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Stoking the flame: Subsistence and wood energy in rural Alaska, United States

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ABSTRACT

Energy costs are large and increasing in rural Alaska communities, so communities are turning to renewable energy. While, many of these communities have a mixed subsistence-cash economy, the relationship between renewable energy and subsistence has not been studied. Tanana, Alaska has a biomass program and we conducted interviews with 61 households in 2017 to understand how residents perceive the program and its association with subsistence activities. We analyzed Alaska Department of Fish & Game subsistence surveys from 89 communities to estimate differences in subsistence harvest between households that harvest wood and those that do not. Interviews indicated that people who harvest wood for the biomass program were six times more likely to engage in subsistence. Subsistence harvests were nearly double (184 kg/per capita) in households that harvested wood for personal use versus those that did not (101 kg/per capita). Equipment used for both activities was similar, and 57% respondents combined wood harvesting with other activities (e.g. subsistence, travel, etc.). Higher household incomes and employment were positively associated with subsistence participation ($p < 0.001$) while only household incomes was positively associated with wood harvest through the biomass program ($p < 0.001$). Overall, the program was perceived as having a positive effect (69%) for the community because it has created jobs (36%), saved people money (23%), promoted sharing (16%), and reduced fuel use by the community (15%). Our research shows that biomass programs have the potential to complement subsistence activities and enhance the sustainability of communities in rural Alaska that are faced with high energy costs.

1. Introduction

Over 200 communities in Alaska are accessible by only air or water. Most remote and isolated communities depend on islanded microgrids that supply power through distributed generation [1]. Bulk diesel for microgrids is delivered by barge once or twice a year, often within a small, four-month window of opportunity or by air. Importing the diesel fuel required to generate electricity and provide heat to homes is one of the largest annual costs in a community [2]. Heating fuel, electricity, and gasoline costs for remote Alaska households (HHs) may consume up to 47% of annual income for rural Alaskan HHs that earn less than $28,000/yr [3]. High energy costs compete with other basic expenses (e.g., food, transportation) [4].

The economy in many remote northern communities is often a mix of wage-earning employment and subsistence activities [5]. As subsistence equipment has become more expensive and fuel prices have increased, the need for cash income has become more important [6,7]. However, the rates of reliable wage employment are low and unemployment rates are high in rural Arctic communities [5]. When full-time employment is available, it may directly compete with time needed for conducting subsistence activities [4,8]. Participating in subsistence practices is nutritionally, culturally, and socially important to rural residents [9,10]. Food in the village stores is often unaffordable, quality is poor, availability limited and unpredictable, and nutritionally deficient [11–13]. Over 80% and 60% of HHs harvest fish and game, respectively, which is then distributed with extensive sharing networks resulting in most HH using fish (95%) and game (86%) [14]. In total subsistence foods provide on average 25% daily caloric needs for rural residents versus 2% in urban areas [14]. In many northern communities subsistence is key to food security [10,15] and is engrained within the identity of individuals

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and the fabric of communities through sharing, ceremonies, and community events [16]. Ideally, economic programs that balance employment opportunities and allow for flexibility to participate in subsistence may optimize overall community wellbeing.

To address energy costs, increase resilience, and reduce dependence on imported fuel, several communities in the Arctic have worked to develop renewable energy programs that integrate local resources into their energy system [17]. Renewable energy projects are those that produce energy generated from renewable resources such as wind, solar, water, and biomass. Currently, there are over 85 utility-scale renewable energy projects in Alaska [18]. Often the goal of renewable energy is to reduce high energy costs, provide jobs to residents, increase self-sufficiency, and improve resilience in isolated communities [19–21]. Many communities have already illustrated resilience to rapid socio-economic changes [6,16] Renewable energy programs may further buffer rural communities from fluctuations in external socio-economic factors if programs foster the perpetuation of key components of local culture.

When talking about energy and associated costs in the Arctic, subsidies are often mentioned since they play an important role in providing affordable energy [22,23]. Currently there are no subsidies available to communities to maintain and run their community-scale biomass programs [24], but they do exist for residents. The Low-Income Home Energy Assistance Program (LiHEAP) is a federally funded, state-administered program that helps low-income families afford utility bills and energy-related home repairs. Tanana Chiefs Conference facilitates the LiHEAP program for the 39 communities in their region, which encompasses 235,000 square miles in interior Alaska. Funding from LiHEAP can be used to support non-fossil fuel energy production such as biomass, but in order to qualify gross monthly incomes must be low (i.e. $<$ $1,898 for a HH of one, $<$ $4,599 for a HH of five in 2017). Meanwhile, the power cost equalization (PCE) program is a state subsidy at the utility level that reduces residential electricity rates for the first 500 kwh. This subsidy is based on a formula that takes into account the amount of diesel fuel a community utility uses for power generation and the subsequent price of generated electricity. The current subsidy formula, dependent on diesel fuel use, seems to undermine renewable energy and promote dependence on fossil fuels [25]. This subsidy helps reduce the cost of electricity in many villages by half [26,27], but costs are still higher in rural Alaska. Without subsidies, especially PCE, energy and electricity would be unaffordable for many rural Alaskans with limited cash economies.

Biomass in the broad sense is the use of plant material, vegetation, or agriculture waste used as fuel [28]. In Alaska, biomass is often limited to wood and used as a popular form of renewable energy for communities in the boreal forest of interior Alaska [20] because of the high volume of accessible white spruce (*Picea glauca*), black spruce (*Picea mariana*), and balsam poplar (*Populus balsamifera*). Biomass programs involve harvest of wood for market while wood harvest is for domestic use. The Alaska Energy Authority indicates biomass energy focuses on wood-fired systems powered by locally harvested fuels that often heat public facilities [29]. In the region, wood has been used for generations to heat homes, cook, smoke fish, and produce artwork [30]. Seasoned firewood ($<$20% moisture content) has a heating value of around 15 MMBtu/cord, that is equivalent to around 100 gallons of heating fuel (524,279 Btu/liter) [31]. As communities are increasingly using or considering biomass energy, the economic, social, and cultural benefits remain unclear. A few studies have indicated that biomass energy could work well at the community scale for interior Alaska [19,20] and qualitative data exists that suggests such programs are beneficial by providing jobs that are consistent with lifestyles in rural Alaska [32,33]. Our study will help address the gap in formal research examining to what extent biomass renewable energy programs can benefit rural communities and complement local economies and lifestyles.

Our overarching goal is to look at the relationships between a renewable energy program, the economy, and subsistence practices of the community of Tanana, Alaska, and then more broadly across a number of communities located within the interior Alaska. Therefore, our objective was to examine four research questions: 1) how do wood harvest and biomass-related employment opportunities effect subsistence activities in Alaska; 2) to what extent does the community biomass program contribute to the local mixed subsistence-cash economy; 3) how does wood harvest relate to harvest of subsistence foods; and 4) what is the perception of the biomass program by residents.

2. Methods

2.1. Study area

We collaborated with Tanana, Alaska to address our research questions. Tanana (65° 10.317′N, 152° 4.733′W; Fig. 1) is a small (n = 246) predominately Diné Alaska Native (86%) community in interior Alaska [34]. The climate fluctuates greatly during the year with an average low of −28 °C in January to a high of 22 °C in July and receives an average of 29.4 cm of rain and 110 cm of snow annually [35]. The community is at the confluence of the Tanana and Yukon Rivers and has long been established as a trading center among Diné throughout interior Alaska. In 2008, city of Tanana received $400 k in funding from the Alaska Energy Authority's Renewable Energy Fund, and installed their first two wood-fired heating devices (e.g. Garns) in the water plant/laundry building. These devices are fueled by cordwood. The community has since installed another 11 wood-fired systems to heat the school, public works building, firehouse, teacher housing, greenhouse, and a new high-efficiency multi-family residential building. In 2011 a Department of Energy Efficiency Conservation Block Grant ($1.5 M) was awarded to help with Tanana school's energy efficiency upgrades and boiler installations. Overall state and federal grants totaling $2.4 million have been used to build up the biomass program. In 2016, Tanana was connected to the road system. Today, residents use this road to travel to Fairbanks for various reasons including purchasing commercial goods such as food and fuel. Unemployment is high with less than half of adults working year-round (46%) and the average HH income is $45,140 [36].

The extensive use of biomass in Tanana provides an excellent opportunity to examine how a renewable energy project integrates with subsistence activity, and the extent to which it is contibuting to community resilience. The community has chosen to structure the biomass program so local residents are actively engaged and can earn additional income. All HHs use subsistence resources and most harvest subsistence resources (86%). Per capita subsistence harvest averaged 440 kg in 2014 with salmon (*Salmonidae* sp.; 314 kg per capita) and moose (*Alces alces gigas*; 89 kg per capita) the dominant resources [36]. Most HHs use wood (89%) for heating, construction and/or crafts and others use heating oil. Wood heat has provided the community the opportunity to save up to 34,000 gallons annually of diesel fuel to heat the laundromat, water treatment plant, and domestic water lines [37]. Harvesting subsistence food is both culturally and financially important for HHs in Alaska. More than half of the Tanana HHs reported participating in subsistence processing of large land mammals (57%) and fish (51%), while only 52%

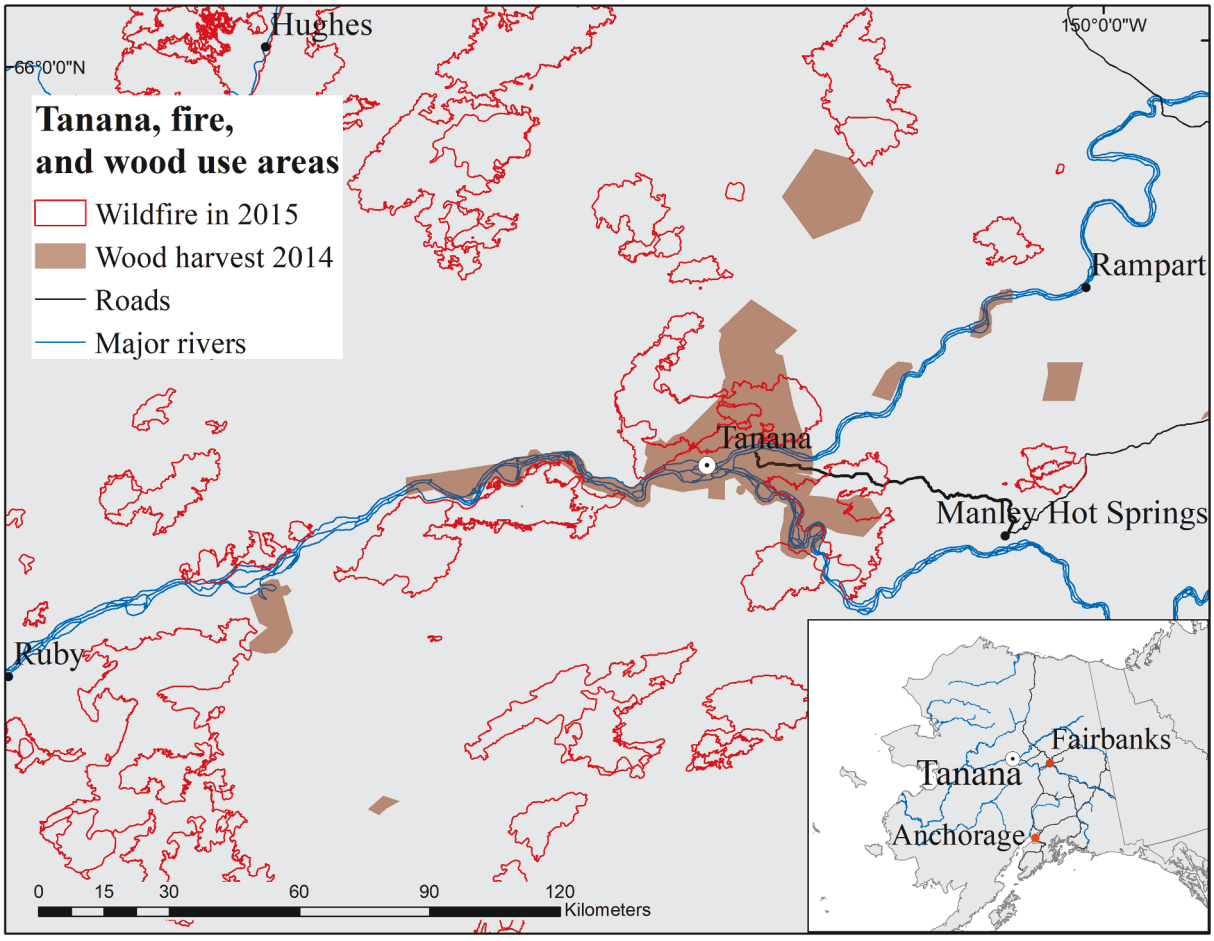

Fig. 1. Tanana wood harvest use areas in 2014 with 2015 wildfire perimeters.

and 40% reported participating in the harvest of these species. Sharing subsistence foods is an important factor in community food security, with 82% of Tanana HHs sharing their harvest with other HHs.

2.2. Interviews and statistics

In November 2017, we interviewed 61 of 96 HHs in Tanana about their participation, perceptions, and attitudes towards the biomass program and participation in subsistence activities in the prior 12 months. However, by limiting the recall period to a year and asking for responses using units that are relatable we hoped to minimize recall bias [38,39]. Also, residents in Tanana are familiar with being asked to recall subsistence activities in the previous year [36]. HHs were selected both with the help of the Tanana Tribal and City Council offices, and opportunistically as residents visited the Tribal Council office. The main survey topics included demographics, economic information, the use and harvest of wood and subsistence resources, and familiarity, participation, and attitudes towards the City of Tanana biomass program, and use of energy subsidies (Appendix A). Participation in the biomass program involves being employed as a wood vendor and receiving money based on the amount of wood harvested. Subsistence participation includes hunting, fishing, and gathering of vegetation, berries, and eggs. We used a mix of closed and open-ended questions allowing participants to provide their thoughts on energy, wood use, subsistence, the biomass harvesting program, and items that associated any of these four topics. The cost of heating oil was $1.19/liter during the interviews and was used to calculate money saved using wood. This research was conducted with IRB approval from the University of Alaska Fairbanks (# 1087928). Interviews were analyzed with a mixed methods approach with qualitative responses transcribed and analyzed in Atlas.ti. Quantitative data was analyzed with basic statistics (i.e. means and frequencies). Differences among categorial variables were assessed with a parametric *t*-test (Chi-square) or non-parametric test including Wilcoxon rank sum *t*-test and Kruskal-Wallis one-way ANOVA ($\alpha = 0.05$) [40]. For analyses that included employment as a variable, retired HH were re-classified as unemployed ($n = 5$).

2.3. Subsistence household (HH) surveys

The ADF&G conducts subsistence HH surveys throughout rural Alaska [41]. The purpose of these surveys is to document customary and traditional uses of fish, game, and vegetation [42]. These surveys are conducted at the HH level and contain information on HH demographics and harvest amounts (kg) in the previous 12 months. Demographics

include HH size, employment status, and number of HH residents 16 years or older employed in the last 12 months. Subsistence harvest (kg) was normalized by HH size since the latter could influence overall harvest amounts (e.g. per capita harvests). This dataset was used to compliment the interviews and explore personal wood and subsistence harvests, HH size, and income at a broader spatial scale. We used data collected from 91 communities (2009–2015) to run a non-parametric Mann-Whitney *U* test to assess whether per capita HH harvests differed among HHs that harvested wood or had at least one employed resident. Two communities did not have the required employment data. Since our per capita subsistence harvest were non-normally distributed we also performed a non-parametric one-way ANOVA (i.e. Kruskal-Wallis) to assess the relationship between HH wood harvest and employment on per capita subsistence harvest ($\alpha = 0.05$) [40].

Two-way analysis of variance (ANOVA; $\alpha = 0.05$) was used to test for the relationship between wood harvest and employment and interactions on per capita subsistence harvests. Even though per capita harvests are not normally distributed ANOVA is robust to violations of non-normal distribution [43]. We also used non-parametric t-tests on each variable to confirm our results from the parametric two-way ANOVA. Results were similar between the t-tests and ANOVA so we report the two-way ANOVA.

3. Results

The following results are based on two data sources: ADF&G subsistence HH surveys from numerous communities and interviews conducted in Tanana. Both examine wood harvest and subsistence, but the Tanana interviews provide deeper insight into biomass programs and energy costs.

3.1. Relationship between wood harvests and subsistence harvests

Interviews with Tanana residents confirmed that wood harvest and use and subsistence continue to be key components of lifestyles among residents. A majority of HH interviewed use wood as their primary source of heat (74%, n = 42 of 57). Residents harvest a mix of standing wood (7.6 cords/annually) and driftwood either along the riverbank or while boating (4.7 cords/annually). Most HH participate in subsistence activities (64%, n = 39 of 61) and only four these HH did not harvest wood. While out looking for subsistence resources over half returned with wood even though it was not their primary reason for going out (56%, n = 22 of 39) and half (54%, n = 21 of 39) also made a mental note of available firewood for later harvest. Residents estimated they saved $1,611 annually on heating fuel by using wood and wood vendors on average made $2,568 in the prior 12 months. Besides monetary benefits, residents reported that wood provides a nice source of heat (87%, n = 52), reduces their energy costs (85%, n = 52), buffers them against changes in heating oil prices (74%, n = 45), and exercise (72%, n = 44).

ANOVA results from the ADF&G subsistence HH surveys indicated a significant relationship among wood harvest ($F = 47$, $\chi = 510$, $df = 1$, $p < 0.001$) and employment ($F = 1$, $\chi = 105$, $df = 1$, $p = <0.001$) with subsistence per capita harvests ($p = <0.001$), but the dominant factor is wood harvest (Fig. 2). Average per capita subsistence harvests were nearly double in HHs that harvested wood (184 kg/per capita) versus those that did not (101 kg/per capita; n = 5,700, Wilcox *t*-test $p < 0.001$). HHs with at least one resident employed in the prior 12 months harvested significantly more subsistence foods (142 kg per capita) than those with no employment (115, n = 5,239; Wilcox *t*-test $p < 0.001$).

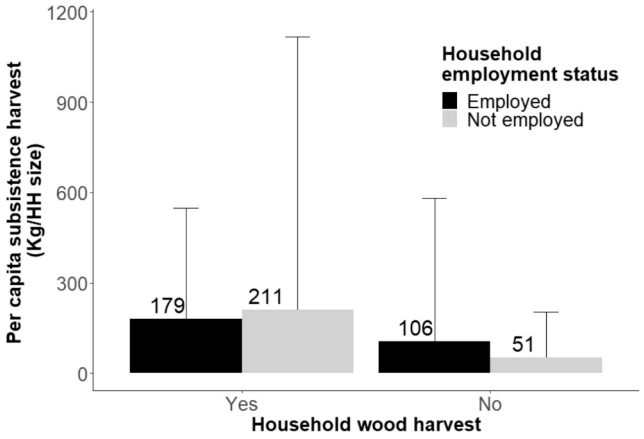

Fig. 2. Per capita subsistence harvest (Kg/household size) among households with 89 communities (2009–2015) that harvest wood and have at least one person 16 or older who worked in the previous 12 months. Data source: Alaska Department of Fish and Game, Division of Subsistence.

Interviews revealed several factors were associated with the means, location, and time when wood is harvested. Most HHs used snowmachines 38% (n = 23) to harvest land-based firewood, followed by boat 26% (n = 16), truck 16% (n = 10), and ATV 10% (n = 6). HHs harvesting driftwood from the river used boats 39% (n = 24) of the time, followed by truck 13% (n = 8), ATV 11% (n = 7), snowmachine 7% (n = 4) and 10% (n = 6) used other methods, including non-motorized transport. Residents also decide where to look for harvestable wood when they are traveling for other purposes which can give HHs an idea of where firewood might be available for later pick-up. Thirty-five percent (n = 21) of HHs make a note of the location of harvestable wood when they are hunting. Thirty-seven percent (n = 22) of HHs harvested wood when that was not the intended purpose of a trip. Thirty-one percent (n = 19) collected wood when on fishing trips, 28% (n = 17) when hunting, 18% (n = 11) when gathering eggs and berries, 16% (n = 10) when camping, 15% (n = 9) when traveling between communities, and 5% (n = 3) when traveling for other purposes. Even though wood harvest and subsistence are common activities, some people do not or cannot participate either. Of 21 HH who said their ability to harvest wood has declined in the last 5 years, 57% (n = 12) reported the decline was due to personal reasons such as health or personal obligations.

3.2. Integration of the biomass program in Tanana with subsistence and the local mixed subsistence-cash economy

Our interview participants were an average of 55 years old (range = 24 – 88, SE = 15) and lived in Tanana for an average of 37 years (range = 2 – 69, SE = 20). Average HH size was 2.5 people (range = 1 – 7, SE = 1.5) and average annual HH income was $48,934 (SE = $32,520). Nineteen percent of that income went towards energy (i.e. electricity, heating oil, gas/propane). Electricity was the largest cost (x= $2,178, SE = $2,107) followed by heating oil (x = $1,978, SE = $2,097), gas/propane (x = $1,360, SE = $2,437), and firewood (x = $435, SE = $566). Most HH heat with wood as their primary source of heat (70%, n

= 35 of 50) while others use vented oil heaters (Monitor/Toyostoves) (18%) or furnaces (12%, n = 6). In 2016, most HH harvested wood (78%, n = 47) and spent approximately $616 on fuel, engine oil, and other costs.

Even though most interviewed HH in Tanana harvest wood (78%, n = 47 of 60), fewer HH participated in the biomass harvesting program (30%, n = 16 of 54), but most HHs are aware of the biomass harvesting program (82%, n = 54). HHs that harvest wood for the biomass program, were six times more likely to engage in harvest of subsistence foods. Most HH that participated in the biomass program also hunted or gathered subsistence resources (81%, n = 13 of 16). Being a wood vendor was significantly associated with increased participation in subsistence (χ = 4.0, df = 1, p = 0.04, Table 1).

Table 1
Relationship between characteristics of residents and their participation in subsistence, level of wood harvest, and satisfaction in the biomass harvesting program. Significance at the α = 0.5 level. Comparing a category with itself is not applicable (–).

Characteristics	Effects on: Subsistence participation	Wood harvest	Satisfaction
Harvest wood (Y)	Increase*	–	NS
Wood vendor (Y)	Increase*	NA	NS
Income (Higher)	Increase+	Increase+	NS
Education (More)	None	NS	NS
Satisfaction (Y)	NS	NS	–
Subsistence harvester (Y)	–	Increase*	None
Household size (Larger)	Increase*	Increase*	NS
Employed (Fulltime)	Increase with employment^	Increase, NS	NS

# Indicates a significant different in means across more than two groups (ANOVA).
* Indicates a significant difference in a test of equal proportions (Fisher exact test).
^ Indicates a significant trend in proportion across ordinal groups (chi-squared test of trend in proportions).
+ Indicates a significant difference in means (Welch's *t*-test).

Those who harvested wood, either for personal use or for the biomass program, tended to have higher incomes (t = -2.8, df = 46, p < 0.001, Table 1). On average wood vendors made $3,489 in 2016 (SE = $2,365, n = 7) and a few others made money selling wood outside the program (x = $417, SE = $161, n = 4). In total $25,675 was paid to wood vendors with an average rate of $350/cord. Overall, HHs using wood estimated they saved $1,479 or 1,245 L of heating fuel annually (n = 18 of 51, $17.03/liter). HHs with fulltime employment were more likely to participate in subsistence than part-time/seasonal, or unemployed (χ = 9.1, df = 1, p < 0.001, Table 1), but there was no relationship between participation in the biomass program and employment.

3.3. Perception of the biomass program by residents of Tanana

Overall interviewed residents were satisfied with the biomass harvesting program (69%, n = 34 of 49) while only (n = 3) were unsatisfied. There were no statistically significant relationships with satisfaction (Table 1). The most mentioned benefit was the employment opportunity (Fig. 3). Drawbacks included air pollution and difficulty finding wood for personal use. While the biomass program does not provide heat for individual homes, residents recognize that it saves the community money and less fuel is needed. A quarter of HH said that harvest of wood for biomass affected their ability to get subsistence foods (25%, n = 14 of 56). Most people believe that in the last 10 years HH wood harvest had not changed (47%, n = 25), but harvest location has changed for 40% (n = 17 of 41) of the HH largely due to personal reasons (35%) and recent wildfire activity (18%; Fig. 1). As part of the biomass program the state of Alaska made an agreement with City of Tanana to place some of the wood from road construction at end near Tanana which residents said increased wood availability (19%, n = 10). Lastly, while personal use of wood helped buffer residents against changes in oil prices, fewer HH thought that the biomass harvest program itself provided a buffer (33%, n = 17).

3.4. Household energy subsidies in rural Alaska and Tanana

Energy assistance subsidies are important in Tanana, and 53% (n = 32 of 61) of HHs interviewed receive home energy assistance. The exact origin of the subsidies was difficult for residents to pinpoint, but HH

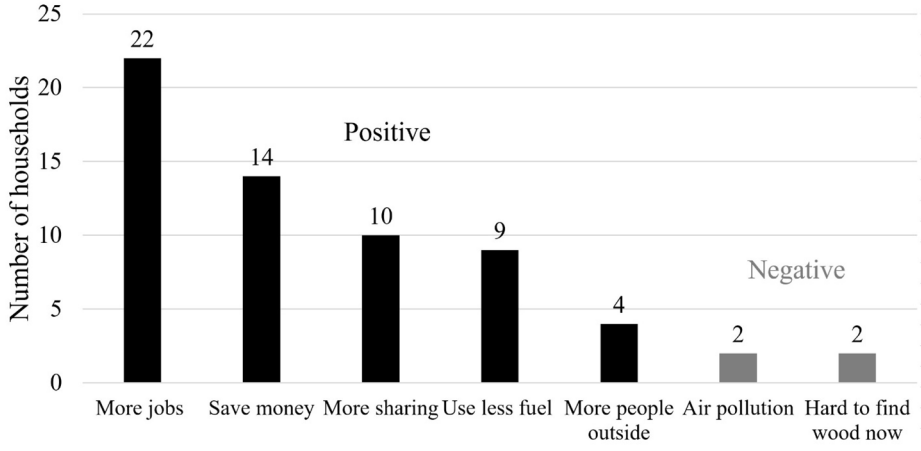

Fig. 3. Perceptions of the biomass program among residents in Tanana in 2017 (n = 61).

reported receiving subsidies for firewood (39%, n = 24), energy such as PCE (33%, n = 20), fuel oil vouchers (8%, n = 5), and heating (5%, n = 3). Subsidies were main item that affected their fuel (i.e. heating and gasoline) costs (34%, n = 21 of 61) followed by construction of the road (28%, n = 17), transportation method used to deliver fuel (11%, n = 7), and global prices (10%, n = 6).

4. Discussion

The use of surveys focused on the biomass energy program and a broader analysis of subsistence surveys across communities in interior Alaska indicate that there is a strong relationship between the practice of harvesting wood and other subsistence harvest activities. Surveys of Tanana residents found that there were relationships between subsistence activities and wood vending, income, education and employment while our broader analysis of communities across interior Alaska demonstrated that employment had the strongest relationship with wood harvest. Overall satisfaction with the biomass program was high indicating renewable energy projects may provide benefits beyond energy and costs savings.

High fuel costs, isolated power systems, and the desire of communities to becomes less dependent on imported fuel has prompted the expanded use of renewable energy in rural Alaska and Canada [23,44]. Renewable energy projects that integrate well with local culture can increase their sustainability while providing benefits beyond energy production [33]. Creation of jobs, income, and knowledge are all direct benefits that can be reaped from successful renewable energy programs. Like our biomass example, the Chaninik Wind Group in rural Alaska has established a successful wind program that trains local residents to maintain and repair wind turbines in five communities [45]. In general, more research is needed to better understand the relationships between rural livelihoods (e.g., subsistence) and renewable energy programs (e.g., wind, solar, hydroelectric). In Nunavut, one reason for the slow expansion of renewable energy is a lack of clarity of how renewable energy will impact the livelihoods of remote communities [46]. Madriz-Vargas, Bruce [47] found that having strong integration with local social structures was key to renewable energy success in South America. Biomass has the potential to strengthen the mixed subsistence-cash economies of northern communities [33,48]. Our research is the first to examine the extent to which biomass programs align with subsistence activities and local economies. The influx of cash from the biomass program and compatibility between wood harvesting and other subsistence activities, indicate favorable alignment between biomass programs and mixed economies. Several challenges were also identified related to the long-term sustainability of biomass programs in small remote communities. These included the capital needed support high labor costs, a small labor pool, and diminishing availability of cordwood in easily accessible locations.

Employment was the top perceived benefit from the biomass harvesting program, though only seven people were identified as paid wood vendors during our survey. The perceived benefit of employment may be due to residents basing their perceptions over the lifespan of the project, in which many people have been employed. Since employment is hard to obtain in remote communities [5,49] any opportunity for jobs is valued. When cash generated through the wood vendor program is spent in the local store or used to purchase equipment for subsistence or wood harvesting the benefits are amplified. A more thorough examination of this effect could be studied through keeping records of employment, payments, and expenditure. However, collaborating with communities over the course of several years to help gather this type of data would be necessary.

Financially HH with wood vendors had higher incomes which may have helped to increase the perception of employment and economic benefits. HH that participated in subsistence tended to have higher incomes and fulltime jobs (Table 1). To ascertain the extent to which income from employment and being a wood vendor was used to bolster subsistence participation would require more research. Several scholars have found that higher HH incomes and employment are linked with increased subsistence harvests [50,51]. Recently Walch, Loring [52] found that lack of money was a common reason limiting peoples use of subsistence resources. By harvesting subsistence foods HH also do not need to rely as heavily on expensive food available at the store [53], potentially increasing HH savings [54]. Given the importance of subsistence, it is crucial that renewable energy projects do not interfere with the environment and ability to harvest resources [46]. Residents in Tanana felt that wood harvest for the biomass did not interfere with their ability to get wood or subsistence activities and had minimal negative impact (Fig. 3). Our research provides empirical support for the ability of biomass to have overlapping social and economic benefits while improving energy security.

Procurement of wood is not something new for residents of rural communities in the boreal forest of Alaska [55,56], however empirically examining the relationship between actions associated with renewable energy and subsistence is novel. We identified a strong linkage between biomass program participation and subsistence, with wood vendors six times more likely to engage in harvest of subsistence foods than HH with no wood vendor. Furthermore, HH with wood harvests had double the amount of per capita subsistence harvests, simultaneously improving energy and food security. Likely reasons for the strong relationship are the use of similar equipment for both activities. Residents of other communities have reported multipurpose trips [4], with both wood and other local resources harvested together opportunistically. Geography, motivations, and sharing also factor into the high levels of wood harvest and preference for wood heat [57]. Tanana is located on the confluence of the Tanana and Yukon Rivers and in a boreal forest. Residents without access to vehicles use chains to harvest driftwood as it floats downstream or walk a short distance (<0.5 miles) from town to find wood [55]. We suspect that even though residents may harvest the driftwood without transportation they borrow it or procure help from other residents to transport it to their house. We did not ask about the extent to which sharing of equipment occurs, but it may be important to follow up on this topic because of the cultural and economic importance of sharing networks in rural Alaska [51]. Motivations for harvesting wood vary but the primary reasons were positive effects on quality of life (i.e. exercise, getting outside, etc.) and financial (i.e. reducing energy costs and buffering against fuel prices). Both subsistence and wood harvest require time outside and a connection to the land which are culturally important [30]. Since not everyone can harvest, wood sharing is very common and the act of providing for others is engrained into traditional values and provides social roles for individuals within a community [16,58].

Sustainability of biomass programs is complex. However, there are some key factors that can help increase the sustainability of programs. Biomass projects often require large amounts of wood, which means communities need to develop a sustainable harvest plan (Fresco and Chapin 2009). Fortunately, communities within interior Alaska have the added benefit of working with the Tanana Chiefs Conference (TCC) and their energy conservation team to help develop forest management and harvest plants. TCC supports communities in planning for their biomass

programs by helping them determine the size of boilers, identify harvest areas, and by providing education about sustainable harvest practices. Previous research has indicated that biomass programs have the ability to reduce vulnerability to changes in fuel prices [19,20], but we only found partial support for this. One factor that potentially weakens this relationship is subsidies. Subsidies were perceived as having a much greater impact on reducing vulnerability to oil prices (34%) than the biomass program (5%). Every residential HH is eligible for a PCE subsidy resulting in a 50% reduction in electricity bills for the first 500 kWh/month [26]. Removal of this program would affect disposable income. While people used wood to reduce their total costs, these savings are predictable and residents are accustomed to this benefit [57]. What is more unpredictable is the availability of subsidies especially within a state dependent on oil revenue for a large portion it its budget [22,59]. The coupled high use and variability of subsidies likely contributes to the perceived lower effect of the biomass program. Less than a quarter of HH felt the program saved money, indicating the value of finding ways to directly benefit HH. Currently the wood boilers only reduce fuel used to heat buildings owned by the City of Tanana, Tanana Tribal Council, and the school. There are current efforts to use biomass heat a greenhouse that produces local food which may increase the positive effects for HHs.

Overall biomass projects fired by cordwood, such as the one in Tanana, have the benefit of having a lower capital investment, but are labor intensive [48]. The surplus wood at the end of the road helped to reduce some of the labor costs associated with maintaining the program, however with this wood source no longer being available, high labor costs have become a challenge. Having a long-term plan for sustainable wood harvest is important that includes clearly identified harvest areas and the capital to meet the labor needs either with personnel or equipment. Tanana is currently struggling to keep the 11 cordwood boilers operating due to limited access to their wood lot and human capital to meet the labor needs. The number of cordwood boilers in Tanana far exceeds those installed in similarly sized communities and may be too many for a community of only 250 residents to support a limited labor pool. Continual maintenance is also critical for keeping the boilers operating. To achieve sustainable biomass programs communities, need to develop a large enough labor pool of wood vendors, wood boiler operators, and maintenance workers. One solution developed by the Chaninik Wind Group to address labor shortages was to develop a pool of laborers that work in multiple surrounding communities as needed, which may be one model that could be adopted by Tanana in collaboration with other communities in interior Alaska [45]. Promotion of renewable energy programs that integrate culture, local residents, and energy independence are key to a sustainable future. Communities in rural Alaska are not new to the challenges of maintaining long-term community programs and given the local support for the program a solution will likely be found.

5. Conclusion

While many papers examine feasibility of renewable energy from a wider view (i.e. policies, regulatory issues, infrastructure, etc. [60,61] this research offers in-depth analyses that explore positive and negative impacts at the community level. Energy security is not only about providing access or availability to energy, but also utility (i.e. socially acceptable (i.e. suitable) [62]. Understanding the acceptance and perceptions of renewable energy is key to facilitating their sustainable development in northern communities [46]. There is an absence of published papers that have explored the nexus between renewable energy programs (solar, wind, hydro) and subsistence. Designing projects with benefits that extend beyond renewable energy to rural lifestyles and economies is important for improving the likelihood that projects will be accepted and sustained long-term [33]. Our research shows that biomass programs are synergistic with mixed subsistence-cash economies common among remote northern communities and help support a desired way of life. In addition to the economic benefits of biomass renewable energy, there are many non-monetary benefits to communities such as equipment sharing, exercise, and increased knowledge of the landscape and resources for other subsistence activities. These non-monetary benefits highlight some of the shortcomings of only considering the financial payout of renewable energy programs to residents. The challenges in maintaining biomass programs are not insignificant. However, working with nearby communities could help overcome shortages in trained workers. Documenting the financial payouts and savings could help illuminate community wide benefits and encourage more people to become wood vendors. Overall, even if the economic impact appears to be small, benefits radiate through small villages providing important roles, well-being benefits, and social continuity. In conclusion, our study highlights the importance of implementing energy security strategies that complement local lifestyles.

Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Table A1

Table A1
Survey instrument used for interviews with households in Tanana, AK during November 2017.

Predicting how subsistence wood harvest activities can result in additional socioeconomic and active habitat management						
Survey Questions					HH ID Interviewer Date Audio file	
I'd like to ask you about your wood harvest and heating oil use **in 2016**						
Please answer these questions to the best of your ability, and if you have questions please ask and I will try to explain the question to you						
1	Do you have a …..?	Yes/No	Does it heat your house?			When do you typically use it?
	Toyo or Monitor Stove					
	Boiler that heats your home with hot water					
	Furnace that heats your home with hot air					
	Wood stove					
2	What is your primary source of heat?					
	If no wood use, move on to question 6.					
		1–25%	26–50%	51–75%	76–99%	100%
3	What proportion of your household heat comes from wood?					
						None
		Yes	No			
4a	Did you or someone in your household harvest wood in the last year?					
4b	Why did or didn't you harvest wood?					
		Yes	No			
5a	Did your household purchase firewood?					
		Yes	No	Why?		
5b	If yes, has the cost of wood changed in the last 5 years? Why?					
		Yes	No			
5c	If yes, did you receive financial assistance, like LiHeap or other financial assistance, to purchase firewood?					
		Yes	No			
6a	Did you get paid to harvest firewood in 2016?					
		Amount ($)	Amount (Units)			
6b	If yes, how much did you get paid and how much did you harvest?					
		Yes	No	Why?		
7a	Has your ability to harvest wood changed in the last 5 years? If yes, why?					
		Yes	No	Why?		
7b	Has your ability to make money from wood harvesting changed in the last 5 years? If yes, why?					
		Yes	No			
8a	Do you trade or barter wood you have harvested?					
		Yes	No			
8b	Do you trade or barter access to a wood harvesting site?					
8c	If yes, what do you typically trade or barter for?					
		Heating	Cooking (including dogs)	Handicrafts	Construction	Transportation (raft)
9a	What do you use the harvested wood for?					
	Other					
			Firewood	Driftwood		
10	In what months do you harvest firewood?	**Month**	Unit (Cords, feet, etc.)	Unit (Cords, feet, etc.)	Comments	
	How much do you typically harvest in that month?	January				
		February				
		March				
		April				
		May				
		June				
		July				
		August				
		September				
		October				

(*continued on next page*)

Table A1 (*continued*)

Predicting how subsistence wood harvest activities can result in additional socioeconomic and active habitat management						
		November December Location description	Transportation Used	Month (s)	Do you harvest other resources in this location?	
11	Where do you **look** for wood (point to locations on a map) Where do you **harvest** wood (point to locations on a map)					
		Yes	No			
11a	In the past 5 years has your harvest area for firewood changed? If yes, please explain why. Also draw on map areas that used to be good but are not anymore.					
		Increased	Decreased	Stayed the same		
12a	Has your household wood harvest increased or decreased over the last 10 years?.					
12b	Why?					
		ATV	Truck	Boat	Snow Machine	Other
13a	Do you currently have a working ATV, snow machine boat, truck?					
13b	What mode of transportation do you typically use to harvest firewood (check one box)?					
13c	What mode of transportation do you typically use to harvest driftwood (check one box)?					
		Yes	No			
14a	In 2016, Did you hunt large mammals, small mammals, fish, hunt waterfowl, gather berries or plants, or gather eggs.					
		Yes	No			
14b	When you hunt for subsistence foods (moose, caribou, etc.) do you remember where good firewood may be for later harvest?					
		Yes	No			
14c	In 2016, did you ever harvest wood when that was not the primary reason for your trip?					
		Hunting	Fishing	Gathering eggs, berries	Camping	Traveling
14d	If yes, what were you doing (check multiple boxes)?					
						Other
		1–25%	26–50%	51–75%	76–99%	100%
15	What percentage of the time did you find or get firewood?					
						None
		Yes	No			
16a	Are there times when you cannot find enough firewood for you to use?					
		No dry wood	All close wood is cut	Don't have transportation	Can't afford gas	Other
16b	If no, why can't you find wood?					
		Yes	No			
17a	Are there people or households that are more vulnerable to not getting enough firewood?					
17b	If yes, what makes them more vulnerable?					
	For the next questions it depends if wood or heating fuel is the primary source of heat.					
		Outside Temperature	Fuel Cost	Wood availability	Almost out of fuel	Heating Assistance Changes
18a	If firewood is your primary heat source, when do you use heating fuel?					
18b	If fuel oil is your primary heat source, when do you use firewood?					
		Yes	No	NA	DN	
19a	Has your household saved money by using wood in the last year?					
19b	If so how much do you think your household saved in the last year?					
19c	If yes, did those saving help you do or purchase something that you wouldn't have purchased?					
		Yes	No	Explain		
20	Do you know about the Tanana community biomass program? If no, skip to 20f					
		Yes	No	Explain		
20a	Do you participate in the Tanana community biomass program?					
		Yes	No	Explain		
20b	Has the Tanana community biomass program changed how important fuel prices are to your household?					

(*continued on next page*)

Table A1 (*continued*)

Predicting how subsistence wood harvest activities can result in additional socioeconomic and active habitat management						
20c	How satisfied are you with the biomass harvesting program in Tanana?	Very Satisfied	Satisfied	Neutral	Unsatisfied	Very Unsatisfied
20d	Why are you satisfied or unsatisfied? (Ex. More people out collecting wood, so it is harder to find, more trails so it easier to access, I make money selling firewood)			Circle if any are mentioned	More jobs Use less fuel Air pollution Save money More people out More sharing Hard to find wood now	
20e	Have wood prices changed since the biomass harvesting program started?	More	Less	Same		
20f	Has wood availability changed? If so, how?	Yes	No	Explain		
21	Has the road to Tanana influenced you? If so, how?	Yes	No	Explain		
22	Has the LIHEAP program changed how important fuel prices are to your household?	Biomass	Road	LIHEAP		
22a	Which has the biggest influence on fuel prices	Reducing energy costs	Physical activity	A heating source	Fuel prices affect me less	Other
23	What is the biggest benefit to harvesting and using wood? Please rate each category: **Strongly disagree, disagree, neutral, agree, and strongly agree**					
24	Do you know how much heating fuel you use annually and how much it costs?	Amount (gallons)	Cost ($)			
25	Do you know how much you spend getting firewood annually, including travel costs?	Cost ($)				
26	Does wood harvesting around the community affect the availability of subsistence foods?	Yes	No			
	Final Questions					
27	Are you Alaska Native?					
28	How long have you lived in Tanana? (years)					
29	What year were you born in?					
30	How many people live in your household?	HH size	# of Adults	# of children		
31	In what year was your house built?					
32a	Have energy efficiency upgrades been made since you moved into your house? If so, what and when?	Yes	No	What and when		
32b	If yes, what upgrades?					
33	Please identify your current job status	Full-Time	Part-Time	Seasonal	Unemployed	Retired
		On - call Heating assistance	Energy assistance	Fuel voucher	NA	DN
34	Do you receive heating or energy assistance, including fuel vouchers? If so how much in 2016					
35	Is your household in the LIHEAP program?	Yes	No			
36	How far did you go in school?	High school	Community college	Some college	4-year degree	Graduate degree
37	Roughly how much did your household earn in 2016?	Amount ($)				
38	Last year how much did you spend on …. If the person cannot say an amount, ask about percent of income and note this *** **End of Survey** ***	Electricity ($)	Heating Fuel ($)	Gas ($)	Firewood ($)	

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