heat and hydrogen production a new energy link is also envisioned: wave energy. During down time or heavy demand on wind energy a wave energy plant would be able to support the hydrogen and heat production.

3. The wave characteristics at Hvide Sande for energy conversion

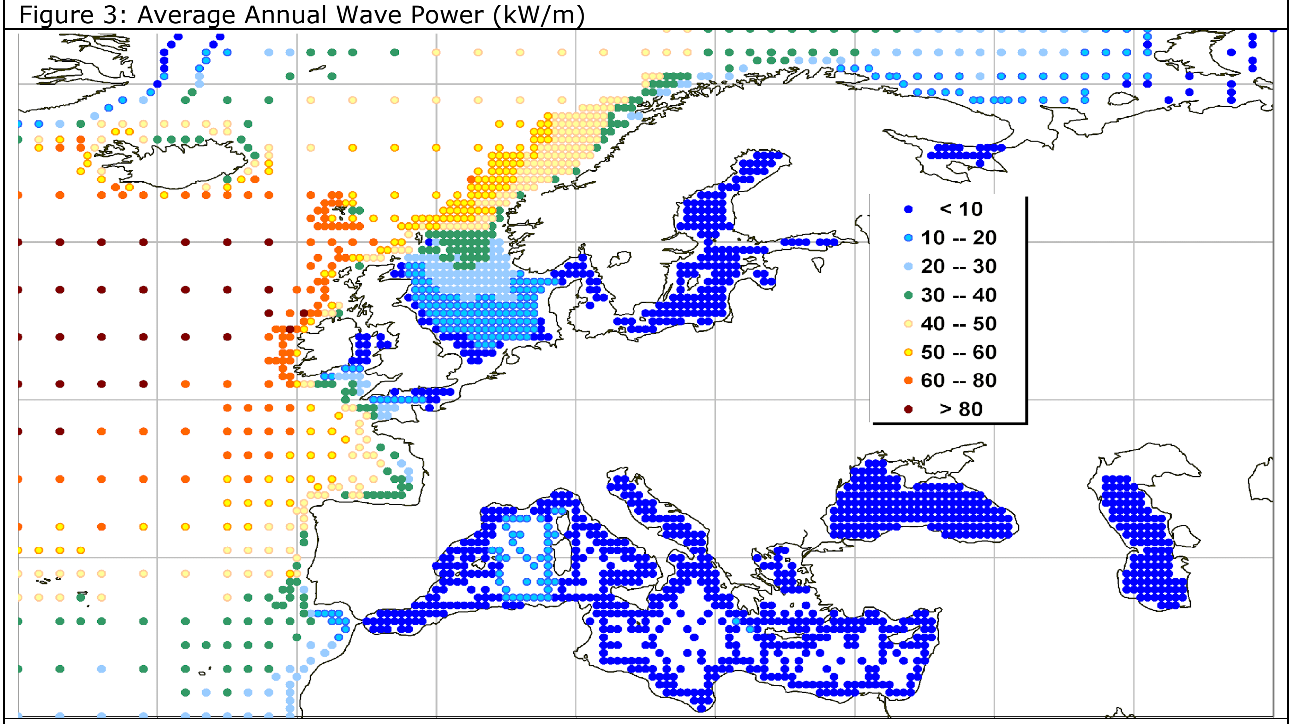
A main parameter impacting in wave energy conversion is the amount of power in the waves. Wave energy potential at a site of interest is usually presented as power per meter of the wave crest and depends on:

- Wave height
- Wave frequency

Wave height and frequency depend on the bathymetry (study of seafloor) and dominating wind speed and wind direction.

Based on these parameters, the average annual wave power (kW/m) of different geographical locations may be assessed. Figure 3 shows a map of wave intensity at different locations in the waters around Europe.

Figure 3: Average Annual Wave Power (kW/m)



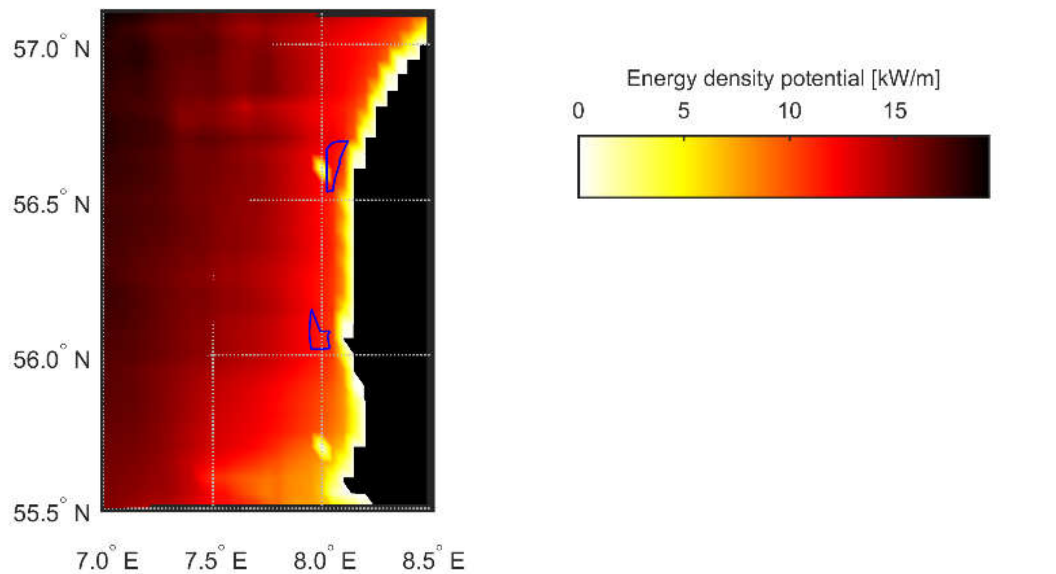
Source: Mørk et al. 2010

As can be seen, there are large differences in the intensity with a very high average annual wave power of 50-80 kW/m at the most western shores such as Ireland, Scotland, and Portugal. In the North Sea the wave intensity is assessed to around 10-30 kW/m. While the relatively smaller wave intensity off the Danish coast compared to e.g., Ireland has an impact on the potential energy that may be harvested, the less harsh wave climate favours the wave energy converters (WEC).

Wave energy potential in a proximity of Hvide Sande is between 10-15 kW/m on average per year at medium depths (of at least 20 m).

Potential optimal locations are in front of the wind power parks planned in this area where existing energy infrastructure (cables, transformers, etc.) for wind power parks may be made available for wave power integration. A closer look at the wave energy potential along the western coast of Denmark is shown in figure 4 and the new wind parks that are planned to be built within the coming years is illustrated with a blue polygon.

Figure 4: Potential annual average wave energy in the sea area near Hvide Sande.



Source: Uppsala University

The potential wave energy in the areas is around 9-10 kW/m. While it is in the low end of wave energy across Europe, with an appropriate choice of wave energy system a considerable amount of energy can be produced on an annual basis. It is estimated that a wave energy converter (WEC) unit should be able to produce between 10-13 MWh/day with these wave parameters.

Picture 1: A Weptos wave energy converter (WEC) unit

Source: Weptos

4. The costs and benefits of wave energy

This section is a description of the economic costs and benefits of a wave energy at Hvide Sande.

<u>Costs:</u>

The economic costs consist of both capital costs, i.e., CAPEX, and operations costs, OPEX. With a thorough description of costs, the section will calculate and describe the benefits associated to the costs.

Table 1 shows the production capacity and potential price of wind energy and solar heat in the case of Hvide Sande.

Table 1: General assumptions on the production of wind energy, solar park and national power grid

Definition	Value	Unit
Energy sales price pr. kWh (wind turbines)	0.03	€/kWh
Energy production (wind production)	42,532	MWh
Solar heat production	5,279	MWh

Table 1 indicates that the three wind turbines in Hvide Sande are able to produce 42,532 MWh and if this entire amount was sold to the national grid, it has a value of approx. 1.3 million Euro.

The generic CAPEX associated with acquiring and installing wave energy converters in Europe is shown in table 2. The values in the table are based on Astariz & Iglesias (2015) and represent an assumed cost reduction of having the WEC units installed to existing structures in the area and price of the Weptos being lower than the value assumed in the article.

The economic values from Astariz and Iglesias (2015) are currently consensus of the economics for acquiring, installing, and operating WECs.

Table 2: The generic CAPEX cost pr. WEC unit

	Value	Unit
Pre-operation cost	5%	of CAPEX
Licenses and permissions	5%	of WEC cost
WEC cost pr. MW	2,550,000	€/MW
Installation	2,970,000	€/MW
Mooring system	1%	of WEC cost
Mooring installation	50.000	€/day
Underwater cable	1%	of CAPEX
Cable installation	2.07	€/m

Source: Astariz & Iglesias (2015)

As can be seen in table 2, the main share of the costs is related to the purchase of the actual WEC unit and to the installation cost.

Table 3 shows the generic OPEX associated with running a WEC. The values shown are based on the adjusted values from Astariz and Iglesias (2015). Values on *Spares* and *Revision & time off* have been modified to reflect the operation in Hvide Sande.

Table 3: The generic OPEX pr. WEC unit

	Value	**Unit**
O&M tasks (low)	20	€/MWh
O&M tasks (middel)	27.5	€/MWh
O&M tasks (high)	35	€/MWh
Revision & time off	5%	of CAPEX
Spares	2%	of CAPEX
Public services	3.5	€/MWh
Insurance cost	10	€/MWh

Source: Astariz & Iglesias (2015)

The generic OPEX has also been adjusted for this example. It is assumed that 'spares' will only amount to 2 % of the initial CAPEX due to the WEC unit being more durable than the ones examined in the generic studies.

The following calculations are based on a wave farm with four Weptos WEC units, with a production of approx. 12 MW/day per unit in a sea area with 10 kW/m.

The market is still developing and there are no WEC commercially ready at the market today. Data is mostly based on small scale testing and calculations and there is thereby a degree of uncertainty attached to the values and available data.

Based on the assumptions described above, the cost of producing one MWh with four Weptos WEC's is detailed in table 4.

Table 4: The cost of producing 1 MWh with four Weptos WEC units			
	Weptos WECs	**Value**	**Unit**
Production and wave characteristics	WEC amount	4	Single units
	WEC production	1.5	MW
	Cabling	200	Meters
	Mooring installation	2	days
Wave energy production	Production days pr. year	347	Days
	Energy production	16,644	MWh/year
CAPEX	WEC and installation	17,850,000	€
	Mooring investment	138,250	€
	Licenses and permissions	191,250	€
	Initial CAPEX	*18,179,500*	€
	Pre-operation cost	908,975	€
	Underwater cable	182,209	€
	Final CAPEX	*19,207,684*	€
	Depreciation	20	Year
	Rent on loan	0.5	%
	Depreciation liner to 0	963,534	€/year
	Instalment on loan	96,353	€/year
OPEX	O&M Tasks	332,880	€/year
	Revision and time off	908,975	€/year
	Spares	363,590	€/year
	Public services	58,254	€/year
	Insurance cost	166,440	€/year
	Total cost	*2,890,027*	*€/year*
	Price	173	€/MWh

As can be seen in table 4, four units of Weptos WECs can produce approximately 16,644 MWh/year, at a cost of 173 €/MWh. There are opportunities to reduce some of the costs by e.g., extending the wave park with additional WECs or through a reduction in costs of the WEC units.

To put the 173 €/MWh in perspective, an offshore wind turbine can produce one MWh for approx. 53 € and an onshore turbine can produce one MWh for approx. 33 €.

The main reasons for the high costs of energy are due to three parameters:

- The capital needed to compensate for time off when there are no or little waves.
- The capital that needs to be allocated for having spare parts in storage.
- The cost and relatively low energy output of the WEC units.

The lack of any large-scale commercial WECs on the market leads to high CAPEX, and when the technology matures it is expected that CAPEX will be reduced. In addition, the power generation of the WEC is another point of concern. A 12 MWh/day capacity per WEC is not a high energy output when compared to the CAPEX and OPEX needed. The amount of energy in the waves is also a concern.

These calculations make the feasibility of a wave energy farm when compared to an investment in wind energy less viable. For the WEC to become feasible an improved energy output is required as well as a reduction in investment costs.

Benefits:

Several benefits are associated with wave energy; however, these are difficult to quantify and thereby compare with costs.

The benefits of wave energy technology are that it may become a potential source of renewable energy in the future, where the importance of renewable energy production is expected to increase due to the need to reach climate targets and deal with increased energy demand.

Apart from the emissions resulting from the manufacturing and installation of WEC units, a strong advantage of wave energy is that it does not emit greenhouse gases while in operation, and does not produce any harmful by-products, waste, or pollution (Lee et al. 2016). This is of significance when considering climate goals. It is also believed to have a low environmental impact (Drew et al. 2009; Pelc & Fujita 2002).

Wave energy technologies have a high energy density (in kW per m^2) and long operating hours (as there always is some water movement), potentially generating energy for up to 90% of the time (Drew et a. 2009; Pelc & Fujita 2002). They are also seen as more reliable, as they depend less on external/weather conditions.

Another benefit is the 'nonvisibility' of the WEC units, as they would not be seen by citizens living/staying along the coast, which will potentially satisfy some people in the area who are concerned with aesthetics (Bedard 2007).

Benefits for the Hvide Sande region include the additional production of renewable energy for the Hvide Sande power grid and the potential to sell excess energy for the national grid or for exports. This would also reduce the reliance on wind and solar energy in the region. Furthermore, there would be potential to use the energy produced by the WECs for hydrogen production.

Some strengths of the Weptos WEC include high power production (high efficiency of wave absorbers) and independence of wave direction. Also, Weptos WECs can be placed at different water depths and react favourably to extreme events (Fernández-Chozas et al. 2014).

5. Perspectives and future development in wave energy

To illustrate how far the technology needs to move to be profitable without subsidies a small projection could be described. If the energy output of a WEC unit increased to 24 MWh/day and the required CAPEX was reduced by 50%, it would bring down the cost of production to 87 €/MWh. In order to reach the same price as a wind turbine at sea, the WEC unit would need to be able to produce 80 MWh/day.

The current WEC technologies are not economically feasible as used in the heat project in Hvide Sande unless significant economic aid is provided by the government to secure a more profitable production cost.

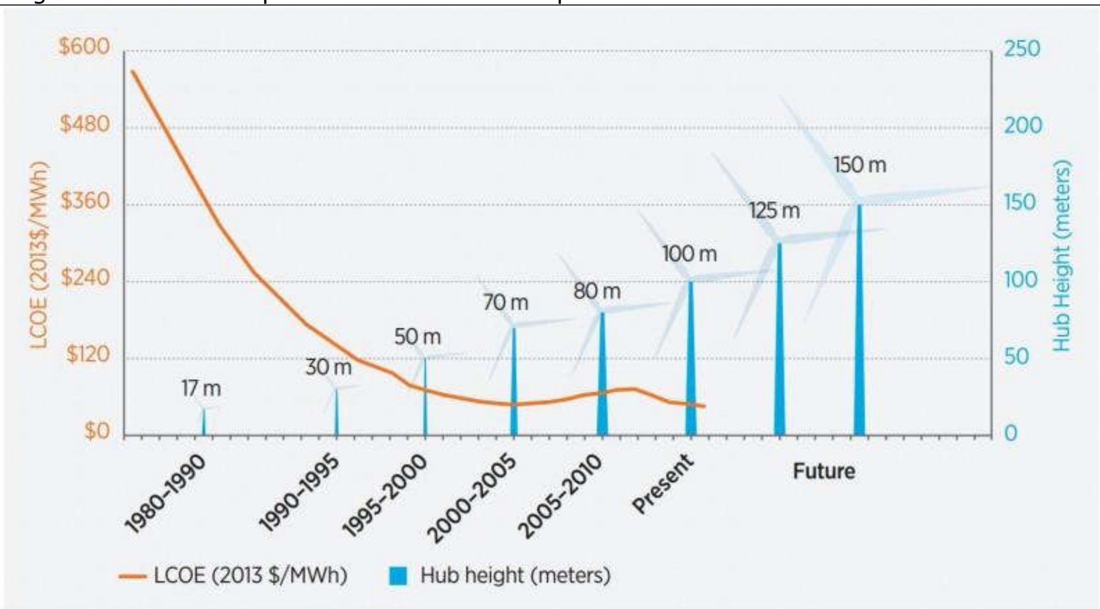
This does not mean that wave energy does not have a future in Hvide Sande or any other places, but there is still a development potential that needs to be realised. This has also been the case with many other technologies such as wind and solar energy that has received large economic support to reach its current state.

To measure the energy costs between different technologies the measure of Levelized Cost of Energy (LCOE) is used. LCOE considers the energy costs over the lifetime of e.g., a wind turbine, WEC, solar panel, etc.

In figure 5 a measure of energy between 1980 and 2013 in USA is shown.

As the technology matured and larger units were developed to achieve greater economies of scale the cost of producing one MWh decreased significantly. Between 1980 and 2013 the average annual reduction in LCOE was 2.8 % per year.

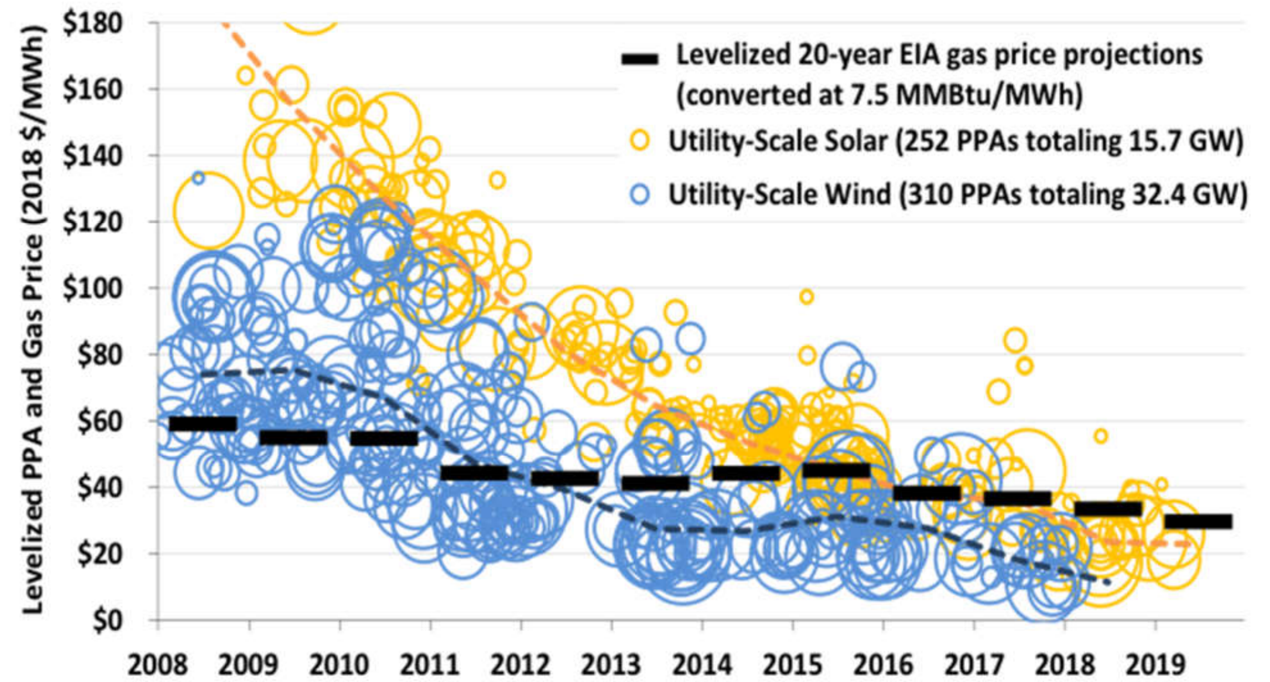
Figure 5: The development in LCOE for wind power in the USA between 1980 and 2013



Source: US Department of Energy

The same principle also applied to the reduction in the LCOE of solar power between 2008 and 2019 as shown in figure 6. Here the average annual reduction was 8.0 % between 2008 and 2019.

Figure 6: The development in LCOE for wind power and solar power in the USA between 2008 and 2019



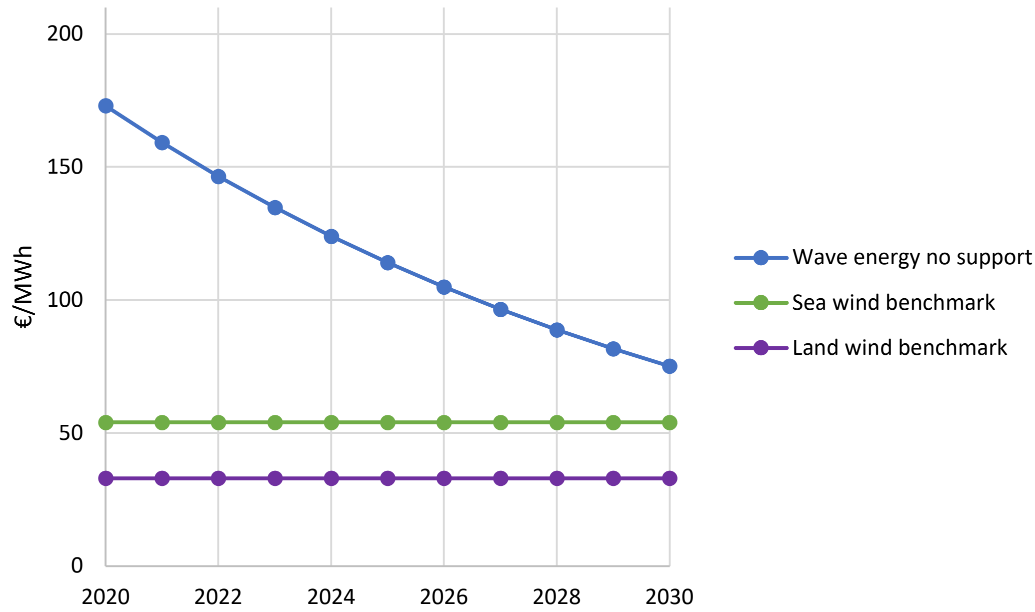
Source: U.S Department of Energy

Figure 6 also shows that wind power and solar power can generate power at lower cost than it takes to produce natural gas for the same amount of energy. This is an important benchmark to pass for the renewable technologies already as natural gas is viewed as one of the likely energy sources to replace coal and other fossil fuels in the energy sector.

Both figures show that the cost of producing energy from renewable sources are high in the early stages, but as the technology matures and the economies of scale are achieved, the economic feasibility of the technology is improved rapidly.

It is therefore likely that wave power will be able to achieve similar reductions in LCOE as wind and solar power.

If it is assumed that wave power technology will mature at the same rate as solar power and that the same average annual reduction of 8 % in LCOE for solar power is applied to the previously analysed cost of wave power, the following trajectory can be made for the decrease in wave power LCOE (see figure 7).

Figure 7: The trajectory for LCOE of wave power over a 10-year period with an average 8 % annual reduction

Own development

Under the given parameters the LCOE for wave power would be 75 €/MWh in 2030.

This is a positive trajectory that relies on wave power technology to either achieve greater scale or in combination with reductions to the initial investment cost and maintenance cost of the production units. If the wave power technology can reach this level of LCOE the technology would however still not be considered economically feasible in the context of Hvide Sande. Further cost reductions or support is therefore needed.

6. Opportunities for economic support

There is currently no economic support for wave energy in Denmark or the EU. Most Danish wave energy projects have either received their funding through research grants or through national, EU and international innovation funds.

Since wave energy is still on a demonstration stage in regard to commercialization, significant private investment or public funding is needed if the technology is to mature into a commercially ready product.

A comparison to the economic support that wind power received through its development in Denmark can be made to illustrate what level of funding a wave project potentially could receive and an evaluation of what level of support it would need to be economically feasible.

During the 1970's and 1980's the Danish state provided economic support to the wind power sector through a 40 % support to investments in the construction of new wind turbines. It should be noted that this support only covered the CAPEX of establishing new wind turbine in operation. Any OPEX was not covered by this support.

This support was gradually reduced and replaced entirely in 1992 when the investment support was switched with an electricity production support initiative of approx. 0.04 €/kWh.

In 2002 the electricity production support was reduced to 0.03 €/kWh. Following an agreement in 2008 the electricity production support initiative was based on a set number of hours with full load at a rate of 0.04 €/kWh. After the wind turbine exceeded the set amount of full load hours the support would be discontinued.

Assuming that the same amount of economic support may be granted to wave power the economics of a wave power would be the following in different scenarios illustrated in table 5.

Table 5: Four different support schemes for wave-power to reach a viable wave energy production

Types of economic support	Level of economic support	Effect of production price WEPTOS	Difference
1. Economic support to investment	40 % of project CAPEX	148 €/MWh	- 25 €/MWh
2. Electricity production support (1992 level)	0.04 €/kWh produced.	133 €/MWh	- 40 €/MWh
3. Electricity production support (2002 level)	0.03 €/kWh produced.	143 €/MWh	- 30 €/MWh
4. Economic support to investment + Electricity production support (1992 level)	40 % of Project CAPEX + 0.04 €/kWh produced.	108 €/MWh	- 65 €/MWh

Source: Own calculations

Based on these scenarios the economic support would improve the production cost for the project but as previously mentioned the last obstacle for the wave power technology examined in this report is the relatively low output of MWh/hour from each unit.

If the WEC units could increase their production output to 24 MWh/day the economic support would have the effect seen in table 6.

Table 6: Four different support schemes for wave-power with an improved production output

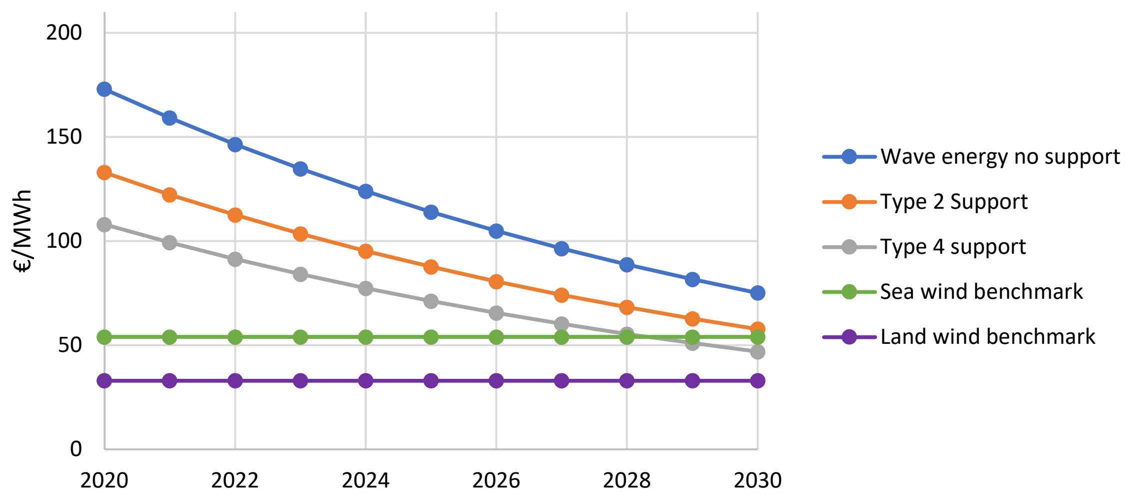
Types of economic support	Level of economic support	Effect of production price WEPTOS	Difference without support
1. Economic support to investment	40 % of Project CAPEX	90 €/MWh	- 82 €/MWh
2. Electricity production support (1992 level)	0.04 €/kWh produced.	63 €/MWh	- 110 €/MWh
3. Electricity production support (2002 level)	0.03 €/kWh produced.	73 €/MWh	- 100 €/MWh
4. Economic support to investment + Electricity production support (1992 level)	40 % of Project CAPEX + 0.04 €/kWh produced.	27 €/MWh	- 145 €/MWh

Source: Own calculations

These scenarios underline the importance of scale in the wave energy production, as a doubling in output results in the more significant reduction to production price.

The economic support would be beneficial in making wave energy more economically feasible, especially in the cases of economic support type 2 and 4. If these types are compared to the development in figure 8, the following decrease in electricity production price could be possible.

Figure 8: The trajectory for LCOE of wave power over a 10-year period with an average 8 % annual reduction and different types of economic support for a 12 MWh/day per. WEC production



Own development

Without economic support the wave energy production could reach 75 €/MWh, 57 €/MWh with type 2 economic support and 46 €/MWh with type 4 economic support in 2030. Further reduction would therefore be needed to reach the same current cost level as wind power or solar power.

7. SWOT analysis for the WEC concept in Hvide Sande

Table 7 illustrates the strengths, weaknesses, opportunities, and threats for the WEC concept in Hvide Sande.

Table 7: SWOT analysis

Strengths	**Weakness**
• Zero CO2 emissions from energy production • Underwater sea cable already exists. • Mooring and foundation costs are potentially reduced due to already existing infrastructure at Horns Rev 1.	• Relative low MW/h output compared to cost. • High CAPEX • Requires sea areas with a good amount of KW/m in the waves. • Uncertain cost reduction path for the WEC units.
Opportunities	**Threats**
• Possibility of selling CO_2 tickets. • Further reduce the reliance on wind or solar energy to achieve the zero-emission ambition of Hvide Sande Central Heating • The energy produced by the WECs would be enough to power the production of hydrogen at the Port of Hvide Sande in theory	• If no agreement with the owners of Horns Rev 1 can be reached, the cost of producing one MWh increases by 100 €/MWh. • The cost of spare parts can increase due to harsh weather in prolonged periods. • Maintenance costs increase due to harsh weather in prolonged periods. • Any lack of significant government aid structures for wave energy development will make the energy production too high compared to sea wind turbines. • Development in wave energy may not achieve the proposed 8 % average annual cost of energy reduction. • Other sustainable energy source (wind and solar) is already developed and commercially ready.

Important strengths and opportunities of the wave energy technology include the possibility of reducing the CO_2 emissions of local energy production even further and decreasing the dependency of non-renewable energies for the Hvide Sande area. Furthermore, excess energy produced from WECs could potentially be used for hydrogen production, which is expected to be of increased demand in the future.

Important weaknesses and threats include the current high production price of WECs, especially compared to competitive energy sources (wind and solar), as well as high capital and operations costs. Uncertainties include weather and wave conditions, as well as maintenance costs throughout the year(s). Moreover, it is not clear whether wave energy technology will receive investments or other economic support in the coming years.

8. Conclusion and perspectives

The energy potential that comes from waves is large, and promising energy systems from around the world are expected to develop this over the coming years.

However, based on the analysis, it can be concluded that the current WEC technologies is not economically viable compared to other renewable energy sources and research and development is still needed to reach commercialisation. A higher power generation in relation to costs is needed to be able to compete against other renewable energy sources such as wind and solar energy.

There are several different wave energy systems being tested and some larger scale systems in the pipeline. There seems to be willingness for supporting these initiatives from national and international research and innovation funds, but a large commercial player could perhaps be the force that may propel the energy systems forward towards commercialisation.

Currently there are no dedicated support schemes available similar to those that exist for both wind and solar energy. Such initiatives, combined with continuous research and development in the area, may lead to a successful development of competitive wave energy within the coming years or decade.

In order for the technology to be economically feasible at its current technology level, it would need significant amounts of economic aid or reductions of its production price. With the current production price, the MW/h output of a WEC needs to be increased to 40-50 from the current 12 MW/h, to be viable.

9. Literature

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