Human Ecology (2023) 51:497–511
https://doi.org/10.1007/s10745-023-00411-2

Firewood and Energy Sovereignty on Navajo Nation

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Accepted: 17 May 2023 / Published online: 24 June 2023

Abstract
Climate-induced drought jeopardizes future access to sufficient energy sources for many people reliant on firewood, especially those underrepresented in forest management decision-making. To identify where interventions might be most effective in facilitating self-determination and sustained firewood harvest, we investigate the case of Diné firewood harvesters. Using data from surveys, interviews and participant observations, we articulate who uses firewood and why, what the costs of firewood are, and who imposes those costs. Reducing both the cost and need for firewood for the Diné and others would support energy sovereignty by facilitating sustained access to firewood.

Keywords Firewood · Environmental justice · Sustainable harvest · Indigenous self-determination · Traditional ecological knowledge · Diné · Navajo Nation · Utah · Arizona · North America

Introduction

Access to energy is a universal human need. This necessity deeply embeds human actions towards harnessing energy for human purposes in nearly all ecosystems on Earth, and implicates human decisions in the global climate change crisis. Today, the majority of the world's population uses energy for heating, cooking, transport, and other tasks through global supply chains embedded within complex socio-political networks (Bilgen, 2014). This energy is generated through a global industry of fossil fuel extraction, processing, production, and distribution centered on hydrocarbon sources (oil, gas and coal, Chen & Chen, 2011). Despite widespread use of fossil fuels, nearly a third of the world's population continues to rely on locally available biomass often in the form of firewood or charcoal (carbonized biomass) produced from nearby or regional forests (Bailis et al., 2015; Smith et al., 2014). Reliance on local biomass situates energy harvest and use among a suite of socio-economic and ecological issues related to access and sustainability of the world's arboreal ecosystems. Geographic variation in the distribution and density of woodlands, forests, and their products creates scenarios where some individuals have easy access to biomass fuels while others are excluded. As woody biomass regenerates slowly, if at all, ecologists and policy makers agree that it is likely unsustainable for a third of the world's population to rely on biomass harvests for their primary fuel source as both population growth and climate change will increase ecological and socio-economic stress for the people reliant on this resource (Bailis et al., 2012, 2015; Ceballos et al., 2015; Morton, 2007; Venter et al., 2016). Systemic, structural inequality affecting access to alternative forms of energy renders Indigenous people — many of whom rely on firewood harvest and use for economic and cultural purposes — among the most vulnerable to these changes (International Energy Agency, 2017; Macchi, 2008).

Over the last century, the development of a globalized energy infrastructure has focused on fossil fuels. While global measures of energy inequality have decreased in recent decades due to increasing connectivity of infrastructure (Lawrence et al., 2013), many people continue to face substantial obstacles to obtaining sufficient energy resources. In many rural parts of the world, distance from distribution centers and infrastructure hubs results in low rates of access to affordable energy, despite the fact that hydrocarbon extraction primarily occurs in these areas

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(Ritchie & Roser, 2019). In reaction to this compounded inequity, many are working to center the concept of energy sovereignty in discussions about the future of the world's energy infrastructure (Timmerman & Noboa, 2022). Although the concept of sovereignty, and energy sovereignty in particular, is not universally defined (see Curley & Lister, 2020 for a critical examination of sovereignty), here we use the concept of "energy sovereignty" to broadly refer to scenarios where communities, as they define themselves, are empowered to exercise self-determination over the sources of energy they use, and are able to access the means of production and consumption of that energy (Energy Sovereignty Institute, 2023; Timmerman & Noboa, 2022). The continued or renewed tradition of firewood harvesting is one grassroots response to disenfranchisement from energy infrastructure in many Indigenous communities (Brewer II et al., 2018). Using locally harvested biomass fuels can offset the lack of access to industrial energy infrastructure in ways that align with cultural identity. The harvest and use of firewood, for example, is considered part of a traditional subsistence practice that maintains local ecological connections as well as a divestment from the same industries that have caused a legacy of harm, especially in Indigenous communities (Linthicum et al., 2021). Thus, the practice can be simultaneously economic, cultural, and political, though individual motivations may align more strongly with one or another aspect. Regardless of the motivation, access to local sources of firewood is an important aspect of how individuals exercise self-determination, and thus an important aspect of energy sovereignty.

While the harvest and use of firewood promotes local energy sovereignty, reliance on local wood fuels is not free from problems. Indigenous patterns of disenfranchisement and divestment from hydrocarbon industries occur within the context of a complex legacy of land tenure rights and diminishment of the ecological health of arboreal ecosystems. The world's forests and woodlands are part of ecological systems with a legacy of land tenure by Indigenous people (Hoffman et al., 2021). In many cases, utilization of local ecological resources such as firewood by local communities contributes to biodiversity, an important indicator of ecological health and sustainability (Bliege Bird et al., 2008; Guadilla-Sáez et al., 2019; Power et al., 2018). In many areas of the world, however, diminished and diminishing access to firewood affects the livelihoods of Indigenous people as well as the ecological health of the arboreal ecosystems adapted to Indigenous use. This diminished access can be from a suite of causes, including overharvest and restrictive land management policies. Climate-driven reductions of woody biomass threaten the sustainability of harvest from arboreal ecosystems. These dynamics influence the energy sovereignty of Indigenous communities across the world (e.g., Bharadwaj et al., 2021; Durkalec et al., 2015; Rahman & Alam, 2016) and work to erode other cultural practices that rely on forest resources (e.g., Turner & Clifton, 2009). The characteristics of the woodlands and forests themselves are changing due to climate change, further complicating the question of the future role of firewood in Indigenous sovereignty and self-determination.

The goal of this article is to situate contemporary firewood fuel harvest and use strategies within the broader political and ecological contexts in which they occur. Specifically, we seek to address questions around how and for what purposes firewood is used, when harvest takes place and by whom, and what some of the costs of firewood harvest are. The research presented here provides a case study for understanding these dynamics by situating firewood harvest and use among members of Navajo Nation, located in portions of Utah, Arizona and New Mexico in the southwestern United States. We report on Diné (Navajo) 'wood hauling' — the local term for the practice of harvesting firewood — in and around Navajo Nation. By articulating these dimensions of the use of a local biomass fuel source, we hope to facilitate discussions about energy sovereignty and identify interventions most likely to improve ecological and humanitarian outcomes given both ongoing colonial legacies and the likely impacts of climate change.

Cultural Context of the Study Area

All information presented here was provided by Diné Tribal members living on Navajo Nation. The study area includes Navajo Nation and surrounding lands where Diné Tribal members harvest firewood. Although the particular details are likely to vary in other cases where people are reliant on locally harvested firewood, the implications discussed below should apply broadly. This is especially true for Tribes neighboring Navajo Nation and for whom the same regional forests and woodlands are part of the traditional land base, such as the Ute Mountain Ute Tribe, Hopi Tribe, Pueblo of Zuni, and Ute Indian Tribe (*Bears Ears Inter-Tribal* Coalition, 2021). While the specific history and cultural identity of each Tribe is unique, a shared legacy of social, political, and economic relationships exist among each other, and all experience harmful and ongoing impacts from Euro-American colonists and the United States federal government.

Firewood harvest began in the greater four-corners area with the first people to inhabit the region, dating to at least 8500 BP and likely much farther back (Bennett et al., 2021; Davis, 1989; Geib & Davidson, 1994; Vance, 2011). Use of the landscape has been continuous since that time. By the arrival of Spanish missionaries and settlers in the sixteenth and seventeenth centuries, a complex political landscape with deep ecological legacies had developed, including patterns of land use and management ranging across foraging and farming subsistence strategies (many details are offered

in Ortiz 1979, 1983). Notable among the many changes brought by successive waves of Euro-American expansion into the region is the arrival of Mormon settlers in the extreme southeastern parts of Utah in the late 19th century, the establishment of Tribal reservation lands in the late 19th and early 20th centuries, and the subsuming of lands not already privately held or reserved by federal land management agencies in the early 20th century (McPherson, 1995). Each of these events and many others hold in common the violent disenfranchisement of Indigenous people from the landscapes they traditionally inhabited through capture, murder, and forced movements such as the Long Walk (among the many detailed accounts are Denetdale, 2015; Forrest, 2000; Iverson, 2002; Johnson, 1973; McCool, 2015; McNitt, 1964). A somewhat recent example important to discussions of economic sovereignty on Navajo Nation today is the Navajo Livestock Reduction Program of the 1930's where a federal mandate to reduce livestock holdings among Diné Tribal members diminished cash earning potential by 50% and severely disrupted socio-cultural systems in the region (Kelly, 1974; Roessel & Johnson, 1974). Although nearly a century has since passed, the losses suffered through this program are still acutely felt, as evidenced by the frequency of discussion at Chapter House meetings and other community settings. Such losses are compounded by the high cost of accessing many needed resources, such as energy.

In many areas of Navajo Nation, the difference between Tribal lands and nearby lands is stark. Figure 1 shows one example of the difference between lands reserved for Native

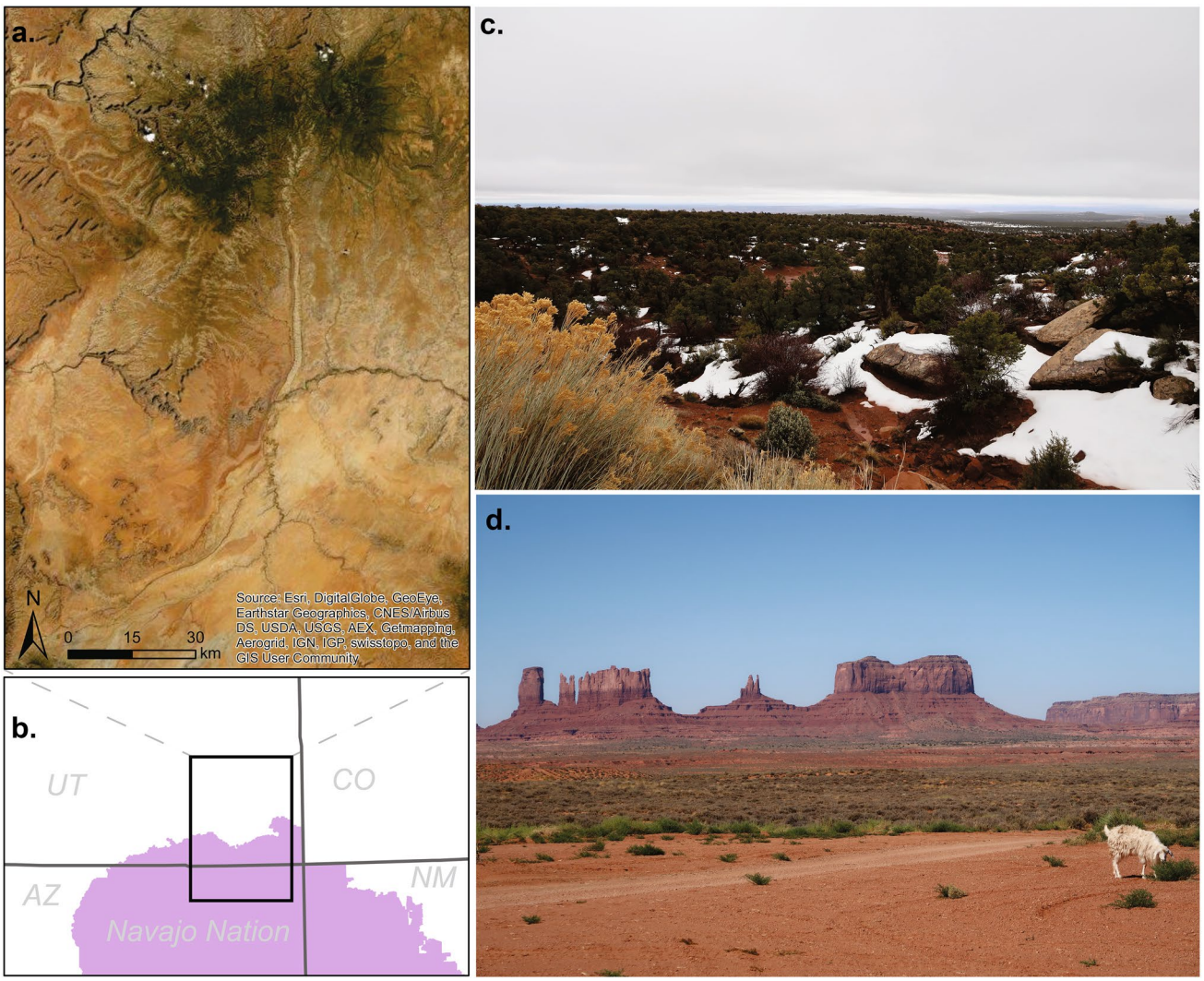

Fig. 1 A sample location and ecological context of wood hauling. **A**. A view of the northern part of the study area via satellite, where the Utah portion of Navajo Nation is situated south of the San Juan River (line bisecting the image horizontally). **B**. The location of the view in **A**. relative to current political boundaries. **C**. North of the river, woody vegetation becomes increasingly abundant. **D**. South of the river, vegetation is diminutive, with few trees

people where the productivity of the land is low, and traditional lands nearby, where woodland resources are more plentiful, but which is now under the administration of federal land management agencies. Resource distributions across the study region are heterogeneous, and often the most abundant traditional energy sources (as well as water, agricultural, and other resources) are distant from reservation lands. Diné and other Indigenous people living in the region today navigate complex dynamics of maintaining a distinct cultural identity while balancing participation in formal and informal economies requiring travel over vast geographic distances to access opportunities (Gilbreath, 1973). While many rural demographics face similar challenges, the burden of this balancing act for Indigenous people is magnified by poverty, lack of access to political systems, and a long history of systemic disenfranchisement from culturally and economically important natural resources (e.g., McCool et al., 2007). Despite these challenges, the importance of firewood to Diné people is fundamental to life in ways that cannot be parsed between culture, economics, or politics.

The practice of being in relationship with fire through supplying, starting, maintaining, and respecting hearths and fireplaces in homes, hogans, and ceremony grounds has been recorded by numerous ethnographic accounts. The list of such published accounts is substantial, but Holiday and McPherson (2005) and Thunder (2001) offer details about the importance of fire in the words of practicing Diné medicine people. An exhaustive list of the roles of fire (and hence firewood) in Diné ceremonies is too extensive to cover here. Examples of common ceremonial contexts noted frequently by participants in this study that require substantial amounts of firewood include táchéédh (sweat lodge) ceremonies, peyote ceremony, and Yei bi cheii (Night Chantway).

Ecology of the Study Area

The ecology of the study area underpins the distribution of woodland resources across Navajo Nation and the surrounding region. Situated entirely within the semi-arid, uplifted Colorado Plateau, geomorphological variation that ranges across deeply incised canyons and laccolithic mountain ranges produce extreme differences in elevation and associated ecological gradients. Within the Navajo Nation, elevations range from about 1500–3400 m (~5,000–11,000 feet) above sea level (Sisk, 1998). Lower elevations receive an average of 18 cm (~7 inches) of precipitation annually, and higher elevations receive over 40 cm (~16 inches; Navajo Nation Department of Water Resources, 2003). Seasonal precipitation patterns are driven by the North American monsoon in the summer months, and Pacific teleconnections in the winter months (Tulley-Cordova et al., 2018). Lands surrounding Navajo Nation that hold woodland and forest resources important to Tribal members are similar. Woodlands where pinyon (called *chá'ol* in Diné, Pinus edulis) and juniper (frequently called cedar in English, or *gád* in Diné, Juniperus spp.) mix to varying degrees are the most common source of firewood in the region. Pinyon-juniper woodlands tend to grow in elevations between 1200–1800 m (~4000–6000 feet). Covarying differences in elevation and precipitation influence a trade-off between which species is dominant, with pinyon increasing in abundance at higher, wetter elevations.

As elevations increase, pinyon-juniper woodland ecosystems give way to other arboreal systems, dominated by oaks (*chéch'il*, Quercus spp.), ponderosa pines (*nídíschíí'*, Pinus ponderosa), and aspen (*t'iisbáí*, Populus tremuloides). While these higher elevation arboreal systems are also culturally and economically important to Diné people, they are not as commonly utilized for firewood as pinyon and juniper, which are the focal species for the remainder of this article.

The dynamics of the pinyon-juniper ecosystem may change significantly with climate change. Recent synthesis of climate science suggests that the southwestern US has among the highest potential in the world for future drought (IPCC, 2021). Semi-arid arboreal systems such as the pinyon-juniper forest relied upon for firewood by Diné people are among the most susceptible to climate change, which is likely to produce droughts of increasing intensity and duration in the study area (Campbell et al., 2020; Gao et al., 2012; Li et al., 2018; Park Williams et al., 2013). Mass regional die-offs of pinyon (as well as other species) since 2000 are linked to increasing drought conditions induced by climate change (Anderegg et al., 2013, 2019; Macalady & Bugmann, 2014). Juniper are more drought tolerant and tend to dominate in lower elevations where precipitation is less (Linton et al., 1998; Padien & Lajtha, 1992; Woodbury, 1947). Most firewood gathered from arboreal ecosystems is taken from dead trees. A preference among Diné wood haulers for recently dead trees (prior to insect infestation or utilization by birds) means that climate-driven tree mortality events may actually increase access to firewood in the short term. At least two such mortality events occurred in the past two decades in the pinyon-juniper woodlands of southeastern Utah (Anderegg et al., 2015), contributing to an abundance of harvestable wood in recent years. However, climate change will likely reduce the total amount of this energy source in the long term, cause the distribution of pinyon-juniper woodlands to change, and make it more difficult for wood users to predict future energy outcomes and maintain ecological relationships. In order to deal with these issues, we need a baseline understanding of wood use now to assess changes over time and mitigate the worst effects where possible.

Political Context of Firewood Harvest

Forests and woodlands in the four corners region range across lands managed by Tribal, federal and state government organizations: the Navajo Nation Division of Natural Resources (NNDNR), Ute Mountain Ute Resource and Environmental programs, the United States (US) Bureau of Land Management (BLM), the US Forest Service (USFS), the US National Park Service (NPS), Utah School and Institutional Trust Lands (SITLA), Colorado State Trust Lands, Arizona State Land Department, and New Mexico State Land Office. Firewood harvest is prohibited on some NPS lands as determined by individual superintendents and on Arizona State Trust Lands (Arizona State Land Code, 1915; National Park Service Organic Act, 1916; Organic Act Amendment, 1978). The remaining agencies are guided by mixed-use mandates that navigate complex issues of public recreational and small-scale harvest uses, commercial economic development, and resource preservation. Each of these mixed-use land management entities provide for firewood harvest in their management plans, but differ in the level of oversight and rules established around harvesting woodland resources (Bureau of Indian Affairs, 2005; Bureau of Land Management Monticello Field Office, 2008; Manti-La Sal National Forest, 1986; National Indian Forest Resources Management Act, 1990; Title R850 of Utah Administrative Code, 2019). For example, the Bureau of Land Management Monticello Resource Management Plan (2008: 41) specifically "allow[s] for traditional Native American firewood harvesting opportunities within areasonable range of the Navajo Reservation, as well as for collection of cottonwood and willow for ceremonial purposes," while the neighboring Manti-La Sal National Forest currently has no similar provisions (Manti-La Sal National Forest, 1986). These differences emerge from variation in the way each agency defines its management goals and interprets those goals into rules pertaining to the public harvest of forest products, as well as the pace each agency updates their governing documents. Depending on local political boundaries, wood haulers find themselves under the jurisdiction of numerous government entities. Information about guidance and regulations surrounding wood harvest and hauling are generally only available at centralized government offices. Private property and individually-enforced prohibitions on harvesting trees near home sites or in depleted areas on Navajo Nation further complicate the task of acquiring wood. Two issues central to wood hauling which are managed to varying degrees by the land and resource management entities listed above are permitting and access.

Permits are required by all land management agencies that do not prohibit wood harvest. Permits are sold per cord of wood. A cord is the amount of dry wood tightly stacked that fits within an area of 3.62 m^3 (128 cubic feet). Permits to harvest a cord of wood range between 4-20 per cord depending on the species of wood. Land managers estimate a full-sized pickup truck, stacked high, equals one cord, and this method of estimating, coupled with a displayed and dated permit, tends to be seen as sufficient for assessing whether permit requirements are met. With few exceptions, permit sales are dispensed at centralized government offices that are frequently distant from wood-haulers' homes or the areas where harvest occurs.

Access to woodland resources consists of a broad suite of details relating to land management. Vehicle access to woodland resources varies considerably across the region, ranging across well maintained paved roads to minimally maintained dirt paths (often called "two-tracks"). Large areas of woodland are not currently accessible by vehicle, often by design under land management plans. A mosaic of land management zones, with associated rules about wood harvest, adds another dimension to issues of access. For example, some BLM and USFS lands are managed as Wilderness Study Areas (WSAs). Wilderness study areas consist of a portion of a land management unit that is managed as if it were federally designated wilderness. These areas are established by land managers because wilderness characteristics, such as roadlessness, have been previously identified, qualifying the area as eligible for wilderness designation under the Wilderness Act of 1964 (The Wilderness Act, 1964). The harvest of wood is not permitted within WSAs in the study region. Printed maps that identify areas where the harvest of wood is permitted, as well as areas where it is expressly prohibited, like in WSAs, is provided by some land management offices when a permit for wood harvest is issued. On the ground, signage indicating the boundaries of where wood harvest is permitted are sometimes posted, but fencing or other clearly identifiable boundaries are frequently absent.

Traditional wisdom learned through generations of lived experience, sometimes referred to as Traditional Ecological Knowledge (TEK), also guides the harvest of firewood. These rules include prescriptions about which qualities, which species, and which portions of a tree, are best for a variety of domestic and ceremonial contexts. Diné wood haulers avoid wood affected by lightning and wood that clearly houses animals such as birds and insects. Diné people also have strong taboos against visiting places with clear evidence of ancient habitation. Many wood haulers report avoiding areas with ancient architecture and the potential for burial sites. Traditional norms and rules are taught starting at a young age and frequently reinforced within communities.

A long legacy of disenfranchisement and variation in ecological and political characteristics create a complex landscape for people seeking to harvest and transport wood.

Methods

To explore firewood harvest and use across the ecological, social, and political landscape detailed above, we employ a multi-method approach that couples socio-cultural, economic, and ecological information. Data about home energy use, firewood harvest, demographic, and economic information was collected via paper survey at six regional fairs in Navajo Nation. The fairs took place in 2018 and 2019 at Window Rock, Arizona, Shiprock, New Mexico, and Tuba City, Arizona. Surveys were administered at a table at a designated vendor area frequented by attendees as they walked through the fair. This method of survey collection was chosen because the fairs are widely attended and considered perhaps the most efficient in-person method of contacting the most representative variety of Diné Tribal members. This decision and the administration of the surveys was done in collaboration with the Indigenous-lead non-profit organization, Utah Diné Bikéyah (UDB, https://utahdinebikeyah.org/). The lead author (KM) attended the table in the vendor halls along with a Diné research assistant (SC), Diné collaborator and native language speaker (JY), and alongside staff and board members of UDB. People passing the table were asked verbally if they would be interested in taking the survey, and some were attracted to the table by a sign and wood hauling display meant to communicate the topic of the survey. Occasional translation into Diné by JY and other UDB board members was available to assist in interpreting the questionnaire. Survey respondents were not compensated. It should be noted that survey respondents self-selected and this study does not attempt to quantitatively assess the representativeness of the survey results. Figure 2A shows an example of the setting used to collect survey responses at a fair on Navajo Nation.

Survey questions were developed in consultation with the UDB board members. Both the University of Utah Institutional Review Board (IRB #00090654) and the Navajo Nation Human Research Review board reviewed the study, including sample questionnaires, and exempted the study from specific oversight. A cultural resources investigation permit was approved by the Navajo Nation Heritage and

Fig. 2 Images show various aspects of data collection and stages of firewood harvest and use. **A**. The table where surveys were administered at the fair in Window Rock, Arizona in September 2019. Setups at the other fairs were similar. **B**. A family breaking apart a fallen dead pinyon tree with axes prior to loading into a truck to bring home for use. **C**. Ceremonial oak wood piled for storage. **D**. Heating wood pile consisting mostly of pinyon wood, stacked and stored for winter use

Historic Preservation Department (permit #C18024-E). The Navajo Utah Commission also supported a resolution in support of this research (resolution #NUCFEB-714–18). An example of the questionnaire questions is provided as a supplement to this article.

Semi-structured interviews were also conducted to further investigate knowledge and attitudes about firewood access, land management practices, and ecological change in the northern region of Navajo Nation (Adams, 2015). These interviews were conducted by KM and SC, with direction in finding and communicating with potential interviewees by JY. Interviews lasted between one and two hours and involved open-ended questions that began with similar topics found in the surveys. Interviews were recorded for future review upon verbal consent with interviewees. Interviewees were compensated for their time with a stipend from UDB.

A total of 137 survey respondents and 9 interviewees provided information about topics related to firewood harvest and use. Survey responses were digitized into Excel and interviews were reviewed and tabulated by SC. To contextualize the socioeconomic status of Diné wood haulers, data from the US Census was compiled and associated analyses were conducted in R software (R Core Team, 2019) by KM and BC (U.S. Census Bureau, 2020). To assess the costs of firewood harvest, MW digitized firewood harvest and use locations from survey maps. KM produced a cost-distance analysis using the sf (v 1.0–1) and gmapsdistance (v 3.4) packages in R software (Azuero Melo et al., 2018; Pebesma, 2018). Data collection via participant observation of wood hauling activities was also conducted in the northern and central parts of Navajo Nation. Information from informal discussions during participant observation sessions is presented here.

Findings

A summary of findings in response to questions relevant to energy sovereignty is provided below. For context, panels B-D in Fig. 2 show different aspects of wood hauling and storage.

Why Firewood?

The harvest of firewood primarily follows a seasonal pattern, with most harvest occurring as average temperatures begin to drop after the summer peak (see Fig. 3). This seasonal pattern suggests that firewood's primary role is to serve as a source of warmth in both household and ceremonial contexts.

Survey respondents indicated that heating was the most common use for firewood (86.9%). Ceremony (68%) and cooking (56.9%) were also important. All other uses for harvested wood were small in comparison (11.7%).

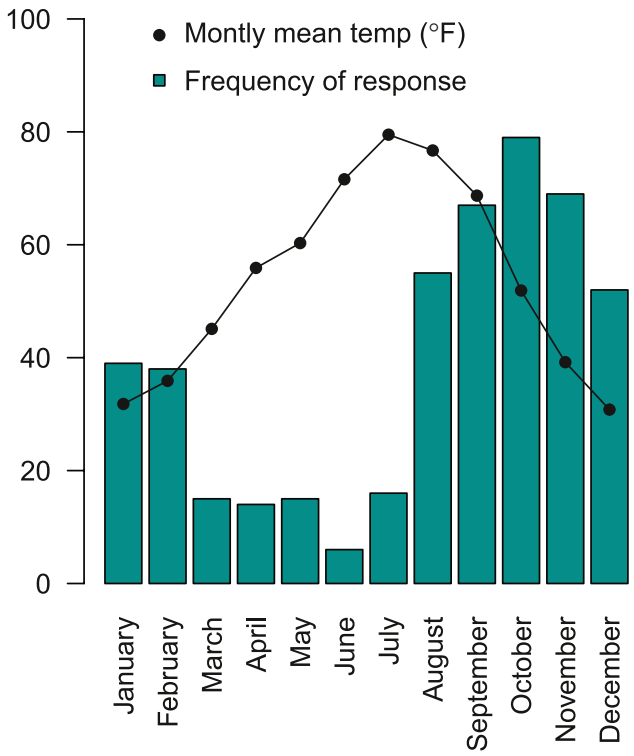

Fig. 3 Teal bars show the frequency distribution of months when survey respondents harvest firewood. Respondents reported multiple months, and each report of each month where harvest occurred is shown here. The month with the greatest number of respondents hauling wood occurs in October, while the month with the lowest amount of wood hauling activity occurs in June. The monthly mean temperature as measured by the Canyon De Chelly, AZ weather station (Vose et al., 2014) during 2018 and 2019 is plotted in black. Although absolute temperature averages vary considerably across the study region, the relationship between temperature trends and firewood harvest frequency should maintain

How Important is Firewood?

Many who participated in this study expressed that, without firewood, their way of life would not be possible. Most survey respondents reported using firewood at home, often in combination with other energy sources (see Fig. 4). Of the 119 respondents who reported using firewood at home as part of the household energy budget (86.9% of all respondents), 42 report using only firewood (30.6% of total respondents) and another 19 respondents report using a combination of firewood and coal (13.9% of all respondents). Other forms of energy are propane (40%), electricity (34.3%), natural gas (8%), pellet (2.1%), kerosene (1.5%), and solar (1.5%).

Interviewees reported needing as little as 2 truckloads of wood per year, so long as they had access to another energy source. In the northern part of Navajo Nation, that other source is often coal. People reported lighting their fires and stoking as needed with wood, but most heating hours were actually spent burning coal. 32 respondents

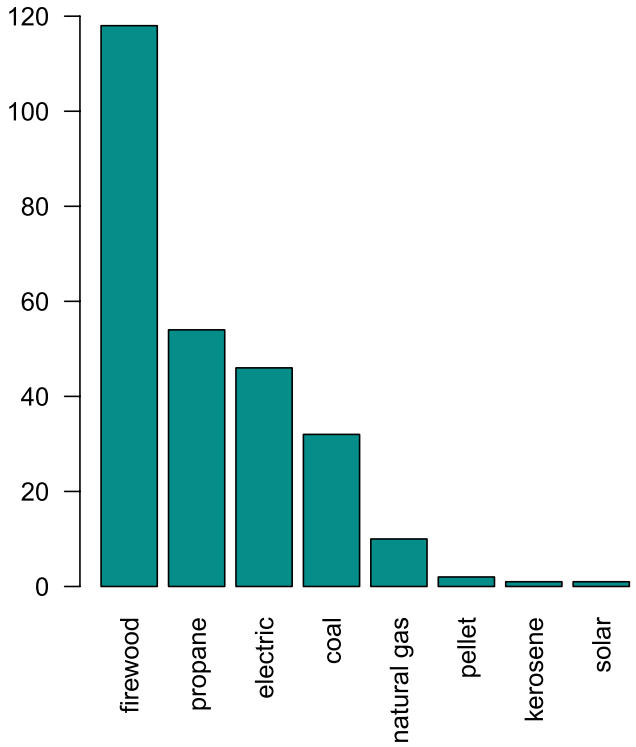

Fig. 4 A histogram showing the frequencies of different types of household energy sources as reported by survey respondents. Many respondents use multiple types of energy and each report of an energy source is counted

(30.5% of those who use firewood) reported using both coal and firewood. Additionally, nobody using coal did so without also using firewood. This info alone suggests that, for the 95 respondents who reported using 2 or more truckloads of firewood annually (comprising 90.5% of those who chose to respond to that question in the survey), firewood constitutes an important aspect of the energy budget.

These findings highlight two important insights. The first is that a substantial number of people rely on firewood as their primary source of energy at home for cooking and heating. An increase in the cost of accessing firewood, or restrictions to access would likely impact this demographic the most. The second insight is that firewood serves as an important supplement to other energy sources. Firewood is a relatively inexpensive and accessible resource that mediates the need for materials like coal used in dual fuel stoves. Firewood also provides energy security in conditions where poor infrastructure limits the reliability of access to other energy sources, such as electricity. For example, some study participants described a weeks-long power outage that forced people to either rely entirely on firewood for heat and increased reliance for cooking, or caused them to disrupt their daily lives to stay with relatives in larger cities and towns.

The frequency of firewood use reported by survey respondents underscores the importance of firewood on Navajo Nation and reflects both the reliability and affordability of firewood relative to other energy sources, as well as firewood's cultural importance.

Who Harvests Firewood?

Acquiring firewood is largely dependent on an individual's time availability, access to vehicles, and tools for harvesting (e.g., chainsaws). Slightly over half of the respondents harvest firewood themselves (52.6%), 11.6% receive firewood from others, and 24.3% purchase firewood.

Wood haulers ranged between the ages of 11–86, with a mean age of 45.5 years old. Men and women harvested firewood in equal proportion. Wood hauler groups are diverse. Some harvest sessions are conducted by one person or a small group of people, often men headed out for a day trip to harvest wood and return to home sites by the evening. Other harvest groups consist of multi-generational family groups that combine firewood harvest with family bonding activities like camping and cookouts. Since survey respondents were self-selected, young children are not represented in the survey data. However, interviewees and interlocutors— as well as co-authors on this article (SC, JY) — report wood hauling at a very young age. Some informants indicated that infants in cradle boards and toddlers are sometimes part of wood hauling groups.

What is the Current Socio-economic Status of Wood Haulers?

Among surveyed Diné households, those who use firewood at home have lower median household incomes than that of all households in the same counties (U.S. Census Bureau, 2020, Fig. 5). The median household income of individuals who harvest and use firewood is similar to American Indian households on or near Navajo Nation, but range lower. Those individuals whose households earn less than $20,000 annually make up 89.8% of survey respondents, and 85.2% of those households rely on firewood.

What Are the Costs of Firewood Harvest?

Although lower income households are more reliant on firewood, the ability to acquire firewood is also dependent on the ability to afford the cost in both time and money. Some wood haulers report having nearby access to woodlands or forests where firewood is available (43.6% live within 20 km, or 12.4 miles of woodlands where firewood can be harvested). Many must travel distances of over 20 km (12.4 miles), and some over 80 km (50 miles) to arboreal ecosystems (Fig. 6).

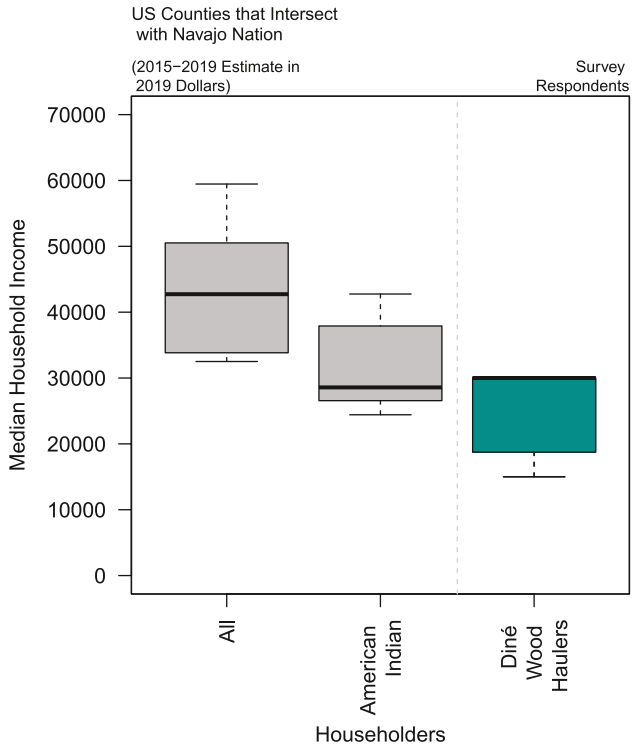

Fig. 5 Box plots comparing the median household income in counties intersecting Navajo Nation. The grey boxes represent census data, and the teal box represents survey data from this study. The median household income for all households is just under $45,000/year. The median household income for both American Indian and firewood-using households is about $30,000/year, however the income level of those households who use firewood has both a lower first quartile and minimum income level

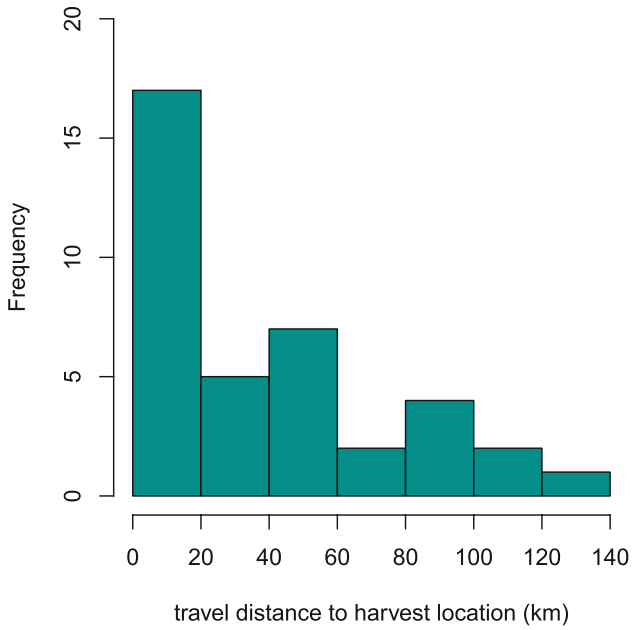

Fig. 6 The one-way driving distance between the home site (i.e., the location where firewood is used) and where firewood is available for harvest varies substantially across Navajo Nation. About a quarter of survey respondents (24.6%) report living where firewood resources are available (travel distance = 0 km). 76.3% of survey respondents report living 40 km or less from a place where they harvest firewood. 23.7% report needing to travel more than 60 km to harvest firewood

Semi-structured interviews and informal conversations reveal that, in addition to travel times, there are numerous challenges faced by wood haulers that are harder to quantify, yet influence decisions around firewood harvest and use. One category of such challenges involves social and psychological stresses imposed on wood haulers following from uncertainty around the rules imposed by land managers. Communication from government offices about the laws and policies around wood hauling, along with legible justification of these regulations, is severely limited throughout the region. Many wood haulers reported fear about being cited for violations of legal codes governing firewood harvest, regardless of whether actual violations occurred. The result is that the act of harvesting firewood is approached as clandestine by many wood haulers. This dynamic can result in an adversarial relationship between local land managers and wood haulers, undermining efforts to sustain traditional cultural and ecological relationships with the local woodlands.

Even in cases where the process for following wood harvest codes is well-known, wood haulers often face a suite of challenges in meeting the requirements. For example, the acquisition of the permit required for each truckload of wood often requires substantial additional travel. In Utah, wood haulers whose local woodlands are on BLM lands in southern Utah must travel to BLM offices during business hours to purchase permits. The location of these offices requires a roughly two-hour drive from many Diné home sites. Embarking on such a trip significantly adds to the travel costs of wood harvest. In many cases, travel for acquiring permits and harvesting wood required leaving Navajo Nation lands, which comes at the additional cost of the risk of exposure to racially motivated hostility (McCool, 2015). Many Diné wood haulers reported encountering discrimination when wood hauling activities required off-reservation travel. This combination of added travel time, uncertainty about whether the offices will be open when they arrive, and anxiety about harassment add layers of financial and psychological burden to wood haulers. Although interactions between law enforcement and wood haulers are rare, wood haulers potentially face citation and seizure of property if caught removing firewood from managed lands without a permit. Aware of this problem, BLM agents in Utah are engaged in ongoing efforts to arrange for the sale of firewood permits on Navajo Nation, however a stable long-term solution is yet to be achieved. Similar obstacles to obtaining firewood permits exist throughout Navajo Nation.

Discussion and Conclusions

Our research results highlight four main conclusions.

1) Firewood is a key economic and cultural resource on Navajo Nation. Access to firewood mediates disenfranchisement from other systems of energy production and distribution.
2) The costs associated with acquiring firewood vary greatly across Navajo Nation and in many cases the highest costs are incurred by those least able to afford them.
3) Diné who harvest firewood usually use it within their own households or share it amongst their personal social networks for heating and ceremony.
4) Those who rely most on firewood are individuals whose household income levels range below other American Indian households and are significantly lower than all households in the counties that include portions of Navajo Nation.

Individual procurement, exchange, and use of wood from the region's woodlands and forests is an activity rich in economic, cultural, and ecological value. While some large-scale commercialization of harvested wood has emerged in the region, most acquisition and trade remain a part of what Diné people identify as a traditional practice. The harvest and use of firewood are an important part of Diné identity, strongly embedded in many social and ceremonial practices and an important aspect of maintaining relationships with traditional lands. As with many aspects of day-to-day subsistence, wood, and in particular firewood, is part of an informal economy that provides security against disenfranchisement from formal economic systems. Although acquiring firewood can be costly in some areas, access to firewood as an energy resource gives individuals agency over how to meet energy needs in a way that aligns with their cultural identity. An important aspect of this identity involves spending time in forests and woodlands with family, where ecological and social connections are reinforced. The option to utilize firewood enhances energy sovereignty. In many parts of Navajo Nation, people have limited access to the broader market economy. However, access to social and economic capital is also an important aspect of successful wood hauling. A vehicle able to haul wood, tools such as axes and chainsaws, as well as gas and maintenance of equipment are all necessary for wood hauling.

Such high levels of reliance on fuelwood is not exclusive to this region, occurring even elsewhere in North America (such as rural parts of Mexico as described by Serrano-Medrano et al., 2014). Given the ubiquity of this issue, we highlight some general solutions and future concerns that we hope will contribute to the future of wood hauling on Navajo Nation and can be adapted to other local circumstances.

Opportunities for Interventions

New actions or interventions in the system of firewood harvest and use should promote the dual goals of fostering energy sovereignty of Tribes and the sustainable management of woodlands. Rather than focusing simply on energy security, a focus on Indigenous sovereignty in managing energy resources will benefit both the future development of Indigenous communities and foster ecological resilience through land management decisions aligned with long legacies of human-ecological relationships (Berkes et al., 2000; United Nations Declaration on the Rights of Indigenous Peoples, 2007). As applied in other parts of the world (e.g., Gonçalves et al., 2021), hydrocarbon subsidies would increase energy security, but may undermine sovereignty given the strong preference for traditional firewood use and the varied level of access to hydrocarbon energy infrastructure. Increasing the efficiency of wood stoves may be a more enduring solution, though long-term studies indicate that even seemingly innocuous interventions like distributing high energy cookstoves may fail due to incompatibilities with the organization of social and task spaces in rural and Indigenous households (e.g., Catalán-Vázquez et al., 2018). These cases further highlight the necessity for any intervention to be developed with local communities, rather than imposed from outside, in order to improve energy sovereignty.

Interventions, then, may most productively and sustainably take the form of enhanced opportunities to participate in political processes wherein the needs of- and knowledge held by- individuals may translate into policies that address both humanitarian and ecological issues. In the study case, the energy sovereignty of Diné (as well as Ute, Zuni, and Hopi) people could be advanced by increasing decision-making power over both the arboreal ecosystems (the local sources of energy in the form of firewood) as well as the interface with global-industrial energy infrastructure. Such a shift in political participation and power would serve as a beginning to rectifying the long history of inequitable resource extraction and export from Navajo Nation (Powell, 2018). Incorporating traditional firewood harvest practices, such as selectively harvesting recently fallen and standing dead wood, has the potential to lead to innovative adaptive forest and woodland management policies focused on aligning local needs with the national mandates frequently associated with conventional land management (Ludwig & Macnaghten, 2020).

In the study region, disenfranchisement of Indigenous people from forested lands began with the arrival of Euro-American colonists and continued through a sequence of events outlined above. In a reversal of these historic trends, Tribes whose traditional lands include what is now southeastern Utah organized a coalition to preserve the area against extractive

industries and codify traditional uses into land management policy. After a series of failed negotiations with county and state leaders, the coalition and their allies successfully petitioned President Obama to designate the Bears Ears National Monument in 2016. The presidential proclamation defining the monument included provisions for co-management with Tribes and federal land management agencies, as well as specifically protected continued access to firewood and other resources (Bears Ears National Monument, 2021). The Bears Ears Intertribal Coalition was formed as an extension of the sovereign authority of the Hopi Tribe, Navajo Nation, Ute Mountain Ute Tribe, Pueblo of Zuni, and Ute Indian Tribe in the interest of the preservation of the Bears Ears region utilizing "Traditional Ecological Knowledge to improve management of this sacred place in a manner that promotes its resilience for all to enjoy" (*Bears Ears Inter-Tribal* Coalition, 2021). This recent action restores codified Tribal involvement in the processes of land management, creating a pathway for Indigenous voices — and the cultural legacy and ongoing relationship between Indigenous people and these ecosystems — to be represented in the future governance of the landscapes of southeastern Utah that hold important cultural and economic resources for Indigenous people, including firewood. The results of this process in practice are currently playing out and remain to be seen. However, access to firewood only addresses the supply side of the issue of energy sovereignty. Demand is partly driven by how access to firewood is coupled with other energy resources.

As mentioned above, firewood is frequently coupled with other sources of energy in households on Navajo Nation. Access to coal and electricity (and occasionally other energy sources) drive how much firewood is needed. For example, many households use firewood to start a fire in a cold wood stove, but coal is then burned throughout the bulk of the time the stove is in operation. Since coal is more energy dense than firewood, less cost and effort are required to acquire enough to heat a household for a season. Interviewees reported in 2018 and 2019 that one or two truckloads of coal per year, supplemented by one or two truckloads of firewood per year, can meet home heating needs. Without coal, the amount of firewood needed to sufficiently heat a home increases substantially. In the Utah and N. Arizona portions of Navajo Nation, many people acquired coal from a public coal field associated with the Kayenta Mine, run by Peabody Energy. The mine's closure in 2019 (soon after the cessation of fieldwork reported here) left many Diné and Hopi people without adequate access to energy for heating. Local organizations acted, providing firewood as well as reducing the demand for firewood by adding winterization technology to housing (Sevigny, 2020). While these local organizations play an important role, limited resources mean their ability to help is also limited. Much broader investments of capital into both making homes more heat and energy efficient, as well as building political structures to empower people to access the types of energy they choose are needed. New investments by the Navajo Nation government in renewable energy development, particularly solar energy, is one example of how regional-level decision-making is able to invest economic and political capital into building more resilient industrial energy infrastructure (Navajo Power, 2020; Yurth, 2020), although many people remain skeptical about the ability of centralized power projects to meet localized energy needs (Kirsst, 2020). Grassroots efforts to create small-scale, decentralized energy sources will also play an important role (Yurth, 2021). Bottom-up efforts would also allow related issues to be addressed in tandem, such as the prevalent concern about indoor air pollution created by household burning of wood and coal (US EPA, 2018). The need to build resilient, adaptive strategies for energy sovereignty is only heightened by climate change.

Climate Change and Sustainability

As droughts continue and new woody biomass growth slows due to related stresses, eventually the need for firewood may outpace the rate of natural replenishment. This has likely already happened in some areas where survey respondents and interviewees expressed concern over deforestation caused by the harvest of live wood. While some live wood uses may be part of cultural practices (such as live branches as part of ceremonial structures, or the need for live juniper trunks in the construction of traditional Hogans), some of this live wood harvest may be the result of a lack of more desirable deadwood for heating. In these regions, the combined ecological impact of lack of access to alternative energy sources and climate change may already be leading to deforestation. Future research is needed to further articulate the causes of reported deforestation. To mitigate this effect of climate change, the adaptive approaches suggested above should include consideration of how to decrease the need for firewood over decadal timeframes, as wood is likely to become more costly to acquire, and pressure on remaining woodlands may exacerbate deforestation.

Conclusions

In many parts of the world, industrialization has replaced local resource utilization with engagement in globalized systems of production and distribution. In possibly no realm of resources has this been more the case than with energy resources. Despite widespread reliance on industrialized energy networks, firewood remains an economically, ecologically, and culturally important component of localized energy economies. Additional work is needed to determine the sustainability of traditional firewood harvest like that on Navajo Nation—especially under future climate

regimes. This work should parallel the study of the tradeoffs and conflicts of interest faced by those currently utilizing firewood for a substantial portion of their household energy budget. The potential to align traditional forestry strategies, including firewood harvest, with land management goals, such as wildland fuels reduction can produce a "win–win" for Indigenous communities and forest managers as has been suggested elsewhere in the world (e.g., Sterling, 2021; Syampungani et al., 2017). We need more high resolution case studies that examine how ecological, cultural, and economic factors couple and how those systems contain specific tradeoffs that individuals face in local contexts relative to larger political structures. In the case of Diné wood haulers, there are many opportunities for interventions that will enhance such potentialities, scaling from simple home improvements for individuals to national-level land management and energy economy policies. Our hope is that the information and analyses offered here will support such efforts and lead to enhanced energy equity and sovereignty for Tribal members and nations.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10745-023-00411-2.

Acknowledgements We are grateful for Tribal leaders who reviewed and approved resolutions allowing this work, for the time and expertise shared by the study participants, and Gavin Noyes for guidance and comments on earlier versions of this article.

Author Contributions KM, JY, SM, and BC designed the study, KM, JY, and SC conducted fieldwork, KM, SC, and MW compiled and analyzed the data, KM, SM, and BC wrote the article.

Funding This work is funded by NSF Award #1714972. We are also grateful to the Resources Legacy Fund for early support.

Data Availability The datasets generated during and/or analysed during the current study will be turned over to the Navajo Nation Historic Preservation Office who, as owners of the data, will make determinations about access. While this office prepares to house this data, requests to access data can be made to the corresponding author. Priority will be given to respecting Indigenous Data Sovereignty while assessing any request for information provided by Tribal members.

Declarations

Ethical Approval Utah Institutional Review Board (IRB #00090654) and the Navajo Nation Human Research Review board reviewed the study, including sample questionnaires, and exempted the study from specific oversight. A cultural resources investigation permit was approved by the Navajo Nation Heritage and Historic Preservation Department (permit #C18024-E). The Navajo Utah Commission also supported a resolution in support of this research (resolution #NUCFEB-714–18).

Competing Interests The authors declare no competing interests.

References

Adams, W. C. (2015). Conducting Semi-Structured Interviews. In K. E. Newcomer, H. P. Hatry, & J. S. Wholey (Eds.), *Handbook of Practical Program Evaluation* (pp. 492–505). John Wiley & Sons, Ltd. https://doi.org/10.1002/9781119171386.ch19

Anderegg, W. R. L., Anderegg, L. D. L., & Huang, C. (2019). Testing early warning metrics for drought-induced tree physiological stress and mortality. *Global Change Biology, 25*(7), 2459–2469. https://doi.org/10.1111/gcb.14655

Anderegg, W. R. L., Hicke, J. A., Fisher, R. A., Allen, C. D., Aukema, J., Bentz, B., Hood, S., Lichstein, J. W., Macalady, A. K., McDowell, N., Pan, Y., Raffa, K., Sala, A., Shaw, J. D., Stephenson, N. L., Tague, C., & Zeppel, M. (2015). Tree mortality from drought, insects, and their interactions in a changing climate. *New Phytologist, 208*(3), 674–683. https://doi.org/10.1111/nph.13477

Anderegg, W. R. L., Kane, J. M., & Anderegg, L. D. L. (2013). Consequences of widespread tree mortality triggered by drought and temperature stress. *Nature Climate Change, 3*(1), 30–36. https://doi.org/10.1038/nclimate1635

Arizona State Land Code, 37 Public Lands (1915). https://www.azleg.gov/arsDetail/?title=37

Azuero Melo, R., Rodriguez T, D., & Zarruk, D. (2018). *gmapsdistance: Distance and travel time between two points from Google Maps*. https://CRAN.R-project.org/package=gmapsdistance

Bailis, R., Chatellier, J. L., & Ghilardi, A. (2012). Ecological sustainability of woodfuel as an energy source in rural communities. In J. C. Ingram, F. DeClerck, & C. Rumbaitis del Rio (Eds.), *Integrating Ecology and Poverty Reduction: Ecological Dimensions* (pp. 299–325). Springer. https://doi.org/10.1007/978-1-4419-0633-5_18

Bailis, R., Drigo, R., Ghilardi, A., & Masera, O. (2015). The carbon footprint of traditional woodfuels. *Nature Climate Change*, *5*(3), 266–272. https://doi-org.ezproxy.lib.utah.edu/https://doi.org/10.1038/nclimate2491

Bears Ears Inter-Tribal Coalition. (2021). Bears Ears Inter-Tribal Coalition. https://bearsearscoalition.org/

Bears Ears National Monument, Pub. L. No. Proclamation No. 10285, 86 FR 57321 57321 (2021). https://www.federalregister.gov/documents/2021/10/15/2021-22672/bears-ears-national-monument

Bennett, M. R., Bustos, D., Pigati, J. S., Springer, K. B., Urban, T. M., Holliday, V. T., Reynolds, S. C., Budka, M., Honke, J. S., Hudson, A. M., Fenerty, B., Connelly, C., Martinez, P. J., Santucci, V. L., & Odess, D. (2021). Evidence of humans in North America during the Last Glacial Maximum. *Science, 373*(6562), 1528–1531. https://doi.org/10.1126/science.abg7586

Berkes, F., Colding, J., & Folke, C. (2000). Rediscovery of Traditional Ecological Knowledge as Adaptive Management. *Ecological Applications, 10*, 1251–1262. https://doi.org/10.1890/1051-0761(2000)010[1251:ROTEKA]2.0.CO;2

Bharadwaj, B., Pullar, D., To, L. S., & Leary, J. (2021). Why firewood? Exploring the co-benefits, socio-ecological interactions and indigenous knowledge surrounding cooking practice in rural Nepal. Energy Research & Social Science, 75, 101932. https://doi.org/10.1016/j.erss.2021.101932

Bilgen, S. (2014). Structure and environmental impact of global energy consumption. *Renewable and Sustainable Energy Reviews, 38*, 890–902. https://doi.org/10.1016/j.rser.2014.07.004

Bliege Bird, R., Bird, D. W., Codding, B. F., Parker, C. H., & Jones, J. H. (2008). The "fire stick farming" hypothesis: Australian Aboriginal foraging strategies, biodiversity, and anthropogenic fire mosaics. *Proceedings of the National Academy of Sciences, 105*(39), 14796–14801. https://doi.org/10.1073/pnas.0804757105

Brewer, J. P., II., Vandever, S., & Johnson, J. T. (2018). Towards energy sovereignty: Biomass as sustainability in interior Alaska. *Sustainability Science, 13*(2), 417–429. https://doi.org/10.1007/s11625-017-0441-5

Bureau of Indian Affairs. (2005). *Indian Forest Management Handbook: Permit Sales of Forest Products* (53 IAM 4-H, Release #64). US Department of the Interior. https://www.bia.gov/sites/bia.gov/files/assets/public/raca/handbook/pdf/53-IAM-4H-Permit-Sales-of-Forest-Products-HB_OIMT.pdf

Bureau of Land Management Monticello Field Office. (2008). *Monticello Field Office Record of Decision and Approved Resource Management Plan* (BLM-UT-PL-09–004–1610). U.S. Department of the Interior. https://eplanning.blm.gov/public_projects/lup/68097/85493/102694/Monticello_Final_Plan.pdf

Campbell, M. J., Dennison, P. E., Tune, J. W., Kannenberg, S. A., Kerr, K. L., Codding, B. F., & Anderegg, W. R. L. (2020). A multi-sensor, multi-scale approach to mapping tree mortality in woodland ecosystems. *Remote Sensing of Environment*, *245*, 111853. https://doi.org/10.1016/j.rse.2020.111853

Catalán-Vázquez, M., Fernández-Plata, R., Martínez-Briseño, D., Pelcastre-Villafuerte, B., Riojas-Rodríguez, H., Suárez-González, L., Pérez-Padilla, R., & Schilmann, A. (2018). Factors that enable or limit the sustained use of improved firewood cookstoves: Qualitative findings eight years after an intervention in rural Mexico. *PLOS ONE*, *13*(2), e0193238. https://doi.org/10.1371/journal.pone.0193238

Ceballos, G., Ehrlich, P. R., Barnosky, A. D., García, A., Pringle, R. M., & Palmer, T. M. (2015). Accelerated modern human–induced species losses: Entering the sixth mass extinction. *Science Advances*, *1*(5), e1400253. https://doi.org/10.1126/sciadv.1400253

Chen, Z. M., & Chen, G. Q. (2011). An overview of energy consumption of the globalized world economy. *Energy Policy, 39*(10), 5920–5928. https://doi.org/10.1016/j.enpol.2011.06.046

Curley, A., & Lister, M. (2020). Already existing dystopias: Tribal sovereignty, extraction, and decolonizing the Anthropocene. In *Handbook on the changing geographies of the state* (pp. 251–262). Edward Elgar Publishing.

Davis, W. E. (1989). The Lime Ridge Clovis Site. *Utah Archaeology, 2*, 66–76.

Denetdale, J. N. (2015). *Reclaiming Diné history: The legacies of Navajo Chief Manuelito and Juanita*. University of Arizona Press.

Durkalec, A., Furgal, C., Skinner, M. W., & Sheldon, T. (2015). Climate change influences on environment as a determinant of Indigenous health: Relationships to place, sea ice, and health in an Inuit community. *Social Science & Medicine, 136*, 17–26. https://doi.org/10.1016/j.socscimed.2015.04.026

Energy Sovereignty Institute. *The Energy Sovereignty Institute*. (2022). Retrieved April 20, 2023, from https://energysovereigntyinstitute.org/the-energy-sovereignty-institute/

Forrest, C. (Ed.). (2000). *A History of Utah's American Indians*. Utah State University Press.

Gao, Y., Leung, L. R., Salathé, E. P., Dominguez, F., Nijssen, B., & Lettenmaier, D. P. (2012). Moisture flux convergence in regional and global climate models: Implications for droughts in the southwestern United States under climate change. *Geophysical Research Letters*, *39*(9). https://doi.org/10.1029/2012GL051560

Geib, P. R., & Davidson, D. (1994). Anasazi Origins: A Perspective from Preliminary Work at Old Man Cave. *Kiva, 60*(2), 191–202. https://doi.org/10.1080/00231940.1994.11758265

Gilbreath, K. (1973). *Red capitalism: An analysis of the Navajo economy*. University of Oklahoma Press.

Gonçalves, P. H. S., Medeiros, P. M. de, & Albuquerque, U. P. (2021). Effects of domestic wood collection on tree community structure in a human-dominated seasonally dry tropical forest. *Journal of Arid Environments*, *193*, 104554. https://doi.org/10.1016/j.jaridenv.2021.104554

Guadilla-Sáez, S., Pardo-de-Santayana, M., & Reyes-García, V. (2019). The role of traditional management practices in shaping a diverse habitat mosaic in a mountain region of Northern Spain. *Land Use Policy*, *89*, 104235. https://doi.org/10.1016/j.landusepol.2019.104235

Hoffman, K. M., Davis, E. L., Wickham, S. B., Schang, K., Johnson, A., Larking, T., Lauriault, P. N., Quynh Le, N., Swerdfager, E., & Trant, A. J. (2021). Conservation of Earth's biodiversity is embedded in Indigenous fire stewardship. *Proceedings of the National Academy of Sciences*, *118*(32), e2105073118. https://doi.org/10.1073/pnas.2105073118

Holiday, J., & McPherson, R. S. (2005). *A Navajo legacy: The life and teachings of John Holiday*. University of Oklahoma Press.

International Energy Agency. (2017). *Energy Technology Perspectives 2017*. https://www.iea.org/reports/energy-technology-perspectives-2017

IPCC. (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. International Panel on Climate Change. https://www.ipcc.ch/report/ar6/wg1/

Iverson, P. (2002). *Diné: A History of the Navajos*. University of New Mexico Press.

Johnson, B. H. (1973). *Navajo Stories of the Long Walk Period*. Navajo Community College Press.

Kelly, L. C. (1974). *The Navajo Indians and Federal Indian Policy*. University of Arizona Press.

Kirsst, R. (2020, February 13). *Navajo Power to launch solar project if Coalmine Canyon agrees*. Navajo Times. https://navajotimes.com/biz/navajo-power-to-launch-solar-project-if-coalmine-canyon-agrees/

Lawrence, S., Liu, Q., & Yakovenko, V. M. (2013). Global Inequality in Energy Consumption from 1980 to 2010. *Entropy, 15*(12), 5565–5579. https://doi.org/10.3390/e15125565

Li, D., Wu, S., Liu, L., Zhang, Y., & Li, S. (2018). Vulnerability of the global terrestrial ecosystems to climate change. *Global Change Biology, 24*(9), 4095–4106. https://doi.org/10.1111/gcb.14327

Linthicum, K., Relford, M., & Johnson, J. C. (2021). Defining energy in nineteenth-century Native American literature. *Environmental Humanities, 13*(2), 372–390. https://doi.org/10.1215/22011919-9320200

Linton, M. J., Sperry, J. S., & Williams, D. G. (1998). Limits to water transport in *Juniperus osteosperma* and *Pinus edulis*: Implications for drought tolerance and regulation of transpiration. *Functional Ecology, 12*(6), 906–911. https://doi.org/10.1046/j.1365-2435.1998.00275.x

Ludwig, D., & Macnaghten, P. (2020). Traditional ecological knowledge in innovation governance: A framework for responsible and just innovation. *Journal of Responsible Innovation, 7*(1), 26–44. https://doi.org/10.1080/23299460.2019.1676686

Macalady, A. K., & Bugmann, H. (2014). Growth-mortality relationships in piñon pine (*Pinus edulis*) during severe droughts of the past century: Shifting processes in space and time. *PLOS ONE*, *9*(5), e92770. https://doi.org/10.1371/journal.pone.0092770

Macchi, M. (2008). *Indigenous and Traditional Peoples and Climate Change* [Issues Paper]. International Union for Conservation of Nature. https://www2.ohchr.org/english/issues/climatechange/docs/IUCN.pdf

Manti-La Sal National Forest. (1986). *Land and Resource Management Plan*. U.S. Department of Agriculture, Forest Service. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5383373.pdf

McCool, D. (2015). *Expert Witness Report by Dr. Daniel McCool in the case of: Navajo Nation v. San Juan County, UT* (2:12-cv-00039-RS).

McCool, D., Olson, S. M., & Robinson, J. L. (2007, March). *Native Vote: American Indians, the Voting Rights Act, and the Right to Vote*. Cambridge Core; Cambridge University Press. https://doi.org/10.1017/CBO9780511811821

McNitt, F. (1964). *Navaho Expedition: Journal of a Military Reconnaissance from Santa Fe, New Mexico to the Navaho Country Made in 1849 by Lieutenant James H. Simpson*. Norman: University of Oklahoma Press.

McPherson, R. S. (1995). *A History of San Juan County: In the Palm of Time*. Utah State Historical Society. https://issuu.com/utah10/docs/sanjuancountyhistory

Morton, J. F. (2007). The impact of climate change on smallholder and subsistence agriculture. *Proceedings of the National Academy of Sciences, 104*(50), 19680–19685. https://doi.org/10.1073/pnas.0701855104

National Indian Forest Resources Management Act, Pub. L. No. 101–630, 25 United States Code (1990). https://uscode.house.gov/browse/prelim@title25/chapter33&edition=prelim

National Park Service Organic Act, 16 U.S.C. §1 (1916).

Navajo Nation Department of Water Resources. (2003). *Navajo Nation drought contingency plan*. https://drought.unl.edu/archive/plans/drought/tribal/NavajoNation_2003.pdf

Navajo Power. (2020). *Navajo Power Secures $4.5 Million Financing, Partners With sPower – Navajo Power*. https://navajopower.com/2020/05/07/navajo-power-secures-4-5-million-financing-partners-with-spower/

Organic Act amendment, Pub. L. No. 95–250, Title I, §101(b) (1978).

Ortiz, Alfonzo & Sturtevant, William C. (Eds) (1979) Handbook of North American Indians: Southwest. Vol 9. Smithsonian Institution, Washington D.C.

Ortiz, Alfonzo & Sturtevant, William C. (Eds) (1983) Handbook of North American Indians: Southwest. Vol 10. Smithsonian Institution, Washington D.C.

Padien, D. J., & Lajtha, K. (1992). Plant spatial pattern and nutrient distribution in pinyon-juniper woodlands along an elevational gradient in northern New Mexico. *International Journal of Plant Sciences*, *153*(3.1). https://doi.org/10.1086/297048

Park Williams, A., Allen, C. D., Macalady, A. K., Griffin, D., Woodhouse, C. A., Meko, D. M., Swetnam, T. W., Rauscher, S. A., Seager, R., Grissino-Mayer, H. D., Dean, J. S., Cook, E. R., Gangodagamage, C., Cai, M., & McDowell, N. G. (2013). Temperature as a potent driver of regional forest drought stress and tree mortality. *Nature Climate Change, 3*(3), 292–297. https://doi.org/10.1038/nclimate1693

Pebesma, E. (2018). Simple features for R: Standardized support for spatial vector data. *The R Journal*, *10*(1), 439–446. https://doi.org/10.32614/RJ-2018-009

Powell, D. E. (2018). *Landscapes of Power: Politics of Energy in the Navajo Nation*. Duke University Press. http://ebookcentral.proquest.com/lib/utah/detail.action?docID=5208904

Power, M. J., Codding, B. F., Taylor, A. H., Swetnam, T. W., Magargal, K. E., Bird, D. W., & O'Connell, J. F. (2018). Human legacies on ecological landscapes. *Frontiers in Earth Science, 6*, 151. https://doi.org/10.3389/feart.2018.00151

R Core Team. (2019). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing. https://www.R-project.org/

Rahman, M. H., & Alam, K. (2016). Forest dependent indigenous communities' perception and adaptation to climate change through local knowledge in the protected area—A Bangladesh case study. *Climate, 4*(1), 12. https://doi.org/10.3390/cli4010012

Ritchie, H., & Roser, M. (2019, September 20). *Access to Energy*. Our World in Data. https://ourworldindata.org/energy-access

Roessel, R., & Johnson, B. H. (1974). *Navajo Livestock Reduction: A National Disgrace*. Navajo Community College Press.

Serrano-Medrano, M., Arias-Chalico, T., Ghilardi, A., & Masera, O. (2014). Spatial and temporal projection of fuelwood and charcoal consumption in Mexico. *Energy for Sustainable Development, 19*, 39–46. https://doi.org/10.1016/j.esd.2013.11.007

Sevigny, M. (2020, January 10). *Coal mine's closure leaves Hopi, Navajo homes without heat this winter*. KNAU. https://www.knau.org/post/coal-mine-s-closure-leaves-hopi-navajo-homes-without-heat-winter

Sisk, T. D. (Ed.). (1998). *Perspectives on the land-use history of North America: A context for understanding our changing environment. U.S.* Geological Survey, Biological Resources Division. https://web.archive.org/web/20060923054050/http://biology.usgs.gov/luhna/cover.html

Smith, K. R., Bruce, N., Balakrishnan, K., Adair-Rohani, H., Balmes, J., Chafe, Z., Dherani, M., Hosgood, H. D., Mehta, S., Pope, D., et al. (2014). Millions dead: How do we know and what does it mean? Methods used in the comparative risk assessment of household air pollution. *Annual Review of Public Health, 35*, 185–206. https://doi.org/10.1146/annurev-publhealth-032013-182356

Sterling, T. G. (2021, January 29). A Home Heating Crisis. A Devastating Forest Fire Waiting to Happen. One Innovative Solution. Slate. https://slate.com/technology/2021/01/wood-for-life-native-elders-heat-williams-mountain-wildfire.html

Syampungani, S., Tigabu, M., Matakala, N., Handavu, F., & Oden, P. C. (2017). Coppicing ability of dry miombo woodland species harvested for traditional charcoal production in Zambia: A win–win strategy for sustaining rural livelihoods and recovering a woodland ecosystem. *Journal of Forestry Research, 28*(3), 549–556. https://doi.org/10.1007/s11676-016-0307-1

The Wilderness Act, Pub. L. No. 88–577, 890 (1964). https://uscode.house.gov/statviewer.htm?volume=78&page=890

Thunder, W. (2001). *Walking Thunder: Diné medicine woman*. Ringing Books Press.

Timmermann, C., Noboa, E. Energy Sovereignty: A Values-Based Conceptual Analysis. (2022). *Science and Engineering Ethics,* 28, 54. https://doi.org/10.1007/s11948-022-00409-x

Title R850 of Utah Administrative Code, 70 R850 (2019). https://adminrules.utah.gov/public/search/R850/Current%20Rules

Tulley-Cordova, C. L., Strong, C., Brady, I. P., Bekis, J., & Bowen, G. J. (2018). Navajo Nation, USA, precipitation variability from 2002 to 2015. *Journal of Contemporary Water Research & Education*, *163*(1), 109–123. https://doi.org/10.1111/j.1936-704X.2018.03273.x

Turner, N. J., & Clifton, H. (2009). "It's so different today": Climate change and indigenous lifeways in British Columbia. *Canada. Global Environmental Change, 19*(2), 180–190. https://doi.org/10.1016/j.gloenvcha.2009.01.005

United Nations Declaration on the Rights of Indigenous Peoples, General assembly resolution 61/295 (2007). https://www.un.org/development/desa/indigenouspeoples/declaration-on-the-rights-of-indigenous-peoples.html/

U.S. Census Bureau. (2020). *Median Household Income: 2015–2019*. https://www.census.gov/library/visualizations/interactive/acs-median-household-income-2015-2019.html

US EPA. (2018, December 3). *EPA and Partners Bring Custom-Designed Cleaner-Burning Stoves to Navajo Homes* [Overviews and Factsheets]. https://www.epa.gov/sciencematters/epa-and-partners-bring-custom-designed-cleaner-burning-stoves-navajo-homes

Vance, M. M. (2011). *Stones without bones: Reconstructing the lime ridge clovis site*. Northern Arizona University.

Venter, O., Sanderson, E. W., Magrach, A., Allan, J. R., Beher, J., Jones, K. R., Possingham, H. P., Laurance, W. F., Wood, P., Fekete, B. M., Levy, M. A., & Watson, J. E. M. (2016). Sixteen years of change in the global terrestrial human footprint and implications for biodiversity conservation. *Nature Communications, 7*(1), 12558. https://doi.org/10.1038/ncomms12558

Vose, R. S., Applequist, S., Squires, M., Durre, I., Menne, M. J., Williams, C. N., Fenimore, C., Gleason, K., & Arndt, D. (2014). Improved historical temperature and precipitation time series for U.S. climate divisions. *Journal of Applied Meteorology and Climatology*, *53*(5), 1232–1251. https://doi.org/10.1175/JAMC-D-13-0248.1

Woodbury, A. M. (1947). Distribution of pigmy conifers in Utah and northeastern Arizona. *Ecology, 28*(2), 113–126. https://doi.org/10.2307/1930946

Yurth, C. (2020). NTEC proposes solar array at Navajo Mine. *Navajo Times*. https://navajotimes.com/reznews/ntec-proposes-solar-array-at-navajo-mine/

Yurth, C. (2021, April 16). Grassroots effort provides solar power to 12 off-grid HPL homes. *Navajo Times*. https://navajotimes.com/reznews/grassroots-effort-provides-solar-power-to-12-off-grid-hpl-homes/