Forest Policy and Economics 73 (2016) 58–67

Contents lists available at ScienceDirect

Forest Policy and Economics

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

Social preferences toward energy generation with woody biomass from public forests in Montana, USA

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ARTICLE INFO

Article history:
Received 15 February 2016
Received in revised form 6 July 2016
Accepted 30 August 2016
Available online 7 September 2016

Keywords:
Renewable energy
Woody biomass
Choice modeling
Willingness to pay

ABSTRACT

In Montana, USA, there are substantial opportunities for mechanized thinning treatments on public forests to reduce the likelihood of severe and damaging wildfires and improve forest health. These treatments produce residues that can be used to generate renewable energy and displace fossil fuels. The choice modeling method is employed to examine the marginal willingness of Montanans' to pay (MWTP) for woody biomass energy produced from treatments in their public forests. The survey instrument elicited social preferences for important co-benefits and costs of woody biomass energy generation in Montana, namely the extent of healthy forests, the number of large wildfires, and local air quality. Positive and statistically significant MWTP is found for woody biomass energy generation, forest health and air quality. MWTP to avoid large wildfires is statistically insignificant. However, MWTP for woody biomass energy diminishes quickly, revealing that Montanans do not support public forestland management that produces more than double the current level of woody biomass harvested for energy generation. These findings can be used by policy makers and public land managers to estimate the social benefits of utilizing residues from public forest restoration or fuel treatment programs to generate energy.

1. Introduction

In 2009, about 83% of energy consumed in the United States came from coal, oil and natural gas (EIA, 2010). In order to reduce greenhouse gas emissions and reliance on imported fossil fuels, the United States government has passed legislation aimed at decreasing fossil fuels use through increased efficiency and increased production of renewable solar, wind, hydroelectric, geothermal and biomass energy (United States Congress, 2005; United States Congress, 2007). About 2% of all energy generated in the United States, representing 24% of renewable energy, presently comes from woody biomass (EIA, 2010), and studies have found that woody biomass could potentially supply up to 10% of US energy needs (Zerbe, 2006). A major barrier to expansion of woody biomass energy in the US has been its high production cost relative to fossil fuels (Gan and Smith, 2006). However, there are significant negative externalities created by the extraction, transport, and combustion of fossil fuels for energy generation (National Academy of Sciences, 2010) and potential positive externalities associated with woody biomass energy that, if accounted for, may make woody biomass energy a socioeconomically efficient component of the energy portfolio in the US.

In order to place a dollar value on the externalities associated with energy generation, nonmarket valuation techniques are required. Nonmarket valuation studies have been used to quantify the value of a wide range of environmental goods and services associated with renewable energy generation, including reduced greenhouse gas emissions (Roe et al., 2001; Longo et al., 2008; Solomon and Johnson, 2009; Susaeta et al., 2011; Solino et al., 2012), improved air quality (Roe et al., 2001; Bergmann et al., 2006), enhanced preservation of landscape quality (Álvarez-Farizo and Hanley, 2002; Bergmann et al., 2006), reduced wildfire risk (Bergmann et al., 2006; Solino et al., 2012) and preservation of wildlife habitat and biodiversity (Álvarez-Farizo and Hanley, 2002; Bergmann et al., 2006). Positive willingness to pay (WTP) has also been found for non-environmental attributes including energy security (Longo et al., 2008; Li et al., 2009) and rural employment (Solino et al., 2012).

Few studies to date have attempted to value externalities associated with woody biomass energy generation specifically. Susaeta et al. (2011) used a choice modeling exercise to assess preferences toward externalities associated with woody biomass energy in Arkansas, Florida, and Virginia. Respondents had positive (but statistically insignificant) WTP for improved forest health, reductions in CO_2 emissions and improvement of forest habitat from reduced wildfire risk. Because

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http://dx.doi.org/10.1016/j.forpol.2016.08.008
1389-9341/

almost 90% of forest lands in the Southern US are privately owned, little of the woody biomass described in the Susaeta et al. (2011) study would come from public lands. In the absence of financial incentives, including markets for carbon, applications of the findings of this study to inform and influence private forest management and woody biomass energy generation appear limited. Solino et al. (2012) found positive WTP in Spain for reduced greenhouse gas emissions, reduced risk of forest fire and reduced pressure on natural resources associated with the utilization of woody biomass for electricity generation.

The US west has unique geographic, ecological, and socioeconomic characteristics - perhaps the most significant of which in this context is the high proportion of public lands compared to other parts of the country. For example, over one-third of the land area of the US state of Montana is owned by the state and federal governments. No past studies have evaluated social preferences regarding woody biomass energy in the western United States, nor have previous studies evaluated preferences specifically toward feedstock generated by forest restoration treatments on public forests. This is an important distinction because optimal decision making with regards to biomass harvesting differs between private landowners and social planners because of differences in private and social accounting of other amenities provided by forests (Hallmann and Amacher, 2014). Additionally, compared to landscapes dominated by private ownership, public preferences are more relevant to, and can be more readily accommodated within, forest management and policy in the western United States.

This study used choice modeling to examine public preferences toward the utilization of woody biomass from public forests for energy generation in Montana. Preferences were characterized in terms of WTP for increases in energy generated with woody biomass harvested from public forests and for potential effects of changes in public forest management on forest health, the prevalence of large wildfires, and air quality. By determining public willingness to trade-off woody biomass energy generation against important environmental attributes, the results of this study can inform public forest management and renewable energy policy in Montana.

The paper proceeds with a description of the geographic and socioeconomic characteristics of the study area, followed by a description of the development of the survey instrument. The econometric model used to analyze the data is presented next, followed by the results of the study, and finally, the study's main findings and implications.

2. Study area and co-benefits and costs of woody biomass energy

Montana's economy has historically relied heavily on agriculture and resource extraction through logging and mining, and the forest industry still accounts for a significant portion of economic activity in several counties in the state (McIver et al., 2013). As has been the trend throughout the rural West, Montana's economy is increasingly service oriented, fueled by tourism and migration based on natural amenities provided by the state's public lands, and recreational opportunities (Rasker and Hansen, 2000). Montana is home to multiple national parks and national forests, which were the main attraction for 11 million of the state's visitors in 2013 (Grau et al., 2014). The state has a large, and expanding wildland-urban interface that allows residents to live among the natural amenities they desire, but also places their lives and homes at risk from wildfires (Rasker, 2014).

Of the 9.4 million ha of forestland in Montana, 3.8 million are classified as moderately or severely departed from natural fire regimes. Forests that are departed from historic fire regimes have increased tree density, structural homogenization, and fuels buildup (Taylor, 2004), resulting from decades of wildfire suppression (Ryan et al., 2013). Forests in these conditions are less able to support native plant and animal species (Huntzinger, 2003; Hiers et al., 2007), are less resilient to disturbances like insect and disease infestation, and more likely to experience unusually severe and damaging wildfires (Schwilk et al., 2009). Forest managers typically mitigate such conditions using mechanized thinning treatments, prescribed wildland fire, or a combination of the two (Rummer et al., 2005). Prescribed fire uses controlled human-ignited fire under favorable weather and fuel conditions to burn excess fuels without igniting the boles and crowns of dominant trees. In contrast, mechanized thinning treatments use heavy equipment to remove and process these fuels, sometimes generating merchantable forest products like sawlogs, pulpwood and woody biomass, which is defined in this context as the limbs, tops, needles, leaves, and other parts of trees and woody plants that are generated as the byproducts of forest management.

Some forestland can be treated with prescribed fire alone, but in cases where very high fuel loads are present, air quality restrictions are in place, or the forest is in close proximity to developed areas, mechanized treatments may be required before, or in place of, prescribed fire (Rummer et al., 2005). Prescribed fire or mechanized forest restoration treatments can increase the area of healthy forests that support a greater diversity of native plant and animal species, and are more resilient to human and natural disturbances like insect outbreaks, non-native invasive species, disease, wildfires and a changing climate (Swanson et al., 1994; Barrett et al., 2012). These treatments can also reduce the severity of large wildfires (Stephens et al., 2009) that can burn homes, damage important municipal watersheds, endanger firefighter and civilian lives, and blanket large areas with wildfire smoke. There is some evidence that, as a result, such treatments result in future fire suppression cost savings, but this effect is difficult to quantify (Thompson and Anderson, 2015).

Woody biomass from timber harvest and fuel treatment is currently used as fuel to generate energy in a number of facilities in Montana, producing 201,000 MW h (MW h) of energy annually (DNRC, 2011; McIver et al., 2013). The majority of this energy is produced by lumber mills that utilize biomass residues created by logging and milling processes to heat and power their facilities, and in one case, to supply electricity to the power grid. Residues from the forest sector are also used to fuel wood heating systems in ten schools and other public buildings throughout the state as part of the United States Department of Agriculture's (USDA) “Fuels for Schools” program. In a case study of one of these wood heating systems, Bergman and Maker (2007) found that the system saved money on fuel costs, with an expected payback period of just under ten years.

Federal legislation like the Healthy Forests Restoration Act of 2003 mandates the federal government to increase the amount of timber harvest and restoration treatment in public forests, and encourages harvesting woody biomass for energy generation (United States House of Representatives, 2003). Mechanized forest restoration treatments typically cut small diameter, subdominant trees with little or no value in traditional timber markets. A woody biomass energy market would provide an outlet for this material and provide revenues to offset the cost of treatments. Additional woody biomass energy generation would also contribute to achieving compliance with the state's renewable energy portfolio standard, which mandates that public utilities and other competitive electricity suppliers serving 50 or more customers obtain at least 15% of their retail electricity from renewable sources as of 2015 (United States Department of Energy, 2015). However, harvesting woody biomass can also have a negative effect on forest health and biodiversity through reduced soil productivity (Thiffault et al., 2011), increasing opportunities for the spread of invasive weeds, and increasing sediment runoff into streams (Shepard, 2006). Additionally, in communities where woody biomass facilities are located, local air quality may be negatively impacted (Chum et al., 2011).

3. Choice modeling survey instrument

Choice modeling is a stated preference non-market valuation technique that allows researchers to estimate the economic values of a set of multiple, divisible attributes, associated with an environmental good. Public preferences toward each attribute are revealed by the choices that survey respondents make when presented with different states of the environmental good, as defined by varying levels of the attributes of which the good is comprised. The various states of the environmental good are generated using statistical experimental design and presented in choice sets that provide multiple alternative scenarios and a status quo option from which respondents must select their preferred state of the world, and in the process, make trade-offs between the levels of the attributes. The inclusion of a price attribute allows for the estimation of WTP for the individual attributes.

Because significant economic benefits are derived from the timber and amenities of Montana's public forests, residents are likely to have strong preferences about public land management policy and practice. In order to determine which socioeconomic and environmental effects associated with woody biomass energy generation are most important to residents of Montana, a focus group meeting was held in Missoula, Montana, in July of 2013. The meeting was attended by stakeholders from the United States Forest Service (USFS), Montana Department of Natural Resources, Montana Department of Environmental Quality, The University of Montana, The Montana Wilderness Association, the forest industry, wildlife and land conservation groups, and local recreation groups.[1] The five most important attributes associated with woody biomass energy identified at this meeting were: homes powered with wood in the state (abbreviated HOMES); unhealthy air days experienced locally (AIRDAYS); large wildfires in the state (WILDFIRES); forest health in the state (FORESTS); and household monthly energy bill (BILL).[2] Each attribute was defined over a ten-year time horizon to provide a realistic time-frame in which to adopt and implement new forest management strategies, while also remaining relevant to respondents. The attributes are defined together with their status quo and alternative levels in Table 1. Quadratic transformations for the choice attributes, also shown in Table 1, are included in statistical models to account for non-linearity in relationships between the attribute levels and likelihood of selecting a particular alternative.

HOMES was used as the metric for biomass energy production based on feedback from focus group participants. It was determined that the number of homes powered would be more easily interpreted than a unit of electric or thermal generation, such as kilowatt hours (kW h) or British thermal units (Btus). The woody biomass energy produced was defined as replacing energy that is currently produced using fossil fuels, and the ability to offset fossil fuel use and reduce long-term impacts of climate change was presented as a benefit associated with HOMES. The assertion of climate change benefits was based on consensus in the scientific literature that the utilization of forest residues from land that stays in forested land use, which is the focus in this study, has the potential to provide long-run climate benefits with no negative short- term carbon balance effects (Gustavsson et al., 1995; Jones et al., 2010; Sathre and Gustavsson, 2011). A detailed discussion of the differing climatic implications of geologic carbon emissions from fossil fuels versus biogenic carbon emissions from biomass fuel, and the numerous factors that affect climate payback times, was not included in the questionnaire, based on feedback during pilot testing that suggested the survey version that did include such information was overly complex.

AIRDAYS was based on the average number of days from 2008 through 2012 that air quality was documented as "unhealthy for sensitive groups" at United States Environmental Protection Agency (EPA) monitoring stations throughout the state, representing the average number of days the average Montanan household is exposed to levels of air pollutant concentrations that are high enough to pose a health risk to older adults, young children and people with specific health concerns (EPA, 2013a, 2013b). The definition explained that long-term exposure to the concentrations of particulate matter present when air quality is "unhealthy for sensitive groups" may pose health risks to all members of the community and reduce life expectancy (Pope et al., 2009).

The WILDFIRES status quo level was determined using a GIS data set from the Monitoring Trends in Burn Severity project (MTBS, 2012). The definition highlighted the average number of homes destroyed annually over the past decade in Montana, but also stressed that the majority of homes were destroyed by a small number of very destructive fires, that the number of fires each year is highly variable, and that wildfires are an important beneficial natural disturbance present in healthy forest ecosystems.

The FORESTS definition emphasized the fact that healthy forests support a greater diversity of native plant and animal species and are more resilient to disturbances. The proportion of healthy forests in Montana was determined using the Vegetation Condition Class classification system, which categorizes the level of departure of current vegetation conditions from a historic reference (Barrett et al., 2010). This proportion includes all forested lands across all ownerships.

BILL, the average monthly household energy bill in Montana was used to define the status quo of the cost attribute (EIA, 2011). This bill includes both electricity and natural gas, or other fuel for heat. Energy bill is an obligatory payment mechanism that is less likely to induce protest responses than a government tax or fee. The annual equivalent of BILL was also provided in the choice sets to decrease the likelihood of respondents interpreting the monthly amounts as inconsequential. The level of BILL was presented as the respondent's total monthly utility bill, rather than as the change in their average monthly energy bill to facilitate accurate accounting of changes in costs by establishing an appropriate absolute starting point at what they currently pay. A potential drawback to this approach is that because the average utility bill varies from respondent to respondent, the status quo level presented will differ from the actual average monthly utility bill of many respondents. However, whether levels of the payment vehicle are presented as a change from the status quo, or as an absolute amount does not computationally affect the ability to estimate preference parameters or welfare measures. In this case, presenting the level of the payment vehicle as an absolute amount was meant to serve a specific purpose. Unlike some applications of choice modeling, where the status quo represents an "opt-out" or "no-purchase option", the status quo in these choice sets does not represent zero-cost option and this approach provides a reminder to respondents that the status quo is not free (see Banzhaf et al., 2001 for more discussion of opt-out alternatives).

Because the experimental design requires that a wide variety of attribute level combinations appear in the choice sets, a statement was made reinforcing the fact that any combination of attribute levels is possible, even if they seemed unlikely to the respondent. Respondents were informed that changes in the level of each of the non-energy attributes were not necessarily tied to a corresponding change in the level of woody biomass energy because factors aside from the level of woody biomass energy can also influence future outcomes of the other attributes. For example, in addition to emissions from energy generation, air quality can be affected by wildfires, prescribed burning, pile-burning of residues, and other sources of emissions. The number of large wildfires varies considerably from year to year and can be affected by drought and climate change. Biomass harvest can have either positive or negative effects on forest health depending on forest-type and harvesting practices.

There are 1536 possible combinations of the attributes and their levels ($4^4 \times 6^1$). Using SAS statistical analysis software and the macros described by Kuhfeld (2010), an efficient fractional factorial experimental design was created with 48 alternative combinations of the attributes. An efficient design size with 48 alternatives was developed

[1] Representatives from tribal forestry, private forest owners, and environmental groups with a strong anti-biomass energy stance were contacted about attending the meeting, but were either unavailable or uninterested in attending the meeting.

[2] A sixth attribute, "Rural Job Creation" was ranked as important and initially included in the survey, but was dropped after peer-review suggested that the survey was overly-complex. "Rural Job Creation" was dropped, rather than one of the attributes, because the economic value of job creation can be estimated from markets, while the other attributes are not presently traded in markets.

Table 1
Definitions of choice attributes and quadratic variables.

Variable	Definition	Levels	Units
Choice attributes			
HOMES	The amount of electric or thermal energy produced from woody biomass produced annually in MT, using residues from restoration treatments on public forests.	10,000, 20,000[a], 30,000, 50,000	Homes per year
AIRDAYS	The number of days per year when air quality is unhealthy for sensitive groups in your community.	5, 10, 15, 30	Days per year
WILDFIRES	The number of wildfires per year that burn at least 1000 acres and threaten homes and watersheds in MT.	6, 9, 12[a], 15	Wildfires per year
FORESTS	The percent of healthy forestland in MT, across all forest ownership categories.	10, 20[a], 30, 60	Percent
BILL	Household average monthly energy bill in MT in US dollars.	80, 100[a], 120, 150, 200, 400	US dollars
Quadratic variables			
HOMES_SQ	Squared value of HOMES		
AIRDAYS_SQ	Squared value of AIRDAYS		
WILDFIRES_SQ	Squared value of WILDFIRES		
FORESTS_SQ	Squared value of FORESTS		

[a] Indicates status quo attribute level.

with 1 status quo and 2 non-status quo alternatives per choice set, and four choice sets arranged in six survey blocks. Respondents were randomly assigned a questionnaire with one of the six versions of the questionnaire.

The 16-page survey instrument contained four sections. Section 1 provided a short introduction and collected information about respondent residence and opinions about energy generation, public land management, and climate change. Section 2 provided background information about energy consumption in the US, forest restoration treatments, and details about what woody biomass energy is, how it is generated, sustainable levels of production from public forests in Montana, and the costs and benefits associated with biomass harvesting and energy generation from biomass. Section 3 defined the attributes and presented the respondent with one block of four choice sets. Respondents were reminded to consider their budget constraints and alternative uses of their income. An example choice set is provided in Fig. 1. Section 4 collected information about the respondents' experience with the survey and sociodemographic information, which allowed comparison between the collected sample and the general population of the state.

A mixed-mode data collection strategy was employed to obtain a stratified random sample of the population of Montana. Respondents were contacted with an invitation letter mailed to their home explaining the purpose of the research and presenting one of the following response options: (a) a web address and unique identification (ID) number that served as a password to complete the survey online, (b)

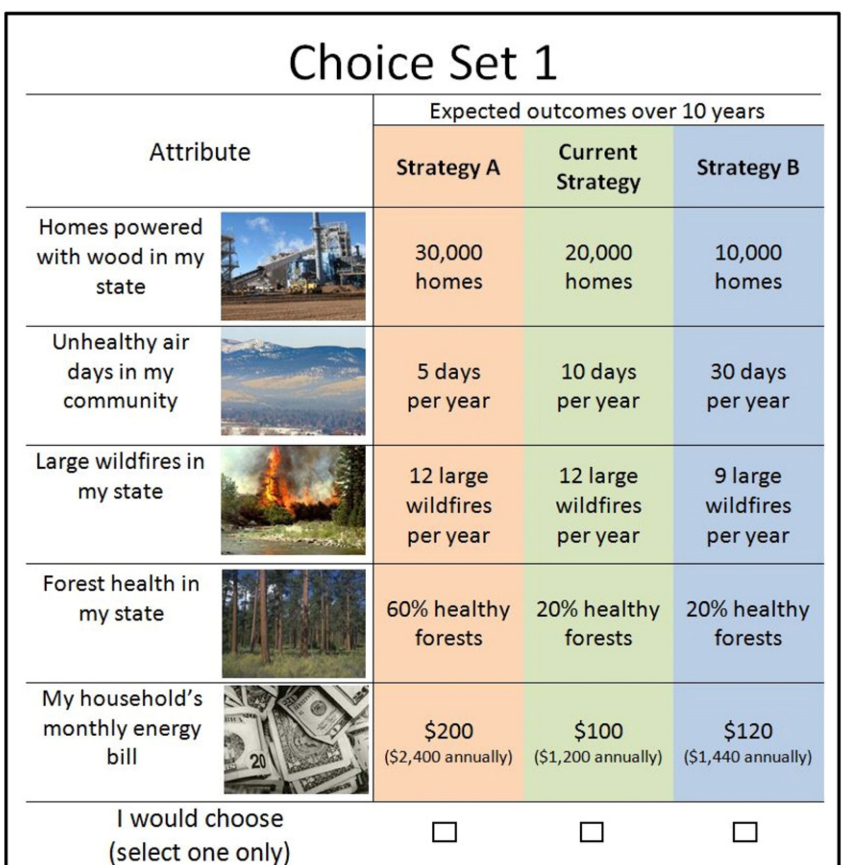

Fig. 1. Example of a choice set used in the questionnaire.

a notification that they would soon be receiving a physical survey packet in the mail, or (c) both a web address with ID number *and* the option to wait and receive a physical copy of the questionnaire in the mail if they did not respond online. Individuals in the online-only group (a) who had not completed the survey after about two weeks received a reminder post-card in the mail. Individuals in the other two survey groups (b and c) were contacted using the four-contact method described in Dillman (2007), which is designed to maximize response rate and minimize non-response bias.

The sample was stratified according to two criteria to ensure coverage of people who live in forested areas and people who live in airsheds with a history of poor air quality. Residents of forested areas were identified using US EPA level III Ecoregions (EPA, 2013a). Poor air-quality airsheds were identified as EPA non-attainment airsheds, which have failed to meet national ambient air quality standards (EPA, 2013b). Residents of forested ecoregions were expected to have stronger preferences toward the WILDFIRES and FORESTS attributes because of their proximity to forestland. Residents of non-attainment airsheds were expected to have stronger preferences toward the AIRDAYS attribute because of their higher levels of experience with poor air quality. Contrary to expectations, preliminary testing of an airshed variable did not produce significant interactions with any of the attributes and was omitted from the final models.

4. Econometric model

The theoretical foundations of the MNL are random utility maximization (Mcfadden, 1973) and the characteristics theory of value (Lancaster, 1966). Random utility explains that the utility associated with a particular alternative from a choice set is composed of both an observable and a random component,

$$U_j = V\left(x_j, p_j; \beta\right) + \varepsilon_j \tag{1}$$

where U_j is the true but unobservable utility associated with the consumption of profile *j*, *V* is the systematic indirect utility function, x_j is a vector of the attribute levels associated with profile *j*, p_j is the cost of profile *j*, β is a vector of preference parameters, and ε_j is a random error term. An individual will only select alternative *i* over alternative *j* if the utility associated with alternative *i* is greater than the utility from alternative *j*.

Assuming the errors in the regression can be described by a Gumbel distribution and are independently and identically distributed, the probability that an individual will select alternative *i* over alternative *j*, can be expressed as

$$P(i|C) = \frac{exp(\mu V_i)}{\sum exp\left(\mu V_j\right)} \tag{2}$$

where μ is a scale parameter inversely proportional to the variance of the error term. By assuming constant error variance, this parameter can be set to equal one (Ben-Akiva and Lerman, 1985).

Two MNL specifications were examined in this study. The first model contained only the choice attributes, represented by Eq. (3). Preferences are assumed to be homogeneous across respondents, which may not hold true because there are individual characteristics that are likely to explain some portion of the preferences that people have toward environmental goods. The second model specification, represented by Eq. (4), was expanded to include socioeconomic and attitudinal characteristics of respondents to account for preference heterogeneity, and squared versions of the attributes to account for non-linearity in relationships between the attribute levels and likelihood of selecting a particular alternative.

$$P_n(i|C_n) = \frac{exp(\beta_{ni}X_{ni} + \alpha C_n + \tau Q_{ni})}{\sum exp(\beta_{nj}X_{nj}\ \alpha C_n + \tau Q_{nj})} \tag{3}$$

$$P_n(i|C_n) = \frac{exp\left(\beta_{ni}X_{ni} + \lambda_{ni}X^2{}_{ni} + \alpha C_n + \tau Q_{ni} + \gamma R_n X_i + \theta R_n C_n\right)}{\sum exp\left(\beta_{nj}X_{nj} + \lambda_{nj}X^2{}_{nj} + \alpha C_n + \tau Q_{nj} + \gamma R_{nj} + \theta R_n C_n\right)} \tag{4}$$

X_{ni} is a vector of terms for the attribute levels encountered by individual *n*; β_{ni} is a vector of associated estimated coefficients; $X^2{}_{ni}$ is a vector of squared attribute levels, with associated coefficient λ_{ni}; C_n is the cost attribute associated with each alternative and α is the associated coefficient; Q_{ni} is an alternative specific constant (ASC), taking a value of 1 for status quo alternatives and zero otherwise, with an associated coefficient of τ; R_n is a vector of case-specific socioeconomic characteristics that is interacted with the alternative-specific attribute-level variables, and has an associated coefficient of γ; and *i* and *j* are as previously defined. The coefficients were estimated using maximum likelihood estimation. Tables 1 and 2 provide descriptions of all the variables used in the models.

The ASC accounts for variation in choice that is not explained by changes in choice attribute levels, average monthly energy bill, or socioeconomic characteristics. Sometimes referred to as "status quo bias", this phenomenon results in decision-makers selecting the status quo at a rate higher than would be predicted by an economic model of consumer decision making (Samuelson and Zeckhauser, 1988). This paper uses the more neutral term "status quo effect" (SQE) to avoid the suggestion that this phenomenon is the result of conscious bias on the part of the respondent or is the result of a statistically biased estimator. There are numerous rational and psychological explanations for the presence of the SQE (Adamowicz et al., 1998; Boxall et al., 2009). Failing to account for the SQE can result in model estimates that overstate the effect of changes in attributes on respondent choices (Samuelson and Zeckhauser, 1988).

In order to obtain policy relevant interpretations of the estimated coefficients, the marginal effects of each attribute must be calculated. Based on the models represented by Eqs. (3) and (4) for attributes 1 through *K*, the average household marginal willingness to pay (MWTP) for a one-unit improvement in the *kth* attribute can be estimated by Eqs. (5) and (6), respectively

$$\frac{\beta_n}{\alpha} \tag{5}$$

$$\left(\frac{\beta_n + \sum_{m=1}^{M}\ \gamma_{nm}G_m + 2\lambda X}{\alpha + \sum_{m=1}^{M}\ \theta_{nm}G_m}\right) \tag{6}$$

where *G* represents the fraction of the population in Montana that falls into each of the *m* socioeconomic or attitudinal categories (as reported in Table 2), λ is the coefficient of the squared attribute level, *X* is the attribute level at which MWTP is being estimated, and all other parameters are defined as above. Based on the method used by Han et al. (2008), Eq. (6) produces adjusted average household MWTP that corrects for the potential that survey respondents were not representative of the demographic characteristics of the study area as a whole.

5. Results

The survey yielded 540 total responses for the state of Montana, of which 488 contained completed choice sets and were included in the data analysis. An additional eight respondents were excluded from the analysis under the assumption that they did not account for budget constraints. These respondents reported household income of less than $25,000 per year and selected profiles with the highest level of energy

Table 2
Sociodemographic and attitudinal variables with Montana and survey sample means.

Variable	Definition	Montana (%)	Sample (%)
SKEPTIC	Dummy variable = 1 for individuals who do not believe in man-made climate change	54.0[a]	50.7
HIGHINC	Dummy variable = 1 for households with annual income > $100K	15.3[b]	18.9
COLLEGE	Dummy variable = 1 for individuals with at least a bachelor's degree	28.7[b]	49.8
SENIOR	Dummy variable = 1 for individuals who are 65 years old or older	16.0[b]	39.5
FORESTED	Dummy variable = 1 for households located within a forested ecoregion	55.6[c]	56.1

Sources:
[a] Yale Project on Climate Change Communication (2014).
[b] Census Bureau (2010a).
[c] Census Bureau (2010b).

bill ($400/month), which represents almost 20% of their income. For each survey mode, the number of responses and the response rate are provided in Table 3. Internet only was characterized by a poor response rate (5.9%), with mail only and mixed mode resulting in 54.1% and 49.7% response rates, respectively. Survey respondents were, on average, older, better educated, and wealthier than residents of the state as a whole (Table 2).

Preliminary questions in the survey revealed respondents have an interest in issues related to the attributes in the choice sets. For example, 88% of respondents agreed that public forests are in need of restoration, to conserve biodiversity, reduce risk of large wildfires, or minimize the impacts of insect and disease infestation. Respondents expressed concerns related to air quality, with 63% of respondents indicating that smoke from wildfires and the burning of slash piles negatively affected the health of people in their community, and 57% of people agreeing that air pollution from cars, industry, power plants and wood stoves negatively affected the health of people in their community.

Respondents were less enthusiastic about woody biomass energy in relation to other energy options, ranking it 6th in preference out of ten options when asked to rank their top three sources of household energy. Hydroelectric was the most popular energy option. Solar (2nd), wind (3rd), natural gas (4th), and geothermal energy (5th) also received more support than woody biomass energy. Woody biomass energy was ranked ahead of nuclear energy (7th), coal (8th), oil (9th), and crop biomass (10th). However, responses to questions about biomass harvest and energy generation revealed generally positive attitudes. For example, a majority of respondents (74%) indicated that they supported higher amounts of woody biomass harvest from public lands to generate energy. Respondents also indicated that they would support biomass energy facilities in their community. Support was higher for small scale biomass energy facilities like ones used to heat schools (76%), than large-scale woody biomass energy facilities that put electricity onto the power grid (61%). In response questions about disposition toward paying a premium for renewable or local energy, less than half (45%) of respondents indicated that they would voluntarily pay higher monthly energy bills for renewable energy, while only 42% indicated that they would be willing to pay higher energy bills for energy that is produced locally.

Table 4 presents the parameter estimates of the two models. It was expected that increases in the level of HOMES and FORESTS would be associated with increased likelihood of an alternative being selected because higher levels of both attributes are benefits. Increases in AIRDAYS, WILDFIRES, and BILL, on the other hand, make the respondent worse off and are expected to decrease the likelihood of an alternative being selected. The coefficients in the base model are all statistically significant at less than the 1% level ($\alpha = 0.01$) and their signs are consistent with expectations. The positive coefficient on the ASC in the base model is statistically significant, suggesting a significant SQE.

In the full model, the coefficients on choice attributes represent the preferences of base-case respondents. Here, the base case represents non-high income earners, who are not seniors, have less than a bachelor's degree in education, do not live in a forested eco-region, and do believe that humans are causing climate change through the burning of fossil fuels. All of the attribute coefficients in the full model have the expected sign and all but the WILDFIRES coefficient were statistically significant at better than a 1% level. Coefficients for *HOMES_SQ*, *FORESTS_SQ*, and *AIRDAYS_SQ* reveal statistically significant diminishing marginal effects of changes in the levels of the attributes on the probability of choosing a particular alternative. As in the base model, the full model has a positive and significant ASC, indicating that respondents

Table 3
Survey response rates.

Survey mode	Sent invitations	Delivered invitations	Responses	Response rate
Internet-only	5433	5059	300	5.9%
Mail-only	174	159	86	54.1%
Mixed-mode	343	310	154	49.7%

Table 4
Regression analysis results.

	Base model		Full model	
	Coefficient	Std. Err.	Coefficient	Std. Err.
HOMES	0.0110***	0.00263	0.0526***	0.0155
AIRDAYS	−0.0436***	0.00486	−0.0844***	0.0246
WILDFIRES	−0.0417***	0.0128	−0.0457	0.115
FORESTS	0.0335***	0.00194	0.159***	0.0141
BILL	−0.00625***	0.000547	−0.00669***	0.000571
ASC	0.345***	0.0675	0.293***	0.109
SKEPTIC × HOMES			−0.0138***	0.00516
SKEPTIC × AIRDAYS			0.0338***	0.0107
SKEPTIC × WILDFIRES			0.0273	0.0252
SKEPTIC × FORESTS			−0.0157***	0.00394
HIGHINC × HOMES			0.0120*	0.00655
HIGHINC × AIRDAYS			−0.000662	0.0127
HIGHINC × WILDFIRES			−0.0188	0.0348
HIGHINC × FORESTS			0.00445	0.00537
COLLEGE × HOMES			0.00186	0.00529
COLLEGE × AIRDAYS			−0.0232**	0.0106
COLLEGE × WILDFIRES			−0.00198	0.0263
COLLEGE × FORESTS			0.00309	0.00411
SENIOR × HOMES			−0.0101*	0.00535
SENIOR × AIRDAYS			0.00279	0.0107
SENIOR × WILDFIRES			−0.0670**	0.0271
SENIOR × FORESTS			−0.00536	0.00407
FORESTED × HOMES			0.00339	0.00531
FORESTED × AIRDAYS			−0.00433	0.0104
FORESTED × WILDFIRES			−0.0427*	0.0259
FORESTED × FORESTS			0.00448	0.00395
HOMES_SQ			−0.000574**	0.000226
AIRDAYS_SQ			0.000961*	0.000561
WILDFIRES_SQ			0.00154	0.00510
FORESTS_SQ			−0.00155***	0.000173
N	5805		5709	
log pseudolikelihood	−1799		−1673	
likelihood ratio test[a]			$p > \text{chi2} = 0.000$	

[a] Null hypothesis of likelihood ratio test is joint insignificance of variables.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

had a preference for the status quo option, regardless of the change in the levels of the attributes.

The negative coefficients on *SKEPTIC* × *HOMES* and *SKEPTIC* × *FORESTS,* and the positive coefficient on *SKEPTIC* × *AIRDAYS*, reveal that respondents who don't believe that humans are causing climate change have a statistically significantly lower WTP for these attributes than respondents who do believe in man-made climate change. The positive and significant coefficient on *HIGHINC* × *HOMES* reveals that high-income respondents have a higher WTP for homes powered with wood. The negative and significant coefficient on *COLLEGE* × *AIRDAYS* suggests that respondents with at least a bachelor's degree are less likely than others to select a strategy where the number of AIRDAYS increased relative to the status quo. Significant negative coefficients on *SENIOR* × *HOMES* and *SENIOR* × *WILDFIRES* reveal that respondents who were older than age 65 were less willing to pay for increases in the number of homes powered with wood in the state, and were more sensitive than others to increases in the number of large wildfires. *FORESTED* × *WILDFIRES* is positive and significant at the 10% level, suggesting that respondents who live in a forested eco-region have a higher WTP to avoid increases in the number of large wildfires.[3]

5.1. Social willingness to pay

Table 5 reports the average monthly household MWTP for the base model and the full model, estimated using Eqs. (5) and (6), respectively. A 95% confidence interval for each value was estimated with 500 bootstrap iterations using the method described by Efron and Tibshirani (1986). The confidence intervals highlight that all average MWTP estimates, except WILDFIRES in the full model, are statistically significantly different from zero. The MWTP estimates from the full model are the focus of the remainder of the paper.

The MWTP of the attributes can facilitate estimation of the economic impacts of changes in the levels of provision of individual attributes. However, because the attributes are measured in different units, MWTP cannot easily be used to compare the relative magnitude of the marginal effects between attributes. One way to interpret the values that facilitates more direct comparison between the attributes is to estimate WTP for a particular percent change in each of the attributes. Using results from the full model, Table 6 provides the annual household MWTP for each attribute, the aggregate MWTP across the 405,525 households in the state (Census Bureau, 2010a), and the aggregate WTP for a 10% improvement in each of the attributes. Viewed through this lens, WTP for improvements in forest health is significantly larger than the other attributes, with an aggregate WTP of $134 million annually to increase the level of healthy forests by 2 percentage points in the next ten years. WTP to for a 10% improvement in *AIRDAYS* is second largest in magnitude at $41 million annually. To provide some context with which to interpret these aggregate MWTPs, the total annual household expenditure on energy bills in Montana was about $414 million in 2011.[4] WTP for the ASC in the full model is $526.68 per household per year. In order to obtain a conservative estimate that represents the lower bound of benefits for any management strategy that deviates from the status quo, WTP for the ASC should be subtracted from WTP for the strategy (Boxall et al., 2009). There are two potential explanations for the large magnitude of annual household MWTP for the ASC relative to the choice attributes. First, WTP for the ASC represents a lump sum, rather than a marginal value because whether or not the status quo is maintained is not a marginal decision. Second, in addition to capturing the SQE, the ASC coefficient captures other unobserved components of preference heterogeneity (Boxall et al., 2009).

Montana residents are willing to pay $36 million per year for a 10% increase in the number of homes powered with woody biomass, which equals an additional 2000 homes with an average annual aggregate energy requirement of 21 million kW h.[5] Therefore a program that increases the number of homes powered with wood by 10% is economically efficient if the costs to supply the energy do not exceed $36 million annually, or $1.74 kW h^{-1}. When compared to the average residential electricity rate in Montana of around $0.10 per kW h^{-1} (EIA, 2011), and the levelized cost of producing biomass energy, also at $0.10 kW h^{-1}, a rate of $1.74 kW h^{-1} appears high.[6] However, the rate of $1.74 kW h^{-1} corresponds to the aggregate amount that the entire population of the state is willing to pay for the additional woody biomass energy, not the amount that individual households are willing to pay for electricity from woody biomass in their own energy bill. The high aggregate MWTP for woody biomass energy relative to the cost of production is likely due to the public good aspects of woody biomass energy, which include the mitigation of climate change through fossil fuel offsets by renewable energy, as well as the potential to facilitate restoration treatments in public forests.

6. Discussion

Montanans are willing to pay for woody biomass energy produced using biomass from public forests, as well as for the broader environmental benefits of resource management, namely improved forest health, better air quality and reduced frequency of large wildfires, although MWTP for the latter was not statistically significant. Priority ordering of the attributes is challenging because of differences in units of marginal change between the attributes; however, the results do suggest forest health is more important to residents than the other attributes considered in this study. In this section, the MWTP estimates of the attributes are compared with published WTP estimates for similar resources in North America, and the implications of findings from this survey for woody biomass energy generation are discussed.

The large MWTP for improvements in forest health and biodiversity conservation are consistent with other estimates from the Western US found in the literature (Garber-Yonts et al., 2003; Loomis et al., 2005; Mueller, 2013; O'Donnell et al., 2014). Positive MWTP to avoid exposure to degraded air quality is also consistent with other estimates in the literature (Dickie and Messman, 2004; Rittmaster et al., 2006; Rittmaster et al., 2008; O'Donnell et al., 2014).

The statistical insignificance of MWTP to reduce the number of large wildfires in Montana was unexpected. Previous studies have found significant WTP for fuels treatments that reduce the probability of wildfire burning one's own private property (Kim and Wells, 2005; Kaval et al., 2007; Kaval, 2009). However, in these studies, respondents were expressing WTP for direct benefits to themselves in terms of reduced burn probabilities around their homes. When surveys are distributed beyond households who will directly benefit from reduced risk of private property loss, diminished WTP has been found. O'Donnell et al. (2014) found statistically significant but small MWTP of Montanans to avoid home evacuations due to wildfire, and provided a discussion on the economic rationale of residents' WTP decisions based on the expected value of their losses due to wildfire. In light of other findings, the statistically insignificant MWTP to avoid large wildfires in the state is not unrealistic, given the fact that the majority of Montana residents do not reside in wildfire prone areas and it is the preferences of residents of the entire state that were investigated. In this case, respondents were revealing their WTP for a good that is mostly public in nature,

[3] In Montana, many high value homes have been built in forested areas with high amenity values. To ensure that living in a forested ecoregion was not acting as a proxy for high income, the correlation between the two variables was tested and no significant correlation was found.

[4] The average household energy bill Montana in 2011 was $84.97 per month (EIA, 2011).

[5] The average household energy consumption in Montana in 2010 was 10.5 MW h per year (EIA, 2011).

[6] The levelized cost of electricity represents the cost per unit energy produced of building and operating an energy plant (EIA, 2015).

Table 5
Household marginal willingness to pay for attributes per month.

Attribute	Marginal unit	Base model			Full model		
		Average household MWTP ($)	95% confidence interval ($)		Average household MWTP ($)	95% confidence interval ($)	
HOMES	1000 homes	1.79	0.89	2.68	3.75	1.96	5.55
AIRDAYS	1 day/year	−6.98	−8.90	−5.06	−8.43	−11.65	−5.22
WILDFIRES	1 wildfire/year	−6.68	−10.47	−2.90	−4.78	−4.88	0.68
FORESTS	1 percentage point	5.36	4.30	6.41	13.74	10.55	16.94
ASC	na	56.69	32.47	80.90	43.89	8.58	79.19

rather than for direct benefits to themselves. The higher WTP for WILDFIRES exhibited by respondents in forested ecoregions is consistent with the hypothesis that WTP to avoid large wildfires is driven by direct benefits of reducing the risk to one's own private property.

The MWTP of $3.75 per month per household ($45 annually) for an additional 1000 homes powered with wood is equal to a price premium of $0.0043 MW h^{-1}, over and above the current price of energy in Montana. This is equal to a 3.7% increase in annual household energy bills. The magnitude of this estimate appears small compared to the value found by Susaeta et al. (2011), who estimated a MWTP of $0.049 kW h^{-1} for electricity produced with woody biomass in Florida, Arkansas, and Virginia. However, their estimate represents the total willingness to pay (TWTP) for the woody biomass energy, while the estimate in this study represents the amount that residents would be willing to pay over and above the current price they pay for energy. In addition, the Susaeta et al. (2011) estimate includes values for multiple positive environmental externalities associated with woody biomass energy generation (i.e. CO_2 reduction from offsetting fossil fuel consumption, and forest heath improvements and wildfire risk reduction associated with increased forest restoration treatments), which were estimated separately in this study.

Montanans are willing to pay higher energy bills to substitute some fossil fuel energy consumed in the state with woody biomass energy generated from feedstock harvested on public lands. This does suggest residents value the public good aspects of woody biomass energy. However, a critical question for public forest policy-makers and managers is 'how much woody biomass harvesting on public lands is economically efficient'? The economically efficient level of woody biomass energy production from public forests in Montana will be where the economic surplus is maximized. That is, where marginal benefits equal marginal costs.

For the purpose of policy analysis, we accept the estimates of aggregate MWTP from this study as the marginal benefit of a program to increase the level of woody biomass energy generated from Montana's public forests. TWTP for alternative levels of woody biomass energy generation was estimated through summing bootstrapped aggregate MWTP for 10,000 to 55,000 home equivalents, in increments of 5000 homes. As illustrated in Fig. 2, TWTP starts to decrease (aggregate MWTP becomes negative) from about 45,000 homes powered with wood. That is, residents' demand for woody biomass energy from public forests is quickly satiated. Since the marginal costs of woody biomass energy generation are not zero, the economically efficient level of energy generation from public forestland in Montana must be <45,000 household equivalents.

About 10.5 tons of forest residues, on a dry weight basis, are required to produce the annual electricity requirements for an average Montanan household.[7] This can be harvested as part of a restoration treatment from about 0.7 ha of public forest.[8] Thus, an additional 700 ha of forest would need to be treated annually to supply the equivalent of 1000 more households with woody biomass energy, assuming a total of 21,000 households. An additional 14,000 ha would need to be treated annually to supply the equivalent of 20,000 more households with woody biomass energy. This represents treatment on an additional 0.04% to 0.8% of the Montanan public forest estate annually.

The survey data support several complementary explanations for the relatively low demand for woody biomass energy generated from public land. First, Montanans' consider woody biomass energy as an inferior good; natural gas and all forms of renewable energy except crop biomass were preferred to woody biomass as a source of household energy. Second, although respondents indicated generally positive attitudes toward utilizing residues from public forests for energy generation (74% indicated that they support more utilization of residues from public forests for energy generation), respondents ranked timber harvesting 7th out of 9 possible uses for public forests. Therefore, if timber harvest is viewed as being in conflict with other more highly ranked goods and services provided by public forests, support for woody biomass energy will be diminished. Third, when asked to indicate the degree to which the various attributes affected their decisions in the choice sets, the percent of respondents who indicated a high or very high level of concern about forest health (65%), wildfires (56%), energy bill (54%), and air quality (46%), all significantly outweighed the desire for more woody biomass energy (24%). Fourth, half of the state's population does not believe in man-made climate change, thus diminishing the perceived public good value of woody biomass energy.

Table 6
Aggregate annual marginal willingness to pay.

Attribute	Annual household MWTP[a]	Aggregate MWTP ($)[b]	Unit change for 10% improvement from status quo[c]	WTP for 10% improvement from status quo ($)[d]
HOMES	45.00	18,248,625	2000 homes	36,497,250
AIRDAYS	−101.16	41,022,909	1 day	41,022,909
WILDFIRES[e]	−57.36	23,260,914	1.2 wildfires	27,913,097
FORESTS	164.88	66,862,962	2 percentage points	133,725,924
ASC	526.68	213,581,907	na	na

[a] Annual household MWTP is monthly household MWTP from Table 5, multiplied by 12 months.
[b] Aggregate annual MWTP is annual household MWTP multiplied by the 405,525 households in the Montana.
[c] Ten percent improvement is the status quo level, multiplied by 0.1.
[d] WTP for 10% improvement from status quo is unit change for 10% improvement, multiplied by aggregate MWTP.
[e] WTP estimates for WILDFIRES are not statistically significantly different from zero.

7. Conclusions

The US has committed to reducing carbon emission from the energy sector to 30% below 2005 levels by 2030, necessitating a shift away from

[7] In a commercial-scale power generation facility (10+ MW output of electricity), 1 ton of woody biomass fuel will produce 10,000 lb of steam, which will generate 1 MW h of electricity (USFS, 2007). Therefore it takes about 1 dry ton of biomass for each of the 10.5 MW h of energy consumed annually by the average household in Montana (EIA, 2011).

[8] There are 9.5 million acres of timberland in need of treatment and 188 million tons of removable biomass on those acres (Rummer et al., 2005). Residues make up 30% of that biomass, so there are 56.4 million tons of removable residues (Perlack and Stokes, 2011). Removable residues divided by treatable acres yields 6 tons of residues per acre, or 6 tons per 0.4 ha. Therefore, 0.7 ha yields 10.5 tons of biomass.

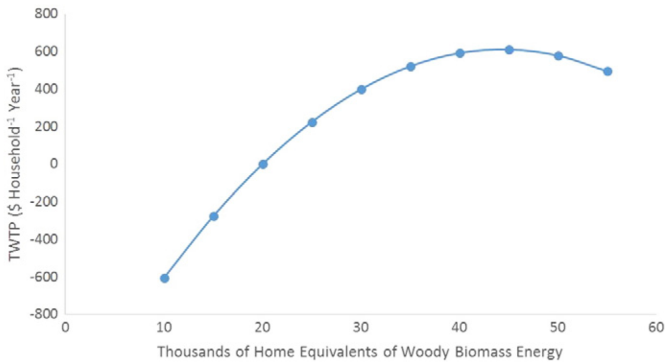

Fig. 2. Total willingness to pay for woody biomass energy generation.

fossil fuels in the nation's energy portfolio (EPA, 2015). There is a need to quantify the externalities associated with alternative sources of energy generation in order to make socioeconomically efficient decisions about how to supply the country's energy needs. This study investigated social preferences toward woody biomass energy in order to quantify the nonmarket costs and benefits associated with it and comment on the socioeconomic efficiency of the energy source. The use of the choice modeling method facilitated the simultaneous estimation of separate values for multiple attributes associated with woody biomass harvest and energy generation. The estimated MWTP values can be used by policy makers and public land managers to determine to what degree the social benefits of utilizing the residues from forest restoration or fuel treatment programs to generate energy offset the costs associated with the programs.

The low and rapidly diminishing MWTP to generate woody biomass energy from public forests in Montana has potential forest management and energy policy implications at the national level. The main conclusion arising from this research is that Montanans do not support public forestland management at a level more than double the current level of woody biomass harvested for energy generation. Further research is necessary to determine whether the preferences of Montanans' for woody biomass energy generated from public forests are applicable more generally throughout the United States. There is also a need for future research to examine whether woody biomass sourced from private forest land may be more acceptable to the public.

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