FACTSHEET ENERGY FROM WATER

TNO innovation for life

TECHNOLOGY DESCRIPTION

Name technology	Wave energy
Date factsheet	11-12-2020
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Description	With a wave energy converter, wave energy can be extracted from rapidly changing water levels. There are many different techniques for extracting wave energy. Some examples are floaters that oscillate or hinge vertically, air chambers in weirs and overtopping converters that use reservoirs to create a head and subesquently drive turbines (Witteveen+Bos & CE Delft, 2019; IRENA, 2014). The wave climate in the North Sea is relatively mild compared to waves on the oceans. Despite the mild wave climate, a number of (Dutch) suppliers are developing wave energy converters that can also be used in the North Sea. The advantage of a milder wave climate is that converters also have to endure lower forces and that learning can be done in relatively calm conditions, after which expansion to other locations with mild wave conditions and the oceans could possibly follow.

TRL LEVEL

	2020	2030	2050
TRL	5-8	9	9
Explanation	In 2019 pilots are carried out all over the world (TRL 5-8), but no commercial projects yet (Witteveen+Bos & CE Delft, 2019 and JRC, 2019).		

CURRENT INSTALLED CAPACITY AND ANNUAL ELECTRICITY PRODUCTION IN THE NETHERLANDS

Installed capacity	-
Annual installed capacity	-
Explanation	There are only a few pilot and demonstration projects, of a limited scale, in the Netherlands.

POSSIBLE LOCATIONS IN THE NETHERLANDS

Locations	The North Sea, including the region of the Wadden Islands. The potential in W/m is lowest in Zeeland and increases to a maximum north of the Wadden Islands. The region with the highest wave energy is further offshore in the North Sea north of the Wadden Islands. Synergy is possible at locations designated for offshore wind projects.
Explanation	The average energy in waves close to the Dutch coast is: 8-11 kW/m (Deltares, 2008; Witteveen+Bos & CE Delft, 2019). Recent research with a numerical model indicates a broader range: 3-6 kW/m at the Channel, 8-20 kW/m at the Wadden Islands and up to 25 kW/m further north from the coast (Lavindas and Polinder, 2019). Wave energy at locations for offshore wind projects is interesting because the existing infrastructure can be used, such as a grid connection and the combination of installation and (planned) maintenance work, which means that costs can be reduced.

POTENTIAL IN THE NETHERLANDS

		2030					2050				
	Unit	Main source	Source 2	Source 3	Source 4	Source 5	Main source	Source 2	Source 3	Source 4	Source 5
Energy potential (technical)	PJ/year						5.5	5	9.4	19	
		Source	*Source*	*Source*	*Source*	*Source*	*Witteveen+E*	*Ecofys 201*	*Sorensen e*	*Sorensen e*	*Source*
Energy potential (economic)	PJ/year	0									
		Ecofys 2017	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*
Mitigation potential	*Unit*										
		Source	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*

Explanation

Existing potential studies are outdated and with new insights into wave energy converters, tightened international standards for potential calculations of wave energy and new calculation methods and models, it is possible to better understand the technical potential (Deltares, 2020) (Lavidas, 2020). Potentials estimated in the outdated potential studies are given here to give an impression of the results from these studies.

The maximum achievable technical potential in the long term by Ecofys (2017) and the technical potential by Witteveen+Bos & CE Delft (2019) are based on Deltares (2008). Deltares (2008) calculates with an average wave energy of 10 kW/m and assumes that a maximum of 50% of the Dutch coast can be made suitable for wave energy. The technical potential can be further honed by identifying more precisely locations where wave energy projects can be technically realized.

Until 2030, the market potential (economic potential that is expected to be realized) is estimated by Ecofys (2017) at 0 PJ/year.

Sorensen and Fernández Chozas (2010) also calculate, based on 10 kW/m average wave energy, a theoretical potential of 2.6 TWh/year (9.4 PJ/year) for the Netherlands, based on a line of wave energy converters along the entire coast (300 km). Sorensen and Fernández Chozas (2010) estimate a higher potential when applying a second line of 300 km, 80 km from the coast (5.3 TWh/year, 19 PJ/year).

COSTS

		2020					2030					2050				
	Unit	Main source	Source 2	Source 3	Source 4	Source 5	Main source	Source 2	Source 3	Source 4	Source 5	Main source	Source 2	Source 3	Source 4	Source 5
Capex	€/kW	7250	5000	9500			5950	2350	6500			3150	1500	5070		
		Hoefnagels	*Hoefnagel*	*Hoefnagel*	*Source*	*Source*	*JRC (2018)*	*JRC (2018)*	*JRC (2018)*	*Source*	*Source*	*Hoefnagels 2*	*JRC (2018)*	*JRC (2018)*	*Source*	*Source*
Fixed Opex	€/kW/yea	300	125	450			208	82	228				60	203		
		Hoefnagels	*Hoefnagel*	*Hoefnagel*	*Source*	*Source*	*JRC (2018)*	*JRC (2018)*	*JRC (2018)*	*Source*	*Source*	*Source*	*JRC (2018)*	*JRC (2018)*	*Source*	*Source*
Variable Opex	*Unit*															
		Source	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*
Grid connection	*Unit*															
		Source	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*
LCOE	€/kWh	0.71	0.29	1.59	0.6	1.1	0.32	0.13	0.35			0.31	0.19	0.52	0.08	0.28
		Hoefnagels	*Hoefnagel*	*Hoefnagel*	*Witteveen*	*Witteveen*	*Calculation I*	*Calculatio*	*Calculatio*	*Source*	*Source*	*Hoefnagels 2*	*Hoefnagel*	*Hoefnagel*	*Calculatio*	*Calculatio*

Explanation

Based on industry data and literature, Hoefnagels (2020) has estimated average costs and a bandwidth for a wave energy system (of the most common design: an Oscillating Body System (OBS)) (NB: this cost data is not specific to the Netherlands). Based on learning curves, Hoefnagels (2020) has made an estimate of LCOEs in 2050. Various assumptions for the learning curves (speed of global growth in installed capacity and learning effect only on investment costs or in combination with learning effect on operational costs) create a bandwidth of results. The average case is based on the scenario with average growth (15% growth per year, worldwide 3 GW in 2050) and learning effect on CAPEX and OPEX (for both a 10% decrease with a doubling of global cumulative capacity). For sensitivity analyses, calculations are based on a growth in worldwide installed capacity of 10% and 20% per year and with learning effects of 5% and 15% for every doubling of worldwide cumulative installed capacity.

Cost price Witteveen+Bos & CE Delft (2019) is based on an EU collective study from 2016 (JRC, 2016).

JRC (2019) estimates the LCOE in 2018 based on the LCOE of 2015 and learning curves. A reference value of 0.56 €/kWh is used for 2018, which corresponds reasonably well with the cost estimates of Hoefnagels (2020) and Witteveen+Bos & CE Delft (2019). JRC (2018) has calculated the Capex and Opex decline for several scenarios based on learning curves. The baseline, minimum and maximum scenarios for 2030 are included in the fact sheet, the minimum and maximum scenarios for 2050. Based on the Capex and Opex data, LCOEs have been calculated based on the other parameters from the SDE ++ and Witteveen+Bos & CE Delft (2019); 2500 full load hours, service life of 15 years and 5.6% actuarial interest.

IEA-OES (2015) estimate the LCOE for first commercial projects at approx. 0.11-0.42 € / kWh. With worldwide cumulative installed capacity, a decrease to 0.09-0.14 € / kWh is foreseen on the basis of learning curves.

Market parties are more optimistic than the predictions of Hoefnagels (2020) and JRC (2019) and forecast costs of 0.25 € / kWh in 2025 and costs below 0.05 € / kWh in the long term (Slowmill and Symphony, 2020). With these estimates, EU SET targets for wave energy (0.15 € / kWh in 2030 and 0.10 € / kWh in 2035 (European Commission, 2018)) come into focus more than on the basis of Hoefnagels (2020) and JRC (2019).

In the SDE ++ 2020 wave energy is included in the category Hydropower, height of fall <50 cm, together with energy from tidal streams (PBL, 2020). The costs of this category are estimated at 0.185 € / kWh, which is low compared to data from other sources. The SDE ++ data is therefore not included.

ENERGY PROFILE	
Energy profile	Waves are variable and so is the energy profile of wave energy. Wave energy lags behind wind at sea by about half a day, so it can supplement wind at sea.
Explanation	*Explanation*
EXPORT POTENTIAL	
Export potential	Estimates of global potential vary widely. It involves many GW and up to 30,000 TWh/year (IRENA, 2014)
Explanation	*Explanation*
POSSIBLE NON-ENERGETIC SIDE EFFECTS	
Ecological effects	The existing knowledge in the international literature on the ecological impact of 'energy from water' technologies has been analyzed and summarized by Copping & Hemery (2020). According to this study, the effect of underwater noise on marine animals represents the highest risk for wave energy converters. Risks from electromagnetic fields, changes in habitat and oceanographic systems and entanglement of marine animals in cables are estimated to be smaller. The OES indicates that there is still a lot of uncertainty about the ecological effects of energy from water technologies and that more data exchange and research is needed. For example, most insights from monitoring energy from techniques are based on small installations (single devices or small arrays). Additional research and monitoring for large-scale implementation is yet to follow and the risks may be different for large-scale implementation (Copping & Hemery, 2020). An increase in biodiversity can be observed after placing objects as anchors on a sandy seabed because the habitat complexity of the environment increases (NIOZ, 2020). Although an increase in biodiversity can be seen as positive, this is not unambiguous because it concerns an increase in species that are usually not found (or to a much lesser extent) on the sandy seabed. Because there are so many different techniques for generating energy from waves, an appropriate assessment per technique is desirable (Witteveen+Bos & CE Delft, 2019) and local research into effects is important (Copping & Hemery, 2020). In the Netherlands, a preliminary test has been carried out for the Slowmill pilot off the coast of Texel, from which significant consequences are excluded for seven habitat types in the Natura 2000 area of the North Sea coastal zone, three breeding bird species, five bat species and twelve non-breeding bird species (Jongbloed et al., 2020). For three migratory fish species, four other fish species, three marine mammal species and six non-breeding bird species, significant consequences cannot be ruled out in advance (Wageningen Marine Research, 2020).
Multiple use	Because wave energy systems reduce wave energy, the wave load on the coast during storms can decrease, thereby contributing to coastal defense (Witteveen+Bos & CE Delft, 2019). When installing wave energy converters at an offshore wind farm, a reduction in wave energy can also improve the accessibility of the wind farm for maintenance work, which can lower the costs for offshore wind (Astariz and Iglesias, 2015). Multifunctional use can also be made of the offshore wind grid connection (Witteveen+Bos & CE Delft, 2019).
Social and landscape effects	Wave energy converters are not visible from the coast. Application in the North Sea can have an impact on shipping and fishing.
Material use/circularity	Wave energy systems are less vulnerable than wind turbines, so less steel is required (Slowmill, 2020). Concrete is needed for anchoring, for which the possibilities of using low-CO_2 concrete must be investigated.

SOURCES	
1	Witteveen+Bos & CE Delft (2019) - Perspectieven energie uit water: Nationaal potentieel voor 2030 en 2050 (in Dutch).
2	JRC (2019) - Ocean energy technology development report.
3	Ecofys (2017) - Overige hernieuwbare energie in Nederland. Een potentieel studie (in Dutch).
4	EWA (2019) - Position Paper Energie uit Water (in Dutch).
5	Sorensen en Fernández Chozas (2010) - The potential for waver energy in the North Sea.
6	Deltares (2020) - Interview 3 July 2020 and feedback on draft factsheet (in Dutch).
7	Lavidas (2020) - Interview 24 September 2020 and feedback on draft factsheet.
8	Hoefnagels (2020) - Techno-economic analysis of the cost reduction potential of marine energy technology through learning curve modelling.
9	JRC (2018) - Cost development of low carbon energy technologies.
10	IEA-OES (2015) - International levelised cost of energy for ocean energy technologies.
11	Slowmill (2020) - Interview 5 June 2020.
12	Symphony (2020) - Interview 10 juni 2020.
13	Europese Commissie (2018) - SET-plan Ocean energy implementation plan.
14	JRC (2016) - Ocean Energy Status Report 2016 edition.
15	PBL (2020) - Eindadvies basisbedragen SDE++ 2020 (in Dutch).
16	IRENA (2014) - Wave energy: Technology brief.
17	Copping & Hemery, editors (2020) - OES-Environmental 2020 State of the Science report: Environmental Effects of Marine Renewable Energy Development Around the World.
17	NIOZ (2020) - Biodiversiteit rondom de Slowmill in 2019 (in Dutch).
18	Wageningen Marine Research (2020) - Slow Mill pilot Texel: Voortoets Wet natuurbescherming (in Dutch).
19	Astariz en Iglesias (2015) - Enhancing wave energy competitiveness through co-located wind and wave energy farms. A review on the shadow effect.