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# Siting assessment for Kinetic Energy Turbines: an emplacement study for sea and river applications

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**Abstract**

The siting and design of a Tidal Energy Converter (TEC) require the characterization of the flow velocity field acting in terms of space and time, in order to assess the hydrodynamic forces, to calculate the structural loading and power capacity, also helping investment strategy and project financing. In this framework, the selection of the emplacement site is of paramount importance for optimizing efficiency of TEC. In this study, we propose site assessment procedures for emplacement of TEC machines, comparing a sea tidal site with two rivers ones. Sites differ each other from geomorphological characteristics. The Cook Inlet (South-Central Alaska) is a large subarctic estuary, which extends about 250 km from Anchorage bay to the Pacific Ocean. Tidally dominated currents control the hydrographic regime, with water levels and currents periodically influenced by tides from the Gulf of Alaska, which are significantly amplified as approaching Anchorage bay. The Cháng Jiāng river (also named Yangtze, China) is the longest in Asia and the third in the world, with a huge flow rate. The Pearl River Estuary (China) has a length of about 70 km, a width of about 15 km and an average depth of about 4.8 m. It is deeper than 20 m in its eastern part, and discharges into a microtidal environment along the northern shelf of the South China Sea. The TEC performances have been compared in the three different geomorphological environments. Results show how TEC in rivers can perform up to 5.47 kW/m$^2$, a huge value compared to the wide sea turbines, able to perform up to 10.76 kW/m$^2$.

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*Keywords:* *TEC, Tidal Energy Converter, geomorphology, marine and fluvial environment, siting.*

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## 1. Introduction

Tidal machines installed in river or sea convert the kinetic energy of moving waters in electricity, therefore the optimal conditions for placement need to be found basing on geometric characteristics of emplacement site. This leads to machine optimization in terms of geometry, fluid dynamics and mechanics.

Predictability of the water speed distribution and energy availability from lump tidal, provide assessment of the possible energy production, once known the flow rate (rivers) or speed (tidal) distribution over the year.

The siting procedure requires the characterization of the spatio-temporal variation of the current velocity (an optimum range is 1.5÷3.5 m/s [1]) and turbulence acting on the machine, in order to provide the hydrodynamic forces and available power estimates over a representative period of time. These parameters are unavoidable for designing the structural loading and power capacity of the machine.

Environmental effects of tidal power generation are almost similar to wave and offshore wind power ones. Less known are the site effects and the energy potential of the river flows in which are installed similar machines. In order to site and operate properly, the environmental risks of these machines must considered [2], taking care to distinguish between environmental effects and impacts. Environmental effects are the broad range of potential measurable interactions between tidal energy devices and the marine environment. Environmental impacts are all the effects that can rise to the level of deleterious ecological significance with a high probability.

Seafloor geology significantly influences the installation of a kinetic energy device. Recent researches on sediment dynamics postulate a threshold value for the initial movement of particles [3]. This is important for evaluating if under critical conditions the removed sediments can impact turbine components such blades and structural parts.

In this paper, some key parameters have been analyzed in order to allow a first order performance comparison between sites. This procedure was applied to a new machine concept characterized by a hollow design, and taking care about the site limitations.

**Nomenclature**

| | |
|---|---|
| $A$ | cross sectional (swept) area of the device |
| $P$ | flow current power |
| $\rho$ | flow density |
| $V$ | instantaneous flow current speed (variable for tidal flows) |
| $V_{av}$ | averaged flow speed |
| $P_A$ | channel average power |
| $A_c$ | channel average cross sectional area |
| $V_p$ | peak surface speed |
| $z$ | water depth |
| $v(z)$ | flow speed at some water depth $z$ |
| $v_0$ | flow speed at a reference water depth $z_0$ (seabed) |

### *1.1. Site energetic parameters [4]*

- *Power Density*

The instantaneous Power Density (W/m$^2$) of a flow incident on a tidal current turbine is given by the equation:

$$\left(\frac{P}{A}\right)_{Water} = \frac{1}{2}\rho V^3 \quad (1)$$

- *Averaged Power Density*

It is the Power Density [W/m$^2$] calculated taking in consideration the averaged flow speed $V_{av}$ from the annual distribution.

$$\left(\frac{P}{A}\right)_{Water} = \frac{1}{2}\rho V_{av}^{3} \tag{2}$$

- *Channel average available power*

$$P_A = \left(\frac{P}{A}\right)_{Water} A_c \tag{3}$$

- *Flow speed at a datum depth*

Depending on the turbine installation and working principle a correction to $V_p$ is introduced, related to the installation depth with the formula:

$$v(z) = v_0 \left(\frac{z}{z_0}\right)^{\frac{1}{10}} \tag{4}$$

Depths are intended from the bottom to the sea level, therefore the seabed is at $z$=0.

## 2. Case-studies

### *2.1. The Cook Inlet, Alaska (case study 1)*

The Cook Inlet is a semi-enclosed, subarctic tidal estuary on the southern coast of Alaska [5] (Fig.1). It is approximately 330 km long, 48 km wide and no more than 60 m depth. The shoreline is regular, with few coves and secondary inlets.

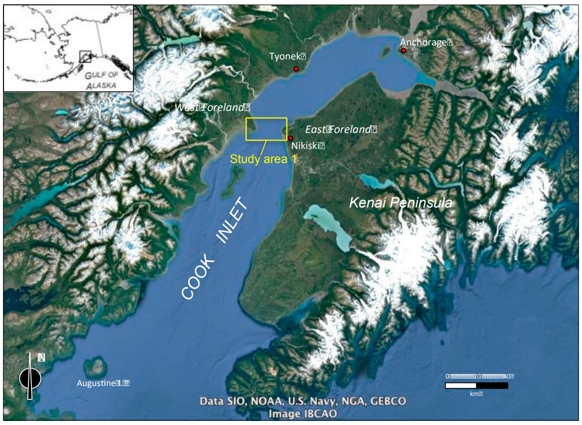


Figure 1 - Map of the Cook Inlet area. In the yellow box is shown the most suitable area for the TEC emplacement.

At its northern end it receives waters from many large rivers, and at its southern part it has marine connections with Shelikof Strait and the Gulf of Alaska. The Cook Inlet has the largest tides in the American continent, with a mean diurnal range in Anchorage of ca. 9.5 m [6]. Water levels and currents are thus influenced by tides coming from the Gulf of Alaska, significantly amplified towards Anchorage (1÷2 m tidal range near the Gulf of Alaska opening and 8÷10 m in the northern part of the Inlet) [7]. In addition to tidal currents, buoyancy driven flows from melting ice, constitute pivotal components of the circulation and mixing in Cook Inlet.

### 2.2. The *Yangtze River (case study 2)*

The Yangtze River (Fig. 2) is one of the largest rivers in the world in terms of mean sediment and water volume discharge. It has a tide dominated estuary (depositional basin), located northwestern East China Sea with a mean tidal range of 2.7 m, and a maximum of 4.7 m. The average tidal current is about 1.0 m/s reaching more than 2.0 during spring tide. The topography of the Yangtze delta plain is characterized mainly by an elevation of ca. 2 m above mean sea level in the central delta plain, rising to 3÷5 m on the periphery of delta plain [8]. Over the past 3 kyr the high sea-level stand has gradually retreated, approaching its present level [9]. Deceleration of sea-level rise by mid-Holocene time induced fluvial sediments to accumulate along the periphery of the delta plain.


Figure 2 Map of Yangtze River;

### 2.3. *Pearl River Estuary, China (case study 3)*

The Pearl River Estuary (PRE), is a complex micro tidal estuary with small tidal amplitudes located in the north shelf of the South China Sea [10]. It has a trumpet-like water area (Fig. 3) with 8 river inlets on its west bank. The Pearl River discharge ca. 4 x $10^3$ $m^3/s$ (minimum) in the winter and ca. 2 x $10^4$ $m^3/s$ (maximum) in the summer. A number of forcing mechanisms including bottom topography, freshwater discharge, wind, tide and coastal current, control the circulation and water properties. This area experiences alternating monsoons every year, which drive multiple effects on local circulation. Moreover, the large-scale wind patterns set up sea level gradients on the shelf, which in turn generate coastal currents.

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Figure 3 Map of Pearl River Estuary (PRE), South China

The PRE tidal range is ca. 0.8÷0.9 m near the Wanshan Islands, ca. 0.9 m near Neilingding Island [11], and ca. 1.7 m near Humen [12]. In such a complex estuary system, it is common that several different circulation regimes coexist and various types of fronts (such as coastal temperature and river plume fronts) form between the circulation regimes in the estuary.

Table 1: case studies: site parameters

| PARAMETER | UNIT | Case study 1 | Case study 2 | Case study 3 |
|---|---|---|---|---|
| Average Channel width | m | 2,450.00 | 1,100.00 | 500.00 |
| Average depth | m | 60.00 | 30.00 | 12.00 |
| Channel cross sectional area | $m^2$ | 73,500.00 | 16,500.00 | 3,000.00 |
| Maximum tidal range | m | 12.00 | - | - |
| Peak surface velocity | m/s | 3.90 | 2.99 | 2.25 |
| Averaged Power Density | $kW/m^2$ | 1.62 | 5.21 | 3.23 |
| Total Available Stream Resource | MW | 118.00 | 85.90 | 9.68 |

*2.4. Energetic parameters*

The aim of the following energetic estimations is to demonstrate how much the potential can be in a river flow, compared to a tidal one, especially if particular machine geometry is involved in. The site selection requires high energized currents together with depth on transect [13]: the actual machines, the wind like ones, due to a wide blades diameter, have a critical seabed positioning and dramatic impact on fauna. Almost all technologies face such problems even though the performances can appear attracting: Table 1 summarizes the energetic and geometric parameters for each site.

## 3. The $W^2$ Avant Gard Technology turbine

The $W^2$ Avant Gard Technology, is applied as a single turbine, moored to the coast by a fixture or structure subjected to a tensile stress [14], characterized by a double (or, for other purposes, single) counter rotating rotors, (see fig. 4) converting, by the built in synchronous generator, the flow kinetic energy in electricity without any other mechanical device (gearbox, shaft etc.) [15].

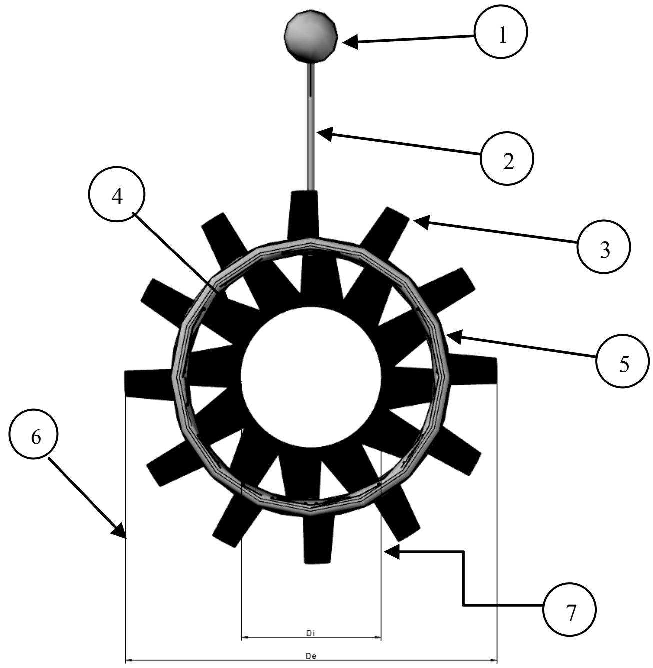
The low weight and the hollow design allow the turbine to work even in shallow water, therefore capturing the fastest currents (see eq. 4). In addition, the mooring system allows a quick repositioning in front of the current for the maximum energetic efficiency in case of tidal applications [16].

The compact, scalable design and cost saving solutions [17] allow to install the turbine in rivers, since the "close to water surface" operation requires smaller channel cross sectional areas and this can be affordable for disadvantaged areas where public infrastructures are poor or missed.

As shown in Table 2, two different configurations have been assumed for the performance simulation, one for a tidal and the other one for a river purpose (for this case, a channel cross sectional area of around 400 $m^2$ has been assumed, requiring a minimum water depth of 15 m).

Table 2: turbine geometry parameters, tidal and river application

| PARAMETER | SYMBOL | Tidal purpose | River purpose |
|---|---|---|---|
| External diameter | $D_e$ | 12.00 m | 5.00 m |
| Diameters ratio | $D_i/D_e$ | 0.35 | 0.35 |
| Swept area | $A_S$ | 100.00 $m^2$ | 17.00 $m^2$ |
| Global power coefficient | $C_p$ | 0.41 | 0.41 |
| Mechanical efficiency | $\eta_m$ | 0.90 | 0.90 |
| Electrical efficiency | $\eta_e$ | 0.85 | 0.85 |




| ref | Description |
|---|---|
| 1 | Floater & axis control |
| 2 | Floater support |
| 3 | External blades |
| 4 | Internal blades |
| 5 | Stator |
| 6 | $D_e$: external diameter |
| 7 | $D_i$: internal diameter |

Figure 4 Hollow design on $W^2$ Avant Gard Technology turbine and main components

## 4. Results and Discussions

The results based on the above parameters are summarized in Table 3:

Table 3: turbines main performances

| PARAMETER | UNIT | Case study 1 | Case study 2 | Case study 3 |
|---|---|---|---|---|
| Peak velocity | m/s | 3.90 | 2.99 | 2.25 |
| Peak Power | MW | 1.07 | 0.93 | 0.39 |
| Maximum turbine Power density | $kW/m^2$ | 10.76 | 5.47 | 2.34 |
| Annual energy production | MWh | 703.49 | 424.42 | 221.59 |

Compared to other marine devices [18, 19] the $W^2$ Avant Gard machine performances are almost the same. The new finding is related to the river solution that appears to be the profitable one in terms of theoretical turbine power density, due to the smaller cross sectional area and huge flow rates.

In order to better understand the order of magnitude, to exploit a power density of 2.34 $kW/m^2$ a wind turbine, at the same geometry, should require a flow speed of 19 m/s, due to a lower density of the flow (air density 1.225 $kg/m^3$ vs water density 1000 $kg/m^3$).

The $W^2$ Avant Gard Technology takes its advantages from the hollow design for the high efficiency and low rotational speed. The few mechanical components are protected from sediments, typically flowing close to the seabed, by a simple mechanism (patent pending). This allows this TEC machine to well operate in rivers [20].

The coastal mooring staves off any impact on the seabed, reducing troubles in finding the best bathymetry. Moreover, a small river cross sectional area allows to install ca. 2.34 $kW/m^2$, a huge power density, if the flow rate is enough as foreseen for the case study 3.

If the comparison involves the costs, the LCOE (levelized cost of electricity) [22] well measures a power source potential, attempting to compare different methods of electricity generation on a consistent basis, calculating the average minimum cost at which electricity must be sold in order to break-even over the lifetime of the project.

The scenario for alternative and conventional energy technologies is displayed in figure 5 [23].

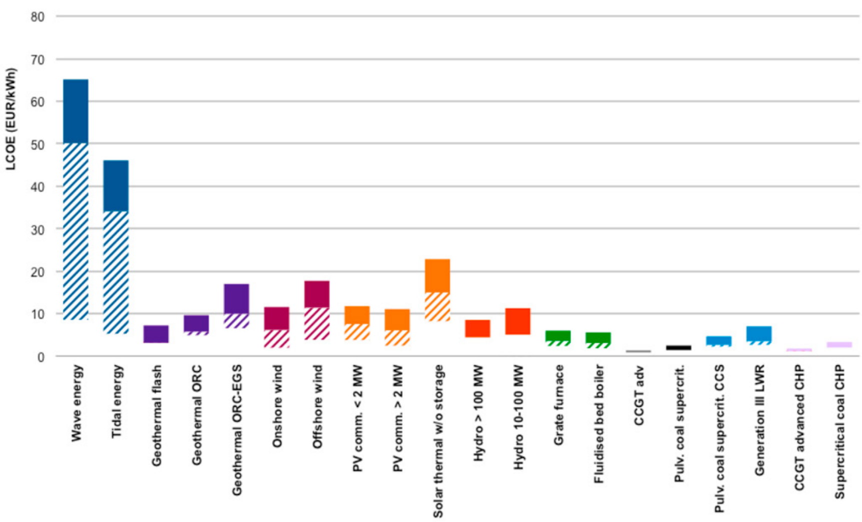



Figure 5 LCOE for different technologies. Solid bars indicate current cost ranges, the shaded the expected future cost reductions.

## 5. Conclusions

This paper shows how the siting assessment is fundamental for optimizing energy release from TECs. Classic turbines (wind like solutions) require an in depth study of flow current (three dimensional approach), seafloor evaluation, sediment load, and flora and fauna impact studies. All these things increase the feasibility costs. TEC machines [21] anchored to the shore or floating, working in shallow waters and, in any cases, far from the seafloor, reduce the feasibility costs, making the siting phase faster and even more reliable in terms of final results for designers and investors.

The $W^2$ Avant Gard Technology, thanks to the hollow design, the new electro-mechanical implementations and the shore operations allows to reduce the capital costs, making this solution more attractive for the deployment, leading to a whole lower investment costs, mostly in the final commercial plant [18], at LCOE of 0.113 €/kWh.

In terms of environmental effects and environmental impacts, further in-depth analyses will be carried out in order to improve the machine reliability in several operating conditions, throughout a new multi-parametric criteria for siting assessment aimed to the environmental protection. The wake and blockage effects, on small channels, will also be evaluated together with the shipping rules.

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