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Abstract

In recent years offshore wind has become one of the fastest growing forms of renewable energy technology worldwide. Nevertheless, there are still several markets with large potential for deployment. In this paper we assess the offshore wind innovation system in one specific country – Poland. We apply the Technological Innovation System approach. This procedure has been widely used to describe the offshore wind innovation system in Europe. However, the existing literature concerned European countries located at the technological frontier, while in this publication we examine this issue in a follower country, which is still waiting to deploy its first offshore wind installation. The upcoming transition of the Polish energy system, resulting from depletion of current coal resources and EU climate policy goals, makes Poland one of the most promising markets for renewable technologies, and the geographical location puts Poland in position of the main actor in kick-starting the offshore wind market on the Baltic Sea. However, in our study we identify a number of challenges for offshore wind technology deployment in Poland. Some of these challenges include the unpredictable public policies, limited grid infrastructure, rather poor quality of research provided by scientific organisations and weak interactions between science and business. To address these issues, we propose a set of policy instruments, which, we believe, will significantly contribute to the development of offshore wind technology in Poland.

Keywords: offshore wind, innovation system, TIS

JEL: Q42, Q55, O31, O33

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Table of contents

Abstract 2

Introduction 4

1. Structural analysis 5

  1.1. Actors 5

    1.1.1 Governmental agencies 5

    1.1.2 Knowledge institutes 6

    1.1.3 Educational organisations 8

    1.1.4 Industrial actors 9

    1.1.5 Support organisations 12

  1.2. Networks 12

  1.3. Institutions 14

2. Stage of development 16

3. Functional analysis 18

  3.1 Entrepreneurial experimentation 18

  3.2 Knowledge development 21

  3.3 Knowledge exchange 22

  3.4 Guidance of the search 23

  3.5 Market formation 25

  3.6 Resource mobilisation 26

  3.7 Legitimacy creation 27

  3.8 Functional analysis summary 28

4. Innovation system failures 28

5. Policy challenges and instruments 29

Summary 32

References 33

Appendix 35

Introduction

Since the beginning of the 21st century, offshore wind technology has experienced rapid growth, especially in European countries with access to the North Sea (EWEA 2016, WindEurope 2017). The Baltic Sea is also being explored, mainly by Denmark and Germany, but its potential is still largely unused. Poland – with its favourable geographical position – is considered to play a pivotal role in kick-starting the offshore market in the Baltic Sea (Kruger 2016). This expectation is strengthened by the fact that, in the coming decades, Poland will have to make a significant effort to meet its energy needs and maintain energy security. The existing coal plants, which are a key element of the current power system, are outdated. Between 2020 and 2035, installations accounting for about 50% of the power generation are intended to be closed, and most of the remaining units need to be modernised. By 2050, only 5 GW from existing installations will still be in use, while the maximum demand is estimated to be about 40 GW (Supreme Audit Office 2015). To meet the long-term national energy demand, as well as EU climate policy goals, there is a need for significant investment in new sources of energy, including renewable energy. In this context, offshore wind technology should be considered as one of the main alternatives for the Polish power sector.

Offshore wind is still a relatively new technology for the generation of energy and its deployment on a new market is to a large extent a matter of the market's readiness for innovation. The literature is dominated by a statement, that introducing innovations is a collective activity and takes place within the context of a wider system, which is usually called an "innovation system" or "innovation ecosystem" (Hekkert et al. 2011). The framing of innovation systems can be defined in a variety of ways: they can be national, regional, sectoral, or technological. They all are based on a principle that the creation, diffusion and use of knowledge are the outcome of a system – its components, relations between these components, and components' characteristics or attributes (Carlsson et al. 2002). Therefore, to shape the innovation process it is crucial to understand how the innovation system is built and how it functions – what are the societal subsystems, actors and institutions contributing to the emergence or production of innovation, and what kind of communication and interaction foster or hamper innovation (Carlsson and Stankiewicz 1991, Hekkert et al. 2007).

In this article we evaluate the offshore wind innovation system in Poland. In doing so we use the Technological Innovation System (TIS) approach. This procedure has been widely used to assess the innovation systems for emerging technologies in the energy sector (e.g. for CO_2 capture and storage technologies, see: van Alphen et al. 2009, 2010, Stephens and Jiusto 2010, Lai et al. 2012). This is also the case for offshore wind. There are several studies analysing offshore wind innovation systems in non-European countries (Gosens and Lu 2013, Karltorp et al. 2017), but the literature in this area is particularly rich for Europe (Jacobsson and Karltorp 2012, 2013, Luo et al. 2012, Wieczorek et al. 2013, 2015, Sovacool and Enevoldsen 2015, Karltorp 2016, Reichardt et al. 2016, 2017, Andersen et al. 2018, Makitie et al. 2018, Normann and Hanson 2018). However, all these articles concerned European countries which could be called technology leaders, as in all of them the technology is already in use and faces rapid growth. In this publication we examine the offshore wind innovation system in a follower country, which is still expecting to deploy its first offshore wind installation.

From the methodological side, we rely in particular on four publications: Bergek et al. (2008) and Hekkert et al. (2011), who provide manuals containing instructions and explanations about the TIS analysis, as well as Luo et al. (2012) and Wieczorek et al. (2013), whose studies are examples of a well-prepared offshore wind innovation system analysis of four European countries – Denmark, Germany, the Netherlands and the United Kingdom.

Following these articles, we divide our TIS procedure into five steps (each step represents one consecutive article section):

1. A structural analysis, which concerns mapping the main components of the innovation system: actors, networks and institutions, and recognising their capacity to stimulate innovation.
2. Defining the technology stage of development, which is necessary as the review of the innovation system occurs differently depending on the maturity of the technology.
3. A functional analysis, concerning an evaluation of how the innovation system is behaving in terms of seven key processes. While structural analysis indicates who is active in the system, the functional analysis provides an answer on what they are doing and whether this is sufficient for technology development (a functional analysis is therefore much more evaluative).
4. Identifying system failures, i.e. looking for causes which hamper technology development.
5. Proposing proper policy instruments, which should answer the problems identified during the whole procedure.

The study is based on quantitative and qualitative analyses. The first two steps were carried out using scientific and industrial literature, scientific publication databases, patent databases, governmental data and our professional knowledge. Then, in order to evaluate the functional characteristics of the innovation system, we conducted 10 in-depth interviews with 12 stakeholders representing public administration, universities, non-governmental organisations and industrial actors. They were asked the same set of questions. We verified the information received using open-source intelligence tools (OSINT) and assessed the responses using a 5-tier scale based on the emotional approach of each interviewee. Then we unified the terminology, made the responses comparable and scored each system's functions. Finally, the 4th and 5th steps are intended to derive conclusions from observations made during previous actions.

1. Structural analysis

1.1. Actors

1.1.1 Governmental agencies

The role of the government in offshore wind TIS broadly concerns the development and administration of legislation, permissions procedures and providing consent (Luo et al. 2012). The Ministry of Energy is the body responsible for determining the general direction of energy policy in Poland, in particular preparing the long-term energy policy strategy and arranging the proposals for legal reforms (together with parliament bodies). However, the Ministry of Energy is not directly engaged in the permission procedure for offshore wind projects. The procedure consists of four main stages – the location decision, connection agreement, environmental decision and building permit. A wide range of public institutions are involved in these steps (table 1).

The location decision for a wind farm is issued by Minister of Maritime Economy, assisted by six other ministers, who prepare their own opinions. Separate location decisions also need to be obtained for submarine and onshore cables. They are issued by the Minister of Maritime Economy, maritime offices and local authorities. The investor is obliged to meet the connection conditions and sign a connection agreement with the national transmission system operator – PSE S.A. (a state-owned company). One of the key milestones is obtaining environmental permission, which is issued by the director of the appropriate Regional Directorate for Environmental Protection. The decision is preceded by the investor carrying out extensive environmental studies and preparing the Environmental Impact Assessment Report. The last step is obtaining the building permits for wind farms and connection infrastructure. The decision is issued by local governors (regional government representatives), who rely on previously obtained permits and investment projects. Before the energy starts to be produced, a concession needs to be obtained to produce energy from RE sources. This concession is issued by the Energy Regulatory Office, which is also responsible for organising auctions for RE generation.

Table 1. Overview of governmental bodies relevant for offshore wind

Institution	Responsibility
Ministry of Energy	Designing the energy policy
Government Plenipotentiary for Strategic Energy Infrastructure	Supervision over energy infrastructure
Ministry of Maritime Economy and Inland Navigation	Location decisions for wind farms; location decisions for submarine cables in exclusive economic zone
Local authorities	Location decisions for onshore cables; building permits
Maritime Offices	Location decisions for submarine cables outside the exclusive economic zone
Regional Directorates for Environmental Protection	Decisions on environmental conditions
Energy Regulatory Office	Auctions for RES; concessions for producing RES energy
PSE S.A. (Polish Transmission System Operator)	Grid connection terms and connection agreement

Source: own elaboration.

1.1.2 Knowledge institutes

As of June 2017, the number of publications from Poland relating to the offshore wind topic on the Web of Science database amounted to 55 (table 2). It is rather low in comparison to other EU countries. The total number of publications from three EU countries with highest offshore wind deployment – Denmark, Germany and United Kingdom – amounted to 2586 (862 on average). The quality of Polish research papers is also unsatisfactory – the average number of citations per item reached 3.7, while in the other aforementioned countries it was 11.2. However, it should be taken into account that the whole research sector in Poland is rather underdeveloped in terms of publications in well-established journals. The number of all publications from Poland in the Web of Science database is almost 5 times lower than from Germany, while the total country population is about half.

The Polish Academy of Sciences (PAS) is the leading organisation in publications about offshore wind. The PAS consists of a number of institutes, of which the most important in the context of offshore wind deployment in Poland are: the Institute of Oceanology in Sopot, the Institute of Geophysics in Warsaw, the Institute of Fluid-Flow Machinery in Gdańsk, the Institute of Hydroengineering in Gdańsk and the Institute of Geological Sciences in Warsaw. The first two organisations are members of a research consortium which received the status of Leading National Research Centre for 2014-2018 (there are only 5 consortia with this status for that period in Poland).

Other important public research institutes (which are not part of PAS) which provide research in areas potentially appropriate for offshore wind are: the Polish Geological Institute, the Institute of Meteorology and Water Management, the Institute of Power Engineering (all with main offices located in Warsaw), the Maritime Institute in Gdańsk and the National Marine Fisheries Research Institute in Gdynia. These organizations provide research facilities for some important steps in the development of offshore wind in Poland, in particular environmental research and seabed exploration. The role of the Maritime Institute is especially worth highlighting, as this institution has been largely engaged in almost all permission procedures initiated so far.

Table 2. Overview of publications occurring in Web of Science database with *offshore wind* as topic indication and *Poland* as country indication

<table>
<tr><th colspan="5">Year of publication</th></tr>
<tr><th>Year</th><th>No. of publications</th><th colspan="2">Year</th><th>No. of publications</th></tr>
<tr><td>2012</td><td>5</td><td colspan="2">2016</td><td>7</td></tr>
<tr><td>2013</td><td>6</td><td colspan="2">2017</td><td>6</td></tr>
<tr><td>2014</td><td>4</td><td colspan="2">Other</td><td>17</td></tr>
<tr><td>2015</td><td>10</td><td colspan="2">Total</td><td>55</td></tr>
<tr><th colspan="5">Most represented organisations*</th></tr>
<tr><th colspan="3">Organisation name</th><th colspan="2">No. of publications</th></tr>
<tr><td colspan="3">Polish Academy of Sciences</td><td colspan="2">16</td></tr>
<tr><td colspan="3">Gdańsk University of Technology</td><td colspan="2">10</td></tr>
<tr><td colspan="3">Warsaw University of Technology</td><td colspan="2">5</td></tr>
<tr><td colspan="3">University of Gdańsk</td><td colspan="2">4</td></tr>
<tr><th colspan="5">Most represented authors*</th></tr>
<tr><th>Author</th><th colspan="2">Affiliation</th><th colspan="2">No. of publications</th></tr>
<tr><td>Dymarski Paweł</td><td colspan="2">Gdańsk University of Technology</td><td colspan="2">4</td></tr>
<tr><td>Zieliński Tymon</td><td colspan="2">Polish Academy of Sciences</td><td colspan="2">4</td></tr>
<tr><td>Dymarski Czesław</td><td colspan="2">Gdańsk University of Technology</td><td colspan="2">3</td></tr>
<tr><td>Kahsin Maciej</td><td colspan="2">Gdańsk University of Technology</td><td colspan="2">3</td></tr>
<tr><td>Żywicki Jędrzej</td><td colspan="2">Gdańsk University of Technology</td><td colspan="2">3</td></tr>
<tr><th colspan="5">Most represented research areas*</th></tr>
<tr><th colspan="3">Research area</th><th colspan="2">No. of publications</th></tr>
<tr><td colspan="3">Engineering</td><td colspan="2">31</td></tr>
<tr><td colspan="3">Energy fuels</td><td colspan="2">9</td></tr>
<tr><td colspan="3">Oceanography</td><td colspan="2">8</td></tr>
<tr><td colspan="3">Geology</td><td colspan="2">5</td></tr>
<tr><td colspan="3">Computer science</td><td colspan="2">5</td></tr>
</table>

** More than one organization, author and research area may be assigned to one article.*
Source: own elaboration based on the Web of Science database (accessed: 27.06.2017).

Research in offshore wind is also conducted by academic authors. The leading organisation in this case is the Gdańsk University of Technology, in particular the Faculty of Ocean Engineering and Ship Technology. The Faculty also publishes the Polish Maritime Research journal (impact factor in 2016 – 0.776), which covers research in engineering, computing and technology, which could have applications in the domain of maritime economy. There is also some kind of knowledge dispersed among other universities of technology, which does not refer specifically to offshore, but may also be useful for this sector (e.g. knowledge related to cables construction or engines).

A special kind of actor in knowledge area about offshore wind is the CTO – Ship Design and Research Centre. It is a state-owned company, which provides vessel model studies, as well as research, design and certification services, in particular for the shipbuilding industry.

An analysis of the abstracts and keywords of publications occurring in the Web of Science database provides the information about the main directions of research in offshore wind in Poland. There is a set of publications, prepared mainly by the team of the Gdańsk University of Technology, covering computer simulations and strength analyses of scaled laboratory models of offshore wind turbines support structures, in particular foundations and TLP platforms. The resistance of such structures to loads due to waves is one of the most frequently studied topics. There are also some papers on the characteristics of marine power grids and plant connection infrastructure. Similarly to observations made by Luo et al. (2012) for Denmark, Germany, the Netherlands and the United Kingdom, a large part of the offshore wind literature in Poland concentrates on how to fit the technology into specific environmental and geographical conditions, rather than on the technology itself.

1.1.3 Educational organisations

There are no academic programmes in Poland which specialise in the particular needs of the offshore wind sector. However, there is a wide range of faculties, which have the potential to create such types of courses, in case of significant increase in market demand for these qualifications. The academic courses related to marine sciences (i.e. engineering, transport, geology, navigation) are concentrated in the Pomeranian region. These faculties cover over 12,500 students and the locations of the universities coincide with the potential locations of offshore wind construction seaports (see subsection 1.1.4). There are also a number of courses offered by higher education institutions in Poland in fields such as power engineering, mechanical engineering, environment and geology, and a growing number of programmes on renewable energy sources (table 3).

Since 2012 is has been possible to obtain the title of Technician of Renewable Energy Equipment and Systems at a vocational pillar of education in Poland. Therefore, many vocational schools have opened courses in this field. Acquiring a certificate of competence in this profession is preceded by a four-year period of training combined with professional practice. A two-stage state exam is the final element of the course. Program graduates are competent in the assembly and operation of RES installations. Moreover, educational organisations located in the Pomeranian region also offer a broad spectrum of vocational courses in marine studies. The courses are mainly dedicated to the shipbuilding industry, i.e. ship mechanics, ship building, port operation and maritime navigation. The vocational educational organisations prepare students either for getting a job immediately after finishing school, or for starting their academic education with an extended level of knowledge in a particular area.

Table 3. Overview of higher education institutions and courses potentially relevant for offshore wind

By university		
Selected universities	Selected faculties	Number of students 2016/2017 (approx.)
Gdynia Maritime University	Faculty of Marine Electrical Engineering	1000
	Faculty of Marine Engineering	1100
	Faculty of Navigation	1800
Maritime University of Szczecin	Faculty of Economics and Transport Engineering	1100
	Faculty of Marine Engineering	800
	Faculty of Navigation	1800
Gdańsk University of Technology	Faculty of Ocean Engineering and Ship Technology	1900
West Pomeranian University of Technology Szczecin	Faculty of Maritime Technology and Transport	400
University of Gdańsk	Faculty of Oceanography and Geography	1300
University of Szczecin	Faculty of Geosciences (including Institute of Marine Sciences)	450
Polish Naval Academy	Faculty of Mechanical and Electrical Engineering	300
	Faculty of Navigation and Naval Weapons	600
By field of study		
Field of study		No. of universities offering a course in the given field
Environment (engineering, protection, management)		68
Geology		13
Mechanical engineering		43
Oceanography		2
Ocean engineering		3
Power engineering		27
Renewable energy sources		14

Source: own elaboration based on government data on faculties and fields of study in the higher education system in Poland, available at: www.wybierzstudia.nauka.gov.pl (accessed 26.06.2017).

1.1.4 Industrial actors

The key industrial actors involved into offshore wind system in Poland are presented in scheme 1. The actors were divided into main value chain steps. The scheme covers the most important companies in the Polish value chain, primarily those who had already taken part in offshore wind investments in other countries. In the case of multinational corporations, the company has only been classified to the Polish value chain if its subsidiary is located in Poland, and only to the stages of the value chain, which can be covered by this Polish branch.

Although there is no offshore wind farm located in Poland, Polish industry can cover a large part of the offshore wind farm investment. There are close to 70 business entities directly active in this sector or ready-to-be involved in this business on local and global scale (for the most important industrial actors – see figure 1). So far, activity in this area shows that the large state-owned companies – PKN Orlen and PGE EO, as well as the privately-owned Polenergia, could be the most important investors and project developers. There are also at least a few significant players on the global offshore wind market, with their businesses located in Poland, i.e.: GSG Towers, Energomontaż-Północ Gdynia, ST3 Offshore, GS Seacon, Aarsleff and Spomasz Żary. These companies specialise mainly in the supply of foundations, towers and substations. Their portfolio is filled by many projects realisations, in particular for offshore wind farms located on the Baltic and North Sea. Moreover, Tele-Fonika Kable is one of the largest European cables producer, whose cables have been largely used in offshore wind investments worldwide. There are also companies (AOS, MEWO, SMDI Advisory Group, SSC Balticwind), which have experience in dealing with administrative procedures and preparing environmental documentation for offshore wind farms.

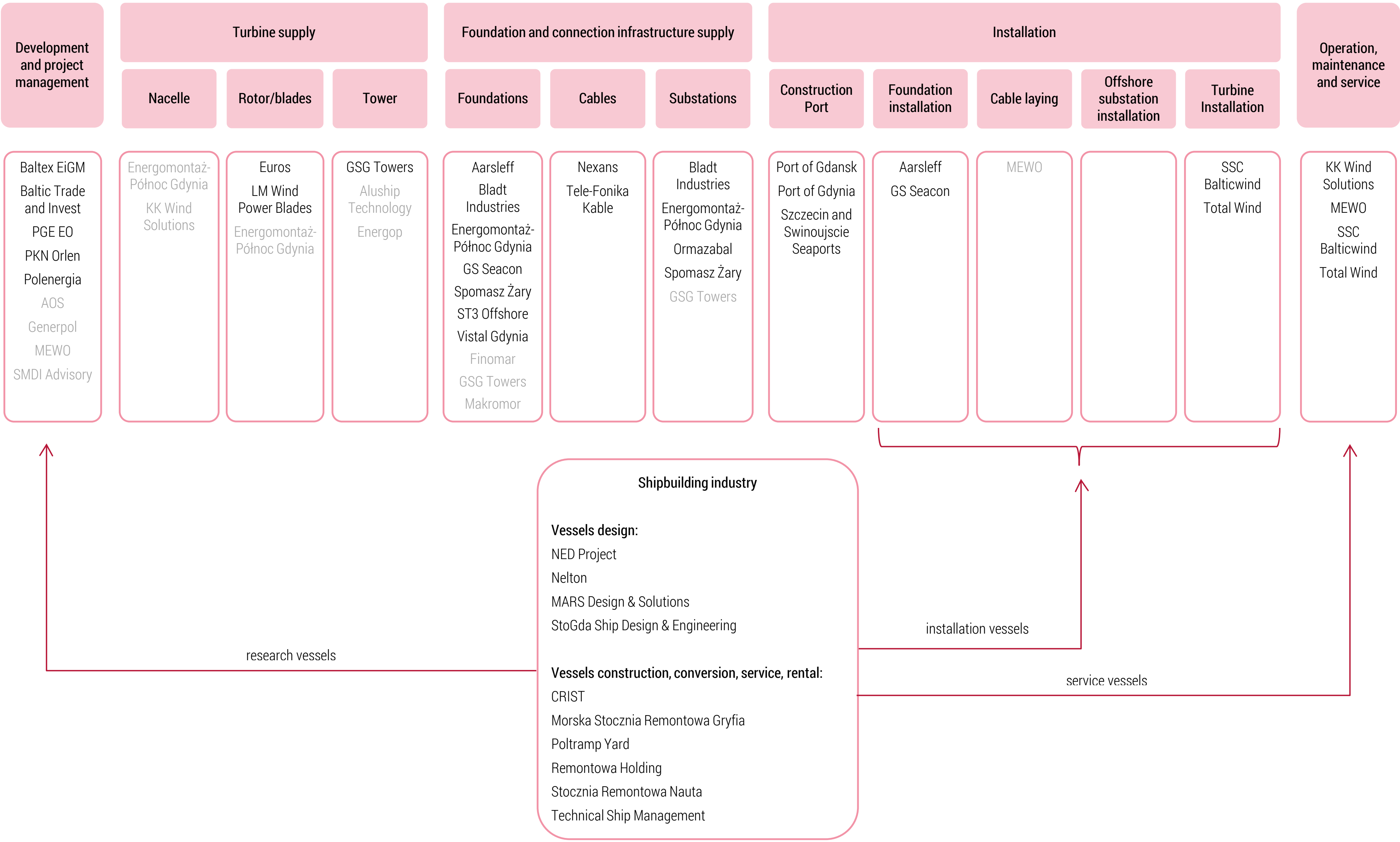
The strength of the Polish offshore wind value chain is a well-developed shipbuilding industry. Offshore wind sector requires specialised vessels for environmental and geological research, transport and installation of wind farm components and wind farms service. The construction and repair of ships and boats industry in Poland includes over 5000 enterprises (of which about 80 employ more than 50 workers), and employs almost 30 thousand workers (2015 data) (GUS 2016). Polish shipbuilding companies offer a few models of vessels dedicated for offshore wind farms investments, which have already been used in offshore wind projects worldwide. Also Polish seaports seem to be sufficiently developed for offshore wind deployment.

However, the nacelle production and some stages of the installation activities are the parts of the Polish offshore wind value chain which are somewhat underdeveloped. Also, the production of rotors and blades is not sufficient, with only two important blade manufacturers: Euros (Senvion subsidiary) and LM Wind Power. The O&M and service stage of the value chain is covered mainly by a few subsidiaries of multinational corporations, although it should develop in parallel with the deployment of technology.

It is worth noting that the range of sub-suppliers, not mentioned in the value chain scheme, could also be important factor for offshore wind deployment in Poland. Poland has large steel producers (e.g. ISD Huta Częstochowa), and offshore wind deployment could become the largest steel-consumption project in recent decades (Purta et al. 2016). Moreover, Polish KGHM is one of the world's largest copper producers, which is primarily used to produce cables for offshore wind installations. Poland has also accommodated a number of industrial investments in production plants, e.g. in automotive industry or onshore wind. Experience in this regard may be transferred to the offshore wind industry in case of market development.

Given the outlined factors and taking into account the investment costs in each phase of the value chain, at least 50% of the offshore wind farm investment costs can be covered by Polish value chain at this moment (Purta et al. 2016). This share can rise up to 70%, assuming the value chain develops in parallel with technology. Still, nacelle, rotor and blade supply collectively account for about one-third of investment costs, and these elements will probably be mostly imported.

Figure 1. Polish industrial actors potentially involved in national offshore wind projects along the value chain



A gray font means that the company may potentially take part in the specified stage of value chain as a sub-supplier.
Source: own elaboration.

1.1.5 Support organisations

The high costs of offshore wind investments make the availability of external financing one of the key issues for the development of this technology in Poland. BGK – the Polish state-owned development bank – should be one of the main capital providers, since it is usually involved in large infrastructure projects in Poland (in the energy sector as well). Also, the European Investment Bank (EIB) may be interested in Polish offshore wind projects, as it has already taken part in financing offshore wind deployment in other countries (especially through the European Fund for Strategic Investments – a joint initiative of the EIB and the European Commission). The probability of obtaining financing at EU's institutional structures may be particularly high for regional marine grid connection projects, covering all EU countries with access to Baltic Sea (see also subsection 1.3). Such projects may receive the status of projects of common interest (PCIs) and become part of an integrated EU energy market.

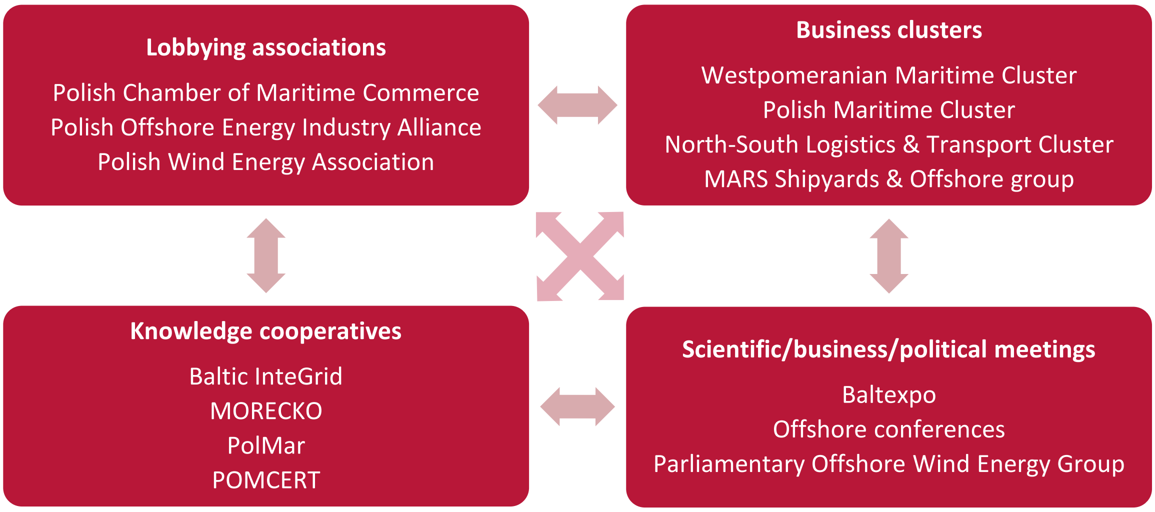
Financial and non-financial assistance for industrial projects is offered by the Polish Entrepreneurship Development Agency and the Industrial Development Agency. Similar activities are also carried out by regional institutions, i.e. the Pomerania Development Agency (coordinator of the 'Invest in Pomerania' initiative) and the Pomeranian Regional Development Agency. These institutions provide access to investment areas, consultation and information services and professional support in obtaining EU funds and other financial support, and also offer their own financial instruments dedicated mainly to small and medium-sized enterprises.

Other important actors for offshore wind in Poland are non-governmental organisations, which care about promoting and lobbying for this technology spread, and also put forward regulatory proposals in that area. There are at least four such organisations: The Foundation for Sustainable Energy, Institute for Renewable Energy, Polish Offshore Wind Energy Society and Polish Wind Energy Association. Their activity is substantially important at the current stage of technology development in Poland and given the high political uncertainty related to whole energy sector (see sections 1.3 and 2).

1.2. Networks

MARS Shipyards & Offshore group is a close cooperative of companies relevant for offshore wind projects. It includes two shipyards – MSR Gryfia and SR Nauta, two companies which specialise in the manufacturing of offshore constructions – Energomontaż-Północ Gdynia and Energop, as well as a marine and offshore design office – MARS Design & Solutions. The owner of the group is MARS Fund, which is managed by the MS Investment Funds Society, a subsidiary of the PGZ - Polish Armaments Group. PGZ is a company, whose sole shareholder is the State Treasury, therefore the companies forming MARS Shipyards & Offshore group can be viewed as state-owned. At the beginning of 2017 the group expanded, as MARS Fund purchased the Szczecin Industrial Park, which covers the area of the former Szczecin Shipyard. Moreover, the Fund holds significant, but non-controlling, shares in the CRIST Shipyard and ST^3 Offshore. The companies gathered around MARS Fund represent a substantial part of the technical potential of Polish industry, that may participate in offshore wind technology deployment in Poland.

Figure 2. Main networks in Polish offshore wind sector



Source: own elaboration.

The Polish Offshore Energy Industry Alliance is an agreement signed by 30 companies from the maritime, steel and electrical industry, representing, among others, the shipbuilding, metallurgy and cable design sectors. The aim of the Alliance is to provide support for the development of the offshore wind energy sector in Poland, which mainly translates into lobbying activities. The initiator and coordinator of the Alliance is the Polish Offshore Wind Energy Society, which gathers a set of offshore wind actors. A similar function, albeit dedicated to the whole offshore sector, is also performed by the Polish Chamber of Maritime Commerce. Another important form of cooperation between companies is merging into clusters. There are at least three important formalised clusters in Polish offshore sector: the Westpomeranian Maritime Cluster, Polish Maritime Cluster and North-South Logistics & Transport Cluster. They cover, in particular, companies related to the shipbuilding industry, as this is the main area of interest of the offshore business sector in the Pomerania region (as indicated in section 1.1.4).

Table 4. Formalised knowledge cooperatives in areas relevant for offshore wind

Name	Members	Mission
Baltic InteGrid	Foundation for Sustainable Energy Maritime Institute in Gdańsk 12 partners from other countries: Denmark, Estonia, Finland, Germany, Latvia, Lithuania and Sweden	Expertise exchange and state-of-the-art interdisciplinary research on the optimisation potential of offshore wind energy in the Baltic Sea Region by applying the meshed grid approach.
MORECKO	CTO – Ship Design and Research Centre Gdańsk University of Technology Institute of Fluid-Flow Machinery (PAS) Institute of Oceanology (PAS) Maritime Institute Pomeranian Special Economic Zone	Integration of activities of consortium partners in offshore wind energy sector in order to achieve synergies and developing research programs in cooperation with the private sector.

PolMar	Gdańsk University of Technology Institute of Meteorology and Water Management Institute of Oceanology (PAS) Maritime Institute National Marine Fisheries Research Institute Polish Geological Institute	Consolidation of scientific, organizational and financial capacities of consortium members, to conduct large research projects in the field of marine research, exploration and exploitation of marine resources, protection and sustainable development of marine environment and the dissemination of knowledge about the sea.
POMCERT	Gdańsk University of Technology Medical University of Gdańsk University of Gdańsk	Integration of specialists in the broadly-understood environmental sciences and technology and environmental engineering. Developing joint research programs.

Source: own elaboration based on: Maritime Institute (2014) and information from cooperatives web sites.

Scientific collaboration within the Polish offshore wind innovation system is relatively high. According to the data from Web of Science database, the average number of authors per publication is 3.7, the share of co-authored publications is 80%, while the share of internationally co-authored papers is 42%. In similar analysis for Denmark, Germany, the Netherlands and the United Kingdom for 1990-2010, these numbers amounted to 1.8, 46% and 17% respectively. An especially important issue for offshore wind technology deployment in Poland is the well-developed international collaboration, as there is still a great need for knowledge absorption in that area. However, an analysis of the publications also showed some deficiencies in terms of cooperation between scientists and the business sector, since there were only 4 publications identified with a company representative as a co-author.

There are a few formalised knowledge cooperatives, which may be important for future offshore wind deployment in Poland (table 4). Baltic InteGrid is a network of several organisations representing countries located on the Baltic Sea, which is working on the concept of regional meshed offshore grid in case of offshore wind deployment. PolMar and POMCERT are consortia of research centres, which concentrate more generally on research in areas related to maritime issues, while MORCEKO's (the Maritime Centre for Eco-Energy and Eco-Systems) activities are dedicated specifically to offshore wind. The main area of interest of scientists engaged in the latter initiative are support structures for offshore wind turbines (i.e. the consortium has realised a research project on the technical, geological and environmental aspects of the optimal choice of the type of support structure for wind turbine in Polish maritime areas, financed by the National Centre for Research and Development).

1.3. Institutions

In 2015, the share of energy from renewable sources in the gross final consumption of energy in Poland reached 11.8% (Eurostat 2017). The Polish obligation according to the EU Directive on national renewable energy targets, has been set to 15% by 2020, and even 15.85% according to the National Action Plan. The probability of this being achieved is assessed as rather low. Assuming that the current conditions for RES deployment (i.e. support policies are in place and have been announced for the period 2017–2020) will continue, the share of renewables in the final energy consumption is forecasted to range between 10.0% and 13.8% in 2020 (Janeiro and Resch 2017). However, it is worth noting that Poland made a significant progress in RES deployment since joining the

EU in 2004. The installed capacity of renewable energy sources has increased from 1.2 GW in 2005 to 8.2 GW in 2016 (Energy Regulatory Office 2017).

The energy sector in Poland is struggling with a high level of uncertainty about the energy policy goals, legal framework and system of support. The key document for the sector is the "State energy policy", which contains an assessment of the implementation of the previous document, and lays down a forecast for a period not shorter than 20 years. The document should be adopted every four years. Despite this, the currently valid "State energy policy up to 2030" is dated 2009. The stakeholders are still waiting for the final version of a new strategy, namely the "State energy policy up to 2050", whose proposals have been changed several times. It is also the key issue for offshore wind, since the current government's position toward this technology deployment in Poland remains unknown.

In 2016, after years of public discussions and several proposals on the optimal support scheme for RE generation, Poland replaced the system based on certificates of origin (valid since 2005) with an auction system. New regulations introduced 7 categories ('baskets') of installations, under which investors are competing for support. The categories refer to several criteria, i.e. the installed electrical capacity factor, volume of CO_2 emissions, legal and organizational form of business activity, and the natural resources used to produce energy. There is no strict technological division, so different technologies can compete in most of the baskets. Also, none of the baskets is dedicated specifically for offshore wind. The most appropriate category for this technology is the basket for installations with a capacity higher than 3504 MWh/MW/year and CO_2 emissions lower than 100 kg/MWh. However, in this basket, offshore wind has to compete with other technologies such as hydro power plants.

Moreover, the requirements for participation in the auction include holding a building permit, which is particularly severe for offshore wind, as in this case, a significant part of the investment costs are incurred before the building permit is obtained (i.e. the environmental research). The difficulties in investment planning may also stem from the short timeframe between the announcement of the auctions and their occurrence. The auction allocations for a current year are announced by the end of November of the previous year, and there is no obligation to hold auctions for all the baskets each year. In the case of offshore wind, the installations that win an auction must begin producing electricity within 72 months of the closing date of the auction (Act on RES 2016).

From a more general perspective, it is worth noting that auctions do not seem to be a proper system to support technologies like offshore wind in Poland, at an early stage of their development (see section 2). In the event that there are no strictly defined technology-specific baskets, this system of support is preferable mainly for mature (the cheapest) technologies (del Rio and Linares 2014). On the one hand, in the categories currently defined in Poland, offshore wind has little chance to compete with other technologies based on price. On the other hand, a separate technological basket for offshore wind would be pointless due to the lack of sufficient competition.

Under the Act on Sea Areas of Poland and maritime administration, offshore wind farms are only allowed to be positioned in the exclusive economic zone, which covers an area of about 22,500 km^2. This means that the minimum distance of offshore wind farms from the coast amounts to around 22 km. In terms of the connection to the national power transmission system, offshore wind farm installations are treated in the same way as other technologies. Thus, investors are required to build the connection infrastructure at their own cost, both on land and sea (Maritime Institute 2016). Moreover, the northern segment of the national power grid is rather poorly developed, as the crucial elements of the current energy system – coal mines and coal-fired power plants – are located mainly in the southern part of the country. In the event of significant offshore wind deployment, it may be beneficial to introduce the concepts of marine network, enabling the collective connection of all Polish offshore wind farms to the national power grid, as well as the connection with power grids of other countries. There are already at least two existing concepts of this kind of network developed in Poland (Marine Power Grid and Baltic Rail) and at least one international initiative in progress (Baltic InteGrid – described above) (Stryjecki et al. 2013, IEA 2016, Maritime Institute 2016).

2. Stage of development

Hekkert et al. (2011) distinguishes 5 phases of technology development in TIS analysis: pre-development, development, take-off, acceleration and stabilisation. So far, no wind farms or their prototypes have been built in the Polish sea areas, therefore the technology phase of development should be assessed as pre-development. As of June 2017, environmental permission has been granted for two offshore wind projects, both with a maximum capacity of 1.2 GW. The owner of these permissions is Polenergia. The next crucial step is obtaining building permits. In the first stage, the investor plans to develop 600 MW on each farm, and the expected year of starting energy production is 2022 and 2025. Moreover, since 2011, governmental bodies have issued almost 40 location decisions for offshore wind farms. However, only 14 of them are still valid (as per June 2017) and only 9 of them have been paid by investors. Two connection agreements have also been signed – for 1.2 GW by Polenergia and 1.1 GW by PGE EO (FNEZ 2017).

Offshore wind technology in Poland is underdeveloped in terms of patent applications. There are only two patents recorded in Espacenet (European Patent Office database) with offshore wind as a keyword and Poland as the applicant country. Both refer to a method of embedding (foundation of) an offshore wind farm. One of the applicants is a business sector representative (Vistal Gdynia) and one is an individual. A similar analysis for Denmark gives 75 records in Espacenet database, for Germany – 325, and for the United Kingdom – 96.

Although offshore wind technology in Poland is in the pre-development phase, it is already in the acceleration phase worldwide. The global installed capacity of offshore wind amounted to 12.1 GW by the end of 2015, while in 2006 it was less than 1 GW. It is expected that the total offshore wind capacity will exceed 40 GW by 2020 and 84 GW by 2024 (WEC 2016). The technological progress due to learning by doing effect and innovation is driving costs of the technology down. The levelized cost of electricity (LCOE) from offshore wind averaged about USD 240/MWh in 2001, and had fallen to approximately USD 170/MWh by the end of 2015. A further decline of the LCOE is expected in the future, due to both technological progress and non-technological factors (site choices, market scale, competition, reduction in financial risk), to USD 95/MWh by 2030 and USD 74/MWh by 2045 (IRENA 2016).

So far, most of the installations are located in European countries, which is advantageous from the Polish perspective, as it gives great possibilities for technology absorption. The market, including the wide range of suppliers, is well-developed especially in Denmark (1.3 GW capacity installed by the end of 2015), Germany (3.1 GW) and the United Kingdom (5.1 GW), which together accounted for almost 80% of global capacity installed by the end of 2015 (WEC 2016). Installations in the North Sea are most widespread – they accounted for 69% of the capacity installed in Europe in 2015, whereas the Baltic Sea accounted for only 13%. The rapid growth of European market will still continue – by 2020 the total installed capacity will more than double in comparison to the 2015 level. The North Sea is also considered to remain the main region for offshore deployment in Europe in the future (EWEA 2016, WindEurope 2017). However, Poland is recognised as playing a pivotal role in in kick-starting the offshore market on the Baltic Sea (Kruger 2016).

Table 5. Potential sea space for offshore wind deployment in Poland

Localisation rating	Distance to land	Depth of seabed	Potential area	Share in potential area	Potential power generation	Dedicated phase of technology deployment
Optimal	<40 km	<30 m	260 km^2	20%	1560 MW	early stage
Moderate	<50 km	<40 m	640 km^2	50%	3840 MW	middle stage
Rather poor	>50 km	>30 m	380 km^2	30%	2280 MW	late stage

Source: own elaboration based on: Stryjecki et al. (2013).

The long coastal line, as well as good wind and seabed conditions, translate into high assessments of the potential of the Polish sea area in the context of the development of offshore wind technology. Due to legal regulations and environmental limitations (large fragments of Polish sea waters are included in the NATURA 2000 network), 3,600 km^2 of Polish sea space is deemed to be available for building offshore wind farms. Given the economic issues resulting from the depth of the seabed and distance from land (at current global technological capabilities), the area is limited to about 2,000 km^2. On the assumption of 6 MW/km^2, that turns into a theoretical potential of 12 GW. However, also taking into account possible conflicts in using the sea area (i.e. concerning localisation and environmental permits) and the geological uncertainty, the estimated area suitable for offshore wind farms amounts to 1,300 km^2, 20% of which is assessed as optimal, 50% as moderate and 30% as rather poor (table 5). On the assumption of 6 MW/km^2, the estimated sea space translates into 7.7 GW potential power generation (Stryjecki et al. 2013). This calculation is rather conservative, as most stakeholders judge the potential of Polish sea space at 8–10 GW. It is conceivable, as the technological progress (e.g. new types of foundations and growth in turbines' size) may allow for greater exploration of seabed and more efficient use of available space, and the meshed offshore grid can make it profitable to build farms at a greater distance from the shore.

The analysis of the wind strength in Polish sea space potentially dedicated for offshore wind shows, that the conditions for placing offshore wind farms are good. The average wind speed amounts to 9-10 m/s (depending on height of measurement), and the efficiency of energy production should exceed 40% (up to 54% in the best-case scenario). By comparison, the average wind speed on the North Sea is between 8.5 and 11.5 m/s, while the efficiency indicator amounts to approximately 41% (Stryjecki et al. 2013; Maritime Institute 2016). Moreover, geological studies show that the soil conditions for building maritime structures in the Baltic Sea are mainly good or sufficient, which suggests that seabed characteristics should not be an important limitation for offshore wind farms foundations (Kaszubowski and Coufal 2008, 2014, Maritime Institute 2016).

3. Functional analysis

The TIS framework captures not only the structural analysis and dynamics of an innovation system, but also focuses on the dynamics of a number of key processes (labelled as functions). To assess the performance of an innovation system, it is insufficient to determine whether the system contains all the necessary components, as its functioning may be disturbed by inappropriate (or lack of) interactions between these components. Therefore, an analysis of the processes that directly influence the development, diffusion and use of technology is essential for the whole evaluation procedure (Bergek et al. 2008).

This part of study is based on the results of a survey conducted during 10 interviews that we carried out in the period between January and June 2018. Our 12 interviewees are the representatives of public administration, universities, non-governmental organisations and industrial actors. We asked the same set of questions during each interview (for the set of questions asked and the list of stakeholders interviewed, see appendix).The information received was verified using open-source intelligence tools (OSINT), which is a discipline of processing knowledge based on scanning, finding, gathering, exploiting, verifying, analysing and sharing information from open sources (Fleisher 2008). We assessed the responses using a 5-scale grading system based on the emotional approach of each interviewee. We took into account the content of the answer, the respondents' personal feelings about the discussed area and our evaluation of non-verbal communication. Finally, we created unified terminology and made the responses comparable. This chapter presents our understanding of the results derived from the answers made by the respondents.

3.1 Entrepreneurial experimentation

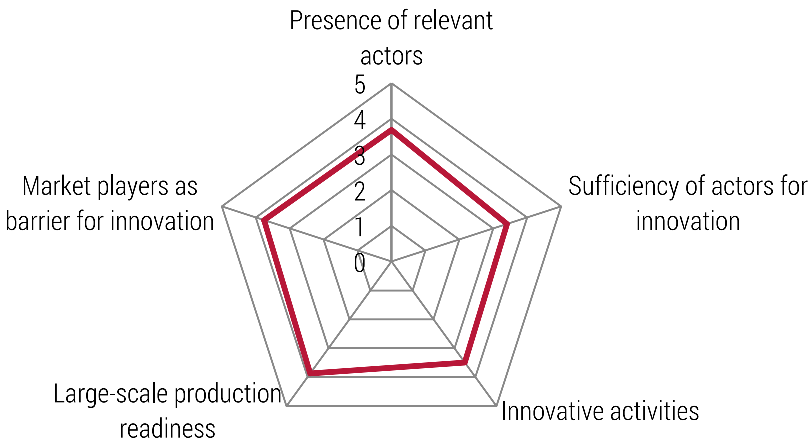
As previously indicated, there is no electricity production from offshore wind facilities in Poland. However, the number of companies who are active and ready-to-be active is significant.

There is a consensus among our respondents that Polish companies are active in almost all elements of value chains. They do not, however, perceive them as innovative. The general feeling about the innovative potential of companies spans from quite bad to good among respondents. However, each group of interlocutors (companies, authorities, associations and educational institutions) sees the innovative potential as modest. Our interviewees indicated innovative potential mainly in new solutions in submarine cables, lighter tower constructions, floating wind farm foundations, new types of substations and the adjustment of components to specific Baltic Sea conditions.

Companies from Poland active in offshore industry are generally perceived as prone to innovation. However, most stakeholders claim that nowadays, innovation comes from outside and not from inside the company. Polish companies tend to adapt already existing solutions, in production, services and organisation to make small innovative changes. This copy-and-improve approach is commonly perceived as the chance for the Polish companies to prove their innovative approach. According to our interlocutors, local know-how gained in other industries – i.e. automotive or onshore wind – may be applicable to offshore wind. However, the early stage of technology development represents a barrier at this moment. Moreover, foreign companies are not incentivised to open production facilities in Poland. They indicate Turkey or Asian countries as being likely to accommodate innovative production plants that will operate internationally, in Poland as well.

This leads to the identification of main obstacle of the Polish offshore wind industrial sector – the lack of local offshore wind market. This has several implications. Firstly, there no willingness to invest own capital, even though co-investment opportunities exist on the market. Secondly, there is no incentive to draw domestic engineers towards the offshore industry. Lastly, for multi-industry companies there is no push towards making a wide offshore offering. Companies tend to choose a wait-and-see approach rather than aggressively compete on the market, including the international market. Many tenders include an obligation for local content, hence the local market is an advantage for domestic companies and may create barriers for their international peers.

Figure 3. Assessment of the fulfilment of the "entrepreneurial experimentation" function



Source: own elaboration based on stakeholders' views.

However, the prospective market for offshore wind production is perceived as large enough to attract the attention of domestic and foreign players, including those with international experience and these that have already proved to be highly competitive not only in pricing, but also in innovation. Poland is also a country where innovative products and services are offered to other sectors. According to the respondents, Polish companies are fast learners and it is only a matter of giving them a clear signal to start developing their offshore offerings. Most respondents agree that even if the companies do not have enough resources for large-scale production, this problem can be easily solved by acquisition and/or expansion once the business has the potential to be operating with positive margins.

The development of innovative solutions requires R&D investment and testing possibilities. One of the issues indicated during the interviews is the lack of experimentation opportunities as a potential obstacle for the development of products and services. After an analysis of the sector, it seems the problem should not be considered as the main factor hindering R&D activities. This is for two reasons. Firstly, the onshore market serves as experimental field for many offshore solutions. Secondly, the experimental facilities in the European Union are available to companies regardless their country of origin. The organisation of testing facilities is considered a large entry barrier, but using external resources might be a reasonable solution to this problem. Moreover, there have been experimental facilities in Poland and companies are claimed to be prone to risk-taking.

In every developed or developing industry it is crucial to learn about potential competition which may block innovation in the country, by pushing it out or by hindering its development. The stakeholders that were interviewed referred to Asian competition, since offshore business has developed in this part of the world. Also, Asian products have traditionally been exported worldwide. Yet the logistics costs and constraints make the long-distance transportation unviable from an economic perspective at the moment. However, Asia is not the only market that may threaten the development of innovation in the offshore wind industry in Poland. Turkey is considered a market threat, once the country has established its offshore industry and has a clear vision to open up to international investors. The European location and large domestic potential could make this country a regional challenger. The other threat identified for international expansion by stakeholders is the United Kingdom's plans to increase local content in their value chain. An undertaking of this kind would limit access to the market.

With respect to all the comments above, it seems that entrepreneurial experimentation is to some extent limited, although this is neither due to lack of experimental facilities nor a lack of readiness for large-scale production, but rather due to the lack of a push trigger at the local market or at least a local market development roadmap.

We bundled the potential innovativeness of Polish enterprises into four baskets with regard to their international presence and likelihood to innovate on the offshore wind market (table 6). We identified companies which, in their day-to-day operations, invest in radical innovations, understood as game-changing innovations which are fundamentally different to incremental innovations. Companies with an international presence in innovating radically are best-positioned not only to succeed on the domestic market in the establishment and development phase, but also on international markets. They invest in innovation either to win or to maintain their position. We have called them "International offshore leaders". Next to them is another group of radical innovators, although this time they do not have a large international exposure. They do not tend to innovate for the offshore sector since the domestic market does not exist. However, their innovation might be transferable to offshore and they have an innovating mindset which entails an R&D budget, planning and organisation structure. Currently their innovations are targeted at other sectors, but they might be considered hidden tigers from an offshore innovation perspective. We have called them "Multi-industrial innovators".

There two more groups of innovators, "Offshore queuers" and "Long-list subcontractors" who innovate incrementally. The first group are companies active on the local market who innovate incrementally either for other sectors or for Polish companies from the above-mentioned groups as subcontractors. Once the local offshore market is established they will try to make business in this sector basing on transferable innovations. However, they will be one of many waiting in line to seize this market opportunity. The last set of companies are "Long-list subcontractors". They are active on international markets and as such have offshore know-how. They participate in offerings along with multiple entities and their innovative activities serves the purpose of not being squeezed off the market. Once the Polish offshore market policy is known they will be in a good starting position to serve as a subcontractor.

In the future, the sector innovativeness may to a large extent depend on the decisions of developers (the companies investing in offshore power generation). Their contribution to innovation is indirect, yet of high importance. By investing their capital, they make final decisions about which offer to choose. Thus, they might stimulate innovation, even though they do not generate it. The chosen procurement pattern may be crucial here. Basically, three systems of investor purchasing behaviour exist: single contracting, multi-contracting, and main areas contracting (turbine, foundations, cable, onshore and transformation stations). Depending on the investor, one of these ordering patterns will be applied. One might expect that the push for innovation in single contract will be relatively smaller, since the vendor will aim at increasing margins after winning the contract. This will not be the case in multi-contracting where every partner will try to win the contract by providing the best service. However, multi-contracting seems less popular then two other patterns.

Table 6. Matrix of potential enterprises' innovativeness

Innovation	International presence: Non-existing/Limited	International presence: Existing
Radical	**Multi-industry innovators** • Large domestic companies with domestic demand in other sectors; • No business trigger for innovating in the offshore sector; • Innovations potentially transferable to the offshore sector; • Big opportunities to compete in case of a domestic market	**International offshore leaders** • Well-established companies on global markets; • No dependency on domestic market; • Radical innovation seen as a way to win and/or strengthen the market position
Incremental	**Offshore queuers** • Companies innovating for other business sectors; • Innovation transferrable to offshore with relatively low outlays; • Once the domestic market is established they will try to be part of it	**Long-list subcontractors** • Companies with a relatively small piece of the offshore market • Incremental innovation as a way to maintain the market position • No trigger or no business division for radical innovations

Source: own elaboration.

3.2 Knowledge development

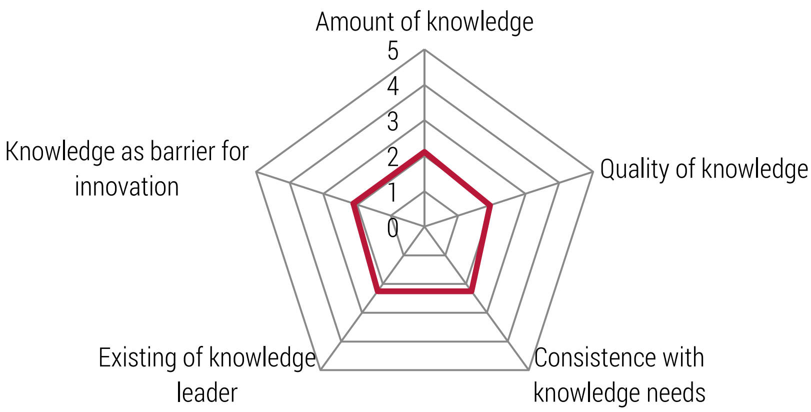
Generally, the quality and development pace of knowledge is considered to be inadequate. Our interlocutors described the average perception of the knowledge status in Poland as limited. The group of respondents that were most optimistic about this matter were public authorities (e.g. the Ministry of Energy), although they were also able to point out many drawbacks.

The attitude of universities towards the development of innovation in this sector is considered to be passive, although some potential has been noticed. Currently, human capital seems to be directed towards other industries. Speaking about exploiting potential and a shift in direction, the photovoltaic market was named as an example for the working pattern of R&D at universities in Poland. Having raised money and guaranteed investments, companies reached out to universities for knowledge creation and received the desired output. The same set of actions might be expected on the offshore market.

Basically, two reasons were identified during the interviews that are responsible for the inadequate development of knowledge. Firstly, the non-existence of the domestic market resulting in an outflow of engineers with potential expertise and no spark of interest in the offshore industry. Secondly, the system of scientist assessments creates bad habits. It rewards scientific publications, even in niche magazines, more than the commercial application of scientific knowledge. In this framework, scientists are not encouraged to work on practical matters.

Polish universities also lack offshore wind testing facilities. However, the question remains of whether the lack of testing facilities is the result of, or reason for, the development of knowledge. Solving this problem does not seem to spur knowledge development. Knowledge acquired at Polish universities follows the copy-and-improve trend, with no break-through solutions. Moreover, with few exceptions it is considered that low value added products and services are being brought to business.

Figure 4. Assessment of the fulfilment of the “knowledge development” function



Source: own elaboration based on stakeholders' views.

3.3 Knowledge exchange

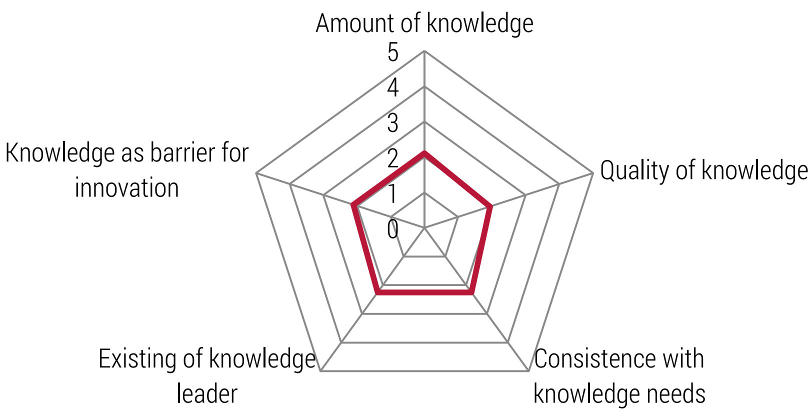
Polish actors were able to name lots of channels for knowledge exchange concerning the offshore wind industry. Generally, stakeholders in Poland are able to acquire knowledge about the offshore sector. The information is currently dispersed not only by source and communication type, but is considered to be available and relatively highly rated when compared to other categories. The missing elements identified on the market were mostly the lack of an acclaimed animator, no knowledge catalogues and no access to scholar papers on the topic.

The same positive evaluation does not apply to cross-sectoral exchange. The depth and scale of knowledge transfer fails generally in two fields: business-education and investor-vendor relations. Associations see passiveness by educational institutions and a lack of access to investor-vendor feedback. The first relationship is based on different expectations. Business requires applicable solutions for reasonable money, while universities expect patents and scholar points. The latter are considered strictly business-to-business contacts and no learnings are publicly available.

The opposite reaction can be spotted on the market with regards to transnational knowledge transfer. There is common agreement that either due to personal relationships, international events or some other channels (exchange platforms, international organisations, cross-border programs) the information is available. However, because there is no local market little use is made of it with respect to innovation development. One of the statements says, "we could gain from it but we don't". There are even opinions that if any knowledge exists in Poland it is international.

One of the problems behind the missing knowledge transfer is lack of a national plan for the development of the offshore sector in Poland, that could spark interest in the sector and launch a quest for knowledge. Regardless of this fact and the critical evaluation of certain knowledge transfer topics, the lack of knowledge exchange is not considered by stakeholders to hinder the development of innovation in Poland.

Figure 5. Assessment of the fulfilment of the "knowledge exchange" function



Source: own elaboration based on stakeholders' views.

3.4 Guidance of the search

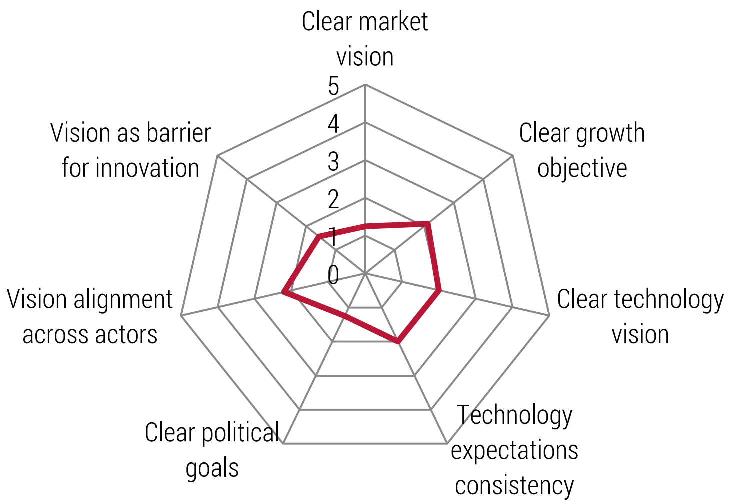
There is lack of a clear vision for the development of the Polish offshore wind sector. Apart from some slogans which have been made public by the decision-makers, there is neither an official roadmap nor an agenda. There used to be a goal in the Energy Policy 2030 of a political target of 500 MW of installed capacity being in the offshore wind sector. This seems to be out of date. No other official goal exists. Market expectations vary between 8 GW and 10 GW of installed capacity. However, the majority of respondents did not know about the policymakers' vision for the development of the offshore wind sector. Regardless of this, the evaluation of this issue was negative with respect to seizing the chance of being global innovators.

Summing up actors' visions and referring to the market development agenda, a number of points need to be made.

1. Market actors do not have reliable or stable information about the offshore development roadmap. In May 2018, the set of expectations was jeopardized even further when the Minister of Energy claimed that the development of offshore wind investments will be reliant on the development of nuclear power plants.
2. There is no market objective with regards to the planned investment size. Based on the licences granted, the actors make calculations, although no official numbers exist.
3. No technological vision has been shared with the market by decision-makers or market players. The lack of a roadmap and investment launch dates make it impossible to make decisions about technology now, and those who have an established plan fear that it may be out-of-date by the time they can start construction. With regards to the expectations on technology, the administration is expected to require local content.
4. All the information gathered on the topic comes from statements by public authorities that tend to be instable. The Ministry of Energy has ordered expertise for the offshore development path. No steps were taken afterwards, and the results remain unknown to the public. The existing policy originates from 2009. Public administration seems to follow a wait-and-see strategy for offshore wind development, at the same time waiting for the price of technology to go down.

For domestic players the wait-and-see approach seems more of a must than a choice. Contrary to the understanding of decision-makers, companies do have their own development visions. The media buzz about offshore has put them in steady position, so one might expect that consistent propositions will not lead to organic, but rather to a radical pace of offshore business development. Their vision is often innovative: higher voltage, floating units, storage utilisation and aquaculture, lighter materials – these are just a small number of the potential innovations identified during our analysis.

Figure 6. Assessment of the fulfilment of the "guidance of the search" function



Source: own elaboration based on stakeholders' views.

3.5 Market formation

As described in chapter 3.4, the market players cannot currently talk about local market development pace with any certainty. They agree that an installed capacity of 4 GW and above will trigger market development. However, this point is subject to uncertainty in Poland. Another perspective is the size of the European market. Companies active on international markets and competing against their international peers, have proved that they are able to gain benefits from the offshore wind sector.

Having analysed the offshore wind development market and the innovative potential of Polish companies, we prepared a futures matrix with four alternatives, based on two dimensions: the pace of development of international competition, and the development of the Polish offshore market to over 4GW, with a clear development agenda (table 7). We identified possible market reactions to future situations.

Since there is no clear vision of the domestic market and no agenda of when this vision might be published, we are not able to estimate a ranking order for the matrix positions. However, due to the growth of the European offshore market and record-breaking net additions in 2017, we are sure that competition on the European market will continue to increase. Due to that, we consider the scenarios at the bottom as less probable, than those at the top. With that in mind, innovation in Poland will be either marginalised or pushed into a tough battle for radical innovation with opportunities to win or lose.

Table 7. Polish offshore wind sector innovativeness in different market formation scenarios

International competition		Polish offshore market: As is	Polish offshore market: 4GW+ capacity with a clear roadmap
	Increasing	**Polish innovation in a marginalised position** • Lost opportunity for innovation • Polish companies pushed out of global/regional markets • No incentive to develop human capital • Waiting for leap frog opportunities with low chances to win	**Radical innovation in Poland to win** • Incremental innovation at experienced companies; • Polish companies forced to innovate radically to succeed on the market; • Business-education link to be developed to seize opportunities and succeed internationally
	As is	**Polish innovation without a trigger to develop** • The innovation gap between Poland and abroad increases • Innovation by sparse, internationally-active companies • Universities shift knowledge capital towards other sectors • Wait-and-see approach	**Awakening of Polish innovation potential** • Polish companies switch from a wait-and-see approach to taking action • Companies innovate to compete with international players and/or to be subcontractors • Universities are approached by businesses for applicable solutions
		As is	4GW+ capacity with a clear roadmap
		Polish offshore market	

Source: own elaboration.

In the first case, the increasing gap of knowledge and know-how will end in no opportunities for Poland-based actors to catch up. Human capital will be transferred to other sectors. The wait-and-see approach will change to waiting for a leap frog opportunity and believing to have chances to be successful by implementing a copy-and-improve approach. However, the starting position of foreign competitors will be much better and it will take a lot of effort to introduce innovations.

The second case is much more beneficial for the development of innovation in Poland. Providing there is clear political vision of the market and international competition is growing, Polish entities (both businesses and educational institutions) will become players in a tough game on equal terms with their international peers. Incremental innovation enables sector-rooted companies to stay in the game. However, those who want to join will need to innovate radically, either in products or services, or in their organisation and efficiency. To effectively seize this opportunity, it is necessary to involve human capital from educational institutions. Polish offshore developers will be looking for high efficiency at reasonable prices. The local market will enable international expansion once innovation has been introduced.

The two remaining scenarios are the status quo of international competition and status quo with local market agenda implementation. No changes are expected in the first case to the situation described in our paper. In the second case, we might expect the awakening from a wait-and-see approach and the launch of competition against international companies on the Polish market. This scenario, however, assumes that international competition will not increase, which should not be expected.

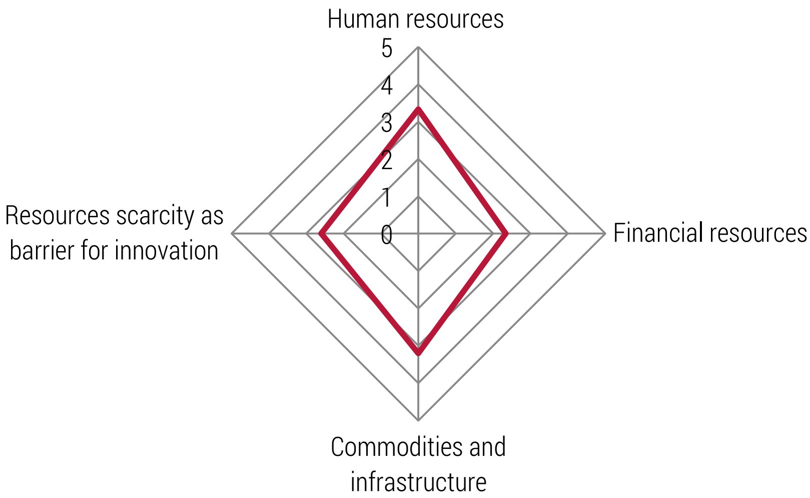
3.6 Resource mobilisation

Market actors were quite positive about the resources available for the development of offshore wind innovation. They saw the resources being available for a wider scope than currently employed. Human capital is valued highly in Poland compared to other dimensions. Two remarks must be made about human capital. Currently, engineers in Poland are perceived as highly-qualified and flexible with regards to sector transfer. Secondly, many Polish engineers work abroad on offshore wind projects. They can be “imported” once the market has launched in this country. Limitations, however, also exist in this field. No access to a local market, to technology and, in some areas, testing infrastructure means that engineers will need to catch up during the innovation processes. The catch-up process will take some time and thus does not give Poland a pioneer advantage in innovation. The engineers currently work on the European market which is not country-specific. Companies compete for the best people to work for them, and the existence of a local market is a must with regards to the perception of the market perspective. Taking all of the above into account, generally the availability of highly-qualified human capital is well perceived on the market.

The same positive approach does not also apply to the availability of financing. On the one hand, there is general consent that the money is available on the market, both as co-financing of environmental-friendly projects and in “investors’ pockets”. However, one crucial variable needs to be taken into account. The lack of legal stability on the renewable energy market might be and apparently is already considered to be a risk factor for external financing parties. This results in a limited willingness to invest in the sector development and entails a higher cost of capital. The latter negatively impacts the return of investment indicators. Thus, in this dynamic business environment in an increasingly-connected Europe, Polish entities operate in a less favourable business environment. The same or similar calculation and risk assessment methods are also true for business investors who still tend to favour other sectors.

With regard to commodities there is a common view that they are available on global markets and the only question is their price. Commodities markets have been internationalized and, in most cases, the prices paid for them do not differ from country to country. A scarcity of resources results in a quest for optimisation and, as such, a push for innovation which is true for any sector. In terms of the local infrastructure for the future development of the offshore sector, market players were generally positive about the planned development of a power grid in Northern Poland. The infrastructural barriers have been described in section 3.1.

Figure 7. Assessment of the fulfilment of the "resource mobilisation" function



Source: own elaboration based on stakeholders' views.

3.7 Legitimacy creation

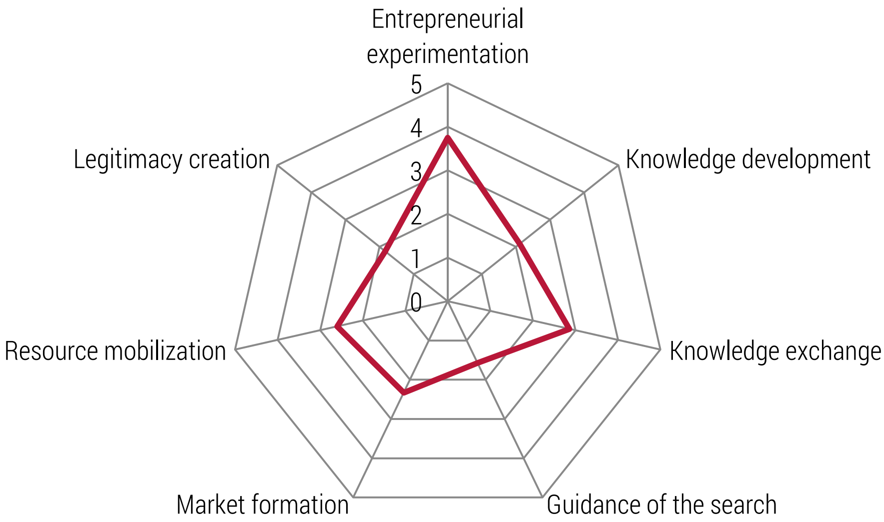
An evaluation of the investment decision-making process – based on stakeholders' opinions – brings us different results. Companies with experience claim the process is too complicated, resulting in unnecessary costs going to many agents. However, they claim they know how to manage it and the complication of these procedures solely boosts expenses. Business associations claim there are many traps in the process which might result in the termination of certain permissions while applying for others. They name procedures which have limited or blocked newcomers from investing in offshore projects. Bureaucracy is seen as part of the procedure and the high costs of obtaining all the documents seem to be inherent part of all activities.

Since Poland has no history of offshore investment, social resistance against the investments seems marginal. A couple of remarks have been made to particular interest groups like the maritime fishing industry, other energy-related projects, sea traffic diversion and changes to sea rescue routes. Companies expect actions by environmental activists but this problem does not seem to hinder offshore investments significantly. Environmental protection issues have been called "part of the game" and proper documentation and actions to mitigate the environmental impact will have to be taken.

3.8 Functional analysis summary

Figure 8 presents the overall assessment of the fulfilment of seven key functions in the Polish offshore wind innovation system. Entrepreneurial activities seem to be a relatively strong point of the system's functioning, although there is still room for improvement in that area. For four processes – knowledge development, knowledge exchange, market formation and resource mobilisation – the final rate ranges from 2 to 3, i.e. between weak and moderate. Some parts of these processes need significant improvements to make an expected contribution to the functioning of the innovation system. However, there are two innovation system functions which were rated even worse – the guidance of the search and creation of legitimacy. These processes are almost absent in the innovation system and require particular policy attention.

Figure 8. Overall assessment of the fulfilment of system functions



Source: own elaboration based on stakeholders' views.

4. Innovation system failures

Having analysed the structure of the Polish offshore wind innovation system, as well as assessing its functioning and the stage of development of technology, we can proceed to identifying the blocking mechanisms of the system and after that, to formulating policy implications. It is worth noting that, in an ideal innovation system, the structure and key processes complement each other. In other words, the negative assessment of any of the key processes may indicate problems in the system structure (Wieczorek et al. 2013). This should be taken into account when identifying innovation system failures.

Our analysis shows that the innovation system is most hindered by the unclear attitude of policymakers to the deployment of offshore wind technology in Poland. This results, among other things, in a lack of a national policy objective, an unknown future market size and uncertainty about the support policy. These issues hamper almost all the functions of the innovation system: incentives for entrepreneurial experimentation and knowledge development, guidance of the search and market formation, and sufficient legitimacy creation. The unpredictable market development may also be an important blocking mechanism for new actors in the innovation system and solving existing deficiencies in its structure.

Moreover, bureaucratic red tape is considered as one of factors which hinders some innovative activities, especially in the case of entrepreneurial experimentation. The extensive and not fully consistent permissions procedure, with many different institutional actors, hinders the investment process. However, this is a factor that slows down, but does not completely block, the deployment of technology. In addition, the public infrastructure needs to be adjusted to the potential deployment of offshore wind technology. This applies especially to grid infrastructure (offshore and onshore) and the development of ports.

The weaknesses of the analysed innovation system stem, to a large extent, from the weaknesses in the knowledge area. Our study shows that the problem of the insufficient contribution of knowledge to the innovation system emerges from both the inadequate number of knowledge actors and the rather poor quality of research. This is due to inappropriate incentives created by science policy. Scientists are not responding to the needs of the private sector, as they are rewarded mainly for writing theoretical scientific papers, and have little gratification for searching for inspiration in business and providing commercially-applicable knowledge. The knowledge transfer within the national innovation system is satisfactory, however, because of the poor quality of knowledge, the benefits from this transfer are small. This could be improved by multinational knowledge exchange, but the incentives for this cooperation are also weak.

The several gaps in the national value chain also are a factor which hinders the functioning of the innovation system. These gaps limit the diffusion of knowledge, limit the directions of research and decrease the lobbying power of the sector. The lack of actors in some key value chain stages also reduces the space for new sub-suppliers to emerge. As a result, these gaps block the expansion of the offshore wind market. The crucial deficiency in this area is the low presence of turbine suppliers (especially supplier of rotors and nacelles), i.e. providers of the most important parts of offshore wind farms, in terms of investment cost and investment management. Therefore, there is a visible lack of a clear market leader who would drag up the whole innovation system.

5. Policy challenges and instruments

Finally, we can move on to specify the key policy issues related to offshore wind technology in Poland. This policy should support the achievement of a desirable structural and functional pattern by strengthening (or adding) the inducement mechanisms, as well as weakening (or removing) the blocking mechanisms (Bergek 2008). However, to properly interpret the results of the work done in respect of the policy issues, general policy goals need to be specified (Hekkert et al. 2011). There are two dimensions of policy goals, which may be important for offshore wind deployment in Poland:

- Environmental/energy goals, related to the contribution to reducing CO2 emissions, meeting energy needs, maintaining energy security and the decarbonisation process. The solution for these challenges is mostly expressed in the Polish national renewable energy target, established within the European Union (described in chapter 1).

- Economic goals, related to the value and contribution of emerging sectors to economic growth, exports and the country's economic position. The goals in this area emerge mainly from the Strategy for Responsible Development – a governmental document adopted in 2017, which emphasises the need for reindustrialisation, intensified investments and the need to move up the global value chain (MID 2017).

Following Luo et al. (2012) we group the policy challenges and recommendations into four aspects: institutional, actor-related, infrastructural and interaction issues.

As previously indicated, the political decision to establish offshore wind as one of the elements of the future Polish energy system, and to support its deployment, is the precondition for the development of the technology in Poland. The actors gathered around the offshore wind technology need information about the feasible size of the market. This can be achieved by setting an official long-term target for the deployment of technology by government institutions, and at the same time a road map which will indicate the planned actions and results at each stage of the planned realisation. These decisions should then be reflected in announced auctions for renewable energy, and determine other institutional activities, e.g. in the area of education. Moreover, a one-stop-shop for investors is needed, which will cluster all the permission procedures required for planning, building and using offshore wind farms in one place (institution). This should result in greater compatibility of all these procedures (this compatibility is desirable, for example in relation to the duration of each permit), and may simplify and shorten the bureaucratic requirements for investors.

The second dimension of policy challenges for offshore wind development in Poland is addressing the problem of the absence of specific actors in the innovation system. The emergence of turbine suppliers in the Polish value chain is the biggest challenge in that case. As in the short term the probability of having a new Polish market player in this area is rather low, public policy should focus on using the available instruments to encourage foreign companies, especially nacelle and rotor producers, to locate their subsidiaries in Poland. The policy may include tax incentives, investment credits, infrastructural subsidies, sharing investment areas (especially in northern part of Poland) as well as other forms of non-financial support. The aim of attracting foreign investors in that area is to stimulate the technology absorption process (e.g. by establishing joint ventures), strengthen the national value chain and, in the long-term, to transform the Polish offshore wind market from the role of a sub-supplier to the position of general contractor.

The second issue in the actor-related dimension is the lack of a sufficient number of scientific institutions and scientists conducting high-quality research in offshore wind topics. To improve this, public policy should encourage (or even force) science sector representatives to take part in internships at foreign scientific organisations which already have experience in offshore wind research, e.g. through special grants or scholarships. We recognise the transfer of knowledge from countries who are global pioneers in innovation in the offshore wind sector as a possible key milestone to achieve an adequate scientific background for an offshore wind innovation system in Poland. Moreover, to stimulate the science sector to look for research inspiration in business needs, the evaluation of the scientific work of research organisations and scientists (which then translates to the level of public subsides) should take greater account of their collaboration with business representatives and the generation of commercially-applicable knowledge.

The adaptation of ports and building new ones, as well as improving the existing grid infrastructure, are the two main infrastructural challenges in the context of potential offshore wind deployment in Poland. The ports need investment, especially in cranes and wharfs, to be able to undertake offshore wind projects. In the context of grid infrastructure, there are two separate issues – onshore infrastructure in the northern part of Poland, which needs large-scale modernization to deal with an increased flow of electricity that will occur after the realisation of the first successful offshore wind projects, and offshore infrastructure which has to be built from scratch. For the second issue, the concept of cross-country marine networks in the Baltic Sea are highly promising, as it could significantly reduce the costs of connection to the grid (incurred in Poland by investors). These ideas require support and involvement from policymakers, especially regarding international cooperation between countries potentially interested in such projects.

Finally, although in general the interactions within the innovation system are satisfactory, in some cases they could be intensified. This applies especially to interactions between business and science representatives, as there is a room for improvement when it comes to the knowledge flows between these two fields. The industry needs to identify the potential benefits of cooperating with science institutions, while science needs to get to know the shortcomings of enterprises and get more incentives to conduct research in response to their requirements. Public policy could stimulate the collaboration, e.g. by subsidising research programs carried out jointly by business and science sectors, or by initiating platforms (conferences) for the exchange of ideas between science and industry.

Creating an effective offshore wind innovation system in Poland requires a simultaneous response to the indicated challenges, and the introduction of proper policy instruments. We believe that implementing the ideas presented in this chapter will significantly contribute to the deployment of offshore wind technology in Poland and, in a broader perspective, to cope with the main long-term policy challenges: a low-carbon transition of the Polish economy, maintaining energy security and improving the country's economic position.

Summary

In this paper we investigated the offshore wind innovation system in one specific country – Poland. We applied the Technology Innovation System framework, which guided us to defining the innovation system structure and technology stage of development, as well as assessing the key processes which influence the performance of the system. These steps allowed us to specify the mechanisms that block the development of technology in Poland, and at the end to identify the main policy challenges and possible policy reactions. The last two elements of the TIS procedure to a large extent summarise the work performed in this study, therefore we do not repeat the main conclusions here.

The contribution of this study to the literature is twofold. Firstly, although the literature is filled with several well-prepared studies about the offshore wind innovation system in selected European countries, none of previous articles concerned the development of technology in Poland, which is now recognised as the crucial market for offshore wind expansion in Europe. Our study provides a kind of guidance to boost the development of technology in this country. Secondly, in comparison to other similar research using the TIS methodology, we apply this framework to technology which is at a pre-development phase in a specific country, but at the same time faces rapid growth in a close neighbourhood. Therefore, our work may be useful for analysing the process of technology imitation in countries located some distance from the global technological frontier.

The study may be extended in the future by applying the same framework to the whole Baltic Sea region, which includes Denmark, Germany, Poland, the Baltic states, Finland and Sweden. The process of technology deployment on the Baltic Sea would, to some extent, be multi-national rather than national. Initiatives such as the international marine grid infrastructure may be crucial for boosting the offshore wind market in this area. Therefore, research covering the whole region may significantly contribute to a better understanding of the main challenges for the expansion of offshore wind technology.

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Appendix

Table A1. List of interviewees

Name and surname	Institution	Position	Group of actors
Marcin Sowiński	Polenergia	Project Manager	Industry
Tomasz Surma	CEZ Polska	Manager	Industry
Paweł Przybylski	Siemens Gamesa Renewable Energy	Managing Director Poland	Industry
Request for anonymity	PGE Energia Odnawialna	Request for anonymity	Industry
Ryszard Maroński	Warsaw University of Technology	Head of Department	Science
Request for anonymity	Ministry of Energy	Request for anonymity	Public administration
Request for anonymity	Ministry of Energy	Request for anonymity	Public administration
Łukasz Tomaszewski	Energy Regulatory Office	Main Specialist	Public administration
Magdalena Kałycka	Energy Regulatory Office	Specialist	Public administration
Request for anonymity	Forum Energii	Request for anonymity	NGOs
Janusz Gajowiecki	Polish Wind Energy Association	President	NGOs
Mariusz Wójcik	Foundation for Sustainable Energy	Project Manager	NGOs

Source: own elaboration.

Table A2. Set of questions asked to stakeholders

Function	Question
Entrepreneurial experimentation	- Are the actors indicated in structural analysis the most relevant? - Are there sufficient industrial actors in the innovation system? - Do the industrial actors innovate sufficiently? - Do the industrial actors focus sufficiently on large scale production? - Does the experimentation and production by entrepreneurs form a barrier for the Innovation system to move to the next phase?
Knowledge development	- Is the amount of knowledge development sufficient for the development of the innovation system? - Is the quality of knowledge development sufficient for the development of the innovation system? - Does the type of knowledge developed fit with the knowledge needs within the innovation system - Does the quality and/or quantity of knowledge development form a barrier for the TIS to move to the next phase?
Knowledge exchange	- Is there enough knowledge exchange between science and industry? - Is there enough knowledge exchange between users and industry? - Is there sufficient knowledge exchange across geographical borders? - Are there problematic parts of the innovation system in terms of knowledge exchange? - Is knowledge exchange forming a barrier for the IS to move to the next phase?

Guidance of the search	- Is there a clear vision on how the industry and market should develop? - In terms of growth - In terms of technological design - What are the expectations regarding the technological field? - Are there clear policy goals regarding this technological field? - Are these goals regarded as reliable? - Are the visions and expectations of actors involved sufficiently aligned to reduce uncertainties? - Does this (lack of) shared vision block the development of the TIS?
Market formation	- Is the current and expected future market size sufficient? - Does market size form a barrier for the development of the innovation system?
Resource mobilistation	- Are there sufficient human resources? If not, does that form a barrier? - Are there sufficient financial resources? If not, does that form a barrier? - Are there expected physical resource constraints that may hamper technology diffusion? - Is the physical infrastructure developed well enough to support the diffusion of technology?
Legitimacy creation	- What is the average length of a project? Is there a lot of resistance towards the new technology, the set up of projects/permit procedure? - If yes, does it form a barrier?

Source: Hekkert et al. 2011.

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