Renewable and Sustainable Energy Reviews 80 (2017) 710–715

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Potential lives saved by replacing coal with solar photovoltaic electricity production in the U.S.

Emily W. Prehoda[a], Joshua M. Pearce[b,c,*]

[a] Department of Social Sciences, Michigan Technological University, USA
[b] Department of Materials Science and Engineering, Michigan Technological University, USA
[c] Department of Electrical and Computer Engineering, Michigan Technological University, USA

ARTICLE INFO

Keywords:
Public health
Pollution
Photovoltaic
Lives
Coal
Solar energy

ABSTRACT

Poor air quality from coal combustion adversely impacts human health including mortality and morbidity effects on respiratory, cardiovascular, nervous, urinary, and digestive systems. However, the continued use of coal are no longer necessary to provide for society's electrical needs because of advances in solar photovoltaic (PV) technology. In order to inform health policy this paper reviews the data for quantifying the lives saved by a replacement of U.S. coal-fired electricity with solar PV systems. First the geospatial correlation with coal fired power plants and mortality is determined for the U.S. at the state level. Then, current life cycle mortality rates due to coal combustion are calculated and current energy generation data is collated. Deaths/kWh/year of coal and PV are calculated, and the results showed that 51,999 American lives/year could be saved by transitioning from coal to PV-powered electrical generation in the U.S. To accomplish this, 755 GW of U.S. PV installations are needed. The first costs for the approach was found to be roughly $1.45 trillion. Over the 25 year warranty on the PV modules the first cost per life saved is approximately $1.1 million, which is comparable to the value of a human life used in other studies. However, as the solar electricity has value, the cost per life is determined while including the revenue of the solar electric generation using a sensitivity analysis on the value of the electricity. These results found that for most estimations of the value, saving a life by offsetting coal with PV actually saved money as well, in some cases several million dollars per life. It is concluded that it is profitable to save lives in the U.S. with the substitution of coal-fired electricity with solar power and that the conversion is a substantial health and environmental benefit.

1. Introduction

Coal combustion for electrical generation not only contributes to high levels of carbon dioxide emissions [1–3] with the concomitant climate disruption [3–6], but also to conventional air pollution [5,7]. Coal fired electrical power plants released 23% of air pollutants [8] and the largest contributors to U.S. carbon dioxide emission is electrical generation (31%) [9]. While coal use is declining due to natural gas resources and renewable energy growth [10], coal combustion still accounts for roughly 30–40% of U.S. carbon dioxide pollution, contributing to ever-expanding climate change [3,12]. Air pollutants are classified into four groups: gaseous, persistent organic, heavy metals, and particulate matter [11]. The literature shows a positive correlation between mortality and morbidity due to outdoor air pollution [12–15]. Specifically, it is well established in the historical and current literature that coal combustion results in emissions of carbon dioxide, methane (gaseous pollutants), particulate matter, nitrogen and sulfur oxides (gaseous), and mercury (heavy metal) [2,4,7,12,16–19]. A review of poor air quality from coal combustion is shown in Table 1. Poor air quality from coal is well known to adversely affect human health including: mortality and morbidity effects on respiratory, cardiovascular, nervous, urinary, and digestive systems. This paper will focus on a review of the mortality due to emissions from coal-fired electrical generation.

A full life cycle accounting of coal reveals an estimated $523.3 billion in damages (including social and environmental externalities), which is roughly $0.27/kW h generated [7]. Thus, the externalities of coal-fired electricity are more than double the average cost of residential electricity in the U.S. of $0.12/kW h [21]. Although coal is detrimental in all stages of its life cycle, combustion is the stage with the heaviest health burden [16] in the form of mortality and morbidity effects due to outdoor air pollutants/emissions (see Table 1).

Most research devoted to addressing issues of coal degraded air quality has focused on mitigation of coal plant emissions using

* Corresponding author at: 1400 Townsend St., Houghton MI 49931, USA.
E-mail address: pearce@mtu.edu (J.M. Pearce).

http://dx.doi.org/10.1016/j.rser.2017.05.119
Received 9 June 2016; Received in revised form 12 April 2017; Accepted 19 May 2017
1364-0321/ © 2017 Elsevier Ltd. All rights reserved.

Table 1
Major health effects from coal combustion emissions.

	Medical condition	Estimated affected individuals[a]	Coal emissions responsible
Respiratory	Asthma	22.9 million	NOx, PMx[a]
	Chronic obstructive Pulmonary Disease	12.1 million	NOx, PMx
	Lung cancer	159,217[a]	PMx
Cardiovascular	Heart attack	7.9 million	PMx
	Congestive heart Failure	5.7 million	PMx
Neurological	Ischemic stroke	104,000	NOx, PMx, SO_2
	Developmental delays	637,233	Mercury[70]

[a] Estimated affected individuals include both mortality and morbidity rates. PMx (particulate matter) encompasses particulate matter size between 2.5 and 10 µm. NOx (nitrogen oxide) [3,11–13,20].

regulations and mechanisms such as cap and trade through permits [22], which are vigorously opposed by the coal industry [23]. These mechanisms decreased some gaseous pollutants by targeting sulfur and nitrogen oxides through a cap and trade regulatory policy [24]. Particulate matter (absorbed through inhalation and ingestion) and carbon dioxide (impacts climate processes) continue to pose severe risks [17,25]. Particulate matter is directly linked to increased mortality due to lung cancer and respiratory disease [12,26].

Fortunately, the continued use of coal and the required complicated emissions controls are no longer necessary to provide for society's electrical needs because of advances in renewable energy sources such as solar photovoltaic (PV) technology [1,4,27]. PV produces no emissions or generate liquid or solid wastes during use and has a well-established environmentally-friendly ecological balance sheet [28–33]. The environmental benefits of PV are found in net energy studies [28], life cycle analysis studies [29,32], emission studies from PV [30], sustainability indicators [31] and when compared to other energy sources [33]. Integrating rooftop solar has potential to provide 39% of the total U.S. electrical generation [34] and with the potential to build solar farms on unused tracks of land [35], transitioning to solar PV has potential to replace coal as an energy source entirely [36,37]. Thus, by replacing coal-fired electricity with PV-generated electricity there is an expected decrease in air and waste emissions (e.g. greenhouse gases and air pollution particulates) that affect overall air quality and would be expected to improve human health. However, how significant this health impact would be is not known.

In order to inform health policy the objective of this review is to evaluate past research to quantify the American lives saved by a complete elimination of the domestic coal industry with the scale up of solar PV systems. First the geospatial correlation with coal fired power plants and mortality is determined for the U.S. at the state level. Then, current life cycle mortality and morbidity rates due to coal combustion are reviewed and current energy generation data is used to determine the current lives saved by PV and the increase in U.S. PV installations to replace coal-fired electrical generation entirely. Then, American deaths/kWh of coal and PV per year are calculated, enabling health policy analysts to determine the number of lives currently saved by existing PV production and the potential for eliminating all premature deaths from coal combustion in the U.S. The first cost for the approach is calculated per lives saved over the life time of the PV systems. Finally, the cost per life is determined while including the revenue of the solar electric generation using a sensitivity analysis on the value of the electricity. Public health impact results and policy interventions are discussed.

2. Methods

Coal-fired electricity emissions [38] were geolocated in the U.S to illustrate the geospatial relationship between coal emissions related mortality. Two shapefiles were obtained from the ArcGis database to analyze current air pollution due to coal-fired electrical production in the United States: (1) a shapefile of the U.S. [39], and (2) a shapefile of the current U.S. coal electrical plants [40]. This data was then transcribed on a map utilizing ArcMap 10.3.1 to indicate potential areas for PV penetration. Then annual mortality due to coal emissions per 100,000 people was added to the map [41].

Total U.S. electrical generation was obtained to quantify the percentage of kWh produced by coal and solar PV in the U.S. [42]. Current U.S. solar penetration data was obtained to provide for the baseline of PV lives saved now and in order to calculate the amount of PV needed to replace coal-fired electrical generation entirely. Current solar PV penetration has reached roughly 27.4 GW [43]. This aggregate of solar PV produces 2.32×10^7 kW h/year [44].

In order for PV to completely eliminate coal, the total DC rated power of PV needed, S_T, is calculated as follows:

$$S_T = \frac{C_T}{(I \times 365)} * 10^{-6} \quad \text{[GW]} \tag{1}$$

where C_T is the total amount of coal-fired electricity produced per year (1.32×10^{12} kW h/year) [45], and I, which is measured in kWh/m^2/day, is the population weighted average U.S. peak sun hours per day that represents solar flux for solar PV generation and is determined by:

$$I = \sum_{s=1}^{50} \frac{(P_s I_s)}{P_T} \quad \text{[kWh/m}^2\text{/day]} \tag{2}$$

where P_s is the 2015 population of each state [46], I_s is the average solar flux in each state [47], and P_T is the total 2015 U.S. population [40]. It was found to be 4.79 kW h/m^2/day.

There is a rich history of mortality studies on energy sources. The contribution to mortality was quantified utilizing a review of the secondary sources for coal [13,14,48–50] and PV [29,32,51,52]. A quantification of emissions throughout the entire life cycle of coal was necessary to determine the average U.S. number of premature deaths per year, F_c. The coal-fired electricity life cycle is divided into four components: extraction, transport, processing, and combustion [7]. The solar-photovoltaic system life cycle is divided into 5 components: mining, purification, manufacturing, operation, and recycling [30]. Waste, in the form of emissions, is calculated at each stage of the technologies life cycle and is aggregated.

Thus, the electricity generation death rate for coal, r_c is given by:

$$r_C = \frac{D_{TC}}{C_T} \quad \text{[American deaths/kWh/year]} \tag{3}$$

where D_{TC} is the total number of deaths due to coal fired electrical emissions, which is 52,000/year [53].

The electricity generation death rate for solar photovoltaic technology, r_{PV}, is given by:

$$r_{PV} = \frac{D_{TPV}}{E_{TPV}} \quad \text{[U.S. deaths/kWh/year]} \tag{4}$$

where the total energy generated by PV, E_{TPV} is 2.32×10^7 kW h/year [44] or 2.65×10^{-3} GW-yr/year, where the GW-yr is a unit of energy. The total deaths per year due to PV is more challenging to determine. For thin film amorphous silicon PV the value is currently zero based on the limited number of cases in the U.S. Environmental Protection Agencies Risk Management Program database [29]. The actual values of deaths from other PV materials is similarly not available. To remain conservative, the values for crystalline silicon-based PV (both mono- and multi-crystalline silicon) were based on the crystal silicon (c-Si)-based semiconductor

Download English Version:

https://daneshyari.com/en/article/5482089

Download Persian Version:

https://daneshyari.com/article/5482089

Daneshyari.com