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Introducing ocean energy industries to a busy marine environment

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ABSTRACT

The immense energy potential of the oceans is being increasingly recognized the world over, at the same time the integrity of marine ecosystems is challenged by pressure from multiple human activities. For good reasons environmental licensing procedures are precautionary and new industries must declare their detrimental impacts and provide mitigation measures. New ocean energy industries target renewable energy sources thus, on a grand scale, partly mitigating climate change. However, on-site environmental impacts are yet to be established. In this review we compare ocean energy industries with a wide range of conventional, better understood, human activities and outline environmental risks and research priorities. Results show that ocean energy systems are thought to incur many pressures, some familiar and others with yet unknown effects. Particular uncertainties regard ocean thermal energy conversion (OTEC) and large fast-moving turbines. Ocean energy industries should not be considered in isolation because the significance of environmental impacts depend on the full spectra of human activities in each area. Marine spatial planning provides a platform for holistic assessments and may facilitate the establishment of ocean energy industries, as long as risk-related uncertainties are reduced.

1. Introduction

The acknowledgement of climate change has raised interest in marine renewable energy. Offshore wind power is expanding and tidal barrage technology is being revived. Additionally, a large number (> 100) of novel ocean energy converters are under development and may be installed at numerous suitable locations all over the world [1–7]. For this sectorial growth to realize and gain space on busy seas, the environmental impact of the new technologies needs not only to be understood but also to be put in relation to other, existing, marine activities that utilizes the same space and affect the same environment.

Ocean energy converters can be grouped into four emerging industries: wave power, tidal current power, ocean current power, and ocean thermal energy conversion (OTEC) (Fig. 1). Few of these converters have been tested at full scale and it has been stressed that their environmental impact is uncertain [8–10]. If ocean energy industries become established, the sector will compete for marine space alongside other marine activities and affect ecosystems already suppressed by preexisting pressures. Any implementation of ocean energy converters needs to comply with environmental regulations [11], which are often based on the "the precautionary principle" (the prohibition of products or projects where scientific data do not permit full evaluation of environmental risks). This proactive legislative approach sets high standards for new industries, particularly those that appear very different from traditional marine activities, such as ocean energy.

The degraded state of environment is the underlying reason for new industries to reduce uncertainties and defining action plans to mitigate environmental impacts. The ocean has long been used by fishing and transport sectors, both of which have undergone extraordinary intensification and geographical expansion since the 19th century industrialization breakthrough [12]. Offshore fossil fuel extraction, marine recreational activities, coastal engineering and aquaculture have also expanded in the past 50 years [12,13]. In addition, the ocean is receiving ever-increasing amounts of pollutants, nutrients and atmospheric emissions from land-based sources. This intensification of ocean exploitation results from the combination of rapid technological development [12] and weak regulation of international waters [14],

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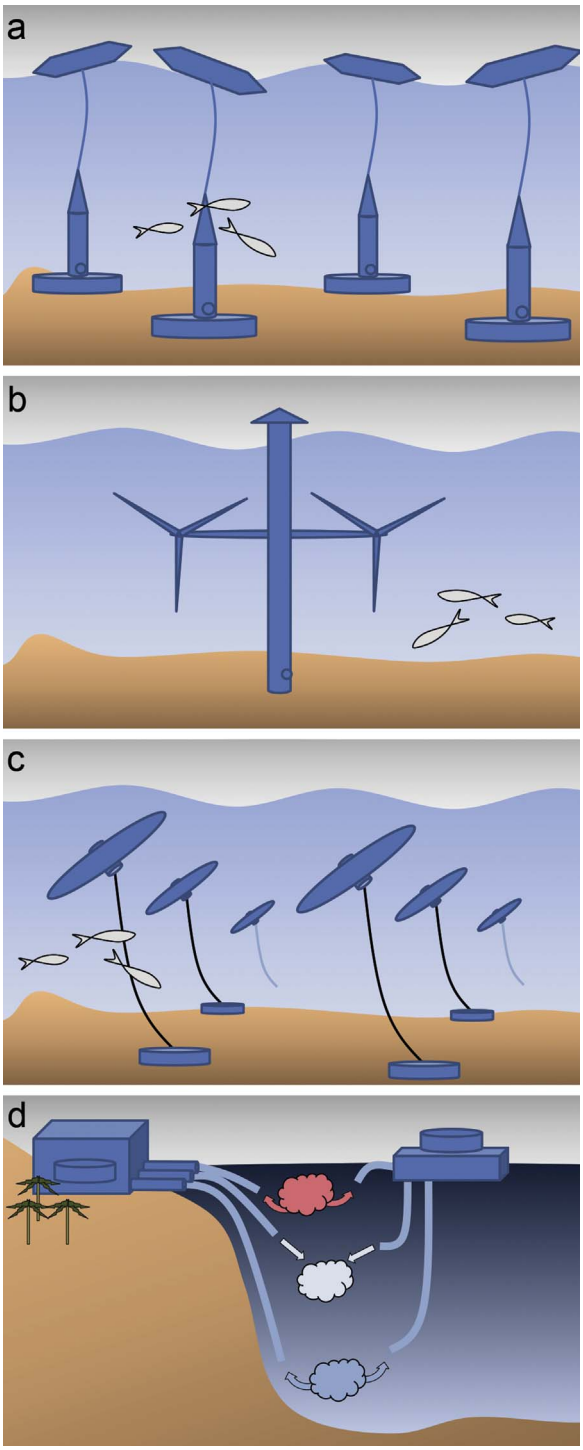

Fig. 1. Ocean energy industries covered in the review: (a) wave power, (b) tidal current power, (c) ocean current power, and (d) ocean thermal energy conversion OTEC (onshore- and offshore power plants illustrated). Within each industry category (a-d) multiple different converter designs are under development. Illustrations are not to scale.

and has led to significant changes of virtually all marine ecosystems including the deep sea [15–17]. Consequently, additional pressures from new industries enter the ocean in a critical situation where the environmental stakes are high and where multi-pressure effects must be considered along with natural physiochemical variation [18]. Yet, renewable energy is needed to alleviate looming threats of climate change and this weighing between local and global environmental costs and benefits is a challenge to marine management.

The ongoing introduction of ecosystem-based marine spatial planning in many countries provides new perspectives. Compared to case-by-case oriented marine management, marine spatial planning is better suited to account for simultaneously operating activities and their effects on ecosystems, and can incorporate standards for cumulative effect assessments [19,20]. One necessary part of this new management approach is to understand what kinds of pressures are or will be produced by each human activity, including both conventional and developing industries, with impact on marine environment. Literature provides several important examples where pressures from various human activities have been listed [21] or geographically illustrated along with their impact on marine ecosystems [15,22,23]. These studies show that human activities may cause several different pressures and that the imprint of human activities reaches all parts of the ocean. There is, however, a general lack of systematic comparison between pressures of different activities and no literature on how expected pressures from new ocean energy converters relate to other marine activities in a cumulative perspective.

The objective of this review is to fill this gap and broaden the understanding on how ocean energy industries compare to other marine activities in terms of pressures to the marine environment. We provide a systematic pressure inventory and comparison in order to answer two central questions important for industry and regulators: (1) which environmental pressures can be expected from ocean energy in relation to other more familiar activities and (2) what research priorities can be recommended for reducing major uncertainties and enable risk-reducing technical adaptations of ocean energy systems.

2. Methods

Pressures are referred to as any chemical, physical or biological entity or change that induce effects on ecological receptors (*i.e.* individuals, populations, or ecosystems). Human activities are potential sources of one or several pressures. Each geographical region has its own composition of human activities and marine ecosystems, and the value of specific receptors is not the same everywhere (since a receptor can play different ecological roles in different ecosystems) [24]. From the generic perspective taken in this review it is therefore not meaningful to rank pressures in terms of intensity or magnitude of ecological impact. Case-specific examples of weighted impacts from different pressures are available elsewhere [22,23]. For in-depth explanation of used nomenclature regarding pressures, effects, receptors and impact we refer to Judd et al. [25].

2.1. Inventory of marine pressures

Anticipated pressures from ocean energy industries were compiled from the scientific literature. Since few field studies have been conducted on environmental impacts of ocean energy extraction, most of the reviewed literature was of qualitative nature. The significance of several pressures is therefore afflicted with uncertainty. For ocean energy pressures we used the criterion: *ocean energy pressures that are –hypothesized– to have ecologically significant impacts on the marine environment*.

These ocean energy pressures were compared with pressures from conventional human activities with known environmental impacts on the marine environment. These preexisting pressures were inventoried through the following procedure: as starting point we used the comprehensive synthesis by Johnson et al. [21], who ranked environmental impacts of pressures from different human activities based on expert workshops. Johnson et al. let experts rank the generic effects of different pressures and categorized effects as *low*, *medium* or *high*. We focused on pressures with effects ranked *medium* and *high* and scrutinized these to verify causality between pressure, effect and impact. Only pressures fulfilling the following criteria were included in our comparison: *pressures from conventional coastal/marine activities and from pollution point sources –scientifically proven– to*

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