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Preliminary Evaluation of Feasibility for Wind Energy Production on Offshore Extraction Platforms

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***Abstract*—**A preliminary evaluation of the feasibility of installing small wind turbines on offshore oil and gas extraction platforms is presented. Some aerodynamic considerations are developed in order to determine the best rotor architecture to exploit the wind potential on such installations, assuming that wind conditions over the platforms are similar to those registered on the roofs of urban buildings. Economical considerations about both advantages and disadvantages of the exploitation of wind energy on offshore extraction platforms with respect to conventional offshore wind plants, is also presented. Finally, wind charts of European offshore winds are presented together with a map of the major offshore installations.

***Keywords*—**Extraction platform, offshore wind energy, vertical-axis wind turbine (VAWT).

I. Introduction

ACCORDING to the estimations of the European Wind Energy Association (EWEA) [1], Europe's offshore wind potential could be able to meet the energy demand seven times over. For such reason, offshore wind deployment is foreseen to expand dramatically in the years to come. This expansion is strongly driven by European Union, through the adoption of national policies that aim to provide a much greater penetration of renewable energy sources. As reported by EWEA [2], a total number of 1,503 offshore turbines are now installed and grid connected in European waters, bringing total installed capacity to 4,336 MW, spread across 56 wind farms in ten European countries. In the first six months of 2012, 132 new offshore wind turbines, totalizing 523.2 MW were fully grid connected (registering an increment of 50% with respect to the same period of the previous year): Fig. 1 represents the evolution of European annual installed offshore wind capacity. The rapid increase of the installed wind power over the past five years is clearly visible.

During the past years, almost every wind farm was built in shallow water, in depths ranging from 10 to 50 m. Nevertheless, such shallow water areas, excluding the North and Baltic seas, are quite rare. In addition, space requirement onshore, together with public pressure to place wind turbines out of visual range, further push the demand for offshore wind plants in deeper coastal waters [3]. The fixed-bottom substructures are not economically feasible in deep water and, in order to exploit wind energy for depths over 100 meters, late research has focused on the development of floating structures. In fact, the long term survivability of floating structures has already been successfully demonstrated by both marine and offshore oil industries. However, the economic convenience that allowed the deployment of thousands of offshore oilrigs has still to be proved for floating wind turbine platforms [4].

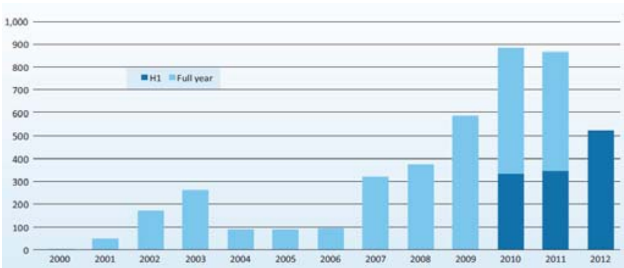

Fig. 1 Annual installed offshore wind capacity [MW] in Europe, H1 refers to the first semester of the year (from: [2])

A strong link is to be registered between offshore wind energy and oil and natural gas extraction. In fact, as observed by Musial and Butterfield [5], the portion of the offshore turbine system below the waterline will largely be determined by experiences and standards that were developed over the past four decades by the oil and gas industry: the design and installation of the electrical grid system, from inter-turbine cabling to laying the cable to shore, will be performed by the existing submarine cable industry. Moreover, all offshore wind projects will employ the existing industry to perform site assessments and geotechnical engineering. Finally, wind turbines will be installed and maintained using existing offshore vessels and equipment.

The present work proposes a closer connection between extraction of natural resources and wind power production, bringing wind conversion systems directly on the existing offshore platforms. In this way, it would become feasible the exploitation of wind energy in sites with high average wind speeds, partially contributing to the production of the energy required by the platforms, using the know-how developed by urban wind energy conversion systems (WECS): in fact, due to the presence of the superstructures, turbulent wind

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conditions on an offshore platform are somehow comparable with those ascertainable on the roof of an urban building.

Installing a series of small-size Darrieus Vertical-Axis Wind Turbines (VAWTs) on offshore oil and gas extraction platforms would allow the production of a significant quota of the energy required by the plant itself. In fact, the array would exploit the wind resource in areas, such as the North Sea, where constant winds are characterized by a high average intensity (8-10 m/s), without the onerous commitment to build offshore foundations especially dedicated to wind turbines.

The idea of using wind energy to partially supply the requirements of an extraction plant is not new and, over the past years, several wind turbines have been installed in proximity of such structures. An example is represented by the Beatrice Alpha Oil Rig plant, in the Murray Firth, north of Aberdeen, where two Repower 5 MW turbines were installed in 2007. As schematized in Fig. 2, electric cables are buried in the seabed sediment to a depth of about 1 m [6].

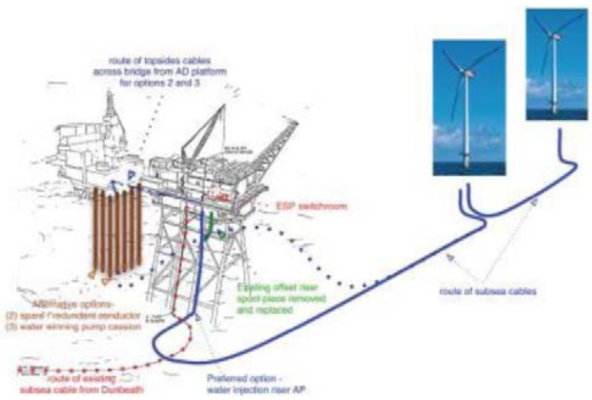

Fig. 2 Schema of the wind turbines and electrical cables at the Beatrice platform, in the Murray Firth [6]

Even though small WECS can't compete with 5 Megawatt class turbines, the adoption of vertical-axis rotors would not require expensive connection work, as the energy would be produced directly on board, thus reducing both commissioning and decommissioning costs.

II. Wind Turbine Architectures

The most common wind turbine architecture is the horizontal-axis one: horizontal-axis wind turbines (HAWTs) are generally used to produce energy in large scale plants, while VAWTs are widely adopted for small scale power generation [7] [8]. Some advantages of the VAWT architecture are:

- both the electrical generator and the gearbox (if present) can be placed at the ground level, thus reducing maintenance costs;
- no need to be pointed towards the wind;
- improved power output in turbulent flows, which are typical of built environments [9].

In recent years, VAWTs have experienced a considerable growth of interest, especially as widespread, small-scale energy production is concerned. In fact, turbulent wind conditions would greatly penalize a horizontal-axis architecture, while are exploitable by vertical-axis architectures, which could become a very valuable source of renewable energy [10] [12].

The specific technology and design issues connected with the adoption of urban wind turbines have been described by several authors: Mertens [13] focused on the design of buildings that maximize wind harvest and examined a set of turbines that provide power for buildings. Stankovic et al. [14] focused on the potential for exploiting wind power in urban areas, identifying three main WECS categories: small wind and retrofitting, large-scale stand-alone turbines and building-integrated turbines. Van Bussel and Mertens [15] provided a literary review of the technical potential of small wind turbines on buildings, considering small VAWTs, whose typical dimensions are around 10 to 20% of the characteristic building height, as a good solution. The Savonius rotor was considered unsuitable for urban installations, due to a fairly low power coefficient. Also the standard Darrieus wind turbine was rejected, due to its too high noise level, while the modification of the Darrieus concept - obtained by reducing the design angular velocity and by applying blade sweep in order to minimize noise production - was considered the best solution for application on existing buildings. Considering the urban landscape to be an array of cubes, Heat et al. [16] described a method for calculating the surface roughness length and displacement height of the urban boundary layer wind profile. The wind flow around a simple pitched-roof building was also simulated using Computational Fluid Dynamics (CFD), adopting a semi logarithmic inflow profile. An array of similar pitched roof houses was then numerically modeled, in order to determine the wind flow characteristics within an urban area. Mean wind speeds at potential turbine mounting points were studied, and optimum mounting points were identified for different prevailing wind directions. A methodology was finally proposed for estimating the energy yield of a building-mounted turbine from simple information, such as wind speed (from wind atlases) and building density. Raciti Castelli et al. [17] presented the results of two dimensional CFD simulations of the flow field around a vertical-axis wind turbine rotor, with emphasis on noise generation and propagation, for application in the built environment. The effect of the central shaft on overall rotor noise emission was analyzed using the Ffowcs-Williams and Hawkings acoustic model, in order to gain a first estimation of the influence of the central shaft on VAWT sound emission. Mertens [18] considered concentrator effects for wind turbines close to buildings, in order to enhance the lower average wind speeds of the built environment. Raciti Castelli and Benini [10] presented a comparison between the annual energy output of a Lift-driven VAWT and a Drag-driven one, characterized by similar swept areas, for a low-wind urban site. Raciti Castelli and Benini [9] presented a CFD study of the turbulent flow over a flat-roof building immersed in an atmospheric boundary layer with the aim of determining the optimal positioning of a power generator system based on a VAWT. Dutton et al. [19] assessed the energy generation potential and technical feasibility of siting wind turbines inside the built environment, analyzing several Building Mounted/Integrated Wind Turbines (BUWTs).

Wind conditions encountered on the roof of a building are likely to be very similar to those that characterize an offshore platform, with the only difference of a higher value of the average wind speed, due to the absence of obstacles on the sea surface. Assuming this similarity of wind flow characteristics, it can be reasonably assumed that a wind turbine designed for operation on top of an urban building can work even better if installed on an offshore platform. Furthermore, the reduced size of these rotors allows their installation in confined spaces, potentially covering all the unused spaces (roofs or support structures in general). An example of integration of wind turbines in structures is presented in Fig. 3, where the installation of three HAWTs on bridges between two buildings in Bahrain is shown, while a series of small VAWTs on the roof of a building is depicted, in Fig. 4.

Fig. 3 Wind turbine integration in the World Trade Center, Bahrain

Fig. 4 Example of VAWT installation on the roof of an urban building (from: [20])

III. Economic Considerations

The estimated cost of offshore wind energy varies widely depending on the specific installation, but is clear that offshore projects cost significantly more than land-based turbine systems [21]-[22]. Most of the price for offshore systems can be attributed to higher costs for foundations, installation, operation and maintenance [5].

The main parameters governing wind power economics include the following [23]:

- initial investment, including auxiliary costs for foundation and grid connection;
- electricity production;
- operation and maintenance (O&M) costs;
- turbine lifetime.

Among these, the most important parameters are the electricity production and the initial investment. As electricity production is highly dependent on wind conditions, choosing the right site is critical to achieve economic viability. For this reason, offshore energy production has acquired more importance during the past years. In fact, as can be imagined, in open sea wind does not suffer from the presence of ground irregularities nor buildings, which can stop the flow and cause turbulence. A faster, steadier wind means less wear on the turbine components and more electricity generated per turbine [5].

The cost of an offshore wind turbine is greatly influenced by the plant type and by its distance from the shore. A typical breakdown of total system costs for a shallow water plant is presented in Fig. 5.

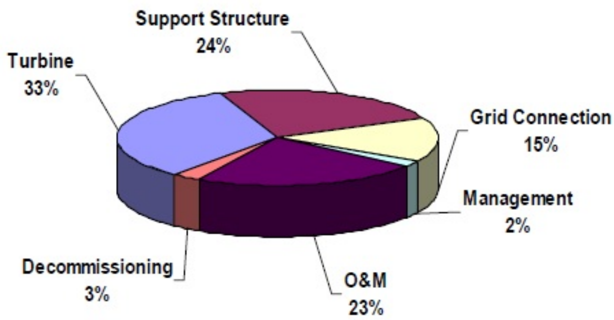

Fig. 5 Typical cost breakdown for an offshore wind plant in shallow water (from: [5])

As can be seen, both electrical and grid infrastructures, foundation and support structures, as well as operation and maintenance represent the major fraction of the total project cost. Furthermore, this costs increases with the sea depth and, therefore, with the distance from the shore, as illustrated in Fig. 6, which shows the manufacturing cost models for 5 MW turbine foundations. It can be seen that turbine foundation costs are greatly influenced by the sea depth (from 2 M€ for shallow water installations to 9 M€ for deep water installations) and by the connected construction technology, whose evolution as a function of sea depth is shown in Fig 7.

In this context, the installation of small and medium wind turbines in already existing platforms, as offshore oil and gas installations, could be an interesting source for future wind power production. The Ropatec 20kW rotor [24] is hereby considered as a case study. With a diameter of 8 m and a height of about 4 m, the turbine is capable of 20 kW nominal power with an installation cost of about 50 k€: the nominal power is quite small compared with the common offshore rotors, but so is its investment cost. Of course, a few rotors can provide only a little amount of the power required by the platform, but a well distributed array can contribute, even minimally, to the energy production of the installation, exploiting unused spaces on platforms. It has to be considered also the fact that a wind turbine sited on an extraction installation can reduce the CO_2 emissions of the plant, reducing not only its impact on the environment, but also the costs related to the emission of gases in the atmosphere.

The main disadvantage related to the installation of wind turbines on extraction platforms is related to the scarcity of available space, making it quite difficult to exploit economics of scale. Only a few rotors of limited dimension can be installed, requiring a careful analysis, in order to obtain an optimal rotor distribution, capable to capture wind energy with the highest aerodynamic efficiency without hindering the normal operation of the plant.

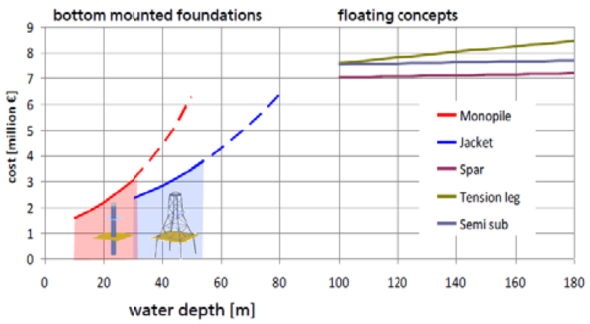

Fig. 6 Manufacturing cost models for 5 MW turbine foundations (from: [25])

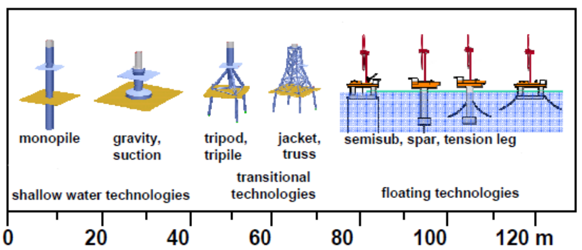

Fig. 7 Evolution of platform technology as a function of water depth (from: [25])

IV. Exploitable Areas in Europe

To fully exploit the potential of offshore wind it is necessary to locate the turbines in sites with high average wind speed. From the analysis of a wind chart of the north Europe seas (Fig. 8), it can be clearly seen that the average wind distribution at 10 meters above sea level, is approximately 8-10 m/s with large areas characterized by an average wind speed of 11 m/s. Such conditions make this area particularly favorable to the exploitation of wind resource, as evidenced by the strong presence of offshore wind farms already active or under construction, as shown in Fig. 9.

A map of the average wind speeds over the Mediterranean Sea is shown in Fig.10. As can be seen, the mean velocity is slightly lower with respect to the distribution over the North and Baltic Seas, but still presents several features favorable for the production of wind energy, with average speeds of 6-8 m/s. However, in this area the offshore energy production is not widely developed, with most of the projects currently at an early stage or dormant, as depicted by Fig. 11.

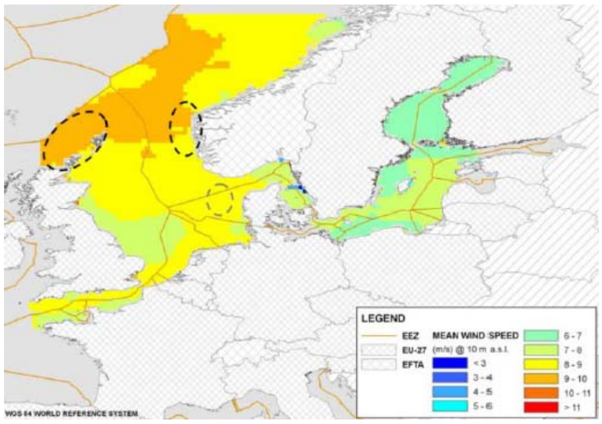

Fig. 8 Average wind speeds at 10 m above sea level over both North and Baltic Seas (from: [27])

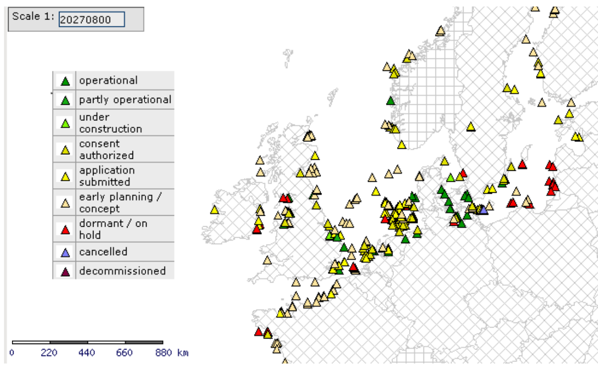

Fig. 9 Wind farm distribution over both North and Baltic Seas (from: [28])

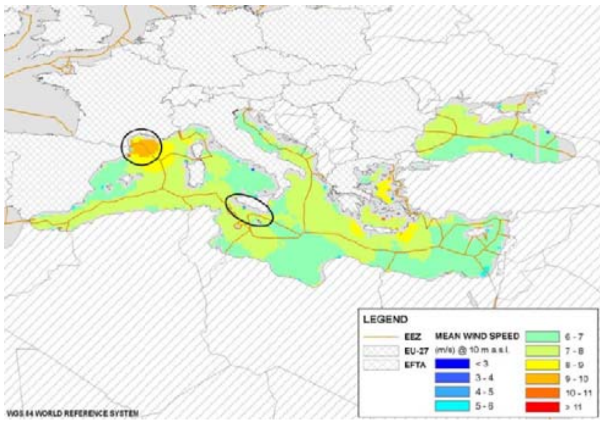

Fig. 10 Average wind speeds at 10 m above sea level over the Mediterranean Sea (from: [27])

A strong presence of extraction platforms is registered in the described geographic locations, as shown in Fig.12. As can be clearly seen, all of the major installations are sited in high

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average wind speeds areas, especially the northern ones, with average wind speeds also of 10 m/s.

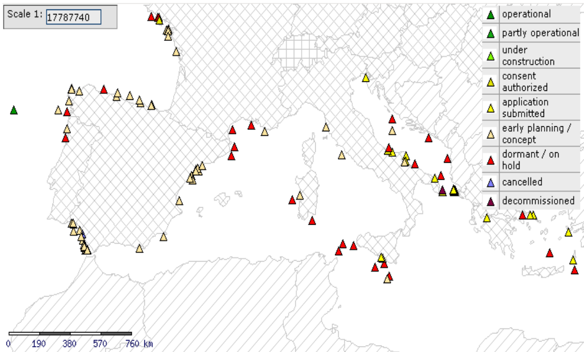

Fig. 11 Wind farm distribution over the Mediterranean Sea (from: [28])

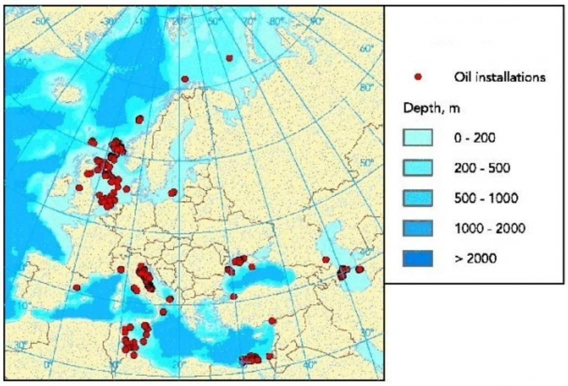

Fig. 12 Location of major offshore installations in Europe and Northern Africa (from: [29])

V. Conclusions and Future Works

A preliminary evaluation of the feasibility of generating wind energy using small Darrieus vertical-axis wind turbines installed on extraction platforms has been presented. Wind conditions around offshore platforms have been supposed to be similar to those registered on top of urban buildings, as far as turbulence level is concerned, while offshore wind potential is clearly much higher. Being VAWTs capable of operating in high turbulent conditions, these rotors are likely to work even better on offshore platforms. Even though a few rotors can provide only a little amount of the power required by the platform, an optimally distributed array can contribute, even minimally, to the energy production of the installation, exploiting unused spaces on platforms and also reducing the CO_2 emissions of the plant.

Further work should be done to prove the feasibility of the project, starting from the assessment of the effective possibility to install the turbines on the structure of a specific platform. A detailed investigation of implementation and maintenance costs related to specific locations of the extraction plant should also be performed.

References

[1] European Wind Energy Association, "Oceans opportunity", www.ewea.org, 2009.

[2] European Wind Energy Association, "The European offshore wind industry-key trends and statistics 1st half 2012", www.ewea.org, 2012.

[3] D. Matha, "Model development and loads analysis of an offshore wind turbine on a tension leg platform, with comparison to other floating turbine concepts", Subcontract Report, NREL/SR-500-45891, February 2010.

[4] S. Butterfield, W. Musial, J. Jonkman, "Engineering Challanges for floating offdhore wind turbines", Conference Paper, NREL/CP-500-38776, September 2007.

[5] W. Musial, S. Butterfield, "Energy from offshore wind", Conference Paper, NREL/CP-500-39450, February 2006.

[6] A. Curvers, J. Pierik, "WP 3: Technologies state of the art", ECN Report.

[7] S. Li, Y. Li, "Numerical study on the performance effects of solidity on the straight-bladed vertical axes wind turbine", *Power and energy Engineering Conference*, 2010.

[8] I. Paraschivoiu, *Wind turbine design with emphasis on Darrieus concept*, Polytechnic International Press, Canada, 2002.

[9] M. Raciti Castelli, E. Benini, “Numerical Prediction of the Turbulent Flow over a Flat-Roof Building for VAWT Application”, *E-NOVA 2011*, Campus Pinkafeld, Eisenstadt (Austria), November 24-25, 2011.

[10] M. Raciti Castelli, E. Benini, “Comparison between Lift and Drag-Driven VAWT Concepts on Low-Wind Site AEO”, *ICAMME 2012: International Conference on Applied Mechanics and Mechanical Engineering*, Venice (Italy), November 28-30, 2011 (in: World Academy of Science, Engineering and Technology, Issue 59, November 2011, pp. 1677-1682)

[11] J. C. Sàenz-Dìez, E. Jiménez Macìas, J. M. Blanco Barrero, M. Pèrez de la Parte, J. M. Blanco Fernàndez, "Two-Dimensional Model of Wind Flow on Buildings to Optimize the Implementation of Mini Wind Turbines in Urban Spaces", *International Conference on Renewable Energies and Power Quality (ICREPQ'10)*, Granada (Spain), 23-25 March 2010.

[12] A. Grant, C. Johnstone, N. Kelly, "Urban wind energy conversion: The potential of ducted turbines, *Renewable Energy*, Volume 33, Issue 6, pp.1157-1163.

[13] S. Mertens, *Wind energy in the built environment*, Multiscience Publishing, 2006.

[14] S. Stankovic, N. Campbell, A. Harries, *Urban wind energy*, Earthscan, 2009.

[15] G. J. W. van Bussel, S. M. Mertens, "Small wind turbines for the built environment", *EACWE4: the Fourth European & African Conference of Wind Energy*, Prague, 11-15 July, 2005.

[16] M. A. Heat, J. D. Walshe, S. J. Watson, “Estimating the potential yield of small building-mounted wind turbines”, *Wind Energy*, Vol. 10, Issue 2, May/June 2007, pp. 271-287.

[17] M. Raciti Castelli, A. Villa, E. Benini, “CFD Analysis of the Influence of Central Shaft on Vertical-Axis Wind Turbine Noise Emission”, *Fourth International Meeting on Wind Turbine Noise*, Rome (Italy), April 12-14, 2011.

[18] S. Mertens, “Wind energy in urban areas: Concentrator effects for wind turbines close to buildings”, Refocus, Vol. 3, Issue 2, March-April 2002, pp. 22-24.

[19] A. G. Dutton, J. A. Halliday, M. J. Blanch, "The feasibility of Building-Mounted/Integrated Wind Turbines (BUWTs): Achieving their potential for carbon emission reductions. Final report", http://eru.rl.ac.uk, 4 May 2005.

[20] http://therecycletimes.com

[21] Deflt University Wind Energy Research Institute, "Offshore wind energy - Ready to power a sustainable Europe. Final Report", *CA-OWEE Duwind 2001.006*, December 2001.

[22] S. Krohn, P. E. Morthorst, S. Awerbuch, "The economics of wind energy", www.ewea.org, 2009.

[23] European Wind Energy Association, "Wind energy - the facts : Costs & Prices", www.ewea.org, 2003.

[24] http://ropatec.com

[25] J. Bard, L. Quesnel, J. E. Hanssen, "Large floating turbines for intermediate water dephts", *Wind* Power *R&D Seminar*, Trondheim, 20-21 January 2011.

[26] J. Bard, "High power, high reliability offshore wind technology", *SET-Plan*, Warsaw, 28-29 November 2011.

[27] J. Murphy, K. Lynch, L. Serri, D. Airdoldi, M. Lopes, "Site selection analysis for offshore combined resource projects in Europe", FP7 ORECCA Project Work Package 2, 28 October 2011.
[28] http://orecca.eu.
[29] http://greenreport.it