Energy Policy 61 (2013) 642–652

Contents lists available at ScienceDirect

Energy Policy

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

Global wind power development: Economics and policies

Govinda R. Timilsina [a,*], G. Cornelis van Kooten [b], Patrick A. Narbel [c]

[a] Development Research Group, The World Bank, 1818 H Street, NW, Washington, DC 20433, USA
[b] Department of Economics, University of Victoria, PO Box 1700, Stn CSC, Victoria, BC, Canada V8W 2Y2
[c] Department of Business and Management Science, Norwegian School of Economics, Helleveien 30, 5045 Bergen, Norway

HIGHLIGHTS

- Global wind energy potential is enormous, yet the wind energy contribution is very small.
- Existing policies are boosting development of wind power.
- Costs of wind energy are higher than cost of fossil-based energies.
- Reasonable premiums for climate change mitigation substantially promote wind power.
- Intermittency is the key challenge to future development of wind power.

ARTICLE INFO

Article history:
Received 29 September 2011
Accepted 18 June 2013
Available online 18 July 2013

Keywords:
Wind energy
Renewable energy technology
Energy policy

ABSTRACT

Existing literature indicates that theoretically, the earth's wind energy supply potential significantly exceeds global energy demand. Yet, only 2–3% of global electricity demand is currently derived from wind power despite 27% annual growth in wind generating capacity over the last 17 years. More than 95% of total current wind power capacity is installed in the developed countries plus China and India. Our analysis shows that the economic competitiveness of wind power varies at wider range across countries or locations. A climate change damage cost of US$20/tCO$_2$ imposed to fossil fuels would make onshore wind competitive to all fossil fuels for power generation; however, the same would not happen to offshore wind, with few exceptions, even if the damage cost is increased to US$100/tCO$_2$. To overcome a large number of technical, financial, institutional, market and other barriers to wind power, many countries have employed various policy instruments, including capital subsidies, tax incentives, tradable energy certificates, feed-in tariffs, grid access guarantees and mandatory standards. Besides, climate change mitigation policies, such as the Clean Development Mechanism, have played a pivotal role in promoting wind power. Despite these policies, intermittency, the main technical constraint, could remain as the major challenge to the future growth of wind power.

1. Introduction

The greatest challenges to global energy supply relate to energy supply security, price volatility, and the need to address greenhouse gas emissions that contribute to climate change. The primary cause of these problems is the predominant share of fossil fuels in the supply mix. Currently, fossil fuels account for more than 80% of global energy supply and that share is not expected to change over the next 25 years under a business as usual scenario (OECD/IEA, 2012). If reliance on fossil fuels is to be reduced, it is necessary to diversify the energy supply portfolio towards cleaner and more sustainable sources of energy, particularly renewable energy (RE) (Anderson and Winne, 2007; Ayres, 2008). RE sources include large-scale hydro, small-scale run-of-river hydro, wind, tidal, solar, wave, municipal solid wastes, geothermal and biomass for the generation of electricity and space heating, and biofuels (bioethanol, biomethanol and biodiesel) for transportation. Some countries have already set targets to increase the share of RE in their energy supply mix. For example, the European Union (EU) has introduced an overall target of a 20% share of RE sources in energy consumption by 2020 (Commission of the European Communities (CEC), 2008), while RE sources are expected to account for 15% of China's total primary energy supply by 2020 (REN21, 2012).

Although most RE sources have exhibited strong growth in terms of installed capacity in the recent years, the deployment of wind power has significantly outpaced other RE sources with the exception of large hydro. During 2004–2011, 190 gigawatts (GW) of wind generating capacity were installed globally, which is three quarters of the added hydropower capacity (250 GW) and almost

* Corresponding author. Tel.: +1 202 473 2767; fax: +1 202 522 1151.
E-mail address: gtimilsina@worldbank.org (G.R. Timilsina).

0301-4215/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enpol.2013.06.062

three times as much as the amount of solar photovoltaic generating capacity (66 GW) installed during the same period (REN21, 2005, 2012). Yet, the share of wind energy in global energy supply remains negligible. Moreover, the recent world energy outlook published by the International Energy Agency projects that a mere 5% of the globe's electricity generation will be met by wind power by 2035 (OECD/IEA, 2012). An obvious question is: Why is the contribution of wind energy to the global energy supply mix currently so small, and expected to remain so in the foreseeable future? The answer is simply that the full economic costs of providing wind power are greater than those associated with traditional electricity generating types. The standard economic solution is that society must subsidize wind-power generation and related R&D activities, and tax fossil fuel generating sources, if it desires a greater role for wind in the generation mix; these policies are required to overcome existing technical, financial and institutional barriers to wind power. The purpose of the current review is to examine the costs of wind power and provide insights concerning its potential as a renewable energy source. It is to determine if the standard economic approach will suffice.

The literature examining the integration of wind power into electricity grids focuses primarily on engineering or technological aspects, although economists have also begun to make inroads into this question. Even so, while we focus on economic and policy issues, the discussion has a technical flavour. There exists a growing literature that addresses policy issues related to wind power development (e.g., Blanco, 2009; Lewis and Wiser, 2007; Liao et al., 2010; Scorah et al., 2012; van Kooten et al., 2013). While a consensus regarding the major problems of wind power – intermittency, storage, externalities, et cetera – is slowly emerging, it is useful at this stage to take stock of what is currently known. To do so, we present a comprehensive analysis of the economics of wind power using data from most publically available sources.

The paper is organized as follows: The status of wind power installation and a review of the global wind energy potential and future development prospects are provided in Section 2. We then analyze the direct costs of wind power generation and discuss various types of indirect costs associated with wind power development in Section 3. Relevant policy instruments to overcome key barriers to wind power development are explored in Section 4. The role of climate change mitigation initiatives to promote wind power is discussed in Section 5. We conclude in Section 6 with some summary observations.

2. Current status and future potential of wind power development

Installed global wind generating capacity expanded rapidly from only 10 MW (MW) in 1980 to 282 gigawatts (GW) of installed capacity by the end of 2012 (see Table 1).[1] At the end of 2012, Europe and North America accounted for more than 60% of global wind power capacity. Overall, developed countries plus China and India accounted for over 95% of global installed capacity. With the exception of China and India, very little electricity is produced from wind in developing countries, and especially in the least developed countries, although wind is used on a small scale to drive mechanical devices such as water pumps. By 2010, wind turbines had been installed in at least 83 countries (ESMAP/WB, 2011). Over the period 1996 to 2012, growth in global wind generating capacity averaged 27% per annum (GWEC, 2013). Despite high growth rates in recent years, the current role of wind power in meeting global electricity demand remains small, accounting for about 2–3% of the global electricity supply (REN21, 2012).

Table 1
Cumulative installed wind power capacity (MW), 1980–2012.
Source: EPI (2008), GWEC (2013).

Year	Germany	U.S.	Spain	India	China	Denmark	Other	Global
1980	0	8	0	0	0	2	n.a.	10
1990	62	1,484	0	0	0	343	41	1,930
2000	6,104	2,578	2,235	1,220	346	2,300	2,617	17,400
2012	31,332	60,007	22,796	18,421	75,564	4,162	70,200	282,482

A number of studies provide estimates of the global potential of wind power generation (Archer and Jacobson, 2005; IEAWind, 2011), but they examine only the physical viability of wind power based on wind availability at various sites while ignoring many economic aspects. Wind power development is driven almost entirely by concerns about climate change and energy supply security (Narbel, 2013). While energy security has been highlighted as an issue in the U.S., for example, most countries can generate electricity from ubiquitous domestic coal resources or import coal from various stable countries (e.g., Australia, Canada, U.S.); alternatively, they can rely on nuclear energy (e.g., France) or increasingly available non-conventional natural gas. Indeed, the recent revolution in non-conventional gas has greatly reduced U.S. emissions of CO_2 as cheap gas has replaced coal in generating electricity. However, the reduction in gas prices has made wind power relatively less attractive to investors than previously. Further, prices of other renewable energy sources and technological developments in the nuclear industry, transportation and other sectors that influence energy prices are downplayed or assumed to favor wind power development (e.g., electric vehicles).

What then are the factors that favor wind? Archer and Jacobson (2005) argue that global wind resources are potentially adequate to meet current energy demand for all purposes (estimated by the authors between 6995 Mtoe and 10,177 Mtoe), and more than seven times the world's electricity capacity in 2000 (1.6–1.8 TW). They arrive at this conclusion by analyzing approximately 7500 surface stations and another 500 balloon-launch stations. More than 13% of all reporting stations experience mean annual wind speeds greater than the 6.9 m/s (m/s) at a hub height of 80 m (i.e., wind power class 3 or greater), which they consider to be low cost wind power resources. They find that northern Europe (along the North Sea), the southern tip of the South American continent, the Australian island of Tasmania, the Great Lakes region, and the northeastern and northwestern coasts of North America have the strongest wind power potential. If turbines were set up in all regions with wind speeds greater than 6.9 m/s, they would generate 72 TW of electricity (54,000 Mtoe). While wind turbines could not possibly be placed in every region identified by the authors, developing even 25% of those sites could satisfy current world energy consumption. Similarly, a study initiated by the United Nations' Environment Program (UNEP) estimated that the wind power potential in 19 African countries could reach 53 TW in those countries alone (InWEnt Consulting, 2004).

In the same vein, the International Energy Agency (OECD/IEA, 2012) estimates wind power development potential under three scenarios that are differentiated only by assumed future government policies. In the first scenario where policies already in place are maintained, global wind power electricity generation is estimated to increase from 342 TW h in 2010 to 2151 TW h by 2035, which corresponds to 5% of global electricity supply from all sources. In the second scenario (the *New Policies* scenario), governments implement the commitments and plans that have been announced; in this case, wind power output could reach

[1] Kilo is abbreviated with k and equals 10^3; Mega (M, 10^6); Giga (G, 10^9); Tera (T, 10^{12}).