IS HARVESTING BLUE ENERGY FEASIBLE IN THE SEA SCHELDT RIVER, FLANDERS, BELGIUM?
FINDING A SUITABLE LOCATION FOR TESTING DIFFERENT IN-RIVER FREE FLOW TURBINES

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ABSTRACT

Interest in harvesting tidal energy, the so-called blue energy, is increasing, as proven by the many research efforts to improve the technology and the many investigations for developable sites. The main goal of the European project PRO-TIDE, funded by the Interreg IVB North-West Europe program is “to increase the use of renewable energy by promoting innovative, sustainable and cost effective solutions for tidal energy through research, development, testing and comparison of different forms of tidal energy at different locations and circumstances, in coastal zones and estuaries”. Within PRO-TIDE Waterwegen en Zeekanaal nv (W&Z), a Flemish governmental waterways manager, investigates the feasibility of tidal energy harvesting in the Sea Scheldt, on the one hand with a conventional turbine at the future tidal lock in Heusden, and on the other hand with free flow turbines in the Sea Scheldt. This second part includes testing of three technologies, each in different stages of development, in the Sea Scheldt. The paper presents the methodology used in search for a suitable location to perform these tests.

Starting from energy density calculations from the results of an existing two-dimensional hydrodynamic model of the Sea Scheldt, the list of interesting locations is narrowed down by considering other aspects, such as shipping traffic, the presence and ownership of existing infrastructure, and the velocity range. Site visits to the remaining locations, and investigation of available bathymetrical data led to three remaining locations, at which current measurements were performed. The results ultimately led to the selection of the bridge at Temse to be a suitable location for performing the turbine tests. At the moment of writing the test period with the first technology has been successfully completed.

Keywords: Tidal current energy, location study, free flow turbines, on-site testing

1. INTRODUCTION

1.1 Study area

Waterwegen en Zeekanaal nv (W&Z) is a Flemish governmental agency responsible for managing and operating the navigable water courses in the centre and western part of Flanders, Belgium. W&Z participates in the European project PRO-TIDE, funded by the Interreg IVB North-West Europe program. The main goal of this project is “to increase the use of renewable energy by promoting innovative, sustainable and cost effective solutions for tidal energy through research, development, testing and comparison of different forms of tidal energy at different locations and circumstances, in coastal zones and estuaries”. Next to W&Z, the PRO-TIDE project includes partners from The Netherlands (Province of Zeeland, lead partner), UK (Isle of Wight Counsil and Dover Harbour) and France (Laboratoire d’Océanologie et de Géosciences). Within PRO-TIDE, W&Z investigates the feasibility of tidal energy harvesting in the Sea Scheldt, on the one hand with a conventional turbine at the future tidal lock in Heusden, and on the other hand with free flow turbines in the Sea Scheldt. This paper only relates to the second part. More information on the feasibility study at the future tidal lock in Heusden can be found in Goormans et al. (2014).

The Sea Scheldt (in Dutch: Zeeschelde) is the Flemish part of the river Scheldt that is influenced by the tide of the North Sea. The Sea Scheldt runs from the border with The Netherlands all the way up to the city of Ghent, situated roughly 100 km further inland of the border. Close to the border the Antwerp harbour is situated. At Ghent, the tidal influence is ‘cut off’ by weir structures. Figure 1 situates the Sea Scheldt. The river is classified as a navigable waterway, and thus falls under the jurisdiction of the designated waterway manager, in this case Waterwegen en Zeekanaal nv, Sea Scheldt Division (this roughly translates ‘Waterways and Sea canal’). W&Z strives for a dynamic management of their waterways, including the areas along it. It wants to stimulate the use of these waterways and this land while taking into account the interests of all stakeholders involved, and while paying additional attentions to sustainable growth, flood protection and integrated water management. The efforts W&Z makes in the investigation of the feasibility of harvesting tidal current energy in the Sea Scheldt clearly fits well in their attention for sustainable growth.
1.2 Applied methodology for site selection

In a previous, more general feasibility study of the possibility of harvesting tidal energy in the Sea Scheldt (IMDC, 2011), an evaluation framework was developed to identify locations with a potential for energy harvesting. In this study, this framework is applied to the Sea Scheldt, to come to a number of locations that are interesting for further investigations. The most important aspects of the evaluation framework are repeated here; for more details the reader is referred to IMDC (2011). The framework considers both conditions that are specific for a location, and that are related to the combination of location and turbine.

The location specific conditions are:
- Hydraulic energy yield, i.e. the theoretical energy yield available in the tidal current;
- Administrative, legal and practical aspects, including nautical constraints.

The location – turbine specific conditions are:
- Considered technology;
- Technical energy yield, i.e. the energy yield after taking all losses into account;
- Costs and benefits;
- Ecological impact.

Although extremely important with regard to developing a tidal energy project, the last two issues will not be discussed in depth here. The W&Z project wants to obtain a more clear view on the potential for harvesting tidal energy from the Sea Scheldt first, before considering any further steps. In Goormans et al. (2013a) a literature review is presented on the possible environmental effects related to harvesting tidal current energy. The following topics were discussed: collisions with the turbine, alteration of hydraulics and hydraulic regimes, suspension of sediments and contaminants, impacts on benthic organisms, toxic components, electromagnetic fields, and nose and vibrations. Possibilities for mitigation are suggested as well.

2. LOCATION SPECIFIC CONDITIONS

2.1 Hydraulic energy yield

2.1.1 Definition

The available power $P_{\text{hydr}}$ [W] of a water flux with flow velocity $v$ [m/s] through an area $A$ [m$^2$] of a fluid with density $\rho$ [kg/m$^3$] can be calculated as:

$$P_{\text{hydr}} = \frac{1}{2} \cdot \rho \cdot C_p \cdot A \cdot v^3$$  \[1\]
in which $C_p$ is the power coefficient, having a maximum theoretic value of $16/27 = 0.593$, the so-called Betz-limit. The energy yield $E_{hydr}$ [J] over a specific time period $T$ can be calculated by integrating Eq. [1] over the given time period. In order to compare different locations, the average yearly specific hydraulic energy yield $e_{hydr}$ [kWh/year/m$^2$] \(^b\) will be considered, i.e. the average hydraulic energy yield per unit swept area, produced over an entire year; $e_{hydr}$ will sometimes be referred to as the energy density in this text.

2.1.2 Determination of flow velocity

To assess the energy density of the Sea Scheldt river, results from an existing two-dimensional hydrodynamic model are used. The model is implemented in the Delft3D software, and can produce depth average flow velocities. It actually consists of 2 models: a model of the Westerscheldt and the Lower Sea Scheldt, up to the mouth of the Rupel tributary ('LowSS' in Figure 1) and a more upstream model, consisting of 6 subdomains ('SD1' to 'SD6'). SD2 basically is the tidal influenced part of the Durme river, and hence is not part of the Sea Scheldt river. It will not be considered further (although it is always included when performing simulations). The same applies for the Westerscheldt in the 'LowSS' model: this part of the estuary is on Dutch territory and falls outside the jurisdiction of W&Z, but is included when performing simulations. More information regarding this model can be found in Maximova et al. (2010).

The main drawback of these models is that they were developed and calibrated for observed water levels; accurate calibration and validation for flow velocities was not done. Therefore the model results should not be used for actually quantifying the energy density; however they can be used to have a qualitative image of the energy density in the Sea Scheldt, distinguishing locations with a higher energetic potential from those with a low potential.

The simulations were performed for a representative spring tide - neap tide cycle, with a variable time step between 6 s and 12 s. The downstream boundary is a water level time series, the upstream boundary a discharge time series.

2.1.3 Energy density results

The results of the simulation consist of time series of the velocity components in both x- and y-directions, $v_x(t)$ and $v_y(t)$ respectively, in every grid point. Before applying Eq. [1], the velocity magnitude is determined in every grid point:

$$v(t) = \sqrt{v_x(t)^2 + v_y(t)^2} \quad [2]$$

This means that the direction of flow is not taken into account. In other words, energy harvesting is assumed to be possible in all directions. In reality the Sea Scheldt shows a rather clear bidirectional tidal pattern, so the requirement for "omni-directionality" can be loosened to "bi-directionality". After applying Eq. [1] for the considered tidal cycle the average yearly energy yield is calculated by extrapolating to a yearly basis. The spatial approach enables the generation of an energy density map, of which a detail can be seen in Figure 2.

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\(^b\) 1 kWh = 3.6E+6 J
From this map the relative contribution in horizontal area of the model grid for each subdomain can be calculated as a function of the specific hydraulic power, which gives an idea of the distribution of the average specific hydraulic power over the Sea Scheldt. This result is depicted in Figure 3. From the figure it becomes clear that the energy density generally is higher in the lower parts of the Scheldt estuary.

Figure 3. Relative contribution in horizontal area of the model grid per subdomain, for values > 400 kWh/year/m$^2$, of estimated average yearly specific hydraulic energy yield for each subdomain of the 2D hydrodynamic model of the Sea Scheldt.

The energy density map is screened for potentially interesting locations regarding energy density. A location (or rather a zone) is considered interesting when the energy density reaches a value of at least 2800 kWh/year/m$^2$. From Figure 3 it can be seen that roughly 10-15% of the model grid area has values above 2800 kWh/year/m$^2$. This is believed to be a good compromise between energetic potential on the one hand and a first narrowing down of interesting locations on the other hand. It should be stressed that no economic aspects were considered in determining this threshold value, nor should it be considered as a minimal target energy yield set by W&Z. The result is a preliminary list of 33 zones, which formed the basis to define a ‘long list’ of locations, taking practical aspects into account.

2.2 Administrative, legal and practical aspects

2.2.1 Possible administrative and legal issues

This aspect mainly concerns possible stakeholder conflicts when starting the necessary administrative and legal procedures for permitting the development of a site. Stakeholders could be e.g. land owners, environmental organizations, water managers, shipping traffic authorities, grid operators, local, regional or national governments etc. For this study only a temporary test set-up is envisaged, making the permitting procedure in Flanders relatively straightforward. Moreover, in this study it is the water manager W&Z itself that is the driving force for installing energy harvesting devices in the water. Therefore this issue was not explored further here.

2.2.2 Nautical constraints

The Sea Scheldt is a heavily navigated waterway, forming an important route for transport of many goods, making it essential for the economy, not only on the regional scale but also on the national and even European scale. So it is obvious that the fairway must be safeguarded at all times, and a possible deployment of one or more turbines – whether it is temporary or permanent, floating or installed on the river bed – can in no way cause any hindrance for shipping traffic. Hence for locations of interest it should always be verified that they are not situated inside the fairway, or close to navigational infrastructure.

In this study, two different types of data were used for this purpose. For the Lower Sea Scheldt, data originate from the AIS (Automatic Identification System) installed on ships. The AIS data give a good overview of where vessels have actually sailed. The data were retrieved and used in the framework of a study on the necessary safety measures to be taken on the Westerscheldt, when separating seafaring traffic from inland and recreational traffic (IMDC i.c.w. Resource Analysis, 2010). In that study, data were available for the year 2007. Analysis showed that most months had a similar traffic intensity, except for the months of March, June and November, which showed a higher intensity (IMDC i.c.w. Resource Analysis, 2010). Therefore the AIS data of November 2007 will be used here. Figure 4 shows these data; only the location of data points is given, not the AIS signal intensity.

AIS is a vessel-to-vessel transponder and positioning system, allowing a skipper to determine his position relative to the surrounding area and surrounding vessels, fitted with AIS. The system sends and receives signals to and from a central traffic control, containing information on position, course, speed, name of the vessel, crew etc. The system is obligatory for maritime vessels, but is more and more implemented on inland vessels as well.
For the Upper Sea Scheldt, i.e. starting from the mouth of the Rupel river and going further upstream, the fairway axis and fairway path as defined in the nautical base plan for the current situation (IMDC et al., 2010) were considered. Figure 4 shows an example of these data. Some conflicts with the potentially interesting zones can already be seen. Unfortunately this often is the case; in the Sea Scheldt the highest velocities – and highest energy density values – are located inside or close to the fairway.

*Source AIS data: IMDC i.c.w. Resource Analysis (2010).*
The 33 points identified thus far, were analyzed for possible conflicts with ship traffic. When there was a conflict to be expected, the point was shifted outside the fairway while keeping it as close as possible to its original location, in other words while keeping the energy yield as high as possible. If this shift caused the average energy yield to become smaller than the above defined threshold of 2800 kWh/year/m², the location was omitted from the list. This exercise trimmed down the number of locations to 27.

2.2.3 Existing infrastructure

Various options exist for installing turbines in the water: floating with moorage to the river bed, a support structure on the river bed (either gravity based or driven piles), or a structure that is suspended from e.g. a bridge or a jetty. Either way, in selecting possible locations for installation of a test set-up, which will be a temporary set-up, it was deemed convenient to have some kind of existing infrastructure close to the site. After all, the infrastructure could be used to install the turbine and its equipment, or it could serve as a fixed point, facilitating moorage, or even just connection of data cables running from possible measurement devices to the processing equipment. Therefore, the 27 above defined locations were each analysed (using satellite photos from Google Maps) for their proximity to existing infrastructure, such as a bridge, jetty, quay wall or pontoon. When there was no potential infrastructure, the location was omitted from the list.

This step in the selection process definitely was the most subjective one, but also resulted in a higher reduction of the number of locations – at least at first glance. The 27 locations were initially reduced to 14, but by screening the Sea Scheldt for possible infrastructure, several additional potential locations were observed, which seemed not that interesting at the beginning of the selection procedure – lower energy yield calculated with the model – but became more appealing because of the nearby infrastructure, resulting in – again – 27 locations. It should be noted that in this stage of the selection, each location was considered as a separate one, e.g. the left and right bank of a zone with a higher expected energy yield became two separate locations.

This iteration is of course natural in a selection procedure. It could have been avoided by first selecting locations based on possible infrastructure. But it should be noted that the framework in IMDC (2011) was worked out for the more general case, with site development as the main goal. Therefore, this step in the selection procedure should be combined with a cost assessment of constructing suitable infrastructure. After all, depending on the expected energy yield, a higher cost for providing infrastructure can be justifiable. Since at this time the main goal is to install a temporary test set-up, an as low as possible cost was aimed for.

One location was added to the list, located along the Rupel river, which is a tributary of the Sea Scheldt and also influenced by the tide. A brickworks company owns a jetty on this river, and expressed its interest in supporting developments in tidal current energy harvesting.

2.2.4 Possibilities for grid connection

In this study, connecting the test set-up to the grid is not a necessary aspect. Nevertheless it might be interesting to screen the locations for possible connections, keeping a possible further development of the location in mind. A screening based on satellite photos (Google Maps) learned that most locations are close to an urban environment. Foreseeing a grid connection hence was not expected to be a decisive factor in selecting a location.

2.2.5 Further narrowing down and site visit

The next step in further narrowing down the number of locations started with listing the owners and operators of the infrastructure from the 28 locations above. Naturally, when W&Z is owner and/or operator of the infrastructure this is undoubtedly an advantage for this study. After all, this exploratory study has an uncertain outcome regarding potential further development, and therefore permission or cooperation of private companies is likely to be more difficult to obtain.

To further decrease the number of locations, the different values of energy yield were compared, with locations having a higher yield obviously being valued higher than locations with a lower yield. Also, locations with a higher maximum velocity were considered as more interesting to install a test set-up, because that way, the turbine is subjected to a broader range of velocities. Next to these quantitative classifications, the nearby infrastructure was assessed for its quality. Of course, poor quality infrastructure was not expected, because then the location would not have made the previous screening (§2.2.3). But differences in expected structural stability were present, e.g. although a wooden jetty could serve as anchorage point, it can be considered less suitable compared to a steel or concrete one. It should be noted that this assessment still occurred using satellite photos (Google Maps).

Taking the above mentioned classification into account, the ‘long list’ of 28 locations could be reduced to a ‘short list’ of 8 locations. A site visit to these locations was conducted on Tuesday 12 February 2013, and an investigation of the available bathymetrical data finally resulted in three locations to install current measurement devices (§4).

3. LOCATION-TURBINE SPECIFIC CONDITIONS

3.1 Short introduction

Tidal current energy convertors extract energy from the water flow, generally by either using the lift forces or the drag forces – originating from the water flow interacting with the convertor – to generate a mechanical motion, i.e. rotation, translation, vibration, of a movable part of the convertor, which in turn is connected to an electric generator. The most conventional convertors are turbines based on converting lift forces or drag forces (or a combination of both) to a rotation.

The lift forces originate from pressure gradients due to differences in flow velocity around hydrodynamically shaped blades. The same principle is applied in airplanes: the wings have a hydrodynamically favourable shape, resulting in a flow pattern that causes a pressure gradient over the wing. The plane is lifted vertically, although the wind flow is horizontal.
Drag forces are the result of the water ‘pushing’ directly against a surface, which sets the surface in motion. The reverse principle was applied to the steamboats sailing the Mississippi in the 19th century. Generally, turbines relying on lift forces have higher conversion efficiencies compared to those relying on drag forces. The latter on the other hand are more straightforward to design and construct.

Two main types of turbines can be discerned: horizontal axis and vertical axis marine current energy convertors. While the latter are omnidirectional by concept, which is undoubtedly an advantage, part of the blade rotor will always move opposite the flow direction, which of course forms an additional resistance. Hence much attention must be given to rotor design.

Because of their operating principle, the application of tidal current energy convertors is not limited to offshore applications. When properly scaled these convertors can be deployed in rivers as well, as envisaged in the W&Z project within PRO-TIDE. An elaborate overview of different tidal current energy convertors can be found in a separate PRO-TIDE report, of the Master Class on Innovative Tidal Energy Techniques, held on Thursday 30 May 2013 at Flanders Hydraulics Research in Antwerp, Belgium (Goormans et al., 2013b).

3.2 Technology selection

So far the average specific hydraulic power has been considered. This is a theoretical maximum, which indicates the amount of energy at a certain location. Of course the actual energy yield will be lower. How much lower depends on the considered technology, but the main goal will probably be to have an as high as possible energy yield.

For a location with a high peak flow velocity, a turbine with a high nominal power output might seem a good choice. However if the peak velocity only occurs during a short time span in the tidal cycle, the turbine will only operate at its rated capacity for a limited amount of time as well. Because of this ‘over dimensioning’ it is likely that the turbine operates in suboptimal results during most of the time, and in the end a device with a lower nominal power output might produce higher energy yields.

A second technological aspect that relates to this, is the so-called ‘cut-in speed’ (Figure 5). This is the flow velocity below which the turbine will hardly generate power – if at all – because of internal losses. For the same location, turbines with a low cut-in speed will probably generate power for a more prolonged period during each tidal cycle. On the other hand, the lower cut-in speed might imply a lower efficiency during the mid-to-high range of velocities occurring at the considered location.

Thirdly, an important phenomenon is ‘stalling’ of the rotor. When the flow velocity becomes too high, the hydraulic conditions around the rotor become less favourable, and the power output drops significantly. With increasing water speed, the power output rises again, but when the flow velocity is too high, power output drops to zero (Figure 5). Not only is stalling to be avoided because of the lower power output, it can also be harmful for the device due to the unstable operating conditions.

The above explanation is based on the more traditional horizontal or vertical axis marine current turbine, but for ‘unconventional’ devices the same principles apply, i.e. some devices are more suitable for a certain velocity spectrum than others. The main conclusion should be that care must be taken when tuning the efficiency to the governing hydraulic conditions at the considered site.
3.3 Technical energy yield

Given the above discussion on power output, the technical power $P_{tech}[\text{W}]$ is defined here as the power actually generated by a turbine with given efficiency $\eta[\cdot]$ and cut-in speed $v_{ci}[\text{m/s}]$. In principle, the efficiency depends on the water speeds, so $\eta(v)$. Also, the power coefficient $C_p[\cdot]$ is a turbine and velocity dependent factor, being lower than the Betz-limit, hence $C_p(v) < 0.593$. Rotor design aims at maximizing the power coefficient.

It is assumed that the turbine is properly chosen, i.e. that the full range of velocities occurring at the site can be coped with by the turbine without stalling. The technical energy yield $E_{tech}[\text{J}]$ over a certain time period $T$ hence can be calculated by integrating the instantaneous technical power $P_{tech}(t)$:

$$E_{tech} = \int_0^T P_{tech}(t) \cdot dt = \frac{1}{2} \rho \cdot A \cdot \int_0^T I_V(v) \cdot \eta(v) \cdot C_p(v) \cdot v(t)^3 \cdot dt$$

with $I_V(v)$ being the indicator function related to the cut-in speed $v_{ci}$:

$$I_V(v) = \begin{cases} 1 & \text{if } v \geq v_{ci} \\ 0 & \text{if } v < v_{ci} \end{cases}$$

The average yearly technical energy yield per unit swept area is, similarly as in §2.1.1, calculated by extrapolating for a time period of one year. Typical values of the cut-in speed vary between 0.5-1.0 m/s. Figure 6 shows the influence of an increasing cut-in speed on the energy density map, at Antwerp. The decrease in energy yield is visible. To show the influence of the cut-in speed, the efficiency and power coefficient are kept constant and equal to unity and the Betz-limit respectively.

![Figure 6](image1.png)

**Figure 6.** Average yearly technical energy yield at Antwerp, at different cut-in speeds.

Upper left: 0 m/s. Upper right: 0.5 m/s. Lower left: 0.7 m/s. Lower right: 1.0 m/s.

Figure 7 shows this influence quantitatively, by depicting the cumulative area (relative to the results of $v_{ci} = 0$ m/s at 400 kWh/year/m²) enclosed by the contour corresponding to the average yearly technical energy yield, for different values of the cut-in speed. The graph is based on the results of the subdomain LowSS of the 2D hydrodynamic model, but the other subdomains gave similar results. From the graph it is clear that, for the case of the Sea Scheldt – and more specific the Lower Sea Scheldt – the cut-in speed should not be higher than 0.7 m/s. After all, up to this value, the decrease in technical energy density remains very acceptable.
4. CURRENT MEASUREMENTS

4.1 Considered locations and used equipment

The locations at which current measurements were performed were: the jetty at Lillo, the pontoon at Steenplein (Antwerp), and the bridge crossing the Scheldt at Temse (see Figure 8). At the first and last location, an RCM-9 (Recording Current Meter) was installed, an acoustic velocimeter based on the Doppler effect capable of measuring magnitude and azimuth of the velocity vector. It is known from experience at these locations that the flow is strongly horizontal so there was no need to use more complex – and expensive – measurement equipment. The RCM-9 is able to sample temperature, salinity and suspended solids concentration as well; these results however were not used in the assessment. For the pontoon at Steenplein it was decided to install a bottom-mounted ADCP (Acoustic Doppler Current Profiler), to detect possible disturbances in the velocity field due to proximity of the pontoon and the quay wall.

Figure 7. Cumulative model grid area (relative to the results of \( v_{ci} = 0 \) m/s at 400 kWh/year/m\(^2\)) enclosed by the contour corresponding to the average yearly technical energy yield, for different values of the cut-in speed \( v_{ci} \), for the subdomain LowSS of the 2D model.

Figure 8. Overview of the locations where current measurements have been performed (yellow dots). The pink dots represent the other locations on the ‘long list’.
4.2 Measurement results and site selection

Each location was monitored during almost one month in the summer of 2013. The Scheldt river has a semidiurnal tidal cycle, with a full spring tide - neap tide cycle lasting about 14 days. So the measuring period comprises at least one full spring tide - neap tide cycle. Table 1 gives an overview. More information on the measurement campaign and its results can be found in the full factual data report (Van Troos et al., 2014).

Table 1. Measurement campaign at three locations in the Sea Scheldt.

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>MEASURED PERIOD</th>
<th>DEVICE</th>
<th>INSTALLATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jetty at Lillo</td>
<td>18/06/2013 - 16/07/2013</td>
<td>RCM-9</td>
<td>suspended from buoy, at 2.7 m depth</td>
</tr>
<tr>
<td>Pontoon at Steenplein</td>
<td>18/06/2013 - 16/07/2013</td>
<td>ADCP</td>
<td>mounted in bottom frame, facing upwards</td>
</tr>
<tr>
<td>Bridge at Temse</td>
<td>20/08/2013 - 19/09/2013</td>
<td>RCM-9</td>
<td>suspended from buoy, at 1.1 m depth</td>
</tr>
</tbody>
</table>

Figure 9 shows the duration curve of the velocity at each location, i.e. the exceedance frequency distribution. For Lillo and Temse these are derived from the actual time series, for Steenplein the average of the upper 20% of the water column was taken. At Lillo the velocity rarely exceeded 1 m/s. This is lower than reported in previous measurement campaigns at a location further inland, but this can be ascribed to the jetty being located in an inner bend of the Scheldt. At Steenplein reported velocities were higher than at Lillo; no noticeable flow towards the quay wall could be detected. Finally it is clear that Temse yields the highest velocities. This is because the proposed location is located along the central axis of the river. At Temse this is possible because the fairway path is directed to the north of the bridge, where there is a movable part. The higher velocities are not only interesting from an energy yield point of view, it also means that an installed device will be subjected to a wider spectrum of velocities, which is of course interesting from a research perspective.

The main advantage of performing the tests at pontoon Steenplein would be that certain manipulations during installation or demobilization of devices could be done from the quay using a stationary crane, rather than from a vessel, which would reduce the costs. On the other hand when servicing the location at the bridge at Temse, a smaller vessel can be used, compared to the vessel used around Antwerp *, which is of course positive for the operational cost during the tests.

Based on the above considerations, it was ultimately decided to use the bridge at Temse as location for testing tidal current energy converters.

5. PRESENT STATUS

In short, the tests comprise of installing turbines in the water, and performing concurrent measurements of flow velocity and power output. Additionally, each fabricator can perform other measurements related to the operation of their turbine, so as to gain new insights in their technology.

After selecting Temse, it became apparent that, for conducting the tests – that are temporary in nature – it might not be opportune to use the bridge pillars for anchorage. Instead, a pontoon of 3 m x 39 m was proposed to serve as a work platform. The floating pontoon is moored between two piles, piled in the river bed. The most straightforward way to attach a turbine to a floating pontoon is to make the test set-up floating as well, and anchoring the turbine-pontoon assembly next to the work pontoon. This offers the additional advantage of capturing the highest velocities typically occurring in the upper layers of the water column. Moreover the velocity measurement devices can be secured to the floating pontoon as well, so

* This is because the governmental service vessel in the area in which the pontoon at Steenplein is situated, is larger, due to the nature of the works it generally performs.
their position relative to the tested turbine assembly remains fixed and is known at all times, contrary to a buoy-mounted device. Figure 10 shows the principle of the test set-up.

![Figure 10. Principle of the set-up for the turbine tests (top-down view).](image)

Three different devices will be consecutively tested during 4 weeks, in order to comprise at least one full spring tide - neap tide cycle. The velocity measurements are executed with two RCM-9 devices, installed on a steel frame that is adjustable in both horizontal and vertical direction (Figure 11). In each test period, high-density turbulence intensity measurements using an ADCP are performed as well by the Laboratoire d’Océanologie et de Géosciences (LOG) from the Université du Litoral Côte d’Opale (ULCO), another PRO-TIDE partner, for a shorter time period, about one week. The aim of these measurements is to investigate how the turbine efficiency can be related to the occurring turbulence patterns.

At the moment of writing the test period for one of the three selected technologies was successfully completed.

![Figure 11. Left: adjustable frame for RCM-9 device. Right: RCM-9 lifted above the water surface.](image)
6. CONCLUSIONS

Within the European PRO-TIDE project, W&Z investigates the potential for harvesting tidal current energy in the tidally influenced Sea Scheldt river. This investigation includes the testing of three technologies in the Sea Scheldt. The paper presents the methodology used in search for a suitable location to perform these tests.

The investigation started with estimating the theoretical energy density in the Sea Scheldt, using results of an existing two-dimensional hydrodynamic model. This resulted in an indicative energy density map that could be used to identify zones of interest, i.e. zones with relative high energy density. In a next step, the requirements for shipping traffic were taken into account: a T-shaped test set-up can in no way obstruct navigation on the Sea Scheldt. Existing infrastructure was accounted for as well: locations with possibilities for anchoring a test set-up were deemed more interesting than others. This resulted in a ‘long list’ of 28 possible locations. After checking ownership of the infrastructure (public body vs. private) and looking at the range of velocities occurring in the model results, the long list was narrowed down to a ‘short list’ of 8 locations. Site visits and further inspection of the available bathymetrical data led to 3 locations being selected to perform current measurements. Ultimately, based on the measurement results, the bridge at Temse was selected. This location shows a high range of velocities, is situated outside the fairway and can be serviced by relatively small vessels.

Currently a work pontoon has been installed at the bridge, enabling straightforward anchorage of floating test assemblies. The velocity measurement devices are attached to the pontoon as well via a steel frame, adjustable in both horizontal and vertical direction. At the moment of writing, the test period of one of three technologies was successfully completed.

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REFERENCES


