FACTSHEET ENERGY FROM WATER

TNO innovation for life

TECHNOLOGY DESCRIPTION	
Name technology	Tidal stream
Date factsheet	11-12-2020
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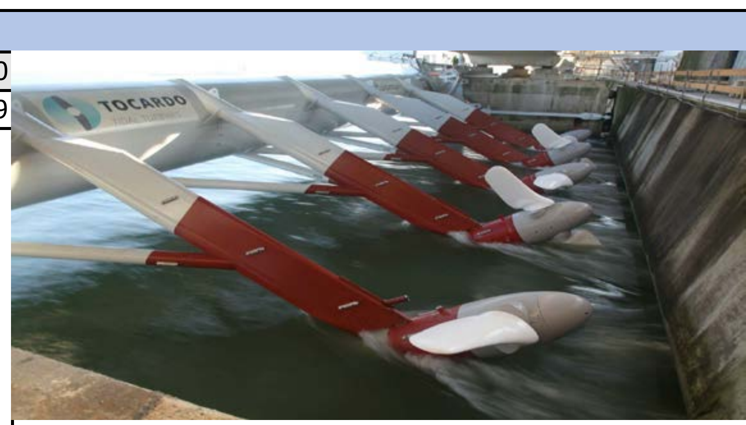
Description	Kinetic energy can be obtained from tidal currents by means of free-flow turbines. This can take place at flood defenses as well as on the open sea. Channels with a funneling effect cause an acceleration of the tidal current, so that more kinetic energy can be gained. Turbines with blades rotating about a horizontal axis are the most mature type of free flow turbines. Other types such as vertical axis turbines and designs using an underwater kite are less advanced. In addition to the open sea, vertical-axis turbines are also suitable for use in rivers and kite concepts can be applied at lower flow speeds, which offers additional market opportunities for free-flow turbines. The Dutch industry is working on all three variants of free-flow turbines (MET support, 2015). As horizontal-axis turbines are further in development, more information is available about this turbine type. This fact sheet generally assumes horizontal axis turbines, unless stated otherwise.

TRL LEVEL

	2020	2030	2050
TRL	5-8	9	9
Explanation	In the Netherlands, turbines with blades that rotate about a horizontal axis are currently being used for the first time on a commercial scale in the Oosterscheldekering (TRL 8). Other techniques (such as vertical axis and tidal kite) have TRL 4-7 (Witteveen+Bos & CE Delft (2019), JRC (2019)).		



Tocardo horizontal-axis turbines near the Eastern Scheldt storm surge barrier. Source: TNO (2018)

CURRENT INSTALLED CAPACITY AND ANNUAL ELECTRICITY PRODUCTION IN THE NETHERLANDS

Installed capacity	1,5 MW
Annual installed capacity	3,75 GWh
Explanation	Tocardo has an installation of 1.2 MW capacity in the Oosterschelde (Witteveen+Bos & CE Delft, 2019). The annual electricity production is estimated on the basis of 2500 full load hours.

POSSIBLE LOCATIONS IN THE NETHERLANDS

Locations	Greatest potential in the Oosterscheldekering, the Afsluitdijk, the Westerschelde, the Waddenzee and other offshore locations (Witteveen+Bos & CE Delft, 2019).
Explanation	The greatest theoretical potential is offshore. Offshore there are also potential opportunities to combine with offshore wind farms (including Borselle and the Dutch coast). How much of this is technically and economically viable is not entirely clear. The feasible potential with the Oosterscheldekering depends on the willingness of Rijkswaterstaat to carry out a larger-scale implementation of the barrier. It is also possible to implement tidal kites near the barrier (SeaQurrent, 2020).

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
							0.9	3			
Energy potential (technical)	PJ/year	*Source*	*Source*	*Source*	*Source*	*Source*	*Witteveen+E*	*Deltares 2(*	*Source*	*Source*	*Source*
			0	0.4							
Energy potential (economic)	PJ/year	*Source*	*Ecofys 201*	*Ecofys 201*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*
Mitigation potential	*Unit*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*

Explanation	Witteveen+Bos & CE Delft (2019) estimate technical potential based on 100 MW and 2500 full load hours. 60 MW of this is at the Oosterscheldekering, whereby the willingness of Rijkswaterstaat to carry out large-scale work on the barrier plays a role in the recoverable potential. Deltares (2008) estimates the technical potential from tidal currents at 5 PJ/year and reasonably exploitable potential at 3 PJ/year. Dutch technology developers estimate the technical potential in the Netherlands at 150-250 MW, which, based on 3000 full load hours, amounts to 1.6-2.7 PJ per year (Tocardo, 2020 and SeaQurrent, 2020), which is within the bandwidth of other sources. Ecofys (2017) estimates business as usual market potential (economic potential that is expected to be realized) in 2030 at 0 PJ/year and with additional policy at 0.4 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
		5100	5250	7500	9750		5900	2320	6440			2400	850	4200	1480	5030
Capex	€/kW	*PBL (2020)*	*Hoefnagel*	*Hoefnagel*	*Hoefnagel*	*Source*	*JRC (2018)*	*JRC (2018)*	*JRC (2018)*	*Source*	*Source*	*Calculation (*	*Calculatio*	*Calculatio*	*JRC (2018)*	*JRC (2018)*
		155	150	400	625		330	130	361			74	26	155	73	246
Fixed Opex	€/kW/yea	*PBL (2020)*	*Hoefnagel*	*Hoefnagel*	*Hoefnagel*	*Source*	*JRC (2018)*	*JRC (2018)*	*JRC (2018)*	*Source*	*Source*	*Calculation (*	*Calculatio*	*Calculatio*	*JRC (2018)*	*JRC (2018)*
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*
		0.185	0.16	0.37	0.65	0.4	0.25	0.10	0.27			0.088	0.031	0.15	0.06	0.20
LCOE	€/kWh	*PBL (2020)*	*Witteveen*	*Witteveen*	*Hoefnagel*	*JRC 2019*	*Calculation (*	*Calculatio*	*Calculatio*	*Source*	*Source*	*Calculation (*	*Calculatio*	*Calculatio*	*Calculatio*	*Calculation*

Explanation	The costs used here are based on cost estimates for horizontal axis turbines. The LCOE for tidal kites is, according to SeaQurrent, comparable to the LCOE for horizontal-axis turbines, with a different Capex and Opex ratio (SeaQurrent, 2020). In the final advice base amounts for the SDE++ 2020 (PBL, 2020), tidal energy from current is included in the category Hydropower, height of fall <50 cm together with, among other things, wave energy. The costs in this category are based on horizontal-axis free-flow turbines and are therefore included here. Witteveen+Bos & CE Delft (2019) mention the investment costs of the SDE+ 2019 and convert the cost estimate from the SDE+ (€ 0.19/kWh) with an interest rate of 3% to € 0.16/kWh. The high limit from the Witteveen+Bos & CE Delft study (0.37 €/kWh) is based on a study by ECN from 2010. Based on industry data and literature, Hoefnagels (2020) has estimated average costs and a bandwidth for horizontal-axis tidal turbines in an array (LCOE of 0.26-1.63 € / kWh, with an average value of 0.65 € / kWh - NB: this cost data is not specific to the Netherlands). The entire bandwidth is higher than the costs of the SDE++ 2020 and Witteveen+Bos & CE Delft (2019). In addition to differences in the assumptions of investment and operational costs, there are large differences in the assumption of full load hours (1200-2400 hours compared to 3700 hours in the SDE++ 2020). IEA-OES (2015) estimate that first commercial projects of 3-90 MW can be realized for a cost of 0.13-0.28 $/kWh (approx. 0.12-0.25 €/kWh). With 10 GW of cumulative installed capacity, the LCOE is estimated at 0.16 $ / kWh (approx. 0.14 €/kWh). JRC (2019) estimate the LCOE in 2018 based on the LCOE in 2015 and learning curves (NB: these cost data are also not specific to the Netherlands). They find a (reference) value of 0.40 €/kWh, but indicate that data from industrial parties indicate lower LCOEs (0.34-0.38 €/kWh). These estimates are also higher than the estimate based on the SDE ++ 2020 assumptions. 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 ++ (3700 full load hours, lifespan of 15 years and 5.6% actuarial interest).

	Based on learning curves, Hoefnagels (2020) has made an estimate of LCOEs in 2050. Due to the relatively high estimate of the LCOE in 2020, this analysis yields a bandwidth (0.2-0.5 € / kWh) above the current cost price from the SDE++ 2020. The assumptions of the learning curves (worldwide cumulative installed capacity of 0.5 GW, 7.5 GW and 81 GW, decrease of CAPEX and OPEX by 0%, 5%, 10%, and 15% for each doubling of worldwide cumulative installed capacity) have been used with the LCOE based on the SDE++ 2020 parameters to arrive at a new estimate of costs in 2050. For reference, the EU SET targets for tidal energy are € 0.15 / kWh in 2025 and € 0.10 / kWh in 2030 (European Commission, 2018).
ENERGY PROFILE	
Energy profile	Variable but predictable energy profile.
Explanation	The energy profile follows the tide, resulting in a sinusoidal profile with peak production every 6.25 hours. After the peak, the flow rate decreases and reaches 0 when the tide turns. Because the tide is determined by the movement of the earth and the moon, it is a predictable energy source - predictable up to a few years in advance (IRENA, 2014). Due to its predictability, it can also be used as a secondary and tertiary reserve (Tocardo, 2020).
EXPORT POTENTIAL	
Export potential	Worldwide theoretical potential is estimated at 3 TW, of which 1 TW is considered technically recoverable (IRENA, 2014). There may be more technically feasible when applying techniques that can operate at low flow rates (such as SeaQurrent's TidalKite or the low-flow turbine under development at Tocardo (now TRL 4)) (SeaQurrent, 2020 and Tocardo, 2020).
Explanation	IRENA (2014) assumes that a minimum flow velocity of 1.5-2 m/s is required for the application of free-flow turbines. With techniques such as tidal kites that can be used at flow velocities of 1-1.5 m/s, the potential export market increases.
POSSIBLE NON-ENERGETIC SIDE EFFECTS	
Ecological effects	For small-scale tidal energy projects, research has been conducted into safety for fish and marine mammals such as seals and porpoises. Research by IMARES shows a changed situation for fish near the Afsluitdijk with respect to movements through the sluice and an increase in the risk of death (IMARES, 2015). The Pro-Tide project investigated fish safety for scale models, from which an increase in mortality has been observed for some fish species while eel survives passage through the tidal turbine (ATKB, 2015). Fish can avoid the tidal turbines more easily than with hydropower plants because the turbines do not cover the entire wet surface, which means that the risk of injury or death is estimated to be lower (IMARES, 2015; Jacob van Berkel, 2020; Witteveen+Bos & CE Delft, 2019). No evidence of impact was found for seals and porpoises at the installation near the Oosterschelde. International research has also found no negative impact of turbines on seals and porpoises (Copping & Hemery, 2020). Based on research into the Oosterscheldekering, the impact on seals and porpoises is estimated to be low, even when more turbines are added to the barrier (Leopold and Scholl, 2019; Seamarco, 2019). For estuaries where there is sand bar erosion, tidal turbines can exacerbate these effects (Witteveen+Bos & CE Delft, 2019). Based on research for two licensed projects near the Eastern Scheldt (existing installation and a similar project not yet completed), there do not appear to be significant effects on erosion and sedimentation (Leopold and Scholl, 2019). Deltares has conducted research into the effect of energy extraction from tidal currents in the Oosterscheldekering on the tides (Deltares, 2018). Measurements from the study show that the tides with turbines appear to fall within a range of natural variations of the tides without turbines. Because the results appear to fall within this bandwidth, the researchers do not draw any definitive conclusions about the impact of the turbines on the tide.
Multiple use	There may be opportunities for coupling with dams and bridges (Scheijgrond, 2020).
Social and landscape effects	
Material use/circularity	
SOURCES	

1	Witteveen+Bos & CE Delft (2019). Perspectieven energie uit water: Nationaal potentieel voor 2030 en 2050 (in Dutch).
2	MET-support (2015). Dutch wave and tidal energy sector: Status, challenges, and roadmap. (on assignment of TKI Wind)
3	JRC (2019). Ocean energy technology development report.
4	Deltares (2008). Water als bron van duurzame energie. Inspiratieatlas van mogelijkheden (in Dutch).
5	Ecofys (2017). Overige hernieuwbare energie in Nederland. Een potentieel studie (in Dutch).
6	Tocardo (2020). Interview 5 June 2020 and written response to draft factsheet (in Dutch).
7	SeaQurrent (2020). Interview 9 juni 2020 en schriftelijke reactie op concept factsheet (in Dutch).
8	PBL (2020). Eindadvies basisbedragen SDE++ 2020 (in Dutch).
9	Hoefnagels (2020). Techno-economic analysis of the cost reduction potential of marine energy technology through learning curve modelling
10	JRC (2018). Cost development of low carbon energy technologies.
11	Europese Commissie (2018) - SET-plan Ocean energy implementation plan.
12	IMARES (2015). Een analyse van effecten van getijturbines op habitat, vis, vogels en zeezoogdieren bij Kornwerderzand (in Dutch).
13	Jacob van Berkel (2020). Interview 27 May 2020 (in Dutch).
14	Deltares (2018). Environmental impact of tidal power in the Eastern Scheldt Storm Surge Barrier. Appendix A: Impact on tidal range due to tidal turbine installation
15	IRENA (2014). Tidal Energy Technology Brief.
16	ATKB (2015). Evaluation of fish injury and mortality associated with the T1 Tocardo turbine
17	Leopold en Scholl (2019). Monitoring getijdenturbines Oosterscheldekering: Jaarrapportage 2018
18	Seamarco (2019). Position Paper: Effects of the Eastern Scheldt Storm Surge Barrier and tidal energy turbines on harbor purpoise (Phocoena phocoene) and harbor seal (Phoca vitulina) movements.
19	TNO (2018). Operations and maintenance simulation for tidal turbines.
20	IEA-OES (2015). Cost of ocean energy technologies.
21	Scheijgrond, Peter (2020). Reactie op concept factsheet (in Dutch).
22	Copping & Hemery, editors (2020) - OES-Environmental 2020 State of the Science report: Environmental Effects of Marine Renewable Energy Development Around the World.