Renewable Energy 85 (2016) 445–453

Contents lists available at ScienceDirect

Renewable Energy

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

Analysis of solar photovoltaic and wind power potential in Afghanistan

Ahmad Murtaza Ershad [a], Robert J. Brecha [a, b, c, d, *], Kevin Hallinan [a, b]

[a] Renewable and Clean Energy Program, University of Dayton, Dayton, OH 45469, USA
[b] Mechanical and Aerospace Engineering Department, University of Dayton, Dayton, OH 45469, USA
[c] Physics Department, University of Dayton, Dayton, OH 45469, USA
[d] Sustainability, Energy and the Environment Program, University of Dayton, Dayton, OH 45469, USA

ARTICLE INFO

Article history:
Received 10 February 2015
Received in revised form
27 June 2015
Accepted 29 June 2015
Available online xxx

Keywords:
Afghanistan
Solar photovoltaics
Wind
Demand
Sustainable development
Residual load

ABSTRACT

Afghanistan has a need for increased access to energy to enable development. In this paper we analyze the potential for large-scale grid-connected solar photovoltaic (PV) and wind power plants in two of Afghanistan's most populous provinces (Balkh and Herat) to meet a large fraction of growing electricity demand. The results presented here represent the first quantitative analysis of potential capacity factors and energy yields of power plants in the country using measured wind speed and typical solar radiation data. Variability of resources is also investigated by comparing temporal profiles with those of electricity demand, using residual load duration curves to determine penetration and curtailment levels for various demand scenarios. We show that solar PV and wind power plants in two provinces could achieve penetration levels of 65%–70% without significant curtailment, which in turn would mean less reliance on unpredictable and unstable power purchase agreements with neighboring countries, longer life of limited domestic fossil fuel resources, and lower imports of diesel fuel, thus avoiding rising costs and detrimental environmental impacts. Our results point to an alternative development pathway from that of previous recommendations for conventional thermal power plants, controversial hydroelectric projects, and a significant dependence on imported power.

1. Introduction

Modern energy systems are a key factor in furthering development [5]. UN Secretary General Ban-Ki Moon has proclaimed Sustainable Energy for All (http://www.se4all.org/), aiming for universal energy access, increased penetration of renewable energy technologies, and accelerated improvements in energy efficiency. Sustainability in terms of energy systems must also include reliability and affordability over the long-term as criteria. In addition, given the challenge of mitigating the effects of anthropogenic climate change, a truly sustainable energy system should respect the need for minimal carbon emissions [12].

In contrast, development paths of industrialized countries over the past two centuries were enabled by the combustion of fossil fuels. Increasing scarcity of fossil resources and the potential for harmful climate change impacts implies that the development path of choice for the wealthy countries may not be available in the future for developing countries. Fortunately, the cost of renewable energy sources has declined dramatically in the recent past. Therefore, it is possible that with careful planning and foresight, an alternate development path is possible, one that looks not only to the necessity of near-term improvements in standard of living, but also to the long-term viability of the chosen energy system.

Energy-system planning, for example in the case of interest here, Afghanistan, can be trapped in the mode of extrapolating the fossil-fuel pathways common in the past, even if this implies relying almost entirely on imports in the form of electricity [4]. Our starting point is that domestic renewable resources should be looked at very carefully as a source of energy that can at the very least provide an important supplement to fossil fuels, but that can also help provide energy security, and in a best-case scenario, might also help lead to the creation of domestic industries.

Over the past two decades, but more noticeably in the past few years, renewable energy technologies have been gaining penetration shares in countries around the world. Wind power and solar

* Corresponding author. Renewable and Clean Energy Program, University of Dayton, Dayton, OH 45469, USA.
E-mail address: rbrecha1@udayton.edu (R.J. Brecha).

http://dx.doi.org/10.1016/j.renene.2015.06.067
0960-1481/

photovoltaics (PV) have been increasing in both installed capacity and in total production by 25%–35% per year over the past twenty years, doubling approximately every three years [3]. Because this growth is a relatively new development, it presents challenges for designing new energy systems in developing economies – the old model of large, centralized fossil-fuel generation for electricity is being disrupted. Although industrialized countries such as Japan, Germany and the United States took an early lead in solar PV and wind power installation, China has quickly caught up and even surpassed these countries over the past five years [3]. This is significant because, whereas wealthier countries are effectively supplementing existing capacity, as well as replacing older existing power generation, for developing countries modern renewables offer a further option for creating sustainable, future-oriented energy systems, as well as domestic manufacturing and other employment capabilities [7].

In this work we present a detailed study of the most populous areas in Afghanistan, where renewable energy sources, specifically solar PV and wind, can meet significant portions of electricity demand in the future. We first describe the background context and our methods in Section 2. Results are presented in Section 3, followed by conclusions in Section 4.

2. Background material and methods

In this section, we first review current energy consumption and production in Afghanistan (Section 2.1) and previous studies regarding the potential of large scale solar PV or wind power plants in Afghanistan (Section 2.2). In Section 2.3 we describe our methodology for assessing wind and solar resource potential. A description of data sources is given Section 2.4.

2.1. Energy consumption and production in Afghanistan

Electricity consumption in Afghanistan was 49 kWh per capita in 2009, one of the lowest rates in the world [8], but is projected to grow at a rate of 8.7% per year through 2032, the time horizon studied in the Power Sector Master Plan [4]. Only 28% of the population was connected to the electricity grid in 2011 with a projection of 83% connectivity by 2032 [4]; in addition, the country's grid itself should become far more interconnected over the same time period.

Current installed domestic capacity of grid-connected electricity generation assets is about 500 MW split between hydropower and thermal (diesel-fired) power plants [4]. Imports from Tajikistan, Uzbekistan, Iran and Turkmenistan account for about 73% of electricity consumption. Solar PV and wind power contribute little to the grid, but play an increasing role in decentralized generating capacity [4].

Total consumption is 3086 GWh [4], with imports making up about 73% of the total. The majority of imported power was thermal-based, with some hydropower from Tajikistan. Domestic hydropower and diesel fired power plants contributed 26% and 1.3%, respectively, although the share of diesel power plants could be higher in reality due to missing and incomplete data.

Stand-alone off-grid solar and wind energy technologies have thus far been seen by the government, donor agencies and communities themselves as a favorable solution only for electrification in rural areas in Afghanistan. The main reasons are lower operating costs, technical simplicity, and short installation time. Currently, there are no utility-scale solar PV or wind power plants. The largest renewable energy system feeding a local grid is a 1 MW solar PV plant with battery storage in the central province of Bamyan.

2.2. Review of previous renewable energy studies for Afghanistan

We now review some of the main recent renewable-resource studies. The U.S. National Renewable Energy Laboratory (NREL) [11] published a 1-km resolution wind map at 50 m height for Afghanistan and quantified a resource potential of about 158 GW. While macroscopically useful, this dataset is insufficient to model the energy production of an actual wind farm since it ignores wind speed variations due particularly to terrain variation and doesn't include wind direction, turbulence and temperature. Tetra Tech [13] used the NREL study along with multi-criteria geographic information system (GIS) analysis and identified a total of 1 GW of economically viable capacity at 10 sites located in the provinces of Herat ($\times$3), Balkh ($\times$5) and Kabul ($\times$2) for future wind farm development.

NREL also produced high-resolution satellite-derived global horizontal and direct normal irradiance data for Afghanistan [11], with datasets in a gridded format and with a ground resolution of 0.1° latitude and 0.1° longitude (8.5 km $\times$ 10 km). Irradiance datasets include monthly averages over a three year period from 2002 to 2005. The feasibility of interconnecting a 10 MW photovoltaic (PV) system with the Kandahar City utility was investigated as part of the Afghanistan Clean Energy Program [2] funded by the United States Agency for International Development (USAID).

USAID [1] also compared a proposed 1 MW grid-tied solar PV power system with a potential 1 MW micro-hydro power plant in Bamyan Province. They concluded that it was a logical choice to install a 1 MW micro-hydro power plant rather than a 1 MW PV system due to lower capital cost, lower cost of energy per kWh, and production and demand profile matching for the particular communities in Bamyan.

In another study, NRECA International [10] evaluated the response of transmission networks in the Balkh and Herat provinces to carry hypothetical levels of wind penetration and determined the maximum installed capacity of wind farms without disrupting the quality of the supplied power to the customers. This study showed that the Balkh and Herat power systems could handle wind power plant installed capacities of up to 85 MW and 16.5 MW roughly respectively if these systems were to be upgraded.

In a major study, Fichtner concluded in the Afghanistan Power Sector Master Plan (PSMP) that solar PV and wind power plants would not achieve high penetration levels in the existing and future power system and their role in the mix of grid-connected power generation is said to be minimal [4]. Fichtner recommends developing distributed hybrid wind, solar and diesel power plants and off-grid solar home systems to meet the demand mainly in rural areas. Although their work represents one model for energy-system development in Afghanistan, we present here a different view of a potential path forward, concentrating on renewable energy resources.

2.3. Methodology for solar and wind capacity assessment

The purpose of this study is to analyze the potential of solar PV and wind power plants in Balkh and Herat Provinces, two of the most promising provinces for future renewable power generation. Factors making these provinces attractive to renewable energy deployment are their wind and solar resources [11] relatively high electricity demand, well developed power system, heavy reliance on imported power (which could thus be reduced), and proximity to the western and northern borders where there is access to imported power (to complement fluctuating renewables).

The potential for solar PV and wind power is quantified by characterizing solar and wind energy resources and determining