Can the development of offshore renewable energy projects and their shore connection have an effect on the evolution of the coastline?

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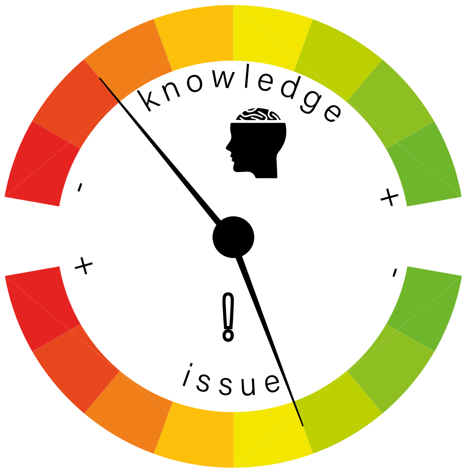
COME3T

COME3T, a committee of experts for environmental issues related to offshore renewable energies, brings together neutral, independent experts to provide scientific knowledge and recommendations in response to environmental issues associated with offshore renewable energy.



Question deemed
"an intermediate issue with regard to current theoretical knowledge"
by the experts

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Introduction

The coast is a dynamic zone which evolves under the combined effect of natural processes (wind, tides, etc.) and anthropogenic processes (artificial land cover, coastal structures, etc.). The development of offshore renewable energy (ORE) projects along the French coasts over recent years raises questions about the potential impact of these new offshore installations, in particular on coastline dynamics.

After a recap of how the coastline functions and its complexity, the experts identified the potentially expected effects of the development of ORE projects on the coastal area based on current knowledge. They also put forward a set of recommendations on the resources to be implemented to assess the long-term impacts on coastline dynamics.

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Definitions

Coastline

Given the different concepts (geomorphological, oceanographic, biological) attributed to the coastline, it is difficult to establish a simple definition. In basic terms, the coastline corresponds to the boundary between land and sea[1]. This **land-sea boundary** corresponds to the strandline[2] for the highest astronomical tide (HAT) in normal weather conditions (no wind and mean atmospheric pressure of 1013 hPa) (Shom, 2021) (Fig. 1).

Fig. 1 *Diagram showing the land-sea boundary which symbolises the coastline*

Land-sea continuum

The land-sea continuum corresponds to the link that exists between land-based activities in the catchment area (farming, industry, etc.) and their impacts on the sea. It results in the transfer of matter (for instance sediment) from land to sea.

Forcing

Forcings are external factors that influence coastline dynamics and cause coastal geomorphological evolution. They can be natural (meteorological, hydrodynamic, climate forcings, etc.) such as wind, waves, currents, precipitation, etc.; or anthropogenic (structures to protect against erosion, port structures, etc.).

Swell

Swell is an undulating movement of the sea surface which propagates over long distances, independently of the wind which initially caused it to form. When swell breaks we talk about waves.

Depth of closure

The depth of closure corresponds to the limit of wave action (Hallermeier, 1981). It corresponds to

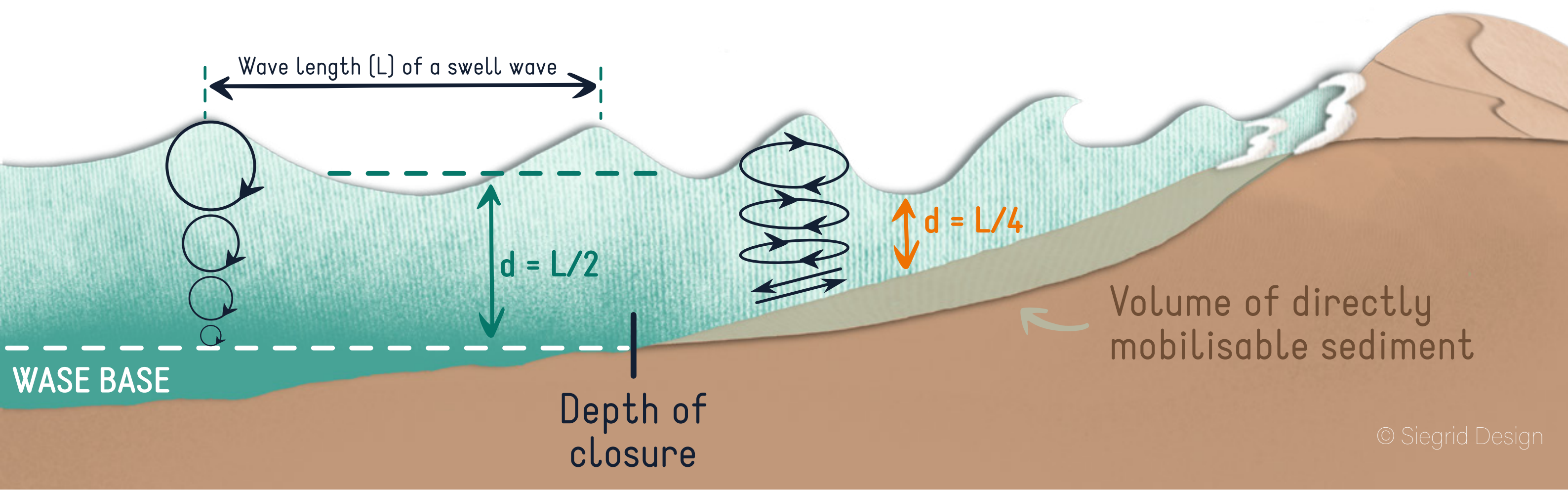

Fig. 2 *Diagram showing the boundary defined by the depth of closure*

the depth at which swell can transport sediment and induce morphological change to the shoreface (Hamon-Kerivel *et al.*, 2020). For several authors (Clifton and Dingler, 1984; Komar, 1998), the influence of the seabed only begins to appear significantly from a quarter of the wavelength (h = L/4), i.e. from a depth equivalent to a quarter of the distance between two successive swell waves (Fig. 2).

Littoral cell

Corresponds to a unit within which sediment transport is independent. The boundaries of a littoral cell are more or less permeable to sediment exchange with adjacent cells and/or the offshore area according to the hydrodynamics of the marine currents. They may be fixed (rocky headlands, seawalls, etc.) or mobile (depth of closure, dunes, etc.) (Fig. 3) (CEREMA, 2015). This theoretical definition corresponds to a littoral cell that functions in a stable manner (constant sediment budget) and is not disturbed by anthropogenic and/or natural exchanges (exceptional storms, etc.).

Sediment budget (or balance)

Relationship between inputs and outputs of sediment within a given area. It may be positive (accretion) or negative (erosion) and will depend on several input sources (cliff erosion, inputs from major rivers, landslides, current action, shoreward transport by wind, etc.) and sediment losses (offshore movement, loss in submarine canyons, anthropogenic removal, offshore transport by wind, current action, etc.).

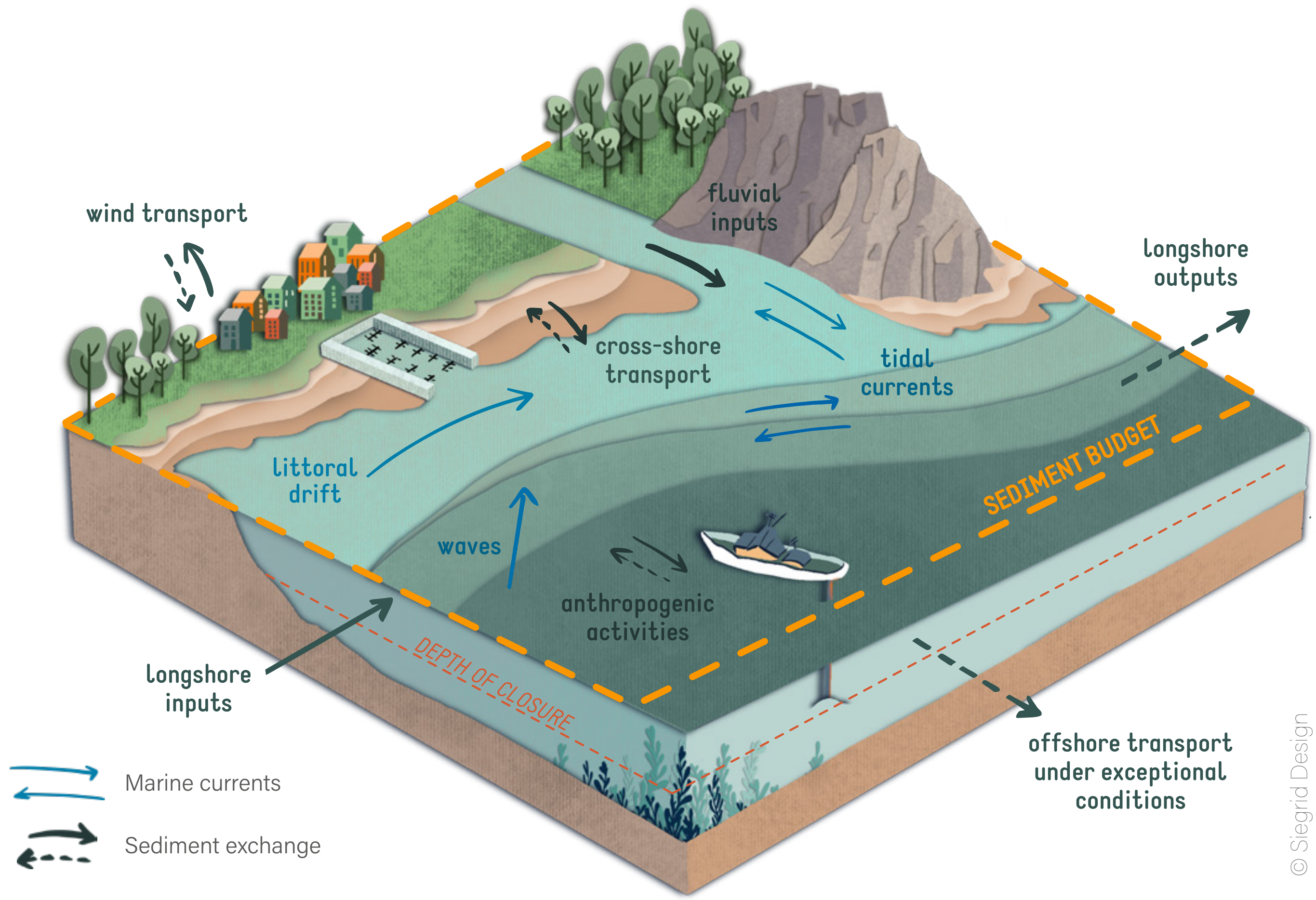

Fig. 3 *Conceptual diagram of sediment exchanges of a theoretical littoral cell. After M. Sauvé – CEREMA & Hamon-Kerivel K., et al. (2020)*

[1] French coastal observation network for Normandy and Upper France (ROLN in French): https://storymaps.arcgis.com/stories/38ab6754531145628e5e-006079a7462b

[2] The strandline is marked by the accumulation of natural (shells, seaweed, etc.) and anthropogenic (nets, litter, etc.) debris left by the sea after every tide.

Offshore renewable energy projects and their potential effects on coastline dynamics

1. Different types of offshore renewable energy systems

Offshore renewable energy covers all the technologies capable of producing power by harnessing resources and forces that govern the functioning of the marine environment. The energy of currents is harnessed by **tidal stream turbines**, that of tidal currents by **tidal power plants** and that of waves by **wave energy converters**. **Offshore wind farms** (bottom-fixed or floating) use wind energy, which is often more homogeneous and constant at sea, to generate power.

Ocean thermal energy conversion (OTEC) is a less widely known process which draws upon the temperature gradient between warm surface waters and cold deep waters to produce power, while seawater air conditioning (SWAC) systems use deep cold waters to run cooling systems. Both these technologies require specific bathymetric and water column stratification conditions. In the French context, they are mainly designed for overseas territories. As they are currently in the early stages of development, they will not be covered here.

In this bulletin, **"offshore renewable energy"** refers to all technologies capable of harnessing energy from the sea to produce power (Fig. 4).

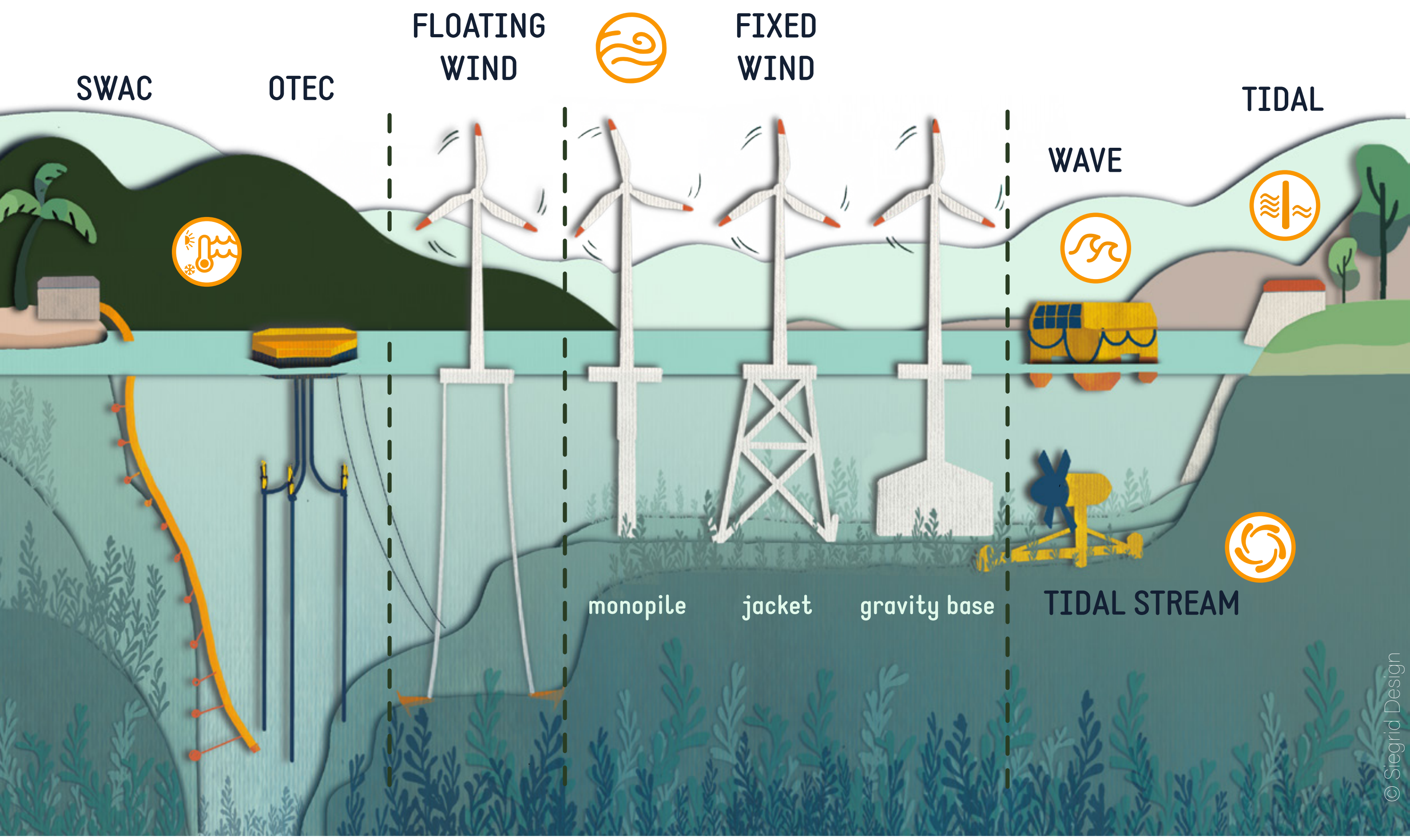

Fig. 4 *The different types of offshore renewable energy systems and the offshore resources/forces harnessed*

2. Coastline dynamics

Coastline dynamics refers to changes in the position of the shoreline in terms of retreat (erosion) or advance (accretion). Its position results from the balance of these opposing forces and depends on the site characteristics (topography, sediment type, coast type, etc.) and forcings at work there (Fig. 5).

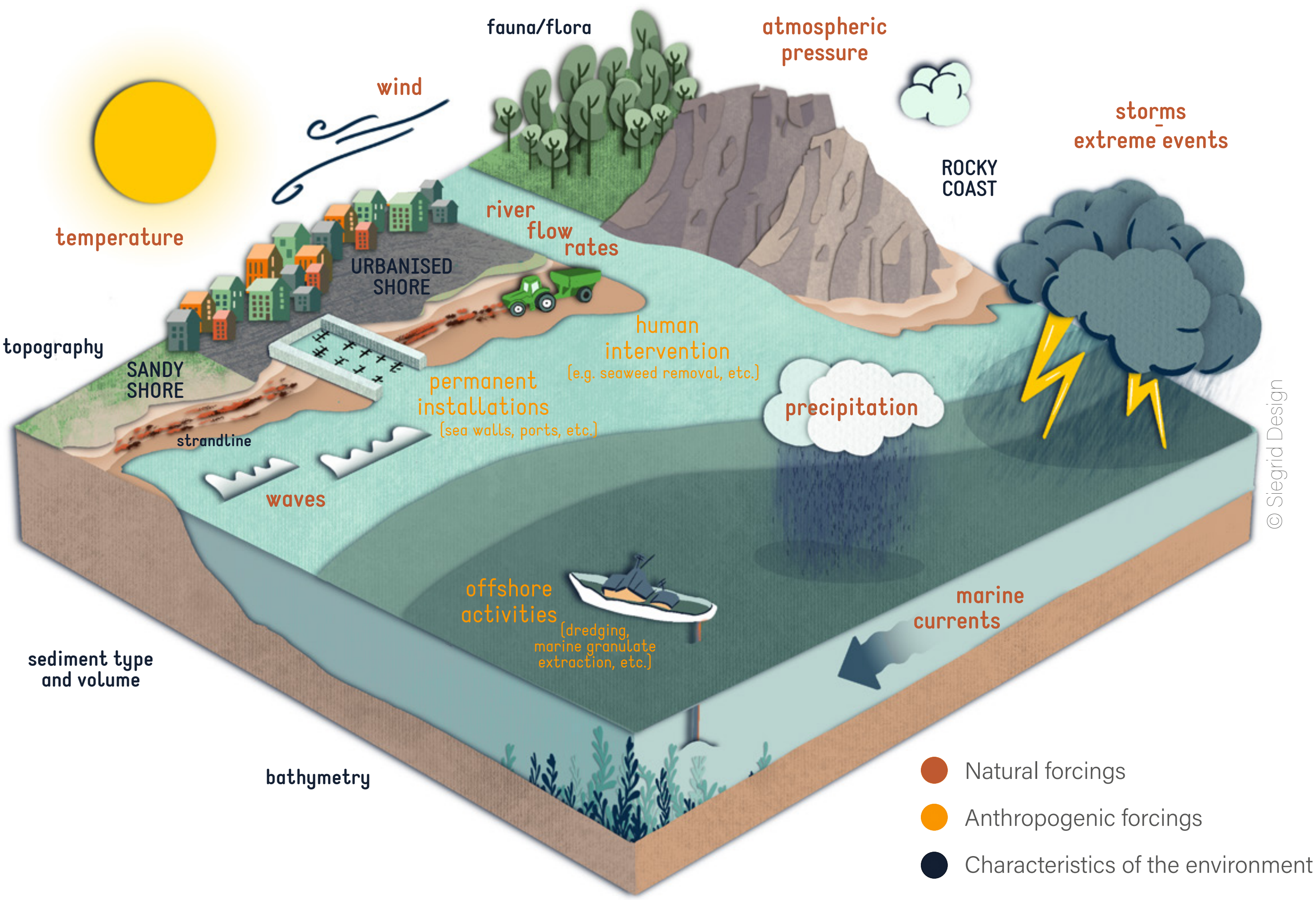

Fig. 5 *Diagram of the main forcings (natural and anthropogenic) governing coastline dynamics*

In the short term, the evolution of the coastline is very dynamic with high variability of accretion/erosion phenomena, while in the long term, at a large (regional) scale, the coastline can present a certain stability (Fig. 6). Distinguishing between the effects specifically induced by ORE systems and those brought about by the major environmental forcings is a challenge for the scientific community.

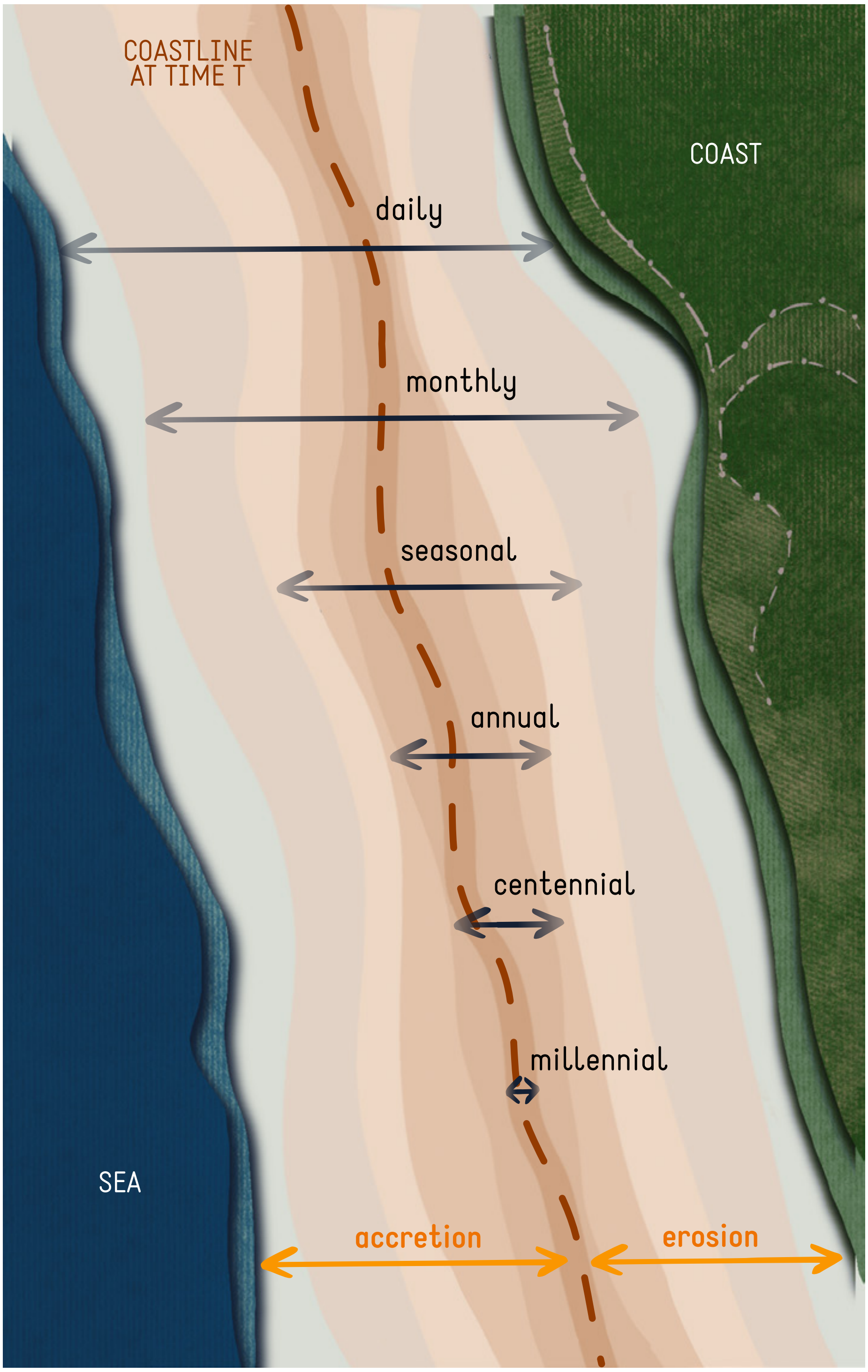

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Fig. 6 *Conceptual diagram showing the evolution of the position of the coastline at different time scales for an environment close to equilibrium. After Terwindt & Kroon (1993).*

3. Potential effects on coastline dynamics (during ORE operation)

The coastline is a complex system. It is not possible to draw up a list of potential effects that would be valid for all types of coast and all types of ORE technology. The observations made for one site and for given operating conditions (number of turbines, spacing, distance from shore, etc.) cannot be extrapolated to another site due to the complexity and diversity of the processes at play. The potential effects identified here are therefore hypotheses put forward by the experts based on current knowledge and draw in part on European experience.

Coastline dynamics are essentially governed by exchanges between the shore and the shallows within the boundaries of the zones defined by the littoral cells. Outside of these boundaries and in normal weather conditions, potential direct effects generated by ORE systems are unlikely (Fig. 7). In exceptional conditions (storms, etc.), the depth of closure can vary and extend the boundaries of littoral cells, thus promoting exchanges, in particular with offshore (deep waters, submarine canyons, etc.). Depending on their location, offshore renewable energy farms can have an impact on the functioning of one or more littoral cells.

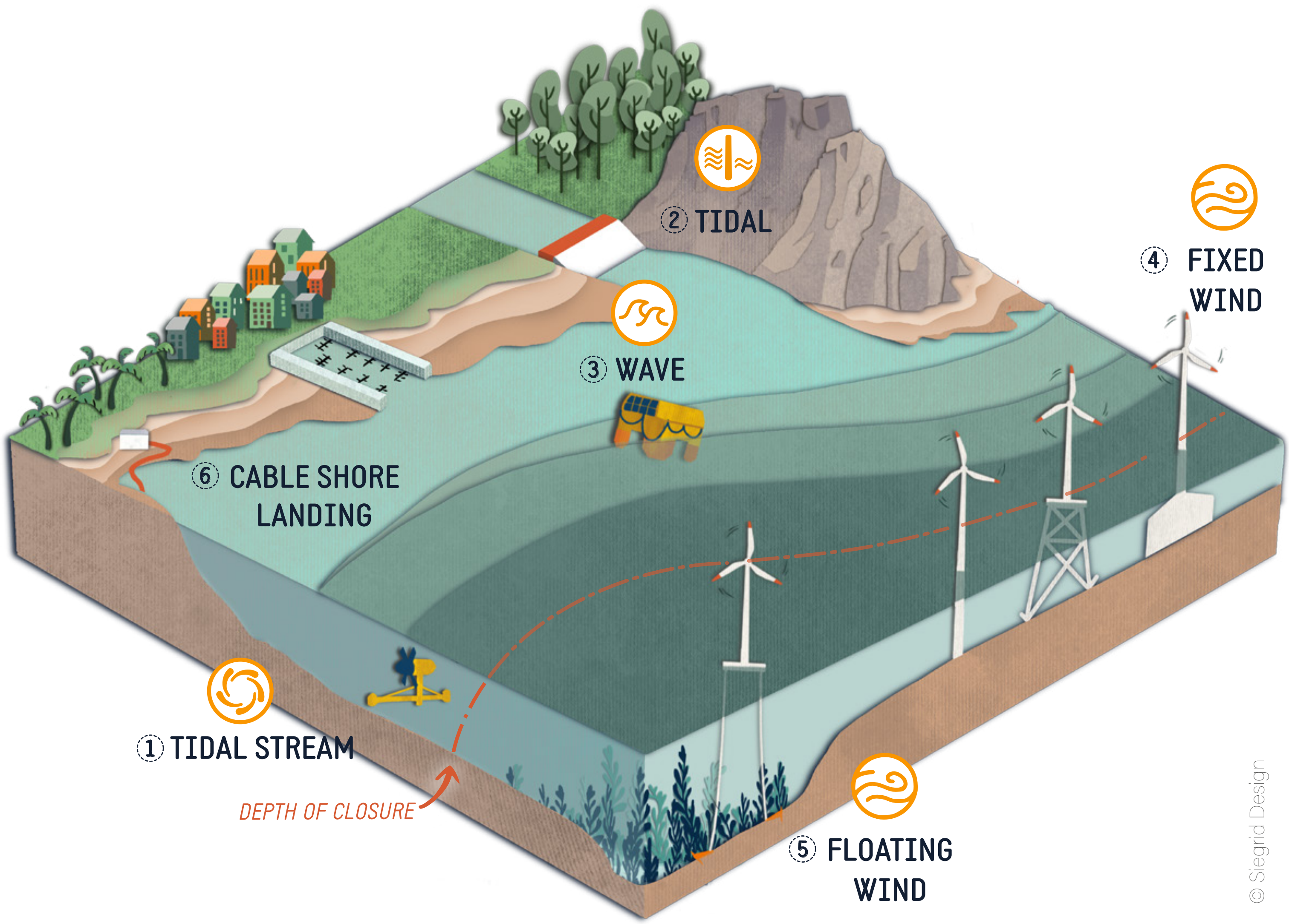


Fig. 7 *Overview of the main offshore renewable energy technologies mentioned in this bulletin and their position in relation to a littoral cell and a theoretical depth of closure (in orange). This is a conceptual illustration and aims to illustrate the main concepts in constant, stable conditions (no scale).*

[1] Tidal stream

Energy	Distance from shore	Potential effects	Consequences	Impacts
Current	4 to 5 km	Change in current speed; increase in sedimentation downstream of the system	The increase in sedimentation downstream of the system can attenuate erosion processes at beaches in the immediate vi-cinity but only very marginally	Positive impacts unlikely

Tidal stream turbines can temporarily reduce the flow rate of currents and can potentially modify local sediment transport. These temporary changes in flow depend on numerous factors (local topography, sediment type, current characteristics, etc.), even though the sites conducive to the installation of tidal stream systems are generally high energy areas where it is difficult or impossible for sediment to accumulate naturally (rocky or stony bottom). For systems capable of bidirectional operation (i.e. generating power with both ebb and flood tides), it may be possible to consider restoring the sediment balance with each turn of the tide.

[2] Tidal

Energy	Distance from shore	Potential effects	Consequences	Impacts
Tide	Nil	Siltation; increased artificial land cover along the coastline; change in current speed and sediment dynamics.	The impacts on the coastline dynamics will be similar to those of equivalent coastal structures.	Negative impacts very likely

If they are not directly installed on the coastline and integrated in a man-made structure, tidal power systems can cause siltation in the high shore area and can affect local flora and fauna. The impacts on current dynamics and sediment dynamics are very likely to resemble disturbances generated by coastal structures such as seawalls, which are already well known.

[3] Wave

Energy	Distance from shore	Potential effects	Consequences	Impacts
Wave	10 to 20 km	Changes to swell and current speed	The decrease in wave energy can attenuate coastal phe-nomena induced by natural conditions	Positive impacts very likely

Wave power extraction by wave energy converters tends to reduce the height of waves downwind of the farm (Abanades *et al.*, 2018). According to the area, this reduction could be exacerbated by the bathymetry and could create a "sheltered" nearshore area (Abanades *et al.*, 2014). In the immediate vicinity of the farm, the wave height is greatly reduced while the effect tends to become attenuated nearer the shore (Rusu *et al.*, 2013). By reducing wave energy, wave energy converters help to diminish the impact of coastal processes (erosion and/or accretion) induced in particular by extreme weather conditions (Abanades *et al.*, 2018). According to certain models, the wave period does not appear to be affected by wave energy converters (Rusu *et al.*, 2013), while the changes in wave direction induced can affect the speed of coastal currents, even though they are deemed negligible (Rusu *et al.*, 2013; Raileanu *et al.*, 2020). Furthermore, the reduction in the energy of the marine environment could be detrimental to species adapted to the wave exposure conditions and could affect the suspension and littoral sediment transport (deterioration of coastal habitats). However, this variation occurs naturally and seasonally; it is therefore reasonable to assume that the reduction of this energy will not have major ecological implications (Schields *et al.*, 2011).

[4] Bottom-fixed wind

Energy	Distance from shore	Potential effects	Consequences	Impacts
Offshore wind	12 to 35 km	Changes to swell, sediment dynamics, currents and surface turbulence	Depends on the distance from shore, the location of the farm in relation to littoral cells and the type of structure (monopile, jacket or gravity foundation)	Negative impacts unlikely

The introduction of vertical structures into the marine environment will mainly have an impact on hydrodynamics and local sediment dynamics. The reduction of bottom currents may lead to the creation of sheltered areas and the deposition of fine particles in the wake of the foundations (Degraer *et al.*, 2019). The possible modification of waves and currents has been modelled by Cooper *et al.* (2002). According to these authors, offshore wind farms constitute a surface obstacle and can induce a reduction in wave height, but to a lesser extent than wave energy converters (Cooper *et al.*, 2002). Likewise, observations made following the development of the Scroby Sands offshore wind farm in England led to the conclusion that the effects on wave direction and shape were limited to the immediate vicinity of the farm. Similarly, changes in current speed near the foundations and the local increase in turbulence may accelerate the dissipation of current energy but will be limited to the scale of the farm (Boon *et al.*, 2018) without influencing large-scale flow patterns (Cooper *et al.*, 2022).

[5] Floating wind

Energy	Distance from shore	Potential effects	Consequences	Impacts
Offshore wind	20 to 50 km	Sediment resuspension and siltation; changes to swell, sediment dynamics, currents and surface turbulence	Depends on the distance from shore and the location of the farm in relation to littoral cells	Negative impacts unlikely

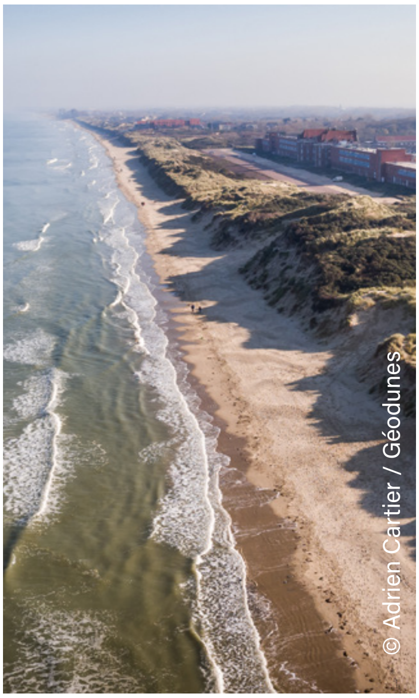
As with onshore wind farms, the development of floating structures anchored in deep waters will mainly have an impact on hydrodynamics and local sediment dynamics. At this distance from the coast (> 20 km), sediment resuspension by the chain movements on the seabed does not appear to contribute to coastline dynamics but may have an impact on sedimentation and siltation of the deep sea and canyons. Float movements, depending on whether or not they are in phase with the swell, can help to increase or decrease its propagation. However, according to Girleanu *et al.* (2021), while a sheltering effect due to wave height reduction is observed between the coast and the farm, this effect decreases as the distance from the coast increases (Girleanu *et al.*, 2021).

[6] Cable shore landing

Potential effects	Consequences	Impacts
Sediment resuspension and siltation	Temporary impacts (only during construction and decommisionning phases) that are similar to the impacts generated by sediment disposal operations or coastal structures.	Negative impacts temporary and very likely

Cable burial is an operation that takes place during the construction and decommissioning phases. It can cause sediment to be resuspended and generate temporary and local disturbance to the sediment dynamics of beaches. The impacts on coastline dynamics will probably be similar to the disturbance caused by the construction/decommissioning work and other existing coastal structures. According to the type of sediment and the sea and weather conditions, the ecological richness of the coastline may be diverse and varied. These ecosystems may be locally impacted during the work phases (cable installation and removal) and may lead to local disturbances of the ecosystem (loss of continuity of seaweed beds, possible increase in turbidity near sensitive habitats - eelgrass beds, for example).

Better monitoring of shorelines and of the effects of offshore renewable energy projects on coastline dynamics



In France, national coastal observation and monitoring networks already exist and monitor local coastline dynamics in different contexts: rocky coasts, sandy beaches and river mouths (e.g. the national observation service SNO DYNALIT led by the iLiCO research infrastructure). We therefore have good knowledge of the coastline in general, even though the majority of French beaches are not monitored. The sites studied by the various monitoring networks are chosen independently of the choice of ORE installation sites. Depending on the sites selected and/or considered for the development of ORE projects, monitoring should be carried out even if, given the time scales characterising coastline dynamics, the information obtained from this monitoring will probably be insufficient to be able to correlate a change in the evolution of the coastline with the presence of an ORE system, over relatively short periods of time (a few years), whatever the study area. The environmental impacts of ORE should be considered against a broader backdrop of fossil fuel dependency and climate change (Schields *et al.*, 2011; Frid *et al.*, 2012; Grecian *et al.*, 2013). It is essential to ensure that ORE projects do not inadvertently create new environmental threats or exacerbate existing threats.

While it is difficult to put forward precise recommendations given the variability of sites and the time scales involved, several general recommendations have been made by the experts in order to optimise the assessment of the potential effects of offshore renewable energy systems on coastline dynamics:

- Map the evolution of beaches and shores in the vicinity of ORE projects, if possible before construction work commences, in order to establish a correlation between coastline evolution and the presence of ORE devices;
- Organise dedicated monitoring, specific to the different types of shores and with an appropriate spatio-temporal scale. To be optimal, prior monitoring should be carried out over a minimum period of 10 years before the roll-out of ORE projects, for example *via* airborne and satellite surveys;
- Consider the development of ORE projects when defining coastline and shoreline monitoring objectives (choice of sites, monitoring frequency, etc.);
- Reinforce existing shoreline and coastal risk observation networks (DYNALiT, etc.) to improve spatio-temporal coverage;
- Improve knowledge and monitoring of marine weather events in order to distinguish between the effects generated by environmental forcings and those generated by ORE systems (and more widely by anthropogenic activities);
- Improve monitoring within ORE farms during the operational phase in order to gain a better understanding of their impacts on hydro-sedimentary transfers, in particular by measuring turbidity, assessing sediment flows (inputs and outputs) and measuring swell characteristics, in order to improve coastal hydrodynamic evolution modelling.
- Monitor coastal habitats and their ecological recovery/resilience in parallel with coastline monitoring.

Conclusion

Whatever the type of technology deployed, the potential effects of ORE development on coastline dynamics will depend on a set of parameters linked to the characteristics of the farm itself (technologies, number of turbines, distance from the coast, etc.) and to environmental characteristics such as: the nature of the sediment, the type of coastline (sandy, rocky, urbanised, muddy, river mouth, etc.), the sediment budget, the physical forcings at work (swell, current, etc.), the site effect, etc.

Although good theoretical knowledge of the functioning of beaches and coastline dynamics is available, knowledge of the effects generated by anthropogenic activities (including ORE) and their consequences on coastline dynamics remains limited. This is especially due to the fact that it is currently not possible to simultaneously model the ORE development area and the beach at a high enough resolution to consider all the physical processes. The potential effects proposed here are based on hypotheses that draw on European case studies (pilot sites, etc.) and the individual experiences/knowledge of the experts involved.

Moreover, coastal areas are in high demand and are exposed to strong pressures (demographic, economic, environmental, etc.); this means that all factors relating to their evolution play a major role. The challenges vary according to environmental conditions, site characteristics and the degree of knowledge of the effects of infrastructure development on the coastline.

Based on current knowledge, ORE development is deemed to have low and unlikely impacts on coastline erosion, and to have less impact than existing coastal developments built in the immediate vicinity of the coastline, partially obstructing littoral transport (port structures, groins, seawalls, etc.).

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FRANCE ENERGIES MARINES

France Energies Marines is the Institute for Energy Transition dedicated to offshore renewable energies. Its missions: to define, set up and apply the scientific and technical environment required to overcome the obstacles related to the development of ORE technologies while ensuring optimal environmental integration. Built on a public-private partnership, the Institute is at the interface between institutional (local authorities, regions, etc.), academic, scientific and industrial (project developers and leaders) stakeholders.

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