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Emergence of floating offshore wind energy: Technology and industry

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ABSTRACT

The paper investigates the construction of strategies aiming to up-scale low-carbon innovations from pilot to full commercial scale. This requires a systemic understanding of the evolution of the technology along with the organizations and infrastructures supporting its development. Technological innovation systems concepts operationalize system building processes, including the establishment of constituent elements and the performance of key innovation activities. The study surveys the national roadmaps published between 2009 and 2014 for offshore wind energy in deepwaters (more than 50 m deep) which inform on how actors expect the system to grow, including the innovation activities crucial to achieve it. The roadmaps point to the role of guidance and legitimacy as triggers of changes in other innovation processes (knowledge creation, experimentation and so on) needed for take-off. The analysis reveals that the growth plans conveyed in the roadmaps are overly optimistic when compared with the time taken to develop offshore wind energy in fixed structures for shallow waters. Several countries have adopted supporting policies following the publication of the roadmaps, but weaknesses in crucial innovation processes (e.g. specialized skills) and external factors (e.g. crisis, regulatory approval) resulted in a delay of the first large investments. Policy should be based on realistic expectations and adequate to the phase of innovation, such as the promotion of technology-specific institutions (standards, codes, regulations and so on) in technology up-scaling. New directions for research are also provided.

1. Introduction

The transition from pilot projects to full commercial scale is essential for the development of emerging innovation systems. Technologies evolve in the early years of the life-cycle and eventually standardize, which typically shifts the focus from product innovation to process innovation [1–3]. At the same time, technologies adjust to their adoption environment in the process of transition to growth [4–6]. Research shows that scaling is a common heuristic in the process of technological development [7]. Technology up-scaling typically precedes market take-off and mass commercialization of technologies, as in the case of the development of onshore wind energy [8]. It requires some degree of institutionalization, namely agreement among the actors on the anticipation of the future of both the technology and markets. This is particularly relevant in the mitigation of climate change, as efforts to avoid catastrophic consequences call for the implementation of low-carbon innovations [9].

Offshore wind energy in floating platforms is a new technology that promises to unlock a huge resource potential in deepwaters, i.e., water depths of 50 m or higher [10,11]. Floating offshore wind is more than a simple extension of the offshore wind industry, constituting a new technology on its own right. It develops under a different environment that is marked by a specific sectoral, technological, geographical and political context. The technology presents a high potential to reduce emissions in the electricity sector, but currently deals with a number of technological and institutional challenges that prevent its market take-off [10,12,13].

The take-off of diffusion requires a minimum agreement on norms and standards that involves the prior formulation of collective expectations and visions. This process is addressed by the technological innovation systems (TIS) literature, which conceptualizes the conditions for the establishment of a new industry that provides a supportive system around the new technology [14,15]. In this vein, the take-off of technological innovation systems depends on the establishment of structural elements including a network of actors and institutions [14]. In addition, TIS studies highlight the importance of key innovation processes (the so-called system *functions*) in the transition to growth. For example, the fulfillment of functions like legitimation and influence in the direction of search can help the formation of a collective strategy with positive effects for the mobilization of resources, the formation of

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demand, and the acquisition of political strength [16,17]. In particular, instruments like roadmaps contribute to shape collective expectations and to establish technology legitimacy [18].

Roadmaps are well-known tools that support technology management and planning [19–21]. They have been increasingly used in the framework of renewable energy technologies [22]. Roadmaps convey a collective vision and strategy that may influence the direction of search and thus the governance of the system transition [18]. They are particularly helpful in the early years of random patterns by enabling technology pioneers to run "in packs with others to create new relationships and institutions for collective survival" (Van de Ven [23]: 40).

Roadmaps are the result of a negotiation process that leads to a compromise between different anticipations of the future. They have the character of anticipatory coordination [24] by reducing the risk and uncertainty in technology growth. However, the compromise may reflect not only the differences in visions among the participant actors, but also their discursive power (capacity to frame an innovation), ideology and political cultures [25]. In spite of this limitation, roadmaps provide a valuable setting to examine the perspectives and proposals that prepare system development.

This research seeks to understand the pathways of development of floating offshore wind energy and its associated innovation system, with a view to answer the following questions: how do innovation systems around emerging technologies, such as floating offshore wind, prepare for take-off?; what are the visions that guide the up-scaling of this technological innovation system?; and how do the mechanisms that lead to the acceleration of a system's growth unfold? For that, we analyze roadmaps as instruments that enable the understanding of the process of formation of visions and guidelines that promote the dissemination of the innovation system around this new energy technology.

The paper is organized as follows. Section 2 reviews the literature on the acceleration of the growth of innovations systems being formed around new technologies. Section 3 explains the methodology followed to study the roadmaps published on floating offshore wind energy. Section 4 presents the results of the roadmaps analysis. The concluding section summarizes the findings and discusses their implications for policy and the literature.

2. Construction of technological innovation systems

Emerging innovations take time to "change gears" and accelerate the take-off [6,26]. A complex environment (actors, and institutions) is necessary to support the development of new energy technologies. Technological innovation systems (TIS) theory [12,19] assesses the challenges faced in the construction of such environments, particularly the establishment of the system structure and functions [26,27]. To understand the underlying processes, this approach is complemented with insights from industrial and technology life-cycle literatures (e.g. [2]) and from the literature that conceptualize roadmaps as instruments to promote systems emergence (e.g. [20]).

2.1. Structure and functions

Technological innovation systems (TIS) scholars conceive innovation as an interactive process involving actors (e.g., firms, users) and networks acting under a particular context of institutions and policies [28]. In these terms, the emergence of a new TIS involves the establishment of structural components – i.e. technology, actors, networks and institutions - dedicated to the focal TIS or shared with other existing TISs [29]. *Technology* is a key element of the TIS structure, including both artefacts and knowledge [30]. *Actors* comprise individuals and organizations (e.g. firms) along the value chain. *Networks* are links established between actors to perform a given task (e.g. knowledge development and diffusion, political lobby). *Institutions* encompass

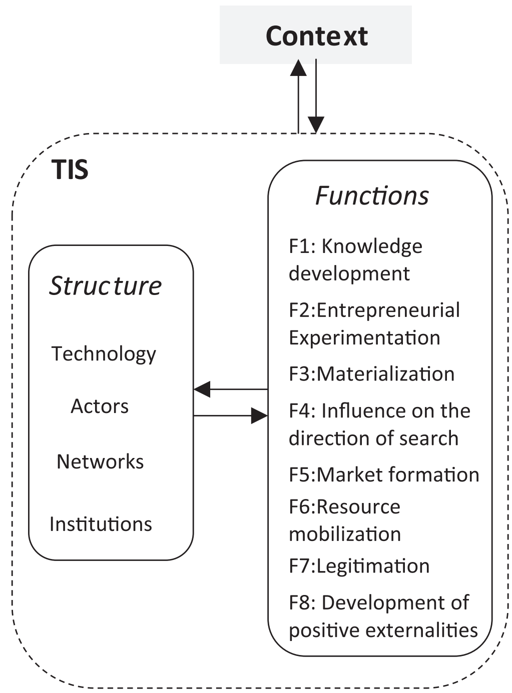

Fig. 1. Basic components of the technological innovation systems approach (Source: authors' elaboration from [26,27,30,39]).

formal rules (e.g. laws and property rights, codes and standards) and informal norms (e.g. tradition and culture) that structure social, economic and technological interactions [31,32].

In addition to these structural components, TIS scholars have increasingly looked at the performance of key innovation processes (the so-called "functions") that are needed for the growth of innovation systems (Fig. 1). A number of functions have been identified in two seminal papers [26,27]: development of formal knowledge, entrepreneurial experimentation, materialization; market formation; resource mobilization; development of positive externalities; legitimation; and influence in the direction of search [27,30].[1]

Development of formal knowledge refers to the way knowledge is created, combined, codified and shared, to form the scientific and technological base that allows the innovation to progress [26,28]. *Entrepreneurial experimentation* refers to the development of more applied, tacit and exploratory knowledge through risk-taking "entrepreneurial" actions, namely to the experimentation of a diversity of designs under a dynamic environment [23]. *Materialization* designates the early investment in capital stock or artefacts, including factories and infrastructures. *Market formation* refers to the creation of demand around increasingly organized markets, from pilot projects to niches and bridging markets. Early demand opens crucial opportunities for learning, while reducing perceived risks in the adoption by consumers [33]. *Resource mobilization* points to the need to attract human capital, financial capital and complementary assets from other sectors to gear up innovation systems. *Development of positive externalities* refers to the strengthening of the system and the dynamics of growth, comprising the capacity to take advantage of spillovers from the fulfillment of system functions, as well as from the structures and resources extant in other TISs to accelerate growth [30].

[1] The rest of the presentation adopts the list of functions as described in Bergek et al. [26,30]. A group of researchers from Utrecht University has developed an alternative list of functions with slight changes to the previous one [27]: entrepreneurial activities; knowledge development; knowledge diffusion through networks; guidance of search; market formation; resource mobilization, and creation of legitimacy.