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Perception, culture, and science: A framework to identify in-home heating options to improve indoor air quality in the Navajo Nation

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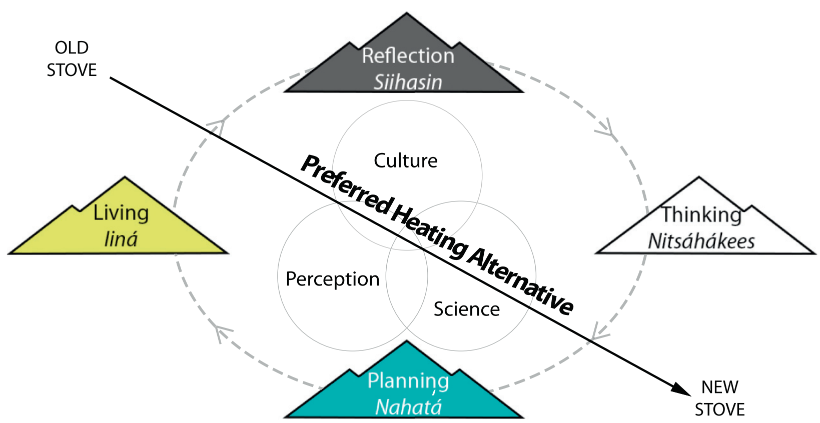
HIGHLIGHTS

- A new framework for identifying appropriate heating alternatives for the Navajo Nation is proposed
- This framework balances reducing health and environmental impacts with Navajo culture, perception, and technical assessment
- This assessment uncovered discrepancies between community perception and the technical results
- Involvement of the Navajo Nation people at the onset and throughout a study such as this, is critical to a successful result

GRAPHICAL ABSTRACT



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ABSTRACT

A 2010 study identified higher than average incidence of respiratory disease in Shiprock, NM, the largest city in the Navajo Nation. That study suggested that the potential cause was the combustion of solid fuels in in-home heating stoves and that respiratory disease could be greatly reduced by changing indoor heating behaviors and improving heating stove quality. Since the Navajo people are deeply embedded in culture and traditions that strongly influence their daily lives, a new framework was needed to identify feasible heating alternatives that could reduce the negative environmental and health impacts related to solid fuel use while respecting the culture of the Navajo people.

The resulting Navajo framework included perception, cultural, and technical assessments to evaluate seven heating alternatives perceived viable by Navajo stakeholders. Cultural experts at the Diné Policy Institute identified potential cultural limitations and motivating factors for each alternative. A limited technical assessment of the health benefits of these options was conducted and integrated into the process. A parallel convergent mixed-methods approach was employed to integrate qualitative and quantitative results. The results and

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Wood
Health and environmental benefits

framework developed and presented here may be useful for decision makers in communities heavily reliant on solid fuels for heat, especially Native Nations, where culture plays an important role in the success of any intervention.

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1. Introduction

1.1. The Navajo Nation

The Navajo Nation (NN) is the largest sovereign Native American nation within the United States (population 175,000) (US Census Bureau, 2014a) occupying about 69,930 km^2 within Arizona, New Mexico, and Utah (Fig. 1). Its population is growing nearly twice as fast as the US average (Navajo Housing Authority, 2011) and 32% of the population is under six years of age (US Census Bureau, 2014b). These populations are at a higher risk of health effects from indoor air emissions (Sly and Flack, 2008). The poverty rate in the NN is 42% (US Census Bureau, 2014c) compared to the US average of 16% (US Census Bureau, 2014d), directly impacting their access to clean energy.

Dinétah (the Land of the People, in the Navajo language) is part of the Colorado Plateau at an altitude of 1680 m. There are two coal-fired power plants (points a and b in Fig. 1) within the boundaries of the NN, and five coal-fired power plants and a hydroelectric plant within 80 km of the NN border (points c–h in Fig. 1), yet 20% of Navajo homes are off the grid/lack electricity (Navajo Housing Authority, 2011).

According to the US Census Bureau (2014e), wood is the primary heating fuel in 63% of all Navajo homes, followed by electricity (12%), natural gas (11%), propane (10%), and kerosene, fuel oil, or other fuels (3%). The Navajo Housing Authority (NHA), however, reported that as many as 89% of rural Navajo homes use wood stoves for heating (NHA, 2011). While not identified in surveys by the US Census Bureau and NHA, unprocessed Black Mesa and Fruitland high-volatile bituminous coals (Kirschbaum et al., 2013), are distributed freely or at low cost and are widely used by NN residents to heat homes primarily at night (Hickmott et al., 1997; Bunnell et al., 2010).

Navajo dwellings include contemporary single family homes (59%), mobile homes (17%), multi-family attached housing (13%), and traditional *hogans* (eight sided homes with a wood burning stove and open roof in the center) (11%) (NHA, 2011). It is estimated that 63% of Navajo homes were built before 1990 (US Census Bureau, 2014f) and are probably in need of weatherization (e.g., caulking and weather stripping).

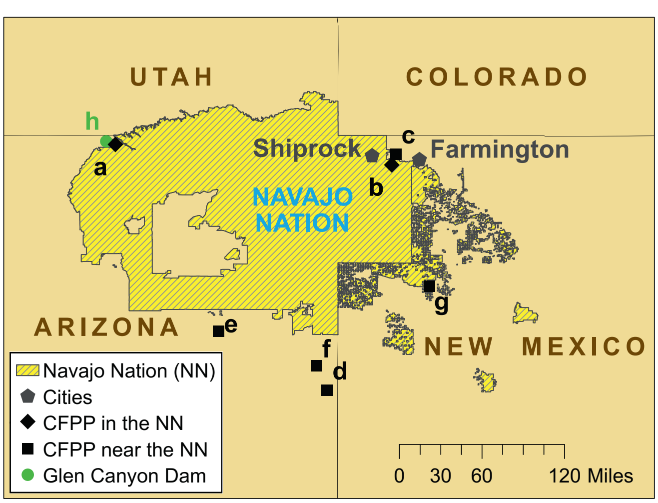

Fig. 1. Map of the Navajo Nation and four corners area (CFPP - Coal-fired Power Plants).

Houses built by the NHA during the 1970's and 1980's often have no attic insulation, while newer NHA homes are more likely to include this feature. Eighty percent of Navajo homes are owned by the residents (NHA, 2011); however, home improvements done by owners may not follow housing codes, including insulation requirements.

1.2. Air quality and health in Shiprock, NM

Shiprock, NM is the largest city (population 9,000) in the NN, is located near the Four Corners Power Plant, and is part of the Farmington, NM Metropolitan Area (US Census Bureau, 2014g). Farmington (population 45,900) lies 50 km east of Shiprock (Fig. 1), just outside the NN border. Average daily high temperatures in the Shiprock-Farmington area range from 24 °C in summer to −2 °C in winter; average daily lows are below −1 °C from November through March, reaching extremes as low as −37 °C (NOAA, 2011). Between 2005 and 2014, this region experienced an annual average of 139 days at or below freezing (0 °C), 18 cm of rain, and 25 cm of snow (NOAA, 2015a).

Heating Degree Days (HDD) are commonly used to assess heating demands and are defined as the difference between the daily mean ambient temperature (e.g., 30 °F) and a defined indoor comfort temperature (e.g., 65 °F). The HDD for this day (65–30) would be 35 °F and then each day's difference is summed over a time period (e.g., if all days had a difference of 35 for a 30-day month, the monthly HDD would be $35 \times 30 = 1050$). In the past 100 years (1915–2014), homes in the NN (New Mexico Climate, Division 1 and Arizona Climate, Division 2) have required 29% more heating than those in the contiguous U.S. annually (5912 vs. 4598 HDD) (NOAA, 2015a). During the past ten years (2005–2014), homes in Shiprock have needed 17% more heating than those in the contiguous U.S. (5064 vs. 4322 HDD annually) (NOAA, 2015b). Weatherizing Shiprock homes should reduce the energy required for heating and indoor air pollution.

Shiprock experiences low wintertime inversions that trap air pollution close to the ground, including combustion emissions from home heating (Hickmott et al., 1997). Wood and coal combustion produce a complex mixture of emissions (Gaston et al., 2016), including fine and ultrafine particulate matter (PM) (McDonald et al., 2000; Bond et al., 2002; Schurman et al., 2015), polycyclic aromatic hydrocarbons (PAHs) (Fine et al., 2004; Chen et al., 2005; Samburova et al., 2016), and carbon monoxide (CO) (Jaszczur et al., 1995; Venkataraman and Rao, 2001). These components have been associated with adverse health effects (Butt et al., 2016; Solomon et al. 2012; Breysse et al., 2013). Correlations between higher outdoor concentrations of $PM_{2.5}$ and decreased life expectancy in the U.S. have been observed (Pope et al., 2009; Fann et al., 2012). Barone-Adesi et al. (2012) correlated higher lung cancer mortality in China with domestic use of bituminous coal, the type mined at the Black Mesa coal field (Kirschbaum et al., 2013). Similar-rank coal from the Fruitland Formation in the San Juan Basin (Kirschbaum et al., 2013) is also used by Navajo residents living near the Broken Hill Proprietary (BHP) Billiton Navajo mine (Bunnell et al., 2010), posing similar health concerns. Recently, the World Health Organization (2014) strongly discouraged any unprocessed coal use indoors.

Bunnell et al. (2010) indicated that 77% of Shiprock residents surveyed ($n = 137$) used an indoor stove for heating and 25% used coal in stoves not designed for that fuel. This use potentially results in increased indoor air pollution because the higher coal combustion temperatures promote cracking of the stove walls, allowing stove

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