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A multi-parametric criteria for Tidal Energy Converters siting in marine and fluvial environments

G.Lo Zupone[a]*, S.Massaro[b], S.Barbarelli[c], R.Sulpizio[b]

[a]RX Carnot Energy Tech (Chengdu) Hi-Tech Industrial Development Zone,Chengdu, Sichuan, PRC
[b] Department of Earth and Geoenvironmental Science, University of Bari, via Orabona 4, 70125, Bari, Italy
[c]Department of Mechanical, Energy and Management Engineering, University of Calabria, 87036 Rende, Italy

Abstract

Marine renewable energy deployment involves site resource assessment as strategic support for installation and optimization. This part of the design needs to be based on best available measurement technologies and deployment methods, minimizing the investments. The siting and design of a kinetic energy converter (like a Tidal Energy Converter ones) require characterization of the variability of the flow velocity acting on the energy capture area in space and time, in order to assess the hydrodynamic forces, to design the structural loading and power capacity of the TEC, helping investment decisions and project financing. In this work, a site assessment procedures for emplacement of TEC machines are shown, comparing sites with different hydrogeological characteristics using the same design approach. In order to define the best conditions for siting, three case studies have been carried out, two for sea and last for river installation. The strait of Messina (Italy), a marine channel with an amphidromic point for the tides, has its minimum depth at 72 m, between Ganzirri and Punta Pezzo, deepening to 1000 m to the North East and down to 2000 m to the South. The Cook Inlet (Alaska), a large subarctic estuary in South-central Alaska which extends about 250 km from Anchorage bay to the Pacific Ocean. Tidally dominated currents control the hydrographic regime, meanwhile water levels and currents are influenced by tides coming from the Gulf of Alaska, which are significantly amplified as approaching Anchorage bay. The Pearl River Estuary and its adjacent coastal waters (China) have a length of about 70 km, a width of about 15 km and an average depth of about 4.8 m, but it has a depth of more than 20 m in its eastern part.

Keywords: TEC machines, siting, marine and fluvial environment,tidal

* Corresponding author. Tel.: +390802147111; fax: +390802140947
E-mail address: glozupone@gmail.com

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1. Introduction

Turbines placed directly in river, ocean, or tidal current generate power from the kinetic energy of moving waters, so, in order to install, at the better conditions, such machine, a correct approach is to focus, from one side the site and its characteristics and from the other side, the machine optimization.

Hydrokinetic devices are ideally installed at locations having relatively steady flow throughout the year and are not prone to serious flood events, turbulence, or extended periods of low water level [1].

The siting procedure requires characterization of the spatio-temporal variation of the current velocity (an optimum range is the 1.5÷3.5 m/s [1]) and turbulence acting on the on the machine so as to provide the hydrodynamic forces and available power estimates over a representative period of record, to design the structural loading and power capacity of the machine itself.

Although each tidal energy site is unique, there are a number of common features affecting the deployment. New approaches to device anchoring may expand the range of operationally feasible sites.

Environmental effects of tidal power generation are almost similar to those of wave power and offshore wind power generation. In order to appropriately site and operate tidal power installations, the environmental risks of the technology must be well understood [2]. In doing so, it is important to distinguish between environmental effects and environmental impacts. Environmental effects are the broad range of potential measurable interactions between tidal energy devices and the marine environment. Environmental impacts are effects that, with high certainty, rise to the level of deleterious ecological significance.

The aim of this work is to establish some key parameters allowing a first raw performance comparison between sites, using a new machine concept and taking care about imposed site limitations. A first guidelines, can be based on a combined multi-parametric criteria:

1. water depth and turbine spacing requirements, to best fit the turbine design and rating power that can be devices accommodated within a tidal inlet or channel;
2. tidal current energy resource attributes, i.e. annual average energy flux per swept area of device;
3. seafloor geology and coastal morphology suitable for device installation and anchoring system;
4. turbine interaction with marine life for an safe environment installation and operation;
5. water salinity, mostly for material lifelong operation.

Seafloor geology significantly influences the device installation. Research on sediment dynamics postulates a threshold value for the initial movement of particles [3], essential to know if hydrodynamic conditions, in the study area, induce critical shear stress velocities enough high to erode sediment surfaces which could be involved in turbines.

1.1. Site parameters

Several parameters have to be considered in order to match the best turbine performances and the site characteristics. The main energetic ones are explained below [4].

- *Power Density*

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

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

where A is the cross-sectional swept area of the device (m^2), ρ is the water density and V is current speed (m/s). For tidal currents V changes with time in a predictable manner.

- *Averaged Power Density*

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

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

- *Channel average available power*

In a site where the device is planning to be installed, it is calculated as (A_C is the cross sectional area of the transect):

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

- *Peak surface velocity correction*

Depending on the turbine depth installation a correction to V_p (the maximum measured flow velocity at surface) is introduced, related to the installation depth with the formula:

$$v(z) = V_0 \left(\frac{z}{z_0}\right)^{\frac{1}{10}} \quad (4)$$

where $v(z)$ is the velocity at some depth z, and v_o is the reference velocity at a reference depth (z_o). Depth at 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 composed of three main regions: the Head, the Upper and the Lower Inlet [5,6], (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 inlets.

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 one of the largest tides of the American continent, with a mean diurnal range in Anchorage of ca. 9.5 m driving the surface circulation [7]. 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) [8]. In addition to tidal currents, buoyancy driven flows from melting ice, constitute pivotal components of the circulation and mixing in Cook Inlet.

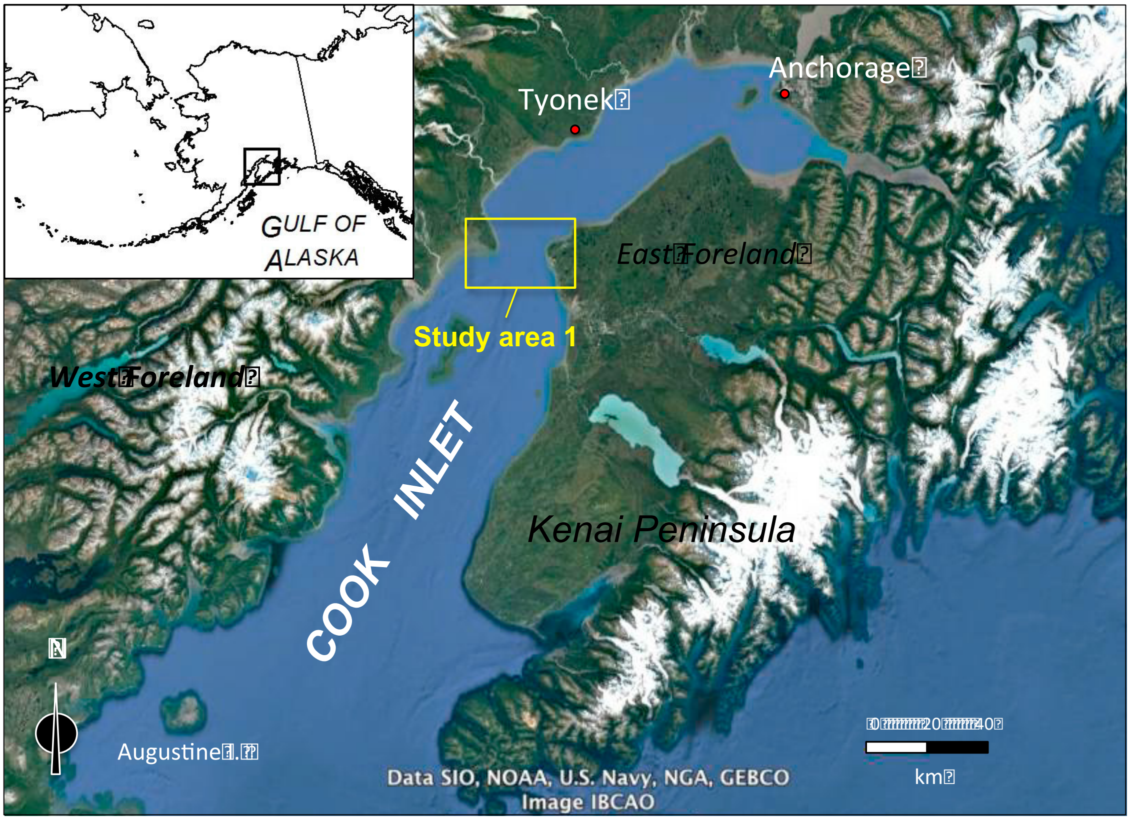


Figure 1 - Map of the Cook Inlet area on the southern coast of Alaska. In the yellow box, the most suitable area for the TEC emplacement.

2.2. The Strait of Messina, Italy (case study 2)

The Strait of Messina (Italy) is a deep canyon between Sicily and Calabria, which separates the Tyrrhenian Basin to the North, from the Ionian Basin to the South (Fig. 2). It shows a smallest cross sectional area of ca. 0.3 km^2, with a mean water depth of 80 m. The physiography of the Strait is strongly linked to the complex geological setting of the central Mediterranean: in the southern part the water depth increases rapidly (800 m depth at ca.15 km south of the sill), in the northern part it increases more gently (400 m depth at ca.15 km north of the sill). Although tidal displacements are very small in the Mediterranean Sea, large gradients of tidal displacements occur because of the predominantly semidiurnal tides, showing roughly phase oppositions. This phenomena, along with topographic constrictions, induce current velocities attain values as high as 3 m/s in the sill region. Morphologically, southward currents including eddies. This complex hydrodynamic setting, together with turbidity flows triggered by the tectonic instability of the area, strongly influence the sea bottom [9]. Mean sedimentation rate in the area is high although some areas can be affected by no-deposition or by strong bottom water currents [10].

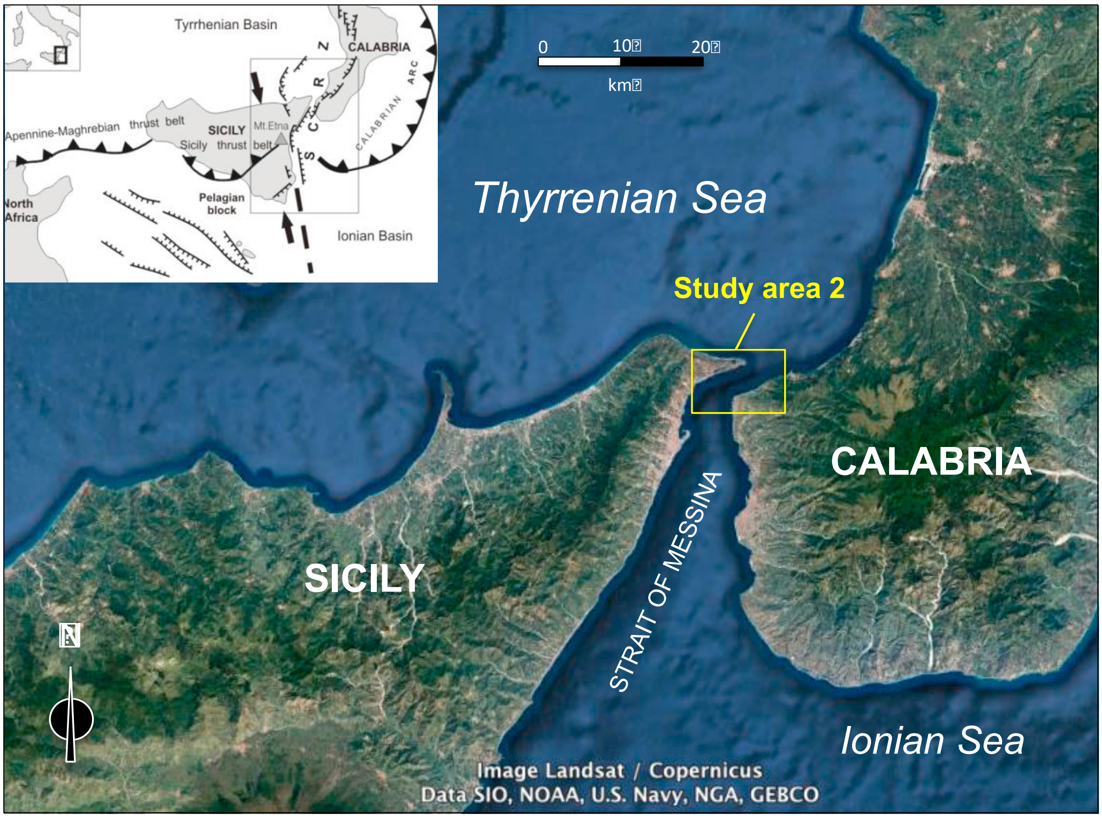


Figure 2 - Map of the Strait of Messina, between Sicily and Calabria (Italy). In the yellow box the most suitable area for the TEC emplacement.

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 [11]. It has a trumpet-like water (Fig. 3) area with 8 river inlets on its west bank. The Pearl River discharge totals 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. In this region, a number of forcing mechanisms including bottom topography, freshwater discharge, wind, tide and coastal current, control the circulation and water properties. Bottom topography is a strong constraint on flow patterns in shallow coastal regions through vortex stretching and squashing. This area experiences alternating monsoons every year which drive multiple effects, as local circulation. Moreover, the large-scale wind patterns set up sea level gradients on the shelf, which in turn generate coastal currents. The PRE tidal range is ca. 0.8÷0.9 m near the Wanshan Islands, ca. 0.9 m near Neilingding Island [12], and ca. 1.7 m near Humen [13]. 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.

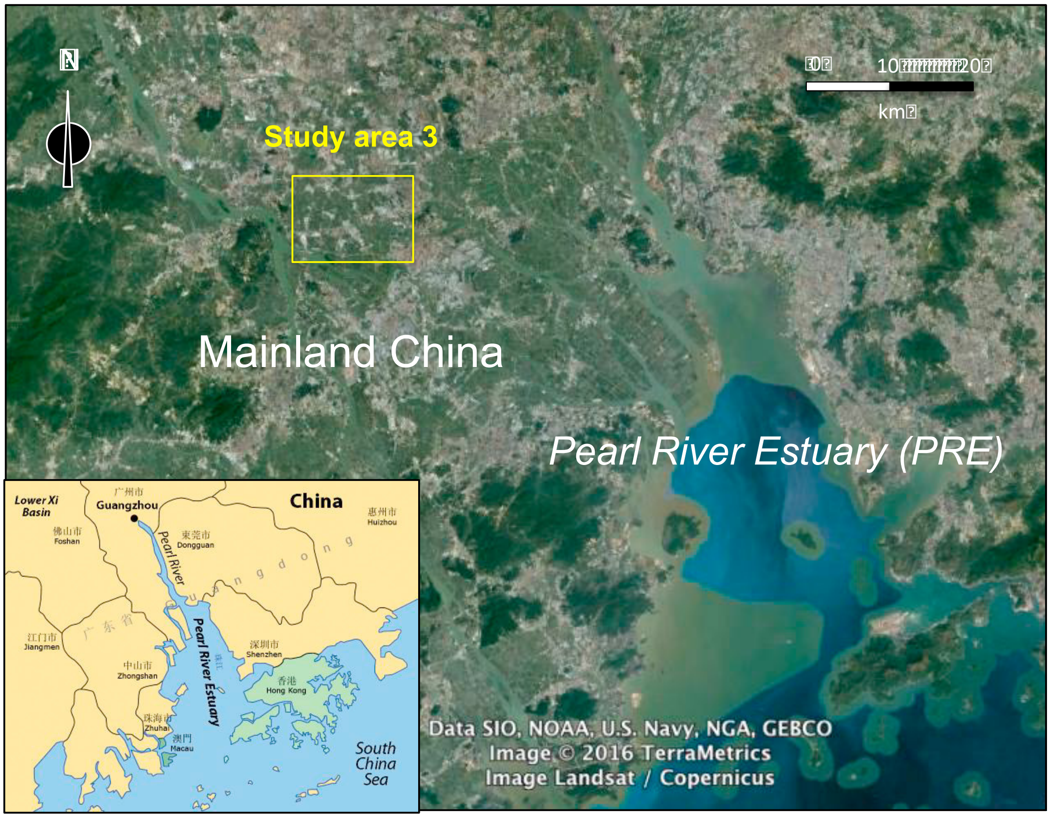


Figure 3 - Map of Pearl River Estuary (PRE), South China. In the yellow box the most suitable area for the TEC emplacement.

2.3. Energetic parameters

The main sites' energetic parameters, useful for turbine placing simulation, are shown in Tab. 1. As seen before, the site selection involves high energized currents and high depth on transect [14]: this does not allows a "free troubles" installation for the actual machines due to a wide blades diameter, critical seabed positioning and dramatic impact on fauna, together with sediment currents involving mechanical parts.

Table 1: case studies: site parameters

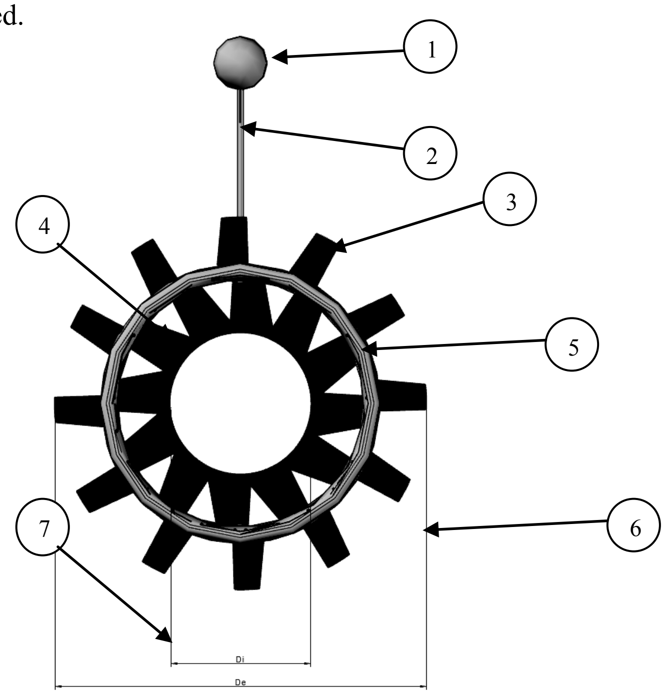
PARAMETER	UNIT	Case study 1	Case study 2	Case study 3
Average Channel width	m	2,450.00	3,200.00	500.00
Average depth	m	60.00	170,00	12.00
Channel cross sectional area	m^2	73,500.00	272,000.00	3,000.00
Maximum tidal range	m	12.00	12.00	-
Peak surface velocity	m/s	3.90	3.00	2.25
Averaged Power Density	kW/m^2	1.62	1.39	3.23
Total Available Stream Resource	MW	118.00	376.97	9.68

3. The W² Avant Gard Technology turbine

The W^2 Avant Gard Technology is a new machine concept for drawing energy from tidal currents consisting in a single turbine, moored to the coast by a fixture or structure subjected to a tensile stress [15]. The machine is characterized by a double (or, for other purposes, single) counter rotating rotors, with a high efficiency hollow configuration (see fig. 4) converting, independently, by the built in synchronous generator, the flow kinetic energy in electricity without any other mechanical device (gearbox, shaft etc.) [16].

The low weight and the hollow design allow the turbine to work almost close to the surface, so capturing the fastest currents (see eq. 4). The mooring system allows a quick repositioning in front of the current for the maximum energetic efficiency [17].

The compact, scalable design and cost saving solutions [18] allow to install the turbine in a wide range of sites: due to the "close water surface" operation, a reduced channel cross sectional area makes it useful also for rivers applications supporting also disadvantaged areas where public infrastructures are poor or missed.



ref	Description
1	Floater/axis control
2	Floater support
3	External blades/Rotor
4	Internal blades/Rotor
5	Stator
6	D_e: external diameter
7	D_i: internal diameter

Figure 4 - Hollow design of W^2 Avant Gard Technology turbine and main components

As shown in Tab. 2, for the performances simulation two different configurations have been assumed, one for tidal purpose and the second one for river purposes.

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 m²	17.22 m²
Global power coefficient	C_p	0.41	0.41
Mechanical efficiency	η_m	0.90	0.90
Electrical efficiency	η_e	0.85	0.85

4. Results and conclusions

The results of the above assumptions, related to the turbine, have been 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	3.00	2.25
Peak Power	MW	0.92	0.43	0.10
Maximum turbine Power density	kW/m^2	10.76	4.99	2.34
Annual energy production	MWh	703.49	505.64	221.59

Compared to other marine devices [19, 20] the TEC machine performances are quite similar, even if the river solution appears to be most advanced in terms of energy production per swept turbine area [21].

The W^2 Avant Gard Technology takes its advantages from the hollow design for the high efficiency and low rotational speed and the few mechanical components are protected from sediments, typically flowing close to seabed, by an easy feature (patent pending) allowing the turbine to be installed in rivers [22], even in disadvantaged areas where public infrastructures are poor or missed as standalone application or in synergy with other renewable sources.

The coastal mooring staves off any impact on the seabed, reducing troubles in finding the best bathymetry. Moreover, a small river cross sectional area (the minimum could be estimated in 400 m^2) 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.

In terms of environmental effects and environmental impacts, further in-depth analyses are carrying out in order to improve the TEC machine reliability in different operating conditions, trough such a new multi-parametric criteria for siting, aimed to the environmental protection.

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Biography

Giacomo Lo Zupone, graduated in Mechanical Engineering at Bari University, teacher of Fluid Dynamics and Propulsion Systems at "Euclide" Vocational High School in Bari. Since 2011 R&D team member at University of Calabria, winner of 2nd prize at "China Innovation and Entrepreneurship Competition for Overseas Talents 2016" Chengdu, where actually is incubated.