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Quantifying environmental and health benefits of using woody biomass for electricity generation in the Southwestern United States

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ABSTRACT

The majority of National Forests in the southwestern United States need fuels-reduction treatments that have not kept pace with tree growth and fuels accumulation. The harvested small-sized trees are commonly disposed of through pile burning on the site due to their low market values. We assessed the environmental and health benefits of using small diameter wood from the fuels-reduction treatments as a renewable energy source for electricity production to increase forest health and environmental quality. Our study area was located in northern Arizona within the Four Forest Restoration Initiative project area. We investigated eight air pollutants, projected stand conditions, calculated pollutant emissions from power generators and assessed damage costs from power production. We further used life cycle assessments to investigate emissions from feedstock production, transportation and power generation. Our life cycle assessment results indicate that the annual total damage costs of three treatment-energy scenarios, 1) no thin-coal, 2) thin & pile burning-coal, and 3) thin-bioenergy, are $978,157, $1,732,300 and $43,216, respectively. We determined that in comparison with the no-action (no thin-coal) scenario, the total environmental and health damage cost avoided by utilizing removed woody biomass for the yearly output of a 1 MW (megawatt) power plant was $934,941 annually.

Several southwestern regional studies in the United States have simulated the effects of wildfires in treated and untreated ponderosa pine forests and found that treatment can significantly decrease negative wildfire effects (Sorensen et al., 2011; Vegh et al., 2013; Huang and Sorensen, 2011). Additionally, studies have shown that intensive fuels-reduction treatments can enhance forest resiliency to projected changes in mean annual temperature and precipitation in ponderosa pine stands (Bagdon and Huang, 2014; Bagdon et al., 2017). The majority of small diameter trees and residues derived from mechanical fuel treatments have commonly been disposed of through pile burning on site due to their low market value in the West (Jones et al., 2010; Bagdon et al., 2016). If the harvested volume were to be disposed by pile burning, the impacts on the environment not only include the emissions from pile burning but also the fossil fuels used to generate the same amount of energy which could have been produced by this renewable energy source. The emissions from both burning of unutilized woody biomass and fossil fuels required to produce the electricity that could have been produced by harvested wood would need to be accounted for. Incorporating environmental and health benefits associated with the utilization of harvested wood for electricity production will present further economic support for conducting the fuels-reduction treatments.

Arizona's Renewable Energy Standard and Tariff (REST) requires 15% of the State’s electricity consumed in 2025 to come from renewable energy resources. However, electricity generated from wood and wood-derived fuels accounted for only 0.09% in 2013 in comparison with 0.40% from wind, 1.86% from solar and 5.22% from hydro (US EIA, 2014). If the target goal of 15% is to be met, woody biomass removed from forest restoration treatments presents an opportunity to generate more renewable energy. The implementation of the Four Forest Restoration Initiative (4FRI), a collaborative effort supported through the Collaborative Forest Landscape Restoration Program to restore forest ecosystems on Coconino, Kaibab, Apache-Sitgreaves and Tonto National Forests (USDA Forest Service, 2016) presents an opportunity to generate more renewable energy in northern Arizona. The 4FRI aims to reduce fuel load, enhance forest health and increase diversity of wildlife and plants by forest thinning and augmenting the use of prescribed fire and wildland fire use in order to achieve restoration objectives. The 4FRI plans to implement restoration treatments across 971,246 ha of ponderosa pine forest and treat 20,234 ha annually over the next two decades.

Energy is essential for a functioning society; estimating the benefits

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of U.S. energy systems to society and the costs of energy projects is considered largely to be "internal" because they are reflected in energy prices or government policies (NRC (National Research Council) 2010, p. 3 and 22, p. 3 and 22). However, the production, distribution, and consumption of energy can cause negative or adverse effects (referred to as damages) and have negative impacts on human health and the environment (NRC (National Research Council), 2010, p. 3 and 22). Electricity production from coal- or gas-fired power plants emits air pollutants that generate negative externalities, defined as uncompensated costs or by-products of economic activity which are external to the market and unpaid by the producers and consumers, and affect members of society uninvolved in the market transaction (Hackett, 2011, p. 49, Harris and Roach, 2013, p. 433). When the air pollutants are emitted into the atmosphere, they cause damages resulting in costs borne by society at large (Tietenberg, 2006, p. 344). The external costs (damage costs) include impacts on human health and societal welfare that result from exposures to air pollutants, and they can be quantified by assessing pollutant emissions from different power systems.

The goal of this study is to evaluate the damage costs of electricity generation by assessing air pollutant emissions from different power systems and associated environmental and health impacts. They are the costs that have not reflected in market prices and should be taken into account in decision making. To examine differences in the damage costs between electricity from fossil fuels versus biomass, this study calculated the environmental and health benefits of using small diameter wood from fuels-reduction treatments as a renewable energy source for electricity production. This study compared three treatment-energy scenarios and the resultant effects of each scenario (Fig. 1). The objectives of this study are to:

1 Quantify eight pollutants emitted from coal-fired, gas-fired and biomass-based power plants. The eight pollutants include 1) three greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), 2) three criteria air contaminants: nitrogen oxides (NO_x), sulfur dioxide (SO_2), particulate matter ($PM_{2.5,}$ $< 2.5\,\mu m$ in diameter), 3) ammonia (NH_3), a common toxicant derived from flue gas treatment in coal-fired power plants, and 4) volatile organic compounds (VOCs) contributing to ozone formation.
2 Calculate the total external costs (damage costs) of electricity generation.
3 Investigate three treatment-energy scenarios to quantity how forest treatments and energy sources would affect air pollutant emissions.
4 Assess the environmental and health benefits (damage costs avoided) of using woody biomass as renewable energy for electricity production.

Casual effect of air pollutants

Pollutant emissions have negative impacts on human health, crops, timber and other natural resources. They can cause deterioration of man-made materials, diminish visibility and adversely affect outdoor recreational opportunities (Muller and Mendelsohn, 2009; Hackett, 2011 p. 73). Long-term exposure to ambient $PM_{2.5}$ has been found to increase the risk of lung cancer and cardiopulmonary diseases (Pope et al., 2002; Laden et al., 2006). The concentration of total suspended particulates in the air significantly affects the risks of female malignant neoplasms, airway obstructive disease, chronic bronchitis and asthma, and elevated levels of ozone increase risk of respiratory cancer and asthma (Abbey et al., 1993). Bell et al. (2004) investigated the relationship between short-term exposure to ozone and mortality, and their results indicate that there is a statistically significant positive relationship between changes in ozone and mortality. Moolgavkar (2000) analyzed the time-series of daily total nonaccidental and cause-specific deaths (i.e., cardiovascular, cerebrovascular, and chronic obstructive pulmonary disease) from 1987 to 1995 in three major U.S. metropolitan areas, monitored PM_{10}, carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2) and SO_2 and concluded that the gases (particularly CO but not ozone) had a much stronger positive correlation with mortality than PM_{10}. Hubbell et al. (2005) examined the health-related benefits of attaining the 8-hr ozone standard at 80 ppb across years of 2000, 2001 and 2002. They estimated the average annual health benefits of attaining the 8-hr standard to be $5.7 billion using the quadratic rollback simulation method and $4.9 billion using proportional rollback simulation method. Fann et al. (2012a) assessed that 130,000 $PM_{2.5}$-related deaths and 4700 ozone-related deaths nationwide attributable to 2005 air quality levels. In addition to epidemiological studies presenting the concentration-response relationship of the impact of air pollution emissions on human health, studies have also assessed the concentration-response relationship between ozone and crop loss (Lesser et al., 1990) or timber loss (Reich, 1987; Pye, 1988); SO_2 and material depreciation (Atteras and Haagenrud, 1982); PM_{10} and visibility (Muller and Mendelsohn, 2006); SO_2, NO_x and ozone and forest recreation (Muller and Mendelsohn, 2006).

The topics of economic value and health burden of pollutant emission associated with electricity production have been studied. U.S. EPA (2005) estimated that approximately 17,000 premature mortalities would be avoided in 2015 due to reduced $PM_{2.5}$ and O_3 resulting from improved emission controls on NO_x and SO_2 emissions from electrical generating units in the eastern United States under the Clean Air Interstate Rule. They indicated that the annual net benefits (1999$) of the Clean Air Interstate Rule in 2015 will be between $83.2 billion (using a 7% discount rate) and $98.5 billion (using a 3% discount rate). Study found that for each megawatt-hour (MWh) generated from 406 U.S. coal-fired power plants in 2005, the mean damage costs (2007$) associated with SO_2, NO_x, $PM_{2.5}$, and PM_{10} emissions were $38.00, $3.40, $3.00, $0.17, respectively (NRC (National Research Council), 2010, p. 92). For each MWh generated from 498 U.S. gas-fired power plants in 2005, the mean damage costs (2007$) associated with SO_2, NO_x, $PM_{2.5}$, and PM_{10} emissions were $0.18, $2.30, $1.70, $0.09, respectively (NRC (National Research Council), 2010, p. 118). If plants are weighted by their net electricity generation, defined as the amount of gross generation minus the electrical energy consumed at the generating stations, the mean damage cost (2007$) was $32 MWh^{-1} from coal (NRC (National Research Council) 2010, p. 92) and $1.60 $MW\,h^{-1}$ from natural gas (NRC (National Research Council), 2010, p. 118). Fann et al. (2012b) projected the economic value of direct $PM_{2.5}$ emission reduction or $PM_{2.5}$ precursor emission reduction from electric generating units in 2016, and they concluded the economic value would be $5,200, $35,000 and $130,000 (2010$) for reducing a ton of NO_x, SO_2 and $PM_{2.5}$, respectively. Fann et al. (2013) also investigated public health associate with $PM_{2.5}$ and ozone air quality levels and projected annual premature $PM_{2.5}$ and ozone-related premature deaths attributable to electric generating unit emissions would be expected to decline from 38,000 in 2005 to 17,000 in 2016 due to regulatory requirements. Machol and Rizk (2013) further assessed that national average economic values of fossil fuel electricity health impacts were $140 ~ 350 $MW\,h^{-1}$; health impacts by fuel type of coal, oil and natural gas were assessed to be $190 ~ 450, $80 ~ 190 and $10 ~ 20 $MW\,h^{-1}$, respectively.

Methods

Study site

Our study site (23,176 ha) is within the 4FRI project area and located on the Flagstaff Ranger District of the Coconino National Forest, a part of the 207,229 ha of contiguous ponderosa pine forests designated for five restoration units across the Coconino and Kaibab National Forests. It is directly to the east of Interstate-17 beginning approximately three miles south of Flagstaff, Arizona (Fig. 2). In choosing our study site, we looked for an area that would have practical application