Renewable and Sustainable Energy Reviews xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Feasibility study of an offshore wind farm in the Aegean Sea, Turkey

Mert Satir[a,b], Fionnuala Murphy[b,d,*], Kevin McDonnell[c,d]

[a] Siemens Wind Power Inc., 3500 Quadrangle Boulevard, Orlando, FL 32817, USA
[b] School of Biosystems & Food Engineering, University College Dublin, Agriculture Building, UCD Belfield, Room 3.06, Dublin 4, Ireland
[c] School of Agriculture & Food Science, University College Dublin, Agriculture Building, UCD Belfield, Room 3.15, Dublin 4, Ireland
[d] Biosystems Engineering Ltd., NovaUCD, Belfield innovation Park, University College Dublin, Dublin 4, D04 V1W8, Ireland

ARTICLE INFO

Keywords:
Offshore wind power
Feasibility study
Aegean Sea

ABSTRACT

Offshore wind power technology holds the potential for tackling major problems associated with energy and climate change as well as triggering economic growth and providing employment opportunities. Offshore wind power has the potential to play a key role for Turkey in achieving stated 2023 energy targets due to the country's favourable geographic location and coastline. However, there are currently no offshore wind farm projects in Turkey. The aim of this study is to determine the feasibility of an offshore wind farm in the Turkish seas. Prior to that, offshore wind market in the EU is reviewed, and the current status regarding the wind power market and supporting mechanisms are reviewed regarding the situation in Turkey. A location is proposed in the Aegean Sea, based on consideration of wind speeds and other factors. Technical analysis is conducted with the use of windPro software, and potential annual energy production of the proposed project is calculated. Combined with the economic analysis, feasibility of such an offshore wind farm is discussed. Issues with the current supporting mechanism are identified, and solutions are proposed for the future development of offshore wind farms in Turkey.

1. Introduction

With accelerating industrialisation and increasing population trends worldwide, many concerns, such as increasing energy demand, fossil fuel depletion, and environmental issues have led countries to search for ways to develop renewable energy capacities. Wind energy is a promising source and has been exploited for electricity production since the 1980s. Research on wind energy gathered momentum, and wind energy penetration first began in the USA after the oil crises in the 1970s [1]. Then it shifted to Europe, with Europe becoming the leading market on the global scene for wind energy since the 1990s [2]. The European Union (EU) has set the 2020 targets to increase the use of renewable energy to 20% under the Directive 2009/28/EC. Today, one of the candidate countries for the EU, Turkey, has been a part of the G20 forum with a rapidly expanding economy with its GDP ranked 18th in the world [3]. All of this enables Turkey to be a major regional power. Marking the 100th anniversary of the foundation of the Republic of Turkey, Turkey set ambitious goals targeting the share of 30% renewable energy sources of total electricity generation and building 20 GW capacity of wind energy by 2023 [4].

Wind energy can be exploited in two ways: onshore and offshore. While onshore wind turbines have been utilized for over a century, offshore wind power has attracted enormous attention recently, and offshore wind power has been increasingly harnessed since 1991 [5]. Higher wind speeds and more stable wind flow beyond the coasts, due to the absence of the obstacles at sea capable of disrupting the wind flow, result in higher power potential of offshore wind energy when compared with the onshore [6]. Also, larger turbines capable of generating more power can be installed on the sea due to the ease of transportation of larger equipment by ships. Conversely, logistic challenges and physical barriers are encountered on onshore wind projects, such as relatively smaller roadways, bridges, etc. Larger turbine sizes reduce the costs of non-turbine project elements considerably. However, offshore wind power is still more capital intensive compared to the onshore counterpart [7].

Installed offshore capacity in the EU has grown considerably since it began in 1991, reaching 12.6 GW at the end of 2016 [7]. Even though Turkey is surrounded by sea on three sides, making it conducive to offshore wind energy, capacity has not yet begun to develop [9]. Moreover, there is a lack of research in offshore wind in Turkey. In this regard, a feasibility study of an offshore wind farm to be located in the Turkish seas is crucial for future planning and development of offshore wind policy.

Feasibility studies determine the attractiveness of investments

* Corresponding author.
E-mail addresses: mert.satir@ucdconnect.ie (M. Satir), fionnuala.murphy@ucd.ie (F. Murphy), kevin.mcdonnell@ucd.ie (K. McDonnell).

http://dx.doi.org/10.1016/j.rser.2017.06.063
Received 27 September 2016; Received in revised form 9 June 2017; Accepted 18 June 2017

based on the net annual energy production (AEP) estimation, price for purchased energy, and capital costs [10]. Various feasibility studies have been conducted for offshore wind farms. Pantaleo et al. [11] examined the feasibility of offshore wind farms in Puglia region. Cost estimation, cost of energy (COE) and profitability analyses, such as net present value (NPV) and internal rate of return (IRR), were determined for four different locations, with the most suitable location being selected. Similarly, Konstantinidis et al. [12] conducted a viability analysis of an offshore wind farm in the Greek sea area based on techno-economical study. Considering the effective wind farm siting and planning, annual energy generation was estimated using the software RETScreen. Followed by the cost estimation, viability of investment was investigated using NPV, IRR, benefit to cost ratio (BCR) and COE. Kim et al. [13] conducted an economic feasibility study and optimal site selection for offshore wind power development around Korean peninsula based on BCR. Effiom et al. [14] also completed an economic evaluation of the viability of offshore wind turbines in Nigeria. The evaluation was completed by deploying a mathematical model, and the COE was presented for various scenarios. Ozerdem et al. [15] conducted a feasibility study of onshore wind power for an area in Izmir, Turkey. This study utilized measured data for AEP estimation, and economic analysis was completed considering COE, NPV and payback period (PBP).

This study presents a techno-economic feasibility analysis of a proposed offshore wind farm in Turkey. Prior to the presentation of the feasibility study, the background to development of the offshore wind power technology is presented. Evaluation of the current support mechanisms in Turkey in line with wind energy development is also given.

2. Background

Total wind capacity of 153.7 GW has been reached in the EU, 12.6 GW of which is from offshore wind farms. In 2016, the EU investments in offshore wind power were the highest of the clean energy investments, including onshore wind, at 56%, which is equal to more than €18 billion [8]. The various advantages and cost reduction opportunities that offshore wind farms offer compared to the onshore counterpart, and the reduced associated risks have encouraged development of wind turbines on seas in the last decade [16]. The first offshore wind farm with a capacity of 4.95 MW, consisting of 11 450-kW turbines, was built in Denmark in 1991. Since then, the development of the offshore wind market has been on the agenda of the wind industry. Accumulation and transfer of experience gained in onshore wind led to the growth of the offshore wind industry gradually in 2000s [17]. Today, the largest operational offshore wind farm is the London Array (630 MW) which began operation in 2013. In 2016, 25 years on from the first offshore wind farm in Denmark, DONG Energy has started to construct the largest offshore wind farm, the Hornsea Project One, in the UK with a capacity of 1.2 GW consisting of 174 7 MW Siemens turbines [18].

As the experience of offshore wind developers and operators has increased, offshore wind power has become one of the fastest developing technologies today, and the offshore wind market is expected to be a future focus and a major contributor to renewable energy in the near future [7]. Fig. 1 shows the increase in the EU offshore capacity since 1991. In the last ten years, the increase in the capacity is remarkably visible. As shown by Perveen et al. [19], the growth trend between 1992 and 1999 for onshore wind power capacity bears a resemblance to growth trend between 2008 and 2015 for offshore wind power capacity. Thus, the development of onshore wind power after 1999 suggests potential further growth for the offshore counterpart.

From the very beginning, the EU has dominated the global offshore wind market, accounting for 88% of the total capacity today. The commercial success of offshore wind energy in the EU encouraged other world powers to start investing on offshore wind farms. China has built 1.6 GW of capacity since 2007, and Japan has recently built a capacity of 60 MW [21]. The first commercial project in the USA with a capacity of 30 MW started delivering power in late 2016 [22]. India has conducted intensive research on offshore wind power lately with the FOWIND project (Facilitating Offshore Wind in India), which is part-funded by the EU, and is planning to install its first offshore wind farm soon. As of end of 2016, there were 81 offshore wind farms in the EU spread across the North Sea (72%), Irish Sea (16.4%) and Baltic Sea (11.5%). Once the ongoing European projects reach completion, a total capacity of 17.4 GW will be achieved [23]. Over the last ten years, the share of offshore wind in the annual EU wind energy market increased gradually as seen in Fig. 2 which shows the annual onshore and offshore wind power capacity installations in the EU.

According to the European Wind Energy Association (EWEA), further 24.2 GW of offshore wind capacity has been approved, and is expected to be installed in the next decade [23]. Also, a total of 65.6 GW is under planning process. The EWEA has announced 2020 target as 23.5 GW, and 2030 target as 66.5 GW [24,25]. Rodrigues et al. [26] presented a comprehensive review of the recently planned and ongoing offshore wind farm projects in Europe.

Offshore wind farms operating in 11 European countries at the end of 2015, were capable of generating 40.6 TW h in a normal wind year. This corresponds to 1.5% of the total EU electricity consumption (2770 TW h) [27]. By 2030, 3187 TW h of electricity demand is expected according to the European Commission (EC) reference scenario [28]. According to the EWEA's wind energy projections for 2030 in the central scenario, offshore wind power will generate 245 TW h, covering 7.7% of the electricity demand whereas onshore wind is expected to generate 533 TW h, covering 16.7% of the total demand [25]. Wind Europe states that Europe has the potential to realise 3500 TW h of offshore energy in 2030 [20]. If all this potential is harnessed, all of the energy demands can be met.

According to the European Environmental Agency (EEA), Europe's combined offshore and onshore wind energy technical potential is 20 times the energy demand in 2020 [29]. The technical potential is found to be 30,000 TW h for offshore and 45,000 TW h for onshore in 2030. This evaluation is for unrestricted case without constraints such as shipping routes, military use of offshore areas, oil and gas exploration, and tourist zones. The figures broken down by European Economic Area countries, including Turkey, are given in Fig. 3 based on the available offshore areas given in the same study.

When considering the potential constraints, environmental constraints have little impact on onshore wind power, but social constraints are influential, thus reducing the onshore potential to 39,000 TW h. However, in the case of offshore wind, wind energy potential is highly affected by both type of constraints. “Using only 4% of the offshore area within 10 km from the coast and accounting for the restrictions imposed by shipping lane, gas and oil platforms, military areas, Natura 2000 areas etc., reduces the potential by more than 90% to 2800 TW h in 2020 and 3500 TW h in 2030” according to the EWEA [29]. Lastly, economically competitive potential for the offshore wind is found to be 3400 TW h. Together with onshore wind, the economically competitive potential is three times the projected demand in 2020. However, EWEA's projected offshore wind generation for 2030 (247 TW h) is far from the economically competitive potential (3400 TW h). Realising all this potential by 2030 is dependent on many factors, including policy support and cost reductions.

2.1. Wind energy policy in Turkey

Even though Turkey has high renewable energy potential, a small number of promotional measures have been proposed, and no financial support was available until the early 2000s. The priority was given to large hydropower projects prior to this [30]. At first, renewable energy was encouraged by the Electricity Market Law (Law No. 4628) in 2001 which paved the way to liberalised competitive power generation and