Renewable and Sustainable Energy Reviews 26 (2013) 294–306

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A review of the European offshore wind innovation system ☆

Anna J. Wieczorek [a,b,*], Simona O. Negro [a], Robert Harmsen [a], Gaston J. Heimeriks [a], Lin Luo [c], Marko P. Hekkert [a]

[a] Innovation Studies, Copernicus Institute of Sustainable Development, Faculty of Geosciences, Utrecht University, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands
[b] Institute for Environmental Studies, Vrije Universiteit Amsterdam, de Boelelaan 1085, 1087 HV Amsterdam, The Netherlands
[c] European Commission, DG JRC, Institute for Energy and Transport, P.O. Box 2, 1755 ZG Petten, The Netherlands

ARTICLE INFO

Article history:
Received 17 October 2012
Received in revised form
9 May 2013
Accepted 20 May 2013

Keywords:
Offshore wind
Technological innovation system
Systemic problems
Systems functions
Systemic instruments

ABSTRACT

Offshore wind has the potential of becoming an important pillar of the future European energy system. It can contribute to policy objectives on climate change, energy security, green growth and social progress. However, the large potential of offshore wind does not automatically lead to a large share in future energy systems; neither does the emergent stage of development of the technology. Recent insights in innovation studies suggest that the success chances of technological innovations are, to a large extent, determined by how the surrounding system—the innovation system—is built up and how it functions. In this paper we assess the offshore wind innovation systems of four countries: Denmark, the UK, the Netherlands and Germany with the objective to provide recommendations for strengthening the overall European offshore wind innovation system. We use the Technological Innovation System (TIS) approach to analyse the system in 2011. Based on the analysis we identify a number of challenges that the European offshore wind sector faces. Some of them include: a serious deficiency of engineers; fragmented policies and poor alignment of national regulatory frameworks; cost of the technology and limited grid infrastructure. Since the problems hinder the entire system development we call for a systemic policy instrument that would support the innovation system around this technology and contribute to its wider diffusion in Europe.

Contents

1. Introduction . . . 295
2. Innovation system theory . . . 296
3. Methodology . . . 297
4. Analysis of innovation system functioning . . . 297
   4.1. Experimentation by entrepreneurs (F1) . . . 297
   4.2. Knowledge development (F2) . . . 300
   4.3. Knowledge diffusion (F3) . . . 301
   4.4. Guidance of the search (F4) . . . 301
   4.5. Market formation (F5) . . . 302
   4.6. Resource mobilisation (F6) . . . 303
      4.6.1. Financial resources . . . 303
      4.6.2. Human resources . . . 303
      4.6.3. Physical resources . . . 303
   4.7. Legitimacy creation (F7) . . . 304
   4.8. Comparison of overall system functioning . . . 305

☆The views expressed in this paper are purely those of the writers and may not in any circumstances be regarded as stating an official position of the European Commission.

* Corresponding author at: Innovation Studies, Copernicus Institute of Sustainable Development, Faculty of Geosciences, Utrecht University, The Netherlands. Tel.: +31 30 253 1625; fax: +31 30 253 2746.
E-mail address: A.J.Wieczorek@uu.nl (A.J. Wieczorek).

1364-0321/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.rser.2013.05.045

5. Conclusions and challenges for the European offshore wind TIS . . . 305
Acknowledgements . . . 305
References . . . 305

1. Introduction

The development and diffusion of offshore wind energy technology is important for European energy policy [1,2]. Firstly, there is a large amount of potential: the European Wind Energy Association (EWEA) expects 150 GW of offshore wind capacity to be realised in 2030, which would supply 14% of Europe's electricity demand [3]. The technical potential of offshore wind in Europe is estimated at 5800 GW [4] and allows for even further expansion after 2030. Offshore wind has thus the possibility of becoming an important pillar of the future European energy system, contributing to policy objectives on climate change, energy security and affordable energy [5]. Secondly, the technology is in the early stages of technological development and, therefore, many business opportunities can be reaped in this emerging sector and thereby contributing to green economic growth. However, a large potential does not automatically lead to a large share in future energy systems; neither does an emergent stage of technological development automatically lead to success for companies and the related economic growth and growth in employment. Innovation and technological change are by definition very uncertain processes. The outcomes are strongly determined by processes of chance and by external events that can hardly be influenced. Nevertheless, the scientific community that studies innovation has shown that a conscious and intelligent management of innovation processes strongly increases the success chances of innovation [6,7,9].

The most important insight that has dominated the field of innovation studies in the recent decades is the fact that innovation is a collective activity and takes place within the context of an *innovation system*. The success chances of innovations are, therefore to a large extent, determined by how the innovation system is built up (defined as *structure* of the innovation system) and how it *functions*. Many innovation systems are characterised by flaws that hamper the development and diffusion of innovations. These flaws are often labelled as system failures [6]; or system problems [7]. Intelligent innovation policy therefore evaluates how innovation systems are functioning, tries to create insight into the system problems and develops policies accordingly.

This paper assesses the offshore wind innovation system of four countries: Denmark, the UK, the Netherlands and Germany with the objective to provide recommendations for strengthening the overall European offshore wind innovation system. We chose the countries mainly because of their largest installed capacity in 2011 (the UK—1586 MW, Denmark—854 MW, the Netherlands—247 MW and Germany—195 MW [3]). The second reason is the potential high contributions of these countries to European offshore wind. We use the Technological Innovation System (TIS) approach to analyse the state of the system in 2011. We also identify the weaknesses that may hinder its further development.

The paper is structured as follows: Sections 2 and 3 describe the theory and methodology applied in this paper. In Section 4 we look into the *structure* and *functioning* of the innovation systems in the UK, Denmark, the Netherlands and Germany. The paper closes with concluding remarks in Section 5 on challenges of the European offshore wind innovation system.

Table 1
Description of the seven key processes of innovation systems.

Key process	Description	Diagnostic question
Experimentation by entrepreneurs	Entrepreneurs are essential for a well functioning innovation system. Their role is to turn the potential of new knowledge, networks, and markets into concrete actions to generate—and take advantage of—new business opportunities.	Are there sufficient[a] and suitable types of actors contributing to entrepreneurial experimentation and up-scaling? Are the amount and type of experiments of the actors sufficient? How much technological up -scaling takes place?
Knowledge development	Mechanisms of learning are at the heart of any innovation process, where knowledge is a fundamental resource. Therefore, knowledge development is a crucial part of innovation systems.	Are there enough actors involved in knowledge development and are they competent? Is the knowledge sufficiently developed and aligned with needs of actors in the innovation system?
Knowledge exchange	To learn relevant knowledge needs to be exchanged between actors in the system.	Are there sufficient networks or connection between actors through which knowledge is exchanged?
Guidance of the search	This system function refers to those processes that lead to a clear development goal for the new technology based on technological expectations, articulated user demand and societal discourse. This process enables selection, which guides the distribution of resources.	Do actors and institutions provide a sufficiently clear direction for the future development of the technology?
Market formation	This process refers to the creation of markets for the new technology. In early phases of developments these can be small niche markets but later a larger market is needed to facilitate cost reduction and incentives for entrepreneurs to move in.	Is the size of the market sufficient to sustain innovation and entrepreneurial experimentation?
Resource mobilisation	The financial, human and physical resources are necessary basic inputs for all activities in the innovation system. Without these resources, other processes are hampered.	Is the availability of financial resources sufficient? Are there sufficient competent actors/well trained employees? Is the physical infrastructure sufficient?
Creation of legitimacy	Innovation is by definition uncertain. A certain level of legitimacy is required for actors to commit to the new technology with investment, adoption decisions, etc.	Do actors, formal and informal institutions sufficiently contribute to legitimacy? How much resistance is present towards the technology, project set up or permit procedure?

[a] Since innovation does not recognize an optimum, it is impossible to judge whether there is *enough* of it. Our discussion on the *sufficiency* of innovative activity in the areas defined by the system functions is, therefore, based on the qualitative evaluation of the capacity of the four analysed systems to grow and accelerate. At the same time we refrain from any quantitative assessment in the context of reaching the European and national targets.