Energy Economics 33 (2011) 584–593

Contents lists available at ScienceDirect

Energy Economics

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

The status and prospects of renewable energy for combating global warming

Douglas J. Arent *, Alison Wise [1], Rachel Gelman

National Renewable Energy Laboratory, Golden CO 80401, USA

ARTICLE INFO

Article history:
Received 18 November 2009
Received in revised form 31 October 2010
Accepted 3 November 2010
Available online 11 November 2010

Keywords:
Renewable energy
Global warming
Greenhouse gas emissions
Energy technologies
Energy markets
Energy investments

ABSTRACT

Reducing anthropogenic greenhouse gas (GHG) emissions in material quantities, globally, is a critical element in limiting the impacts of global warming. GHG emissions associated with energy extraction and use are a major component of any strategy addressing climate change mitigation. Non-emitting options for electrical power and liquid transportation fuels are increasingly considered key components of an energy system with lower overall environmental impacts. Renewable energy technologies (RETs) as well as biofuels technologies have been accelerating rapidly during the past decades, both in technology performance and cost-competitiveness — and they are increasingly gaining market share. These technology options offer many positive attributes, but also have unique cost/benefit trade-offs, such as land-use competition for bioresources and variability for wind and solar electric generation technologies. This paper presents a brief summary of status, recent progress, some technological highlights for RETs and biofuels, and an analysis of critical issues that must be addressed for RETs to meet a greater share of the global energy requirements and lower GHG emissions.

1. Introduction

Renewable energy technologies (RETs) – often defined to include wind, solar, geothermal, ocean thermal and kinetic, hydrokinetic, biomass and hydropower (up to about 100 MW-excluding large dams) – are the subject of considerable analysis and evaluation. Recognized as a critical element of a low GHG energy economy (see, for example, Caldeira et al., 2003), RETs are well known for a large, but geospatially specific resource base; historically high costs compared to fossil fuel technology options; rapid market expansion; and resource variability. The academic literature has addressed many of these aspects; for example, (Verbruggen et al., 2010) have recently published a summary of costs, potentials, and barriers in which they present a concrete framework to help clarify multiple and often conflicting definitions of “potential.” All estimates of RET potential rely on fundamental physical resource information, which is thus the critical starting point for any assessment. Martinot et al. (2007) published a comprehensive assessment of the market and policy status of RETs; and many articles have addressed policy issues (for example, see (Fischer and Newell, 2008; Komor and Bazilian, 2005; Popp, 2010), life cycle assessment, or GHG impacts (for example, see (NRC, 2010; Crutzen et al., 2007; Koshel and McAllister, 2010), or even possible direct climate impacts (Keith et al., 2004; Wang and Prinn, 2010) related to increased use of RETs within the context of climate change and other policy objectives. This paper – while brief and, therefore, not fully comprehensive – synthesizes the current status of RET markets and economics, presents some example concepts to exemplify ongoing technology innovation, and then discusses the critical issues that are required for RETs to meet a greater share of the global energy requirements and contribute toward mitigating future climate change.

2. Overall trends in renewable energy capacity, investment, and markets

2.1. Key market trends in renewable energy development and deployment

2.1.1. Capacity growth

In 2008, renewables (sometime referred to as “new renewables,” excluding large hydropower, and traditional biomass) contributed about 3.4% (depending on the calculation rules applied) to global energy generation demand. Including large hydropower and biomass, renewable generation increases to about 19.8% (REN21, 2009; BNEF, 2010). In 2008, new renewables represented about 229 gigawatts (GW) (excluding large hydro and biomass) of the electricity generating capacity, which is nearly 5% of total global power capacity (about 4700 GW). In 2008, global wind capacity was 53% (121 GW) of global renewable capacity (excluding large hydro and biomass), small hydropower was 37% (85 GW), grid-connected solar photovoltaics (PV) was 6% (13 GW), and geothermal was 4% (10 GW). As a percent of installed capacity, renewables increased by about 50% between 2000 and 2008 (see Fig. 1) — the share of new renewables in global electricity production is also increasing. In 2008, the highest installed

* Corresponding author. Tel.: +1 303 384 7502.
E-mail address: doug.arent@nrel.gov (D.J. Arent).
[1] Now at Ecotech Institute, Denver Colorado

0140-9883/$ – see front matter © 2011 Published by Elsevier B.V.
doi:10.1016/j.eneco.2010.11.003

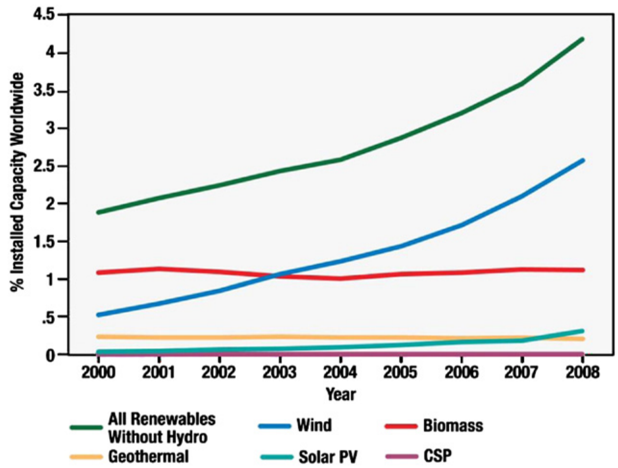

Fig. 1. Renewables as a percent of total installed capacity worldwide. Source: DOE (2009b).

capacities were found in China (76 GW), the United States (40 GW), Germany (34 GW), Spain (22 GW), and India (13 GW). Further, renewable energy accounted for ~10% of global energy infrastructure investment, for 25% (40 GW) of new electricity generating capacity, and 6.2% of installed generation capacity in 2008 (BNEF, 2010).

Multiple metrics are used for energy, including capacity, energy generation, and primary energy share. Here, for the sake of simplicity, we have focused on installed capacity, as it is directly correlated with market penetration (e.g., investment), while recognizing that comparison on energy terms will depend on capacity factor usage for all contributing technologies.[2,3]

The growth in RE markets is dominated by a few countries, namely Germany, Spain, the United States, India, China, and Japan (REN21, 2009).

2.1.2. Investment

In recent years, the world has experienced major developments in research, demonstration, and deployment of new renewable energy technologies. In 2008 and 2009, investors devoted $174 and $162 billion, respectively, to new renewable energy capacity, manufacturing plants, research and development, and carbon-related finance (REN21, 2009; BNEF, 2010).[4] The 2008 investment in the renewable and carbon-finance sectors was an increase of 60% from 2006 (UNEP, 2010; NEF, 2008a). The first three quarters of 2008 experienced a similar trend, although the global financial crisis appeared to have slowed this acceleration in investment somewhat, leading to overall reductions in 2009 investment. In late 2009, activity returned to ~$30–35B/quarter, indicating positive response to global stimulus activities and regaining health of the global financial markets (BNEF, 2010; NEF, 2008a; Greentech Media, 2008; Cleantech Group, 2008).

In 2008, the United States led the world in renewable energy investments ($24 billion), followed by Spain ($19 billion), and China ($15.6 billion). In 2009, investments in China led globally at more than $34 billion, followed by the United States at $18 billion, which indicates substantial differences in availability of capital and strength of the government stimulus and market programs (BNEF, 2010).

Venture capital (VC) funding has recently favored solar, biofuels, and grid infrastructure/demand-management investments. In the first three quarters of 2008, solar technologies received $1.58 billion, followed by investments in players within the development of the "smart grid" at $272 million which will be required for regulation of voltage and phase matching, load following and peak load management, and (in third place) biofuels with $219 million in venture capital funding. VC investment in solar in the third quarter of 2008 of $1.58 billion (in 26 deals) — has already topped 2007's $1 billion total. Several innovative thin-film solar firms such as SoloPower and AVA Solar (now Abound Solar) received financing rounds greater than $100 million (Greentech Media, 2008).

Next, we examine recent trends in select RET markets and identify key developments related to the integration, use, and impacts.

2.1.2.1. Wind market development. The wind industries in the United States, European Union (EU), China, and India continue to grow, including both onshore and increasing offshore (particularly in the EU) installations. In 2006/2007, the wind power industry was experiencing supply chain difficulties due to booming demand. Worldwide, the wind industry has seen enormous growth in both generation and installed capacity in the past two decades.

Germany's consistent policy approach created the largest wind market worldwide for capacity installed for a number of years. Spain as experience major growth since its policy was passed in 1997. Denmark's wind industry experienced steady growth through the 1990s, although new growth has tapered in the past few years as market saturation and land constraints have been reached. Although surpassed in capacity by Germany in the late 1990's due to the effectiveness of the German FIT policy, the United States also has a strong growth curve for wind, driven largely by the production tax credit (PTC). Since its establishment in 1992, the PTC has experienced a series of short-term extensions, but it was allowed to lapse in 3 years: 1999, 2001, and 2003. The PTC expirations reduced the annual growth rates in the United States to less than 10% for the year following the expiration. Currently, PTC credits are available through the end of 2012.

As of 2008, Europe has 55% of the global share of wind capacity (65,946 MW of total 120,798 MW). Germany and Spain – two European Union member states with aggressive feed-in tariff (FIT) policies – account for more than 60% of the EU-27 installed wind capacity. EU member state Germany has 23,903 MW of installed capacity, Spain follows behind with an installed capacity of 16,754 MW, and Italy has a capacity of 3736 MW (GWEC, 2008).

Integration of wind power, at significant scale, becomes increasingly complex given the intermittent nature of wind. Multiple studies have been conducted for different operating systems that show that for wind capacity up to ~20–40% of the system total generation capacity, depending on the geospatial dispersion of the wind and the system attributes to "flex" on the appropriate time and power scales, nominal system level investments and operational changes will be required for regulation, load following, and unit commitment requirements (Institute of Electrical and Electronics Engineers (IEEE), 2009). Results are very system dependent and show ranges of $3–5/MWh additional costs to accommodate wind capacity from 10 to 30%. Other systems, most notably in Denmark, accommodate up to 100% of their power requirements at specific times during the year, relying on integration with other markets and ramping of thermal units on the order of 50% (International Energy Agency (IEA), 2009).

[2] It is also worth noting that primary energy comparisons are also often made, and also depend not only on capacity factors, but also on the analysts assumed "equivalent conversion" of delivered energy to primary energy, which has often defaulted to an equivalent fossil power plant efficiency of approximately 30%. We do not use one metric over the other, but recognize their differences and assumptions in derivations.

[3] Also, it may be useful to note that there are several renewable energy technologies that receive little attention within the scope of this article, including wave and tidal energy and hydrogen energy. We have prioritized attention to those technologies that are attracting considerable investment across the finance continuum from R&D to projects to public companies. That said, innovations in both technical development and unforeseen deployment opportunities for all renewable energy technologies may mean they have more of a part to play within climate change mitigation over the course of many decades.

[4] Literature sources report a range of $148–$174 billion for 2008. We refer to $174 billion, because it is the most recently reported figure (UNEP, 2010; BNEF, 2010). The values reported are exclusive of mergers and acquisitions and thus represent the total transaction values of new investments in the sector, and include $43B of R&D, indicating net new investment of ca. $120B in 2009. Mergers and acquisitions, investments into companies and projects are reported in the range of $60B.