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Barriers and opportunities for bioenergy expansion in Chinese rural areas

Xiaoqian Xu [a,b], Guangzhe Liu [a,*], Blas Mola-Yudego [b,c]

[a] College of Forestry, Northwest A&F University (NWAFU), P.O. Box, 712100 Yangling, China
[b] School of Forest Sciences, University of Eastern Finland (UEF), P.O. Box, 80101 Joensuu, Finland
[c] Department of Crop Production Ecology, Swedish University of Agricultural Sciences (SLU), P.O. Box, 7043, S-750 07 Uppsala, Sweden

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ABSTRACT

Bioenergy can contribute to the development of a more sustainable environmental friendly alternative in rural areas in China. The perceptions, preferences and awareness concerning bioenergy among farmers are assessed in a systematic study of 594 Chinese farmers in 33 towns in the province of Shaanxi, using a generalized mixed model approach. In addition to the farmer's background and socio-economic variables, the spatial variation in the perceptions is addressed by mapping the residual between-county variation. The overall awareness of bioenergy as a viable alternative is still low ($N = 80$). Education and preferences on centralized heating systems play the most important role to explain the willingness to use biomass for domestic use or bioenergy from power plants. Users of large amounts of coal and electricity for heating increase the willingness to pay for bioenergy; users of firewood and raw residues are less prone to change their current energy uses. Nearly 75 % of farmers see bioenergy as a promising alternative to current consumption and production patterns of energy. The results show that not only the farmer's profile but the local context concerning energy mix, land uses and socio-economic factors are influencing their views, presenting defined spatial patterns and reflecting local geographies. Over one-third of respondents provide spontaneous recommendations to develop bioenergy markets. The results contribute to a better understanding of farmers' motivations, perceptions and views concerning energy uses, and can be used as an empirical basis for local energy planning towards a more sustainable energy transition in rural areas.

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Introduction

Currently, China's energy production is mainly dominated by mid-sized coal-fired plants (Tong et al., 2018). The use of biomass for energy production is predicted to play a significant role in China already along this decade (Wang & Watanabe, 2016). China has large quantities of biomass material from forests and agricultural fields (Zhang, Yang, Chen, & Chen, 2009), with 7×10^8 tons of coal equivalent biomass potential in the country (Zhang, Yang, Jin, et al., 2009). Switching to bioenergy, could also affect the carbon emissions levels: a 1 MW biomass power plant can reduce 7200 tons of CO_2 and 40 tons SO_2 compared to the current coal power plant (Li et al., 2009).

The advantages of bioenergy are particularly relevant in rural areas in central China, which are often lacking behind the main energy trends in urban areas, where householders are more often connected to more advanced, standardized and eco-friendly energy infrastructures (Liu et al., 2013). Rural China entails 551.62 million inhabitants (ca 39.40 % of the whole population, NBS, 2019), playing an important role in the energy transition towards more sustainable and efficient systems. Currently, the main fuel sources are coal and biomass residues (from firewood or crops) often used for domestic heating and cooking, accounting for about 70 % of the total rural energy consumption (Zhang, Yang, Chen, & Chen, 2009). In fact, until recently, it was estimated that nearly 100 % of the renewable energy consumed in China was direct combustion of biomass in rural areas (Chang et al., 2003), resulting in very low energy conversion efficiency (Zeng et al., 2007). Besides their climatic effects, emissions from burning coal and biomass residues in domestic stoves are an important health risk for the population (Carter et al., 2017; Gan & Yu, 2008), and the use of non-regulated raw wood biomass can increase illegal logging as well as deforestation or erosion (Sang & Zhu, 2011).

More advanced uses of biomass in sustainable bioenergy systems offer an alternative to both coal and raw biomass that addresses these problems. Domestically, the use of higher value biomass fuels as briquettes or pellets presents a more homogeneous fuel quality and stable combustion process (Nussbaumer, 2003), reduce particles and emissions, increase the overall energy efficiency (Lamberg, Nuutinen, et al., 2011), improve the provision of energy through automatization (Lamberg, Sippula, et al., 2011), and present an overall better

* Corresponding author.
E-mail address: gzl66106@nwsuaf.edu.cn (G. Liu).

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environmental performance (Jiang et al., 2000). At a larger scale, the use of modern bioenergy technologies for the generation of heat and electricity can involve Combined Heat and Power (CHP) or biogas plants (Zhao & Yan, 2012), substantially increasing the conversion efficiency, showing an improved environmental profile, decreasing emissions of particles (González-García & Bacenetti, 2019), and overall expanding the role of biomass in the primary energy consumption structure (Chang et al., 2003).

At the same time, the use of domestic sources of biomass translates into a local economic incentive, contributing to the development of rural areas playing an essential role in microeconomic sustainability (Buchholz et al., 2009). However, the successful development of advanced bioenergy systems in rural areas requires the necessary implication and acceptance of local farmers, who are key stakeholders influencing the establishing stage among market supply chains (Dale et al., 2013). As both producers of biomass and consumers of energy, farmers influence the bioenergy market developments (Rossi & Hinrichs, 2011). Previous studies, however, have demonstrated very low awareness as many farmers were unfamiliar or uncertain with the concept of bioenergy (Qu et al., 2016) and perceive important risks in the deployment of biomass supply chains (Wang & Watanabe, 2016). Recent studies also highlight the complexity of the factors involved in the farmer's attitudes related to energy preferences (Carter et al., 2020); many questions remain unknown concerning their preferences for specific biofuels, for domestic versus large scale bioenergy supply or about the role than local factors (such as the socio-economic context of the area) may play in their perceptions, among others.

The present paper aims to investigate the farmers' attitudes about bioenergy in rural areas in central China, focusing on i) the overall awareness of bioenergy as an alternative source of energy for their communities and ii) the factors that may condition their willingness to use biomass for domestic heating or bioenergy for heat and power. The focus area is the province of Shaanxi, which presents a great diversity of socioeconomic and ecological areas representative of rural areas in China. The results of this study provide a solid empirical basis to analyze the transition towards sustainable energy production with policy and economic applications.

Material and methods

Study area

The study focused on the province of Shaanxi, located in central China around the city of Xi'an. The province covers 20.56 million ha area and 38.64 million inhabitants with 43.06 % forest cover; that is 12.37 million ha forest and 0.51 billion m^3 standing timber (SPBS, 2018). Concerning agriculture, the province's main cultivations are orchards (1.11 million ha), tea plantation (0.14 million ha) and numerous other crops, presenting a large potential for biomass from primary residues (SPBS, 2019). The yet to be exploited biomass is seen as a promising source for local energy markets, according to the current provincial annual energy supply, estimated at 564 dry tons annually (SPBS, 2019).

The province is divided into three main regions, encompassing the northern, central and southern parts of the province. The northern region (Shanbei) covers from the desert areas nearby *Inner Mongolia* to the *loess plateau* area in the center of the province. This region presents harder climatic conditions than the rest of the province, as well as limited forest resources; e.g. drought, sand-dust storm and frost, among other disturbances affecting the local farm crops (SPBS, 2019). The central region (Guanzhong) covers the main urban and industrial centers, and presents both forest and agricultural industries, which gross output is proportionally higher than in the rest of the province, and presents the most developed infrastructure, on hubs gathering around Xi'an, the capital of Shaanxi. In the same region, Yijun is the second biggest apple production county in Shaanxi. Finally, the southern region (Shannan) is located between Qinling Mountains (3771 m), which are the landmark for dividing the *Yellow River* basin and *Yangtze River* basin, and *Ta-pa Mountains* completely located in a sub-tropical climate zone. This region presents the largest forest resources, with over 60 % of forest coverage, and it is abundant in biomass and water resources (OSC, 2001). However, the large mountainous areas, which accounts for 36 % land area (OSC, 2019), limit the logistics, mechanization potential and suitability for agriculture or plantations. Climatically, the region presents the highest annual average temperature (ca 14–16 °C) compared to Guanzhong (ca 12–14 °C) and Shanbei (ca 7–12 °C, OSC, 2019).

Data collection

The data collection was based on a questionnaire addressed to local farmers in the area. Preliminary interviews were performed prior to the final version of the questionnaire, in order to incorporate feedback and to test the viability and relevance of the questions. The questionnaire was performed in 2016 by face-to-face interviews. The structure of the sampling aimed to cover the whole province of *Shaanxi* in a systematic and cost-efficient way. For that, first some target counties were selected, with the following criteria: have to be representative of the main land-uses of the province, they must represent the climatic conditions and economic variables and must be geographically dispersed to avoid spatial correlation. A total of eleven counties were finally set, geographically distributed along the province (Fig. 1), being 3 in the northern areas (Shanbei), 5 in the central region (Guanzhong) and 3 in the south (Shannan).

For each county selected, three towns were selected, following the same criteria than used for the county selection. In total, 33 town centers were approached. Finally, for each town, three villages or rural centers were selected also with the same systematic criteria used previously, resulting in a total of 99 villages included in the sampling.

In each village, 6 farmers were interviewed, chosen at random, for a total of 594 respondents. The criteria to be included was: must have agricultural or forest land and the land must be located within the target village. The responses included both variables and open-ended questions, and included the respondents' personal background, and their willingness and preferences on several bioenergy related topics. The treatment of the data was anonymous, and the treatment and storage of data was according to standard ethical standards.

A portfolio of variables (predictors) was constructed based on the answers in the questionnaire. The first block was basic information from the respondents, concerning age, gender, education, household size and income. The second block was related to energy consumption, which was divided in two types of variables: dummy variables concerning domestic use of firewood, coal, straw, biogas, liquefied petroleum gas, electricity and solar, (adopting the values var = 0 when not used, and 1 otherwise), a continuous variables with the amounts reported (in kg, kWh or barrels), and percentage variables with the amounts reported as a total energy consumption per household. To estimate the latter, the energy contributions of the feedstocks (firewood, coal, straw, biogas and liquefied petroleum gas) were converted to energy units using generic conversion factors. In the case of solar energy it was not possible to retrieve the exact amount produced, and it was only considered in the electricity amount. Finally, the third block included questions related to the farmers perceptions on related topics, such as preference in heating systems (whether domestic production or district heat and power plants), preference in biofuels (pellets, charcoal, biogas or wood chips) or opinions concerning the purpose of planting trees (whether for environmental protection, firewood or income) (Table 1), for a total of 28 variables. In addition, it was considered the town, county and region of the respondent.

Concerning the target questions (dependent variables), 5 main variables were considered: awareness of bioenergy, acceptance of use biomass for domestic energy among farmers, preferred biomass fuel to be used (pellets, charcoal, biogas, woodchips), willingness to pay for bioenergy (price) and willingness to use bioenergy (energy generated).

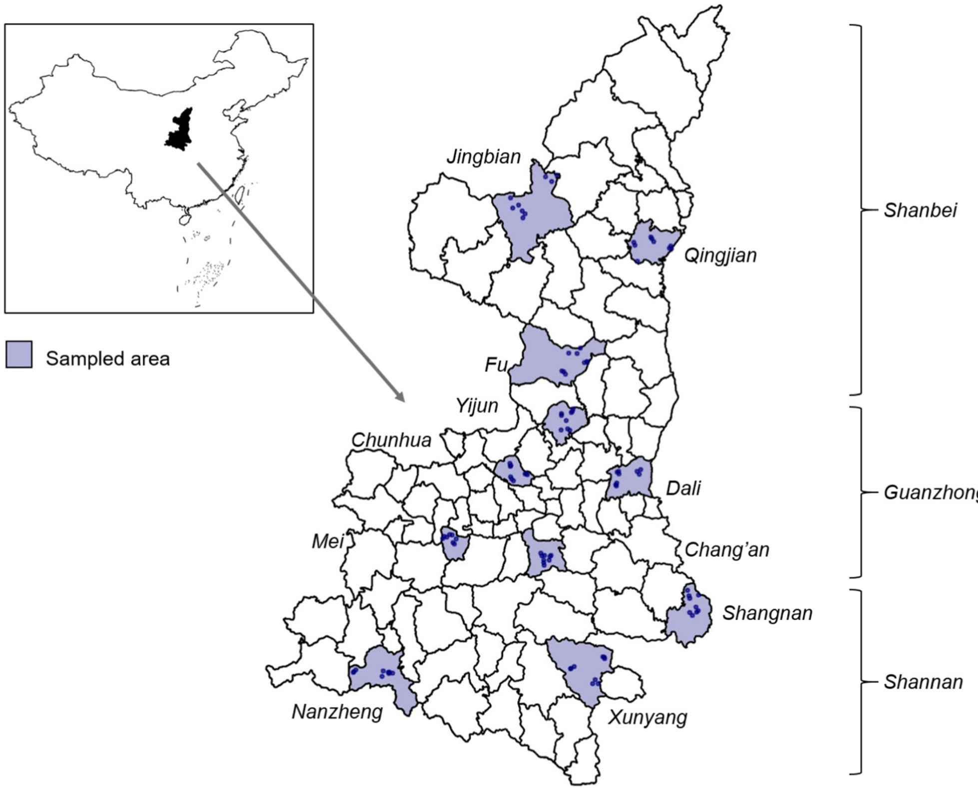

Fig. 1. Study area counties included in the data collection in the province of Shaanxi (capital: Xi'an) in central China. The province is divided in three main areas, in the north (Shanbei), central (Guanzhong) and south (Shannan). A total of 594 farmers were interviewed in 11 counties in the province. Geographic data modified from NMDS (2020), Natural Earth (2020) and GADM (2020).

Finally, a set of open questions were proposed concerning access to information (i.e., farmers' main information channels concerning energy preferences) and farmers' preferred characteristics concerning energy products, main barriers for full bioenergy deployment in Shaanxi region and proposals for developing the bioenergy sector and its share in the energy mix of the region.

Statistical methods

First, the main variables were studied for possible interactions and effects. For that, a portfolio of descriptors was used and analyzed systematically in order to retrieve possible predictors. The target variables were: awareness of bioenergy, in its various forms, as an alternative source of energy (*Know.B*), willingness to use sustainable biomass feedstocks for own production of energy (*Will.Bio*), willingness to pay for bioenergy (*Will.P*), preferred bioenergy feedstock (*Prefer.A*) and willingness to consume energy from bioenergy plants (heat and/or electricity, *Will.H&E*).

Given the large number of potential predictors and their interactions, the analysis was based on multivariate models, in which one or several predictors and their interactions were tested systematically in order to better understand the profiles of the farmers. The ultimate goal was not predictive but rather to retrieve a combination of variables that could effectively explain the farmer's preferences, while at the same time presenting a parsimonious model (max 3 variables), significant at the 0.05 level.

Table 1
Description of the variables considered in the analysis.

Variable type	Variable	Description	Value
Basic information	Age		<40/40–50/50–60/>60
	Gender	Household owner	Male/female
	Education		No education/primary (~7–12 yrs)/middle (~12–15 yrs)/secondary (~15–18 yrs)/university or equivalent
	Members	Persons per household	1 person/2 persons/3 or 4 persons/>5 persons
	Income	Household's gross annual income	<10,000/10,000–30,000/30,000–50,000/50,000 (CNY)
Energy consumption	User	Respondent's household current energy use in each energy alternative	Consumption on biogas/coal/electricity/firewood/liquefied petroleum gas/solar energy/straw
Heating pref.	Prefer.S	Respondent's preference in heating system	Domestic (own management)/district or community management
Planting	Purpose	Respondent's purpose of planting trees	For environmental protection/firewood collection/income/other purpose
Willingness (domestic)	Will.Bio	Willingness to use biomass for (domestic heat/cook)	Yes/no/conditional to price/conditional to other restrictions
Willingness (district)	Will.H&E	Willingness to use energy resulting from bioenergy plants (district heat/power)	Yes/no (inc. "not sure" and "it depends")
Preference	Prefer.A	Respondent's preference in biomass alternatives if have to use bioenergy	Wood pellets/wood chips/charcoal/biogas/don't know/other
Awareness	Know.B	The respondent has heard and knows the concept of bioenergy	Yes/no (inc. "don't remember")
Price	Will.P	The maximum affordable price of bioenergy (willingness to pay)	<200 CNY/200–500 CNY/500–1000 CNY/1000–1500 CNY/1500–2000 CNY/2000–2500 CNY/2500–3000 CNY/>3000 CNY

For the variables that presented continuous or semi-continuous values (willingness to pay, expressed in annual CNY), a linear model was proposed. In case of variables presenting a dichotomous nature (willingness to use, expressed as yes/no), a binomial logistic model was proposed. However, regional parameters may affect the preferences, as farmers live in town, within a county, which are grouped in at least three distinct regions (with different land uses and distinct socio-economic characteristics). This hierarchical structure of the data was addressed by using a generalized mixed effects model.

For the linear mixed model, the willingness to pay price for bioenergy products had the form:

$$y_{ijk} = b_0 + b_1 x_{ijk} + \ldots + \mu_i + \mu_{ij} + \mu_{ijk} \tag{1}$$

where y is the maximum annual amount (CNY) to be paid for bioenergy per household for farmer i in county j in region k, x_{ijk} are the predictors and their combinations, b_0-b_i are parameters to be estimated, μ_i is the effect of region i, μ_{ij} is the effect of county j in region i, and μ_{ijk} is the error term.

Concerning the binomial preferences, a generalized mixed effects model was constructed, with the form:

$$y_{ij} = accept\ (1)\ or\ reject\ (0)\ \text{the statement} \tag{2}$$

$$\text{following } y_{ij} = binomial\left(1, p_{ij}\right) \tag{3}$$

$$logit(p) = logit\frac{p}{1-p} = b_0 + b_1 X_{ij} + \ldots + \mu_j + \mu_{jk} \tag{4}$$

where, p is the willingness of a farmer to use bioenergy, expressed as a probability from 0 to 1, b_0-b_i are parameters to be estimated, and μ_i and μ_j are the effects of county j in region i. For both models, the between-county and between-region variability, expressed as random variables, was estimated, assuming mean = 0 and std. deviation σ_{cou} and σ_{reg}, respectively.

After the models were fitted, the random effects resulting from each model were plotted in the area, in order to visually identify possible spatial patterns that could better explain the context of the preferences for each county and region. The values were spatially interpolated using a universal kriging method (Krige, 1951), for a better understanding of the spatial dimension of the responses.

Finally, some of the questions were open, so as to include more detailed views from the farmers interviewed. These data were analyzed using a discourse approach based on Grounded Theory, but restricted to the initial steps for encoding respondents' discourse rather than full extension of the theory (Wüste & Schmuck, 2012). The coding themes were based on open-ended questions in the questionnaires, the respondents' initial discourse were grouped into phrases then classed into subcategories. Processes for each question were encoded as:

$$All\ answers \rightarrow \begin{matrix} Content\ answers \rightarrow Refined\ into\ phrases \rightarrow Sub\ categories \rightarrow Topics,\ or \\ Null\ content\ answers (answered\ as\ "I\ don't\ know") \end{matrix}$$

The overall analysis and calculations were performed in R v4.0.4 (R core Team, 2020). The generalized mixed effects models were using the *lme4* package (Bates et al., 2014), and the spatial interpolation using *automap* (Hiemstra et al., 2009). The maps were adapted from public domain sources (NMDS, 2020; Natural Earth, 2020; GADM, 2020).

Results

The data provided an extensive profile of the farmers in the province as well as their views on bioenergy as an alternative source of energy. The most common profile was a 50–60 year-old man, with middle education (12–15 years old), over five persons living in the household, using coal (mainly for heat) as well as electricity (mainly for power), with an annual income between 10,000 and 30,000 CNY (Fig. 2).

When asked directly for using processed biomass for energy (for example, in the form of pellets or wood chips, for direct consumption), a large majority of farmers supported the use, although several

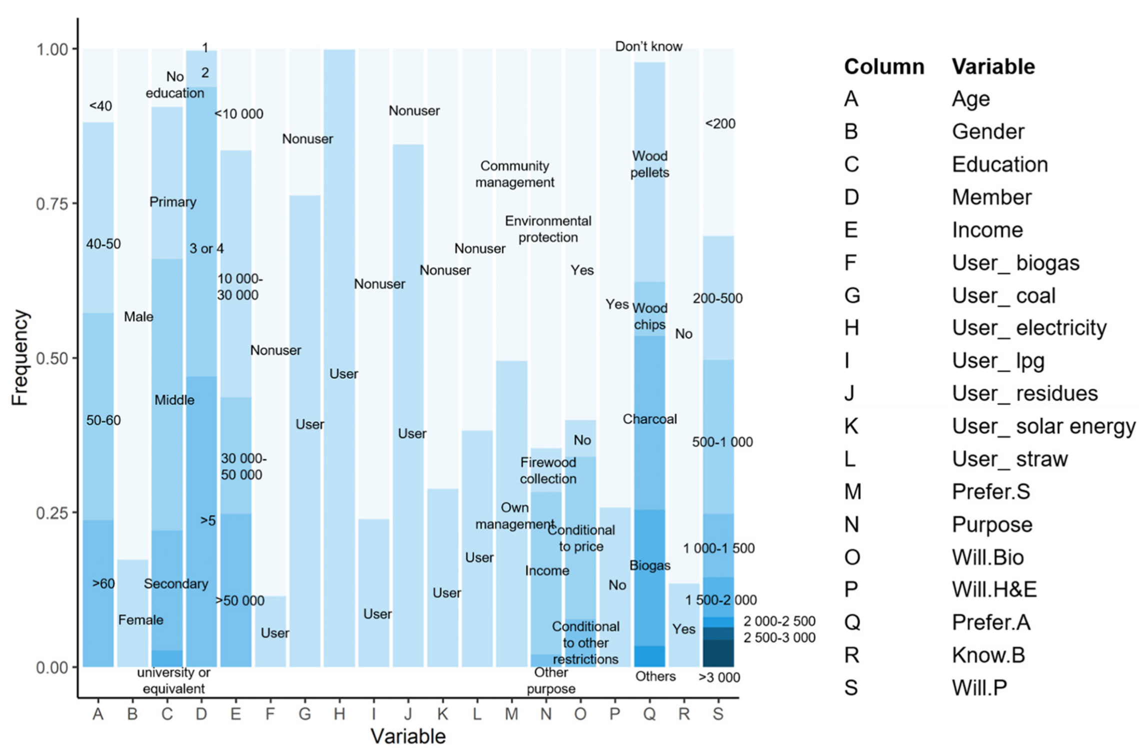

Fig. 2. Profiles of the farmers included in the analysis (594 farmers from 33 towns in 11 counties) concerning their preferences and perception on bioenergy.

respondents showed a conditional support subject to the price to be paid, or its convenience. The support was slightly lower among younger and older farmers, and it was higher among men (Fig. 3). The current usage of energy in the area, the three main sources of fuel were firewood, coal, and straw, reported by 502, 453 and 227 farmers, respectively. The average consumption of firewood per household was 2957 kg (st. dev = 10,344), of coal was 992 kg (st. dev = 1478) and straw was 1516 kg (st. dev = 6678). In the case of electricity, all interviewed farmers reported access and use (one respondent reported to have off-grid solar panels), for a mean consumption of 1969 kWh (st. dev = 6007). However, farmers perceived the use of bioenergy similarly, regardless of the current fuels used in the household, except for the users of firewood, which showed a stronger support (Fig. 4).

Respondents showed the largest preference on wood pellets for domestic energy use (Fig. 5). Among the respondents, the farmers with the portfolios of mid-low income, coal and firewood users, having willingness to use biomass for their own production of energy as well as having positive willingness to use energy resulting from bioenergy plants (heat or electricity) were more likely to use wood pellets. In addition, they also showed interest in charcoal and biogas.

Despite the large number of variables tested, only a few showed a significant effect linked to the responses (Table 3) when modelled

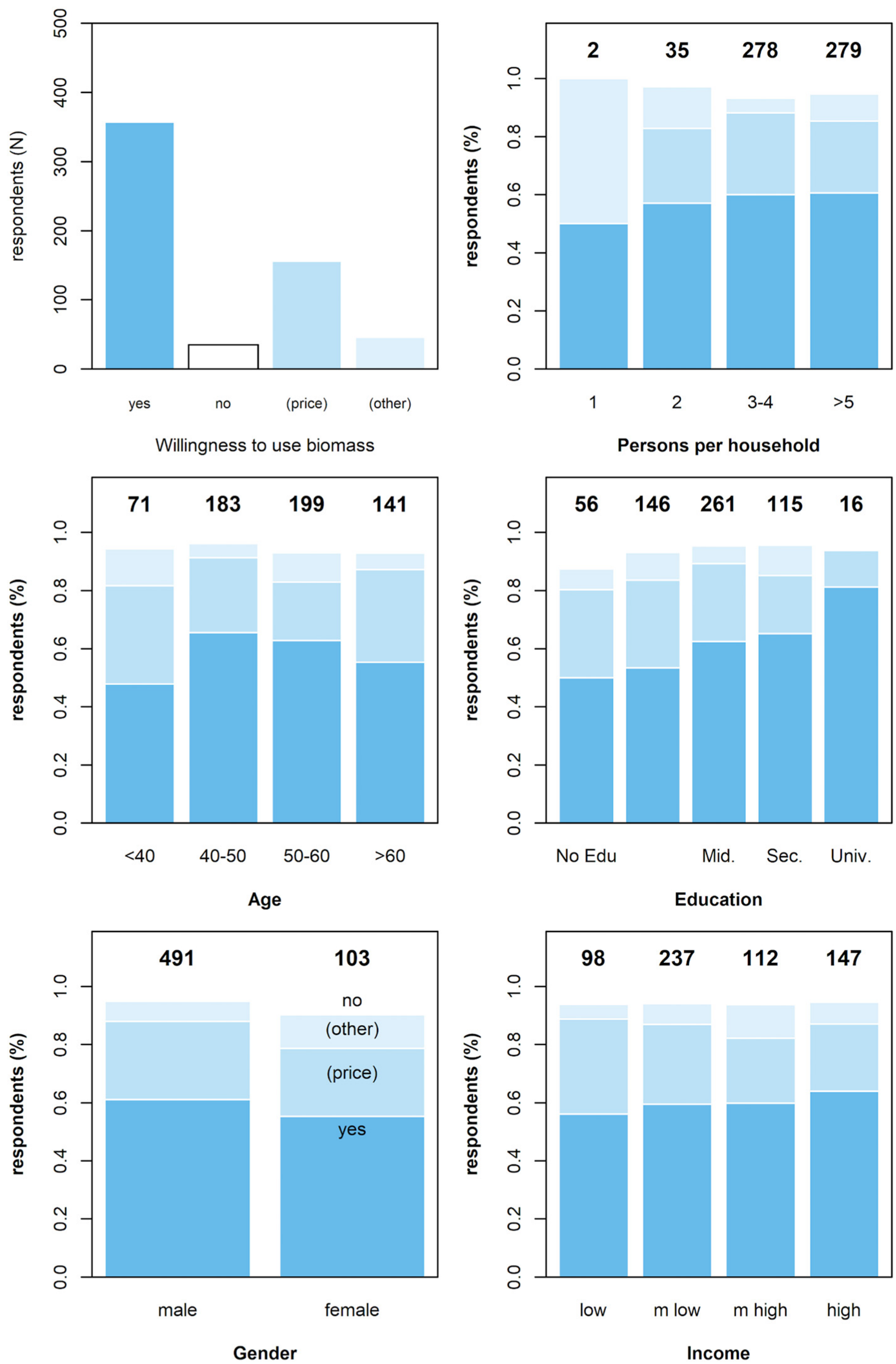

Fig. 3. Acceptance of biomass for energy among farmers in Shaanxi (central China) as an alternative to existing uses, according to age, gender and household. $N = 594$; *yes*: would consider bioenergy, (*price*): conditional to price, (*other*): conditional to other restrictions, *no*: opposes it. Numbers on top indicate the absolute number of respondents per option.

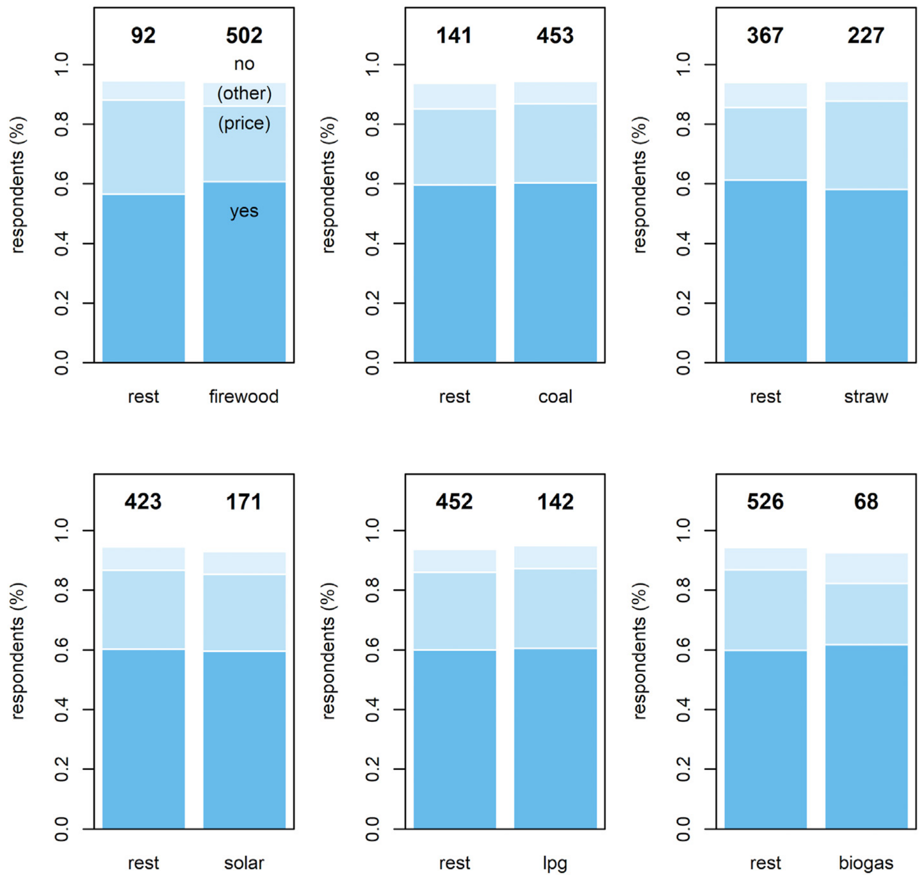

Fig. 4. Acceptance of biomass for energy for own production among farmers in Shaanxi (central China) according to their current use of energy. (lpg: liquefied petroleum gas).

together. The predictive power of the models was low (for *model 2*, the estimated $R^2 = 0.06$, and for the rest of the models, the McFadden's log likelihood was 0.06, 0.04, 0.03 for *model 1*, *model 3* and *model 4*, respectively). Despite these low values, some of the variables showed a very strong significance.

For the willingness to use biomass products (*model 1*), education and preferences over the heating system (whether domestic or district based) showed significance (Table 2) indicating a stronger support among educated farmers and among those preferring district heating. In the case of willingness to pay (*model 2*), the main variables were positively related to income, and also reflected a farmer with preference for district systems and environmentally conscious (*purpose of planting trees for environmental protection*). Farmers with large consumption of electricity or coal (both fuels that must be purchased by the farmer, unlike current biomass residues, which are largely free of costs) were also positively related to a willingness to pay a higher price for bioenergy. Concerning awareness of bioenergy (*model 3*), only education showed a significant effect: the concept is more likely to be known with an increasing level of education, particularly with university level. When farmers showing awareness were asked where or how they learnt about the concept, the most common spontaneous answer related to the China Yangling Agricultural Hi-Tech Fair as well as programs from TV agricultural channels. Finally, concerning the farmer's willingness to use energy (heat or power) supplied by bioenergy plants, the variables are also related to preference for district energy systems (in opposition to domestic production of energy) and a positive correlation with education level. Other combinations of variables or interactions showed no significance, resulted in a lower predictive power or in excessive model complexity.

The predictions of the models (Fig. 6) showed a strong increment in the willingness to pay for bioenergy associated with electricity consumption, up to an annual consumption about 2000 kWh, from which the increment is smaller. In the case of coal users, the main variation affects mainly small users. The variation due to education, income and environmental attitudes ranges from 300 to 500 CNY. Concerning awareness of bioenergy, is significantly higher among farmers with university education, and likewise for their willingness to consume bioenergy.

Spatial differences among counties, however, proved to be larger. The between-county share of the variability had an estimated standard deviation of 0.03 (linear mixed model, between-respondent standard deviation 0.413), 0.156 (logistic mixed model) and 0.296 (logistic mixed model) for willingness to pay, bioenergy awareness and willingness to use bioenergy, respectively. However, the overall between-region variability was very low in all models, did not contribute to the explanatory power, and was finally excluded. Similarly, a between-town variability random factor was tested but not included in the final version of the models, as it increased the model complexity with no remarkable improvements in the overall goodness of fit.

The resulting realizations of the random variables for each county (the estimated intercept value per county, μ_i) allowed a spatial analysis of the preferences of local farmers towards bioenergy, reflecting the land-use, current energy uses and socio-economic reality of the province. Discounting the variables that were significant in the models, the willingness to use biomass for energy was higher in the northern parts of the province. Concerning the willingness to pay for bioenergy (*model 2*), local farmers of Chang'an (central parts of the province, 74,462 CNY estimated GDP per capita (SPBS, 2019), second in the analyzed counties after Jingbian, 103,335 CNY per capita (SPBS, 2019)) were more prone to pay a higher price than in Dali (20,949 CNY per capita (SPBS, 2019), lowest among the counties analyzed), already discounting the other variables of the model. About awareness, there was a clear division between northern areas (lower awareness of the concept) than in the south (higher awareness). Finally, concerning

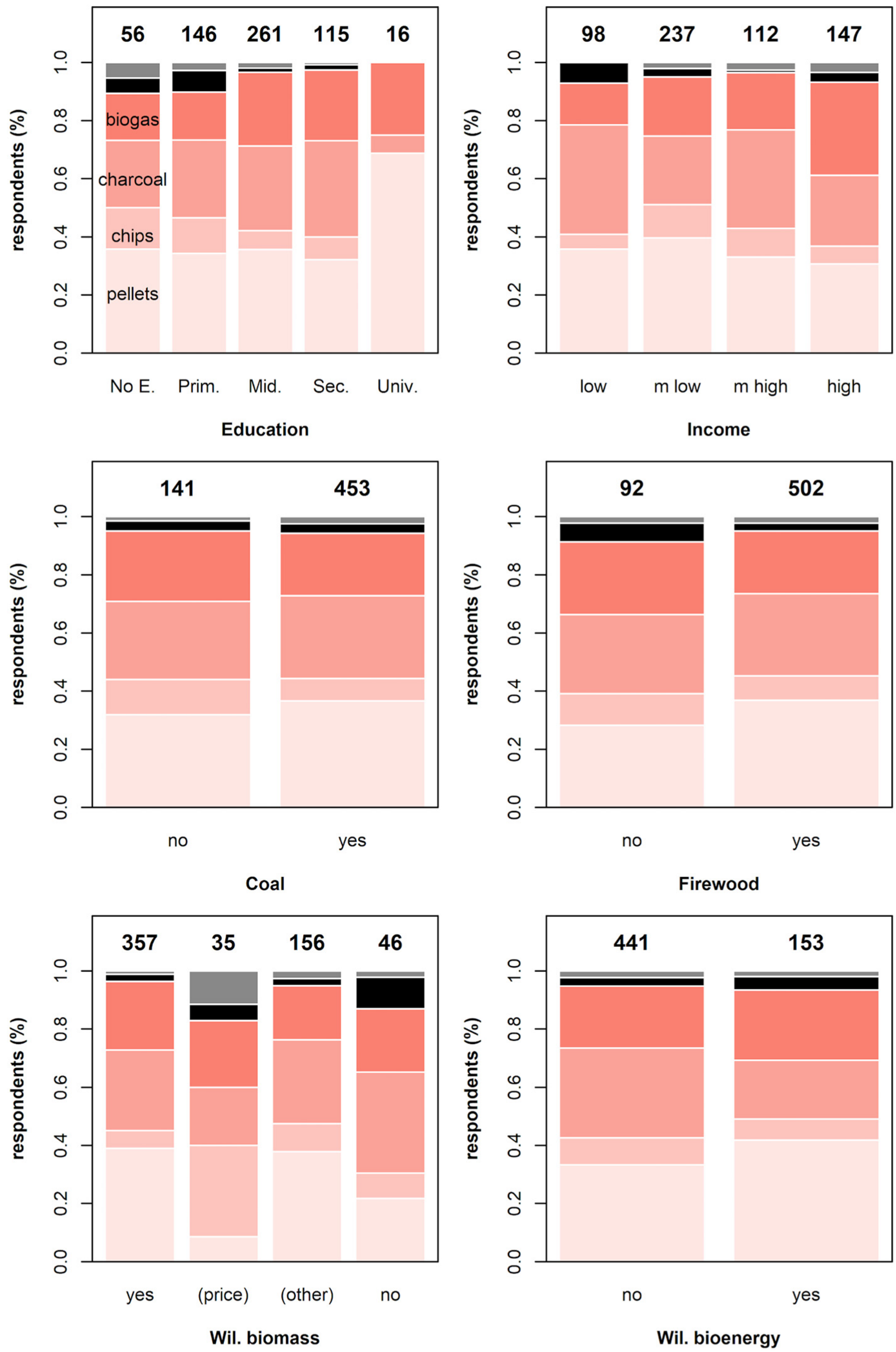

Fig. 5. Preferences in bioenergy alternatives (pellets, wood chips, charcoal, biogas) among farmers in central China, according to education (prim: primary ~7–12 yrs, mid: middle ~12–15 yrs, *sec*: secondary ~15–18 yrs, Univ: university or equivalent), income (low: <10,000 CNY, m low: 10000–30,000 CNY, m high: 30000–50,000 CNY, high: >50,000 CNY), current domestic use of coal and firewood and willingness to use biomass for own production of energy, and willingness to use energy resulting from bioenergy plants (heat or electricity). No clear answer is represented in black, and other options, in gray.

the willingness to consume bioenergy (in the form of energy resulting from a power plant), the pattern was more complex, with farmers from largely central and northern counties more prone than the rest (Fig. 7).

Concerning the channels where farmers accessed information on bioenergy and energy alternatives, TV programs and participating local training were considered as the most efficient (Table 3). The responses reflected that processed bioenergy products (e.g., wood pellets) have been promoted in agricultural TV shows. Concerning the preferences on the characteristics of energy products, clean and affordable were the most frequent answers, as well as safety and reliability.

From the farmers' perspective, the main barriers for the effective deployment of bioenergy systems in rural Shaanxi were the lack of supportive policies, the lack of the expertise and the lack of activity of the current bioenergy market (Table 4). Due to the lack of subsidies, farmers may have to pay full price on the wood pellets and boilers, for instance. Lack of the industrial goals and producing standards may also restrict the market to provide sufficient and sound bioenergy for the farmers. It is difficult for farmers to make clear evaluations on bioenergy if they lack the expertise as well as hard to use the bioenergy for their own household without the guidance. Besides, collecting updated information about bioenergy is also challenging for farmers when they must

Table 2
Parameters, standard errors (SE) and significance values of the variables concerning willingness to pay for bioenergy as a source of energy (annual CNY per household), awareness of the concept of bioenergy and willingness to use bioenergy.

Model	Variable	Estimate	SE	*p*-Value
Model 1	b_0	3.136	0.783	<0.001
	b_1 (Prefer.$S_{own\ management}$)	−1.111	0.395	0.005
	b_2 ($Education_{primary\ (\sim7–12yrs)}$)	0.690	0.553	0.213
	b_3 ($Education_{middle\ (\sim12–15yrs)}$)	1.257	0.530	0.017
	b_4 ($Education_{secondary\ (\sim15–18yrs)}$)	1.345	0.639	0.035
	b_5 ($Education_{university\ or\ equivalent}$)	1.049	1.135	0.356
Model 2	b_0	2.2370	0.1419	<0.001
	b_1 (Prefer.$S_{own\ management}$)	−0.0953	0.0343	<0.01
	b_2 ($Income_{>5000\ CNY}$)	0.0879	0.0411	0.0327
	b_3 (log10($User_{electricity}$ + 1))	0.1120	0.0444	0.0120
	b_4 ($Purpose_{environmental\ protection}$)	0.0398	0.0186	0.0330
	b_5 (log10($User_{coal}$ + 1))	0.0310	0.0136	0.0228
Model 3	b_0	−2.3172	0.4714	<0.001
	b_1 ($Education_{primary(\sim7–12yrs)}$)	−0.3025	0.5722	0.5971
	b_2 ($Education_{middle(\sim12–15yrs)}$)	0.5523	0.5012	0.2705
	b_3 ($Education_{secondary\ (\sim15–18yrs)}$)	0.6929	0.5324	0.1931
	b_4 ($Education_{university\ or\ equivalent}$)	2.3013	0.6863	<0.001
Model 4	b_0	−0.4276	0.3153	0.1751
	b_1 (Prefer.$S_{own\ management}$)	−0.4936	0.1961	0.0118
	b_2 ($Education_{primary\ (\sim7–12yrs)}$)	−0.7937	0.3594	0.0272
	b_3 ($Education_{middle\ (\sim12–15yrs)}$)	−0.4784	0.323	0.1386
	b_4 ($Education_{secondary\ (\sim15–18yrs)}$)	−0.2332	0.3552	0.5115
	b_5 ($Education_{university\ or\ equivalent}$)	0.6853	0.5847	0.2411

retrieve it themselves. Potential risks from the market also result in the uncertainty of supply, as for instance, farmers may run out of bioenergy products without future supply from the local if the logistics system is not fully established.

Finally, when farmers were inquired about measures to incentivize bioenergy development in rural areas, 36.36 % of respondents ($N = 216$) gave spontaneous suggestions, which were grouped into 1) enhancing farmers' expertise about bioenergy, 2) offering the non-monetary benefits particularly on local environmental situation if establish industries there, 3) forming sound market supply chains, 4) issuing supportive policy for related stakeholders (Fig. 8). For instance, promoting bioenergy strengths through public sources (e.g. TV programs) to rural households as well as the guidance from local technicians can help farmers get familiar with bioenergy boilers for household use. Besides, bioenergy training or courses can reduce farmers' skepticism about this energy as well. Developing sustainable systems both for the production and the consumption can provide unceasing biomass materials as well as protecting the environment. High standard and stable manufacturing processes can not only provide a long-term market but also benefit the locals' livelihood, for instance, providing employment opportunities for the locals. Financial support, such as subsidies and insurance to the landowners or managers can reduce the production risks. Besides, the policies may also adapt to the local economic and natural situations.

Discussion

Farmers are important stakeholders in developing bioenergy as a sustainable alternative to the existing energy uses in rural China, both as producers and consumers. In this paper, farmers are mainly considered as end-users of bioenergy, although they are also active suppliers of biomass for energy, as over 80 % were collecting and using available biomass for domestic energy to a certain extent. The basis of the analysis is an extensive questionnaire distributed along the entire province,

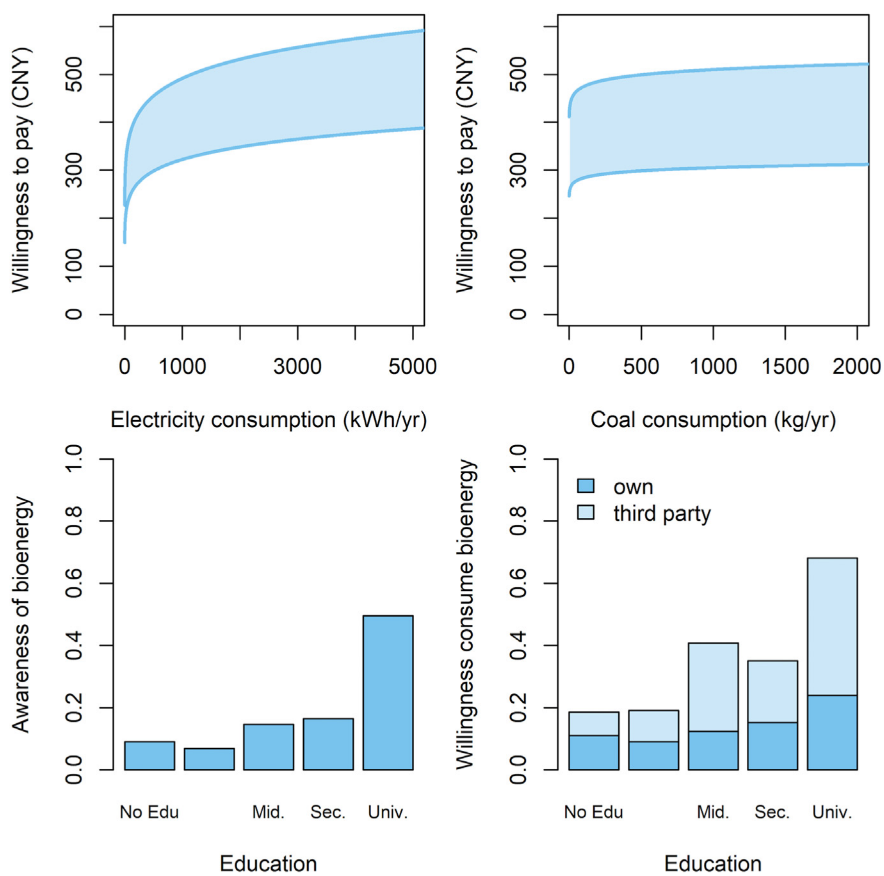

Fig. 6. Predictions based on the models for willingness to pay for bioenergy (annual CNY per household) as a function of electricity and coal consumption per household. The lines represent the lowest (low income, low environmental awareness) and the highest (high income, >50,000 CNY annual per household, high environmental awareness) thresholds. Awareness (bottom, left) and willingness (bottom, right) to use bioenergy raises with university education. All variables significant at the $p < 0.05$ level, based on a mixed effects model at county level.

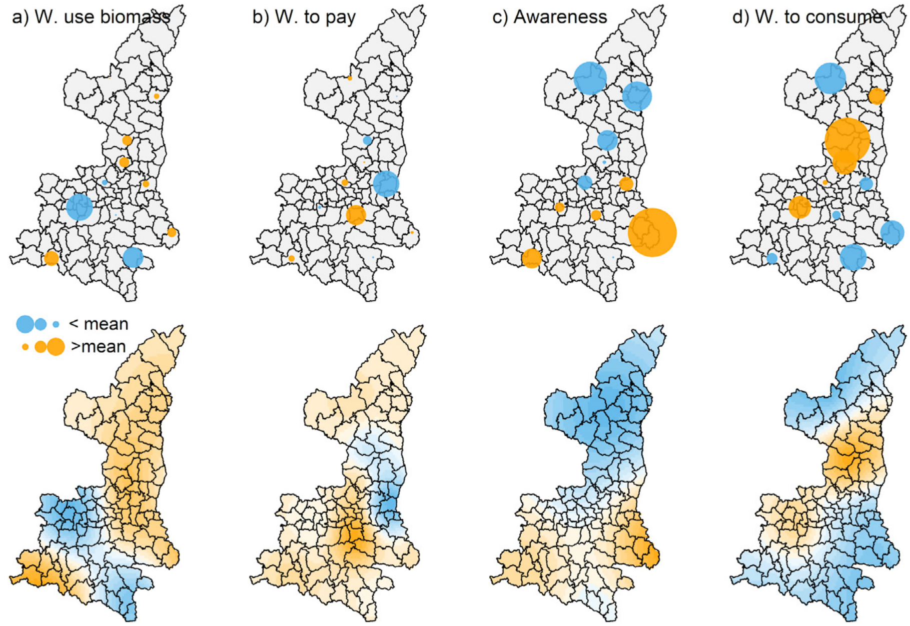

Fig. 7. Regional variation for the models tested for a) willingness to consume biomass (domestic, *Will.Bio*), b) willingness to pay for bioenergy (*Will.P*), c) awareness of bioenergy (*Know.B*) and d) willingness to consume bioenergy (*Will.H&E*). The estimated between-county standard deviations were 0.21 (logistic mixed model), 0.03 (linear mixed model), 0.156 (logistic mixed model) and 0.296 (logistic mixed model), respectively. Up: The size of the circles represents the scaled deviation, and the color, whether above or below the average predictions. Bottom: Spatial interpolation of the values of the between-counties (μ_i) effects.

aiming at representing the farmers in the area. It was not possible to access an official farm registry that would enable retrieving farmers data (which would allow a fully randomized sampling). This limitation was compensated by the systematic structure of the sampling method, which aimed to a full regional representation, and by the selection of the interviewees, which was as close to randomized as possible. In addition, the personal interviews facilitated a full response ratio, and included those farmers with low levels of literacy. The overall number of completed questionnaires ($N = 594$) compares well with similar studies about bioenergy perceptions (a systematic review of 44 studies is provided by Radics et al. (2015)) and provides a solid basis for analysis.

In fact, the data provided a detailed representation of the farmer population in the area, reflecting the ongoing trends in the rural population in China. Concerning objective economic indicators, the results showed an average annual net income (6810 CNY) close to the official estimates of rural areas in Shaanxi (6503 CNY (NBS, 2013)), and significantly lower than the urban areas in the same province (24,109 CNY). The labor force migration from rural areas to the urban settlements is also well reflected in the data, as respondents younger than 40 years old only accounted for 11.95 %. In addition, this is also a consequence of the general ageing trend in China: the population older than 60 years old (25 % in the sample) represented 16.24 % in Shaanxi, when the questionnaire took place (SPBS, 2019). This figure has increased recently to 18.12 % (being 18.13 % for the whole country in 2019). UN estimates indicate the trend will double in the next decades (UN, 2020) resulting in a significantly aged rural population.

Despite some authors underlining the importance of age concerning the use of biomass for energy (e.g., Joshi and Mehmood (2011)), the results of this research show that education, rather than age, is the most critical variable determining the views and understanding of bioenergy among farmers. More educated farmers have a better understanding of biomass uses and sustainability concepts and may have the tools to adapt to changing market situations, increasing their acceptance of alternatives in the energy system. This is in agreement with previous results in north-east China, proving that education and income are key factors in the farmer's perception of risks concerning biomass supply (Wang & Watanabe, 2016). The same trend was confirmed in a similar study among farmers in China (Qu et al., 2016), which showed that the effects of education overcame the effect of age to explain farmer's attitudes in rural China. Education also influenced the preferences concerning biomass alternatives, as pellets were the most preferred option, particularly among the most educated segments, among the users of firewood or higher income farmers. In addition, biogas was highly

Table 3
Access to information and overall energy preferences a) Farmers' main information channels concerning forest practices or agriculture. b) Farmers' preferred characteristics concerning energy products. For both cases, expressed in percentage of each topic's frequency.

a) Channels	%	b) Characteristics	%
TV	28.79	Clean	23.68
Training	28.28	Low price/affordable	21.27
Talking to peers	11.73	Safe and reliable	15.04
Mobile phone	6.57	Convenient/use	13.52
Computer	5.27	Subsidy available	10.04
Newspapers	4.32	Good quality	7.35
Radio	3.81	Follow-up service	3.93
Family	3.25	Convenient/supply	3.14
Magazines	0.95		
Others	2.47	Others	0.17
No preference	4.55	No preference	1.85

Table 4
Main barriers for full bioenergy deployment in Shaanxi region as perceived by local farmers ($N = 594$).

Key aspect	Reported main barrier	Frequency, %
Policy	Lack financial support	26.21
Expertise	Lack technology guidance	22.73
Expertise	Unfamiliar with bioenergy	19.02
Policy	Lack policy about industrial goals and producing standards	14.31
Expertise	Difficult to access bioenergy information	6.40
Market	Difficult to transport bioenergy products	3.42
Market	Difficult to have large-scale production	3.42
–	No opinion	3.37
–	Others	1.12

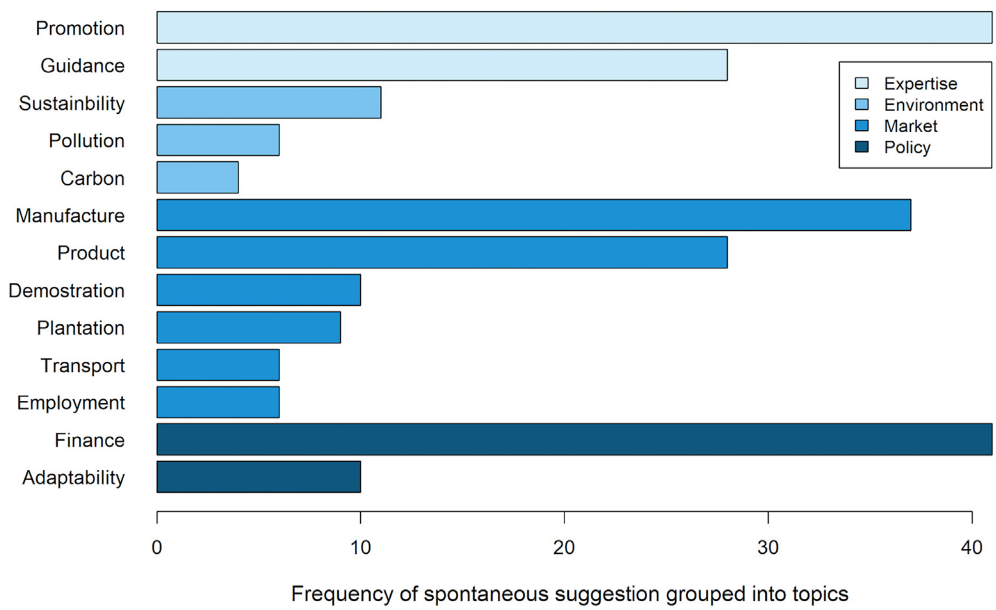

Fig. 8. Spontaneous suggestions by farmers in Shaanxi (central China) to develop bioenergy at industrial level in the region, grouped according to *expertise*, *policy*, *market* and *environment* ($N = 204$).

regarded among the most educated farmers; in both cases can be linked to the higher added value of the product and the advantages in its utilization.

However, the study of stakeholders' perceptions on renewable energy implies a high level of complexity, as hardly can be explained by a single variable. In addition, many additional variables are linked to context, psychology (e.g., trustworthiness in cooperation (von Bock und Polach et al., 2015)), and personal factors that can have an important effect in the individual farmer's perceptions (Devine-Wright, 2008). Despite several related variables being systematically tested, many did not result in significant effects, and were removed from the final models. For example, the use of other renewable energy, such as solar energy, was expected to have an influence in the farmer's willingness to use bioenergy, but it showed no significance when included in the model, although the effect can be confounded by many other factors, and perhaps geographically restricted. Overall, the performance of the modelling approaches was in line with similar studies (Qu et al., 2016) as well as the number of variables having an effect. However, the modelling approach, allowing for the study of variables in combination, identifying possible interactions, and addressing the effects of context through the grouping factors at different administrative levels (determined among others by different availability of resources and socio-economic factors) supposes and advantage versus other approaches solely based on logistic regression (e.g., Qu et al., 2016; Wang & Watanabe, 2016; Zhang et al., 2020).

Farmers' opinions and perceptions are influenced by their location, as local factors condition the way they access information and frame the context for their perceptions (Thomas et al., 2020). An experimental study of Hoffmann (2009) showed that adding regional values into decision tools could improve the viability of the establishment of bioenergy facilities, especially when oriented towards a large market. The large diversity presented in rural China, and included in the results, varies concerning the socioeconomic context, the land uses and the traditional values and attitudes of farmers. The results showed some clear geographical patterns that, despite the low predictive power, explained the context of the answers and the factors that affect the farmer's perceptions and motivations towards bioenergy. Additional parameters, representing the towns ($N = 33$, lower scale) and region ($N = 3$, higher scale) did not contribute to increase the explanatory power of the models, and were discarded, as possibly require a larger dataset to be properly addressed.

Local restrictions from current land uses affect the supply and the demand of bioenergy in rural Shaanxi. The hard climatic conditions for agriculture and forestry in the northern areas (Shanbei region) is a challenge for the establishment of reliable biomass supply chains from domestic feedstocks, which may restrict biomass feedstock supply from the upstream in the market of the region. Concerning natural conditions, the logistics in mountainous regions hinders transportation of solid bioenergy products (Junginger et al., 2011) as well as investments in bioenergy power plants (see empirical study of Reise et al. (2012)). This applies to the southern areas (Shannan region), where lacking infrastructure for the distribution in the southern areas may prevent farmers to consider industrial level bioenergy as a viable alternative as topography not only restricts to expand areas for bioenergy crop plantation (Owen et al., 2013; Plieninger et al., 2006) but also limits the establishment of bioenergy power plants as well as the transportation of wood pellets or wood chips. Some solutions for this have been proposed; for example, establishing a social network (e.g., biomass sharing), which has been applied in Philippines and Vietnam for using rice straw as energy (Minas et al., 2020), which could be also implemented in China.

In addition to land use or topographic restraints, local variables have consequences on bioenergy development. Regional conditions related to population density, existing land uses or economic development, can either support or limit the market scale of bioenergy (Snäkin et al., 2010) and competition from other energy alternatives influences bioenergy market expansion. The energy consumption in northern areas (Shanbei) mainly relies on coal, as the rural households' cooking systems in the area are connected with the heating system (i.e., from the kitchen to the bedroom when coal is burnt for cooking). There, the higher heat demand, scarcity of domestic biomass resources and favorable prices make coal more competitive in the energy market (Kerimray et al., 2017; Wang & Watanabe, 2016). Similarly, studies of farmers in Indonesia similarly reflected that biogas was not competitive compared with direct use of firewood (Gaul, 2012). In parallel, wind-power generation systems have been established in the region (particularly in the extreme northern, at Jingbian county), which also presents certain advantages over bioenergy and may explain the lower willingness towards using bioenergy among local farmers in that area. The implementation of national energy projects, as an external factor, is influencing the local energy preferences as well: for instance, the construction of the gas pipeline in the center areas of Shaanxi (*Natural Gas Transmission from West to East China* from Xinjiang to Shanghai) facilitates access to natural gas in cities such as Baoji and Xi'an, and explain why farmers from the area show more willingness to use natural gas. Finally, the southern parts of the province have large forest resources and collecting fuelwood (at low or no cost) has traditionally been the main energy source. This can explain the lower willingness to consume bioenergy despite the higher awareness, since it is perceived as a more expensive option.

It is important to make a distinction, since the use of firewood (common in the area) differs from the energy generation from added value biomass products, in both environmental and health effects (Carter et al., 2020). For example, the Dali county has large areas of orchard plantations (on the easternmost areas), which produce several residues (Xu et al., 2022) that are currently used as firewood for heating and cooking, with nearly no costs for the farmer. Wang and Watanabe (2016) showed that processing of low-cost residues in the form of pellets may give an opportunity for this energy product to enable competition with fossil fuels and allow better logistics of biomass products and less environmental and health effects. However, those respondents concerned about general costs of biomass products disregarded pellets as an option in favor of wood chips. This perception may be justified in previous studies raising doubts about the economic feasibility of pellets in China, particularly over coal (Wang & Yan, 2005). In this line, pellets require the stove to include heat insulation to reduce heat losses, increasing potential derived costs and users mentioned that small volumes of wood pellets could not provide enough heat to cook the same meals compared to firewood. Thus, charcoal may present competitive advantages due to the familiarity many farmers and forest owners have towards it, which explain the overall preference for it (Brobbey et al., 2019).

About the farmer's awareness about bioenergy, the study found a higher level of knowledge among farmers than in previous research (Qu et al., 2016), indicating that the concept of using biomass for energy is expanding in the region. It also found a clear spatial component, as the results reflected the level of awareness was higher in areas around the urban centers (e.g., Xi'an and the main economic corridor of the region crossing east-west). The role of the universities in the area and the China Yangling Agricultural Hi-Tech Fair seem to have played a role in spreading and educating about the concepts, acting as a knowledge hub, which was confirmed in the spontaneous responses of some of the interviewees, in agreement with other studies stressing the role of university education as a factor in raising awareness about bioenergy (Qu et al., 2011). Particularly in Shaanxi, two pilot CHP projects have been established (NEAC, 2018): one in Weinan and another in Yan'an. These two CHPs have an annual consumption of 401,000 t of biomass from agricultural and forest residues, generating heat and power (NEAC, 2018). These results are of great interest, as they justify the efforts invested on bioenergy development and awareness in China where 136 CHP demonstration projects based on bioenergy have been established in the last years (NEAC, 2018).

Finally, the main barriers perceived by farmers highlight the need to primarily address profitability, in line with Rossi and Hinrichs (2011). Respondents expect financial support in the form of subsidies for biomass production, factory facilities, household combustion systems or transportation systems (Bambara et al., 2019), as well as affordable prices (Rao & Ravindranath, 2002), sound product performance and long-term follow-up services; these factors stimulate and ensure the overall consumers preference on bioenergy products (Selkimäki et al., 2010). Lacking expertise restricts famers to have the motivation or confidence to manage biomass crops, plantations or forestry residues for bioenergy production. Participating in forestry or agricultural training is considered by some respondents as a passive channel to obtain information, since the training could occupy farmers' time if they need to work in other places simultaneously for extra income. Thus, regular hands-on teaching at the farmers' forests or agricultural lands could help farmers manage forests or plantations, which is a time-saving way guided by technicians. Besides, to expand trade into national and even international markets, more opportunities and barriers need to be considered, such as manufacturing standards and tariffs (Junginger et al., 2011). Finally, the overall socio-economic benefits in the area also influence the stakeholders' support on bioenergy transition (Falcone et al., 2021).

Due to the common socio-economic features with other nearby provinces, the results can, with due caution, scale up to the entire central areas of China (Liu et al., 2002), with a similar reliance on coal, agricultural residues and firewood (Yu, 2012). Finally, policy makers are required to consider the stakeholders' interest beyond multiple sectors and to adapt their efforts to the right local scale, even when aiming for national or international energy goals (Silveira & Johnson, 2016).

Conclusions

The study provides a comprehensive profile of the energy consumption patterns of farmers in rural communities of central China, mainly relying on coal and electricity as main sources of energy and highlights the main factors that affect their awareness and willingness on bioenergy as an alternative energy source. Awareness of bioenergy as a viable option is broader than in the past, but still superficial. Expertise, training, financial support and industrial investments are suggested as ways to develop bioenergy markets at local level. Farmers' education and preferences on heating systems play a major role when they decide to pay for bioenergy as a source of energy. In general, farmers in rural China see bioenergy as a promising alternative to current consumption and production patterns of energy, particularly among educated farmers and in areas with favorable conditions.

However, the results also demonstrate that, in addition to the farmer's profile, there is a large spatial component that determines the farmer's awareness, willingness and overall attitude towards energy uses. The local context concerning energy availability, land-uses and socio-economic factors contribute to a complex geographical variation in the factors analyzed. The overall results help a better understanding of farmers' motivations, perceptions and views concerning energy uses, and can be the basis of a more local energy planning in the efforts towards a more sustainable energy supply in rural areas.

Declaration of competing interest

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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