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Analysis

Determinants of forest owners attitudes towards wood ash recycling in Sweden - Can the nutrient cycle be closed?

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ABSTRACT

The use of biomass, in particular wood, has increased this last decade as a result of the European Union's objectives to reduce the use of fossil energies. This has amplified the use of whole-tree harvesting and the exploitation of forest residues from traditional timber harvest. However, these practices have some ecological consequences because they remove nutrients from the forest, thus potentially reducing soil fertility. To compensate for this nutrient loss, it has been proposed to recycle wood ash to reintroduce the exported nutrients. In this paper, we assess private forest owners' willingness to pay to spread ash in Västmanland, Sweden, where ash recycling is not widely adopted, though an increasing supply of wood ash. In particular, we take into account behavioural motives that may explain forest owners' willingness to pay (Theory of Planned Behaviour and environmental sensitivity). We conclude that Swedish forest owners generally have a positive willingness-to-pay for wood ash application in their forests, but that this measure is highly dependent on their attitudes. We also show that a forest owner's decision to apply ash to all or a portion of his/her forest is explained by two different characteristics: the landowner's environmental sensitivity and his/her perceived control of wood ash recycling.

1. Introduction

The use of biomass, in particular wood, has increased this last decade as a consequence of the European Union's renewable energy targets, and is explicitly mentioned in the EU's target to reach a 20% share of energy derived from renewables by 2020 (EU, 2009). The latest report on the European bioeconomy from the Standing Committee on Agricultural Research (SCAR) and the European Bioeconomy Panel (European Commission, 2014) also identified sustainable biomass production as a main issue. With this demand for wood energy, new harvesting techniques such as whole-tree harvesting and the exploitation of harvest residues from traditional timber harvest have become more popular. However, these practices may have important ecological consequences since they remove nutrients from the forests (such as calcium, magnesium, potassium, nitrogen and phosphorus), thus reducing soil fertility. Compared to traditional harvesting techniques where only trunks are harvested, whole-tree harvesting and harvest residues also include small branches that contain relatively more nutrients than the trunks. A recent meta-study by Ranius et al. (2018) concludes that extraction of harvest residues (called “slash” in the article) is associated with risks for decreased biomass production. Achat et al. (2015) find in another meta-study the tree growth as overall negatively and significantly impacted by removing harvest residues in European countries.

To compensate for this nutrient loss, ash recycling in forests has been proposed in order to reintroduce the exported nutrients (Egnell, 2011; Väätäinen et al., 2011). Experimental research shows that spreading wood ash may increase tree growth. However, the impacts depend very much on the soil and forest types (Huotari et al., 2015). Furthermore, it has also been shown that ash use on certain forest soils has positive environmental impacts, e.g., to improve the acidification of soils and surface waters caused by acid deposition (Ekvall et al., 2014). In comparison with chemical fertilisers, wood ash has the advantage of not necessarily inducing a decrease in soil pH (Jokinen et al., 2006; Molina et al., 2007; Saarsalmi et al., 2012). Moreover, applying wood ash could also be seen as a measure of sustainability since it returns nutrients to the forest (except nitrogen) that were removed during harvesting, and can therefore be considered as an environmentally-

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friendly measure. Furthermore, ash recycling reduces the demand for the deposit of wood ash in landfills. According to Väätäinen et al. (2011), the majority of the 150,000 tons of wood ash produced annually in Finland is deposited in landfills. Despite these positive aspects of ash recycling, forest owners have been reluctant to recycle ash (Bohlin and Roos, 2002). First of all, spreading ash in forests implies the costs of raw ash treatment (e.g., granulation or enrichments), transport and spreading (Väätäinen et al., 2011). In a Canadian study of barriers to ash recycling, Hannam et al. (2018) find that the cost of getting regulatory approval of ash recycling represents also an important barrier. These costs may be higher than the value of the expected gains in productivity. Moreover, uncertainty about impacts on forest ecosystems and the lack of knowledge about wood ash application, e.g., questions about quantities to be applied, timing, expected impacts and spreading technologies, may be a barrier to the adoption of ash recycling. However, the cost of wood ash disposal in forests is slightly higher than other options like applying ash in producer-owner landfill, but these findings do not consider the potentially high value of environmental services (Hope et al., 2017). It is also well-known that non-industrial forest owners may have other management objectives than just profit maximisation (see, e.g., Petucco et al., 2015). Therefore, we may also expect that forest owners considering the sustainability of their management may be more prone to adopt ash recycling. Understanding private forest owners' preferences for ash recycling and the factors underlying its adoption is crucial for closing the nutrient cycle in a future with an increasing demand for biofuel. The present study was conducted in the county of Västmanland (central Sweden) with the cooperation of the forest owners' association, Mellanskog. In this county, forest owners have not yet adopted wood ash recycling on a large scale, whereas power and district heating plants produce abundant quantities of ash, which they consider to be a waste product (Rolfsson, 2018).

1.1. Wood ash recycling in Sweden

Sweden has 23.2 million hectares of productive forests (representing a total of approximately 57% of the total land area), with a total standing volume of 3.0 billion cubic meters (Swedish Forest Agency, 2014). An increased demand for bioenergy in the last decades, resulting in nutrient export, has contributed to the acidification of the soils in Sweden.

As a consequence of the requirements imposed by the Swedish national environmental objective, *Reduced Climate Impact*,[1] the power and district heating plants in Sweden, which tend to have good fuel substitution possibilities, have largely switched to biomass-based sources. These district heating plants are therefore the main source of ash. There are several alternatives when it comes to how ash resulting from the combustion of wood can be utilized. A part of the ash is contaminated because it is mixed with other types of fuels (e.g., waste wood from house renovations) and must be deposited at waste disposal sites. However, the most common applications for the remaining ash is as cover material for landfills, as improved frost-resistant material in gravel roads, or for ash recycling in forests (Olsson et al., 2008).

In addition to the combustion of logging residues in district heating plants, ash is also generated by the forest industry through the combustion of spill from sawmills and as a by-product of pulp factories. However, this ash usually has a lower nutrient content and a higher level of environmentally-hazardous substances, which make it unsuitable for recycling on forest land (Swedish Forest Agency, 2008).

Wood ash was spread on some 10,000 ha of forests in 2013, mainly in the Götaland and Svealand regions (south and central Sweden, respectively), wood ash fertilisation being most efficient in the presence of organic soils. Indeed, studies have shown that wood ash fertilisation has the highest positive effect on productivity on organic soils. On the mineral soils that are mainly present in the north of Sweden, wood ash fertilisation has not been shown to have particularly strong effect on productivity (Jacobson, 2003; Ekvall et al., 2014). The volume of recycled ash distributed in the forests in Svealand (where the county of Västmanland is located) in 2016 was approximately 2725 t, corresponding to about 24% of all ash distributed in Swedish forests (Swedish Forest Agency). This amount has been roughly constant for the last seven years. The majority of the ash, 75% in 2016, is distributed in the southernmost region, Götaland, which is the region that was historically most affected by acid rain. Practically, ash is applied either with a ground spreader, often a converted tractor, or by helicopter. Both techniques are used, but ground application is considerably more common.

As emphasized in Ekvall et al. (2014), ash has several alternative uses, whereas no explicit market for forest ash exists in Sweden. One fundamental problem with the use of ash on forest land is the large number of actors involved in the chain, from forest fuel extraction to the application of the stabilised ash. A private forest owner usually contracts a forest company to conduct the extraction of forest fuels. The forest company then sells the forest fuel to a forest fuel supplier, who has contracts with a number of energy companies or individual district heating plants where the ash is produced. District heating plants pay entrepreneurs to get rid of the ash. These entrepreneurs further refine and distribute the ash. Finally, private forest owners pay to have the ash distributed on their land. In some areas, the district heating plants themselves initiate ash recycling, whereas in other areas, it is the forest fuel suppliers who do so. Due to the lack of wood ash markets, it was not possible to reveal forest owners' demand for ash recycling on the basis of market prices and observed behaviour. Furthermore, in the county of Västmanland ash recycling has hitherto only been sporadically adopted.

1.2. Objectives and hypotheses

This paper contributes to the literature in three ways. We first assess the Swedish forest owners' motivations to use wood ash. We estimate their willingness-to-pay (WTP) to spread wood ash in their forest, applying a choice experiment (CE). Even though a sustainable use of wood for energy purposes will depend on private forest owners' adoption of ash recycling, few studies have investigated their willingness to apply such measures. Given that wood ash application is a rather new measure, it is difficult to determine market adoption based on forest owners' real behaviour.[2] A choice experiment based on stated preferences is an approach to evaluate a hypothetical demand. Choice experiments have also been used to analyse landowners' willingness to accept to participate in hypothetical agri-environmental schemes or in the adoption of alternative management regimes (see Horne and Petäjistö, 2003; Broch and Vedel, 2012; Vedel et al., 2015a; Vedel et al., 2015b; Kuhfuss et al., 2016 and Vaissière et al., 2018). In our choice experiment, we considered three attributes (increase in forest productivity, free technical support and a cost attribute), for describing scenarios with ash recycling, and we wanted to test the following hypothesis:

Hypothesis 1. (H1): The decision to adopt wood ash depends on its cost, the possibility to receive technical help and the expected increase in forest productivity.

Second, and contrary to the previously quoted papers, we propose

[1] https://www.miljomal.se/Environmental-Objectives-Portal/Undre-meny/About-the-Environmental-Objectives/1-Reduced-Climate-Impact/, accessed May 29, 2018.

[2] Wood ash recycling has been implemented in Nordic countries (such as Sweden and Finland) for two decades. However, ash recycling has only been extensively used in some regions and no markets for ash recycling have been developed.

an original approach in which we elicit the forest owners' preferences and intentions regarding the environment and ash recycling. In this way our study is related to empirical works on the adoption of a new technology or product (see McCluskey et al., 2003 for a study on the adoption of genetically modified food by Japanese consumers or Ziegler, 2012 for the determinants of car buyers to purchase green cars). In our study, we used a questionnaire developed in the psychological literature (Milfont and Duckitt, 2010). Indeed, the adoption of wood ash recycling may be explained by different reasons that are not directly linked to the expected impact on the profit of forest exploitation. It might be that forest owners are interested in closing nutrient cycles by spreading ash in their forests because they are conscious of the impact of their actions on the environment, and that they prefer this method over the use of chemical fertilisers. In this paper, we refer to environmental sensitivity as the fact of taking the impact of one's actions on environmental quality into account. We wanted to test the following hypotheses:

Hypothesis 2. (H2): Forest owners who are the least sensitive to environmental matters have a preference not to engage in ash distribution.

Hypothesis 3. (H3): Those expressing a high sensitivity have less strong preferences for increases in soil fertility.

The intuition is that the forest owners with a high environmental sensitivity give relative more weight to the recycling aspect of ash spreading in forest than the impact on forest productivity. Therefore, the forest productivity attribute will have less impact on the choice of scenarios with ash recycling for environmental sensitive forest owners.

Moreover, consistent with Börger and Hattam (2017), we also elicit the intention of forest owners to apply ash according to the Theory of Planned Behaviour (Ajzen, 1991). The aim of this theory is to identify individuals' determinants to adopt a given behaviour. We believe that this theory is adapted to our study because the decision for a forest owner to recycle wood ash is a significant change in management. In our study, we will test the following hypotheses:

Hypothesis 4. (H4): Those expressing confidence in being able to apply wood ash (high control) choose an alternative other than the status quo alternative.

Hypothesis 5. (H5): Those expressing a high control are less interested in receiving technical help.

We show how this theory can help to explain why forest owners decide to apply wood ash. Our results therefore provide important information for forest agency communication strategies with forest owners.

Finally, similarly to Kuhfuss et al. (2016), each time a respondent chose an alternative different from the status quo, we asked him/her to indicate the proportion of his/her forest that he/she would treat with wood ash under the chosen scenario. The aim of this question is to quantitatively assess the demand for wood ash as well as to more deeply investigate forest owners' motivations to apply wood ash in their forests. Indeed, with this question, respondents are encouraged to consider the relevance of ash recycling as a function of the specificities of their forests. In this sense, the choice experiment is expected to get closer to the root of real behaviour. We therefore test the following hypothesis:

Hypothesis 6. (H6): The choice of the proportion of the forest to be treated with wood ash depends negatively on the cost and positively on the forest owner's sensitivity and control.

The present study, and the econometric analysis that follows, are intended to test these different hypotheses. The rest of the paper is organized as follows. We present the methodology of our study and the survey in the following section. In Section 3, we present the results on forest owners' preferences regarding wood ash, and discuss the results and provide a conclusion in Section 4.

2. Methods

2.1. The discrete choice experiment (CE)

To determine forest owners' willingness-to-pay for wood ash application, we designed a choice experiment with three attributes. The first attribute, *Forest productivity*, describes the increase in forest productivity as a result of spreading wood ash, measured in the percentage of increase of wood production over a rotation period (0%, +10%, +15%, +20%). This attribute served to evaluate to what degree the forest owners' demand for ash is determined by the expected impact on wood productivity. Concerning this attribute, different results are found in the literature, depending on the type of soil and on the quantity of ash used. Pérez-Cruzado et al. (2011) compared two quantities of ash (10 t and 20 t per ha). They determined that, for both quantities, the diameter of trees increased, on average, by +16%, and the height by +11%. In another study, Saarsalmi et al. (2014) determined that the use of three tonnes of ash per hectare on Scots pine stands led to an increase in productivity of +11% after four years of treatment. On peatland sites, they did not find any significant changes in productivity during the six years after treatment. However, they did observe a significant increase in productivity of +25% at seven to 16 years after treatment.

In the introduction to the CE, the owners were explained that the impact on productivity depends on a number of factors, including type of ash, soil and forest type, and they were asked to imagine that these proposed productivity levels would be possible on their land. The second attribute, *Free technical support*, informed the forest owners whether they would obtain additional technical support, taking the form of a free 2-hour visit from an expert, access to a list of ash producers, and advice on how to apply wood ash. This attribute was added because the use of ash is a rather new measure in the region we surveyed. Forest owners may want some advice on how to apply ash (questions about ash quantities and qualities, and when and where to apply it). This attribute serves two purposes, firstly, to reveal to what degree information and knowledge may be barriers to ash recycling and, secondly, to provide important information to forest co-operatives about the demand for technical advice. Two levels were considered (yes and no). The last attribute, *Cost*, informed the forest owners about the additional cost per hectare that they would bear when applying ash in their forest. The cost includes the price of ash, the transport to the forest and the spreading. Attributes and their levels are summarized in Table 1.

The levels of the cost attribute were based on estimations found in the literature. Väätäinen et al. (2011) estimated that the total cost of wood ash (including its purchase, transportation and dispersal) is €167/

Table 1
Attributes and their levels of the discrete choice experiment.

Attribute	Levels
Productivity	+0%
	+10%
	+15%
	+20%
Free technical support	Yes, free technical support
	No free technical support
Cost	0 SEK/ha[a]
	100 SEK/ha
	250 SEK/ha
	500 SEK/ha
	1000 SEK/ha
	1500 SEK/ha
	2000 SEK/ha
	3000 SEK/ha

[a] These costs correspond to approximately €0, €10, €26, €51, €102, €153.44, €205 and €307, respectively (January 2018).

ha if ground dispersal is chosen, and €241/ha with helicopter dispersal. Pukkala (2017) estimated a total cost of €370/ha.[3]

Our study consisted of 16 choice tasks that we blocked into two different questionnaires (with eight choice tasks per respondent, in random order). In each choice task, respondents were given three options: “Situation 1”, “Situation 2” and “No wood ash” (corresponding to the status quo option). An example is presented with Fig. 1. Using Ngene software, a D-efficient design was generated for a multinomial logit model with some priors based on expert knowledge.[4] Before presenting the different attributes of our choice experiment to the respondents, we explained to them that they would have to make decisions between different options, in different scenarios, in which wood ash would be applied, with some effects on the forest. We asked them to choose among the different options, considering their own forest and their perspective of management for their forest in the next 10 years.

Once the respondents finished with their eight choice cards, those who always responded “No wood ash” were asked the reason for this choice, making it possible to identify potential protesters.

2.2. Theory of Planned Behaviour

In keeping with Börger and Hattam (2017), we asked questions intended to elicit the forest owner's intention to apply wood ash (the questions asked are given in the Appendix A). The Theory of Planned Behaviour (TPB) was initially proposed by Ajzen (1991). It measures the individual's intention to undertake a given task according to three dimensions: perceived behaviour *control* (i.e., whether individuals think they can undertake the action easily or not), *subjective norms* (i.e., the way the considered behaviour is generally perceived by others), and *attitudes* towards the considered behaviour (i.e., the individual's own evaluation of the behaviour).

In the literature, the theory participated to explain different types of behaviours. Börger and Hattam show that the respondents' intentions are a strong predictor of choice behaviour. In another study, Läpple and Kelley (2013) use this theory to elicit the intention of Irish farmers to adopt organic farming. They show that farmers are influenced by social norms (the behaviour generally adopted by their peers) and their own ability to adopt organic farming. The ability, or perceived control of the new proposed method, is also found to be a determinant regarding the decision to grow biofuel sugar beet in Mattison and Norris (2007).

In our case, it might be that respondents distribute ash on their soils because they have seen other forest owners doing it. Another possibility to explain the adoption of wood ash recycling might be that forest owners think that they are able to apply wood ash (it is not only beneficial but also tractable for them), in order to ensure the future productivity of their soils. In this paper, we therefore attempt to better understand forest owners' decisions to adopt ash recycling. Indeed, as previously emphasized, wood ash application is a form of recycling that may be of particular interest for individuals the most sensitive to environmental matters.

2.3. Environmental sensitivity questionnaire

To determine the Swedish forest owners' environmental sensitivity, we used the ten questions proposed in Milfont and Duckitt (2010) related to the implementation of a new environmental measure. The objective of the set of questions is to elicit the forest owner's support for an intervention aimed to protect the environment. It consists of ten affirmations (the questionnaire is presented in the Appendix B), with five pro-environmental behaviours (positively framed sentences) and five anti-environmental behaviours (negatively framed sentences). The respondents had to give their level of agreement according to a 5-Likert scale between “*I totally disagree*”, “*I disagree*”, “*Neutral*”, “*I agree*” and “*I totally agree*”. We recoded the answers to the pro-ecological behaviours from 1 for “I totally disagree” to 5 for “I totally agree” (and conversely for the anti-ecological behaviours).

2.4. Choice modelling and willingness-to-pay

The choice experiment is analysed based on the random utility model (McFadden, 1973). The (random) utility of choosing alternative j for individual n in choice situation t, with p_{jt} the price of alternative j in scenario t and the other attributes included in the vector x_{jt}, is given by:

$$U_{njt} = \alpha_n p_{jt} + \beta_n' x_{jt} + \varepsilon_{njt} \tag{1}$$

where $\boldsymbol{\alpha}_n$ and $\boldsymbol{\beta}_n$ are the parameters to be estimated, and ε_{njt} is the random unobserved utility component, with $\boldsymbol{\varepsilon}$ assumed to be identically and independently distributed according to an extreme value distribution.

In addition to eliciting the forest owners' preferences regarding wood ash, we are interested in determining their willingness-to-pay (WTP) for wood ash application. Thus, rearranging Eq. (1), we obtain a representation of their preferences in the WTP space (Train and Weeks, 2005):

$$U_{njt} = \alpha_n (p_{jt} + c_n' x_{jt}) + \varepsilon_{njt} \tag{2}$$

where $c_n' = \frac{\beta_n}{\alpha_n}$ is the vector of marginal WTP estimates. An advantage of estimating the utility model in WTP space is that the distribution of willingness to pay is directly defined by the researcher and therefore often gives more reasonable values (Scarpa et al., 2008; Hole and Kolstad, 2012). The distribution of the WTP that applies to the preference space model implies taking the ratio of two distributions and may result in arbitrary distributions.

3. Results

In this section, we present the results of the estimations we conducted. We begin with a description of the obtained data. We then analyse the attitudes of the forest owners (environmental sensitivity and Theory of Planned Behaviour), and finally conduct some econometric analyses.

3.1. Data

The questionnaire was developed in co-operation with and tested by the Swedish forest owners' association, Mellanskog. Furthermore, the design of the choice experiment benefited from a previous related choice experiment with French forest owners (Abildtrup et al., 2017). However, in the present survey, the questionnaire and experimental design were modified to account for specific research questions and the Swedish context. For example, compared to France, ash recycling is actually permitted and applied in Sweden.[5] In the county where the survey was carried out (Västmanland, central Sweden), only a few forest owners currently recycle ash (only two out of the 89 participants in the survey have applied ash before) but pressure to accept ash recycling on forest owners selling wood for energy purposes implies that adoption of ash recycling in private forests in Västmanland is an important question (Rolfsson, 2018).

The data was collected through *Limesurvey*, an online survey platform. The invitation to participate to this study, with a link, was emailed in October 2017 by Mellanskog. In total, 800 emails were sent to the forest owners from Mellanskog. A total of 227 of them followed

[3] These are only estimates given that a market for wood ash does not really exist at this time.

[4] We used only assumptions about the signs: productivity and free technical advice have positive signs and cost has a negative sign.

[5] Wood ash recycling is not allowed by law in France, but the government is currently reconsidering this possibility.

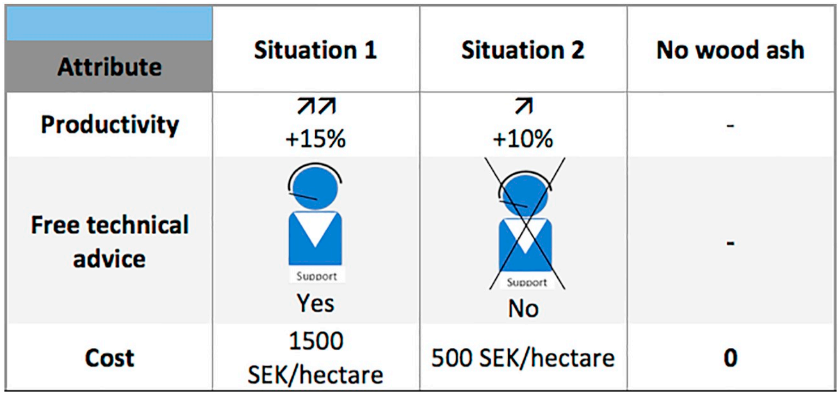

Fig. 1. Example of a choice card.

the link to participate, but only 92 completed the questionnaire (response rate of 11.50%). We excluded three respondents because they stated in the follow-up questions that they did not understand the idea of our choice experiment. Finally, our total sample is composed of 89 respondents, with a balance between the two blocks: 41 respondents in the first block and 48 in the second one.

The characteristics of the sample are presented in Table 2. We observed a relatively homogenous distribution of forest sizes in the interval of 21 to 500 ha. In our sample, 49.44% of forest owners are < 56 years old, and 42.69% of them have a master's degree. Finally, most of the forests are certified, at least partially.

3.2. Theory of Planned Behaviour (TPB) and environmental sensitivity

Three sets of questions were asked to elicit the forest owner's *attitude*, *social perception* and *control* regarding wood ash application (the questions are provided in Appendix A). We recoded the answers from one to seven, and summed up the score per behaviour measured (*attitude*, *social perception*, *control*). Mean scores per item and standard deviation are presented in Table 3.

Overall, these measurements seem to indicate that forest owners perceive that they have good control (the mean score per item is higher than the midpoint of the Likert scale): they think that they are able to apply wood ash in their forests. However, it seems that the social perception of the other forest owners does not necessarily have an influence on their choice to apply wood ash (the score is below the midpoint). Regarding attitude, since the mean score per item is close to the midpoint, we can neither conclude a positive nor a negative attitude towards wood ash.

Table 2
Characteristics of the sample.

Characteristic	Interval	%
Size of forest	0–5 ha	3.37
	6–20 ha	8.99
	21–50 ha	28.09
	51–100 ha	28.09
	101–500 ha	30.34
	> 500 ha	1.12
Age	18–40	14.61
	41–55	34.83
	56–70	42.70
	> 70	7.87
Gender	Male	87.64
	Female	12.36
Main activity	Forester	5.62
	Farmer	21.35
	Self-employed	10.11
	Employed	43.82
	Retired	15.73
	Other	3.37
Level of education	No diploma	1.12
	Secondary school/high school (professional)	26.97
	Short education	28.09
	Master's or higher	42.69
	Other	1.12
Certification (FSC, PEFC)	All of the forest	58.43
	Part of the forest	1.12
	No	40.45

Table 3
Mean scores per item and standard deviation of the behaviours measured by the TPB.

Behaviour measured	Mean score per item	Standard deviation
Attitude	4.13	1.73
Social perception	3.43	1.70
Control	4.81	1.91

Using a Spearman correlation test, we find that the attitude towards wood ash and the forest owner's social perception are positively correlated ($\rho = 0.710$, $p < 0.01$). This is also the case for the attitude and the control ($\rho = 0.209$, $p = 0.049$) and the control and social perception ($\rho = 0.281$, $p < 0.01$).

Regarding the questions on individual environmental sensitivity, we obtained a Cronbach's α equal to 0.86, meaning that our ten questions measure only one dimension, as expected (environmental sensitivity in our case).[6]

Using a Spearman correlation test, we found that environmental sensitivity is not significantly correlated with the control behaviour of the TPB ($\rho = 0.055$, $p = 0.606$), whereas it is with the attitude ($\rho = 0.289$, $p < 0.01$) and the social perception ($\rho = 0.233$, $p = 0.028$). Thus, in our econometric analysis, we included a variable for individual environmental sensitivity and one for individual control regarding wood ash application.

3.3. Willingness-to-pay

We estimated the utility model (1) using conditional logit, with a variable for the productivity increase due to wood ash application (*prod*, modelled as a continuous variable), one for technical help (*tech* modelled as a dummy variable equal to 1 if there is free technical help), one for the *cost* (modelled as a continuous variable) and one for the status quo (*SQ*, modelled as a dummy equal to 1 if the status quo is chosen). To test our hypotheses (discussed in the introduction), we also included crossed variables in a second model: *SQ∗control* and *SQ∗sensi*, to capture the effect of choosing the status quo alternative while expressing more control and having a higher environmental sensitivity,

[6] The mean score per item is 3.88, with a standard deviation of 1.16.

Table 4
Conditional logit estimation.

Variable		Model 1 Coef.	Model 1 Stand. err.	Model 2 Coef.	Model 2 Stand. err.	Model 3 Coef.	Model 3 Stand. err.
One percent increase in productivity	*prod*	8.065***	1.013	8.394***	1.045	11.055*	6.049
Technical help	*tech*	0.422***	0.131	0.393***	0.134	1.843**	0.579
Cost	*cost*	−0.001***	0.000	−0.001***	0.000	−0.001***	0.000
SQ	*SQ*	0.993***	0.160	5.777***	0.593	7.024***	1.083
	SQ∗control	–	–	−0.214***	0.032	−0.302***	0.048
	SQ∗sensi	–	–	−0.069***	0.012	−0.078***	0.023
	Sensi∗prod	–	–	–	–	−0.057	0.148
	Control∗Tech	–	–	–	–	−0.142**	0.055
89 forest owners, 712 choices							
LL		−604.106		−557.835		−554.323	
Pseudo R-squared		0.228		0.287		0.291	

Significance levels.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

respectively.[7] Finally, in a third model, we included two other variables to account for the effect of receiving technical help when an individual expresses a high control over wood ash application (*Control∗tech*), and another one to account for the effect of obtaining higher productivity while being more sensitive to environmental matters (*Sensi∗prod*). According to H5, we expect that an individual who expresses a high control over wood ash application (he/she perceives herself as someone who is able to apply wood ash) would not need to receive technical help (the coefficient of the variable *Control∗tech* should be negative). Secondly, according to H3, an individual who is highly sensitive to environmental matters may not necessarily be interested in an increase in soil fertility: the protection of the environment might be the priority (the coefficient of the variable *Sensi∗prod* should be negative as well). The results of the conditional logit regression are presented in Table 4.

As expected, in the three models, we observe that the forest owner's utility increases with a positive impact on forest productivity and with free technical help. On the contrary, the forest owner's utility decreases when the cost of applying wood ash increases. Therefore, we cannot reject hypothesis H1.

The significant positive coefficient associated with the SQ variable indicates that forest owners, in average, prefer no ash in a scenario with wood ash application, compared to a scenario where wood ash is free (zero costs) but in which there is no productivity effect and no free technical help. However, taking the psychological variables into account, we also determined that those owners expressing a higher control over wood ash application, and those with a higher environmental sensitivity were less likely to choose the SQ alternative (in the second model). Therefore, we cannot reject hypotheses H2 and H4. Our intuition regarding an individual expressing high control over wood ash application is also verified with our third model: he/she would be less interested in receiving technical help (third model). We cannot reject hypothesis H5. However, we did not find any significant negative effect of being more sensitive to environmental matters on the preferences for productivity increase. Being environmentally sensitive may also include a concern for future fertility of the soil, which may be represented by the productivity variable. Environmentally-sensitive forest owners have the same preferences for fertility as the other ones. We therefore rejected hypothesis H3. We found that the pseudo R-squared is on an acceptable level for choice experiments.[8]

To account for heterogeneity of preferences and to obtain monetary values, we estimated model (2) using simulated maximum likelihood methods (GMNL procedure in Stata; Gu et al., 2013), with 750 Halton draws and assuming normal distributed coefficient distributions. The results are reported in Table 5. We determined that all the estimated means of the coefficient distributions are significant. It appears that forest owners are willing to pay 45 SEK/ha for a 1% increase in forest productivity, and 184 SEK to receive two hours of technical help to apply wood ash in their forest.[9]

Note, however, that the most environmentally sensitive forest owners, and those expressing a higher control regarding wood ash application would pay less for having the SQ alternative, i.e., not having ash in their forests. Another way to interpret the SQ value is the willingness-to-accept (WTA) ash in their forest given no effect on productivity, no technical help and no costs. This means that forest owners should be compensated for using ash in their forests. However, this WTA is sensitive to owners' feelings of control and their environmental sensitivity. Even then, accounting for the impact of environmental sensitivity and feelings of control, we found a significant heterogeneity in preferences over forest owners. All of the attributes have a significant standard deviation (Table 5) with the exception of technical help.

On the basis of these results, we carried out simulations regarding forest owners' willingness-to-pay for wood ash application in their forests with 2 h of technical help, varying the increase in forest productivity and the environmental sensitivity (ES) score. The results are presented in Table 6.

These simulations highlight the fact that the median forest owner (in terms of environmental sensitivity and expressed control) has a positive willingness-to-pay for wood ash application in his/her forest. However, varying the total environmental sensitivity score, the willingness-to-pay becomes negative for forest owners with the lowest sensitivity to environmental matters: they would require to be paid to apply wood ash in their forests, even in the most optimistic scenario (corresponding to a 15% increase in soil fertility). Environmental sensitivity is therefore a key determinant of forest owners' willingness-to-pay for wood ash application, as expected (H2).

In contrast, the estimated willingness-to-pay measurements appear to be less affected by changes in the control score because, contrary to changes in the environmental sensitivity score, the measured willingness-to-pay is always positive, except for the case of a 5% increase in forest productivity.[10]

[7] Both the variables *control* and *sensitivity* are modelled as continuous variables.

[8] We propose latent class estimations with class membership function in the Appendix C. We obtain similar results.

[9] These amounts correspond to €4.56 and €18.66, respectively (as of January 17th, 2018).

[10] Even though control has the highest standard deviation per item (see Table 3).

Table 5
Willingness-to-pay space.

Variable	Coefficient (Marginal WTP in 1000 SEK)	Stand. err.
One percent increase in productivity	0.045***	0.005
Technical help	0.184***	0.053
SQ	3.407***	0.395
SQ*control	−0.072***	0.017
SQ*sensi	−0.059***	0.009
Price	2.959***	0.560
SD		
One percent increase in productivity	−3.756***	0.359
Technical help	0.018	0.046
SQ	0.519***	0.078
SQ*control	0.059***	0.006
SQ*sensi	0.013***	0.001
Price	1.750***	0.299
89 forest owners, 712 choices		
LL	−391.392	
Prob > chi^2	< 0.001	

Significance levels: *p < 0.10; **p < 0.10; ***p < 0.01.

Table 7
One-inflated beta model estimation.

Variable	Coefficient	Standard error
Proportion 0 < y < 1 (n = 317)		
One percent increase in productivity	1.021	0.981
Technical help	0.102	0.116
Cost (per hundred euros)	−0.028***	0.010
Sensitivity	0.025**	0.010
Control	−0.041	0.029
Constant	−1.216*	0.653
One inflate (y = 1) (n = 28)		
One percent increase in productivity	2.482	4.079
Technical help	0.288	0.482
Cost (per hundred euros)	−0.049	0.057
Sensitivity	−0.090*	0.051
Control	0.175*	0.106
Constant	−1.130	2.768
Ln_phi intercept	1.207***	0.066

Significance levels.
* p < 0.10.
** p < 0.05.
*** p < 0.01.

Table 6
Simulations of willingness-to-pay for wood ash application.

Increase in forest productivity	Forest owner with median environmental sensitivity and control (TPB) score	Forest owner with median control score and 10% of the lowest ES score	Forest owner with median control score and 10% of the highest ES score	Forest owner with median ES score and 10% of the lowest control score	Forest owner with median ES score and 10% of the highest control score
+5%	89.55 SEK/ha (€9.08)	−515.31 SEK/ha (−€52.24)	575.81 SEK/ha (€58.38)	−147.06 SEK/ha (−€15.03)	304,65 SEK/ha (€31.14)
+10%	313 SEK/ha (€31.74)	−291.86 SEK/ha (−€29.59)	799.26 SEK/ha (€81.04)	76.39 SEK/ha (€7.81)	528.10 SEK/ha (€53.99)
+15%	536.45 SEK/ha (€54.40)	−68.41 SEK/ha (−€6.94)	1022.71 SEK/ha (€103.70)	299.84 SEK/ha (€30.65)	751,55 SEK/ha (€76.83)

3.4. Surface area of forest treated with wood ash

Consistent with Kuhfuss et al. (2016), we now explain forest owners' decisions to treat a proportion of their forest. Indeed, when choosing one of the two alternatives different from the status quo, forest owners had to decide what percentage of their forest they would treat with wood ash.

Out of the 89 respondents, 62 chose an alternative different from the status quo at least once (corresponding to a total of 345 alternatives different from the status quo (minimum value of 2.22%). These forest owners would treat, on average, 40.09% of their forest.[11]

As in Kuhfuss et al. (2016), we estimated a one-inflated beta regression, i.e., a specific econometric method to explain proportions (Cook et al., 2008). This model separately estimates the fact that a forest owner decides to treat his/her entire forest, or a part of it. The assumption is that the determinants to fully treat the forest are different from those of treating a part of the forest only. Thus, the density function $g(.)$ for this model is given by:

$$g(y;\pi;\mu;\varphi) = \begin{cases} (1-\pi)f(y;\mu;\varphi),\ if\ y<1 \\ \pi\ if\ y=1 \end{cases}$$

where $f(.)$ is the beta distribution with mean μ, φ is the precision parameter and π is the parameter accounting for the probability of having observations at one. The model is estimated by maximum likelihood.

The results are presented in Table 7. It seems that the decision to fully treat the forest or to treat a part of it corresponds to two different behaviours. In the latter treatment, it is the environmental sensitivity that explains the decision to treat the forest with wood ash (positive and significant coefficient at the 5% level). The cost has a significant negative effect (significant at the 1% level). This is normal since a decreasing marginal productivity of ash with an increasing share of land where ash is applied can be expected. The results also correspond to what we obtained in the discrete choice model: higher productivity and lower costs increase the likelihood of applying wood ash. Contrary to the previous results, there is no effect due to the expression of a higher control on wood ash application or of being offered free technical assistance.

Regarding the decision to fully treat the forest, it seems to correspond to a different behaviour: the coefficient associated with environmental sensitivity is now significantly negative (at the 10% level), while the one associated with the control that a forest owner has over wood ash application is significantly positive (at the 10% level). This could indicate that a forest owner who is environmentally sensitive will generally be more prone to use ash recycling and a larger share of land – but less prone to applying it to all of the land. It could be hypothesized that an environmentally sensitive owner will apply only ash recycling on her/his land where ash spreading is ecologically feasible. On the other hand, an owner who feels that he/she is in control will be less likely to make such considerations.

We also estimated these proportions with a fixed effect panel data model. Still in keeping with Kuhfuss et al. (2016), when analysing the decision to apply wood ash to a part or all of an individual's forest, there may be a selection bias due to the fact that some unobserved factors influencing the choice of an alternative (different from the status quo) may be correlated with unobserved factors affecting the decision to treat a part (or all) of the forest. A fixed effect panel model avoids this potential bias. The results are reported in Table 8.

Contrary to the previous model, the coefficient associated with

[11] The maximum value (100%) was chosen 28 times (7.67%).

Table 8
Panel model with fixed effects.

Variable	Coefficient	Standard error
One percent increase in productivity	0.103	0.119
Technical help	0.028***	0.010
Cost (per hundred euros)	−0.004*	0.002
Constant	0.398***	0.041

62 forest owners.
Significance levels: *p < 0.10; **p < 0.05; ***p < 0.01.
Bootstrapped standard errors (1000 replications).

technical help is significantly positive (at the 5% level), thus indicating that the forest owners who receive technical help accept to treat more of their land with ash. This result may be due to the fact that, contrary to the previous model, the proportions of forests treated are pooled (we do not disentangle the decisions to fully treat the forest and those regarding a treatment of a part of the forest). Moreover, in the previous model, there were few observations regarding the decision to fully treat a forest. Considering these two estimations, we conclude that we cannot totally reject hypothesis H6.

4. Discussion and conclusion

Given the increasing demand for biofuel, ash recycling may represent an important measure to close the nutrient cycle and ensure sustainable use of the forest. This paper focuses on the importance of understanding the factors that influence forest owners to adopt ash recycling and, in particular, the types of forest owners that are most likely to spread ash in their forests. This approach provides important information for forest organisations and regulators in Sweden and other countries where biofuel demand from forests is increasing.

We therefore assess forest owners' attitudes to and willingness-to-pay for wood ash application in their forest. To do this, we have proposed an original approach that combines a choice experiment with psychological questionnaires to better explain the factors that motivate forest owners' to adopt wood ash.

Our results indicate that, overall, Swedish forest owners would agree to pay 45 SEK/ha for a 1% increase in forest productivity under wood ash application. We also show that the forest owners who are most sensitive to environmental matters, as well as those who express a high control over the way to apply wood ash, are willing to pay more for wood ash. Furthermore, forest owners will pay an average of 184 SEK for two hours of technical help with wood ash application. In particular, owners who do not feel in control will pay a higher value for technical help. Our result regarding the link between environmental preferences and the willingness-to-pay corroborates the findings of Taye et al. (2018) who also highlight such a relationship. In accordance with Läpple and Kelley (2013), we found that the Theory of Planned Behaviour and, in particular, the perceived control regarding a new management practice, explains the decision to adopt wood ash application.

From a public policy point of view, these results seem to indicate that a regulator or ash-producing company seeking to promote wood ash adoption should target specific forest owners, e.g., those who are the most sensitive to environmental matters. As emphasized in the simulations in the previous section, the measured willingness-to-pay is less sensitive to a forest owner's control score regarding wood ash application, than when we vary his/her environmental sensitivity score. We could therefore recommend raising forest owners' awareness about environmental matters even more.

The fact that Sweden has been an early adopter of ash recycling also means that the research results will be potentially important for other countries (Hannam et al., 2018), notably France where ash recycling is currently only allowed on agricultural land. However, ash recycling in forests features prominently in the policy debate and the French Environmental and Energy Management Agency (Agence de l'environnement et de la maîtrise de l'énergie) in particular is funding research underpinning potential new regulation allowing wood ash use in forest (Saint-André et al., 2019). Our results will, in particular provide useful information for the design of potential subsidy schemes including providing an approach that can be useful in testing such schemes before implementation. As our results are based on forest owners' stated behaviour, one could ask if the results could be prone to hypothetical bias. Therefore, future research should survey adopters and non-adopters in regions where ash recycling is more widely adopted and where markets exist for it with the purpose of replicating our results observing forest owners' real behaviour.

A limitation of our study comes from a relatively low responses rate and, consequently, a relatively small sample size. Note that previous surveys targeting forest owners also often have a low response rate (Petucco et al., 2015). It should also be noted that the main objective of this study is not to estimate a national or regional demand for wood ash but to obtain insights into the factors that influence forest owners' adoption of wood ash application. In this way, we believe that our results may still provide useful information for policymakers since we were able to test our initial hypotheses. The number of observations does not allow for an application of latent variable models that account for potential endogeneity of environmental sensitivity and a feeling of control (Hess and Beharry-Borg, 2012). Therefore, one should be careful when interpreting the significant impact of the attitudinal variables on choices as causal relationships. However, it is still an important result for policymakers that we found a statistically significant relationship between environmental sensitivity and choices about ash recycling.

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Appendix A. Theory of Planned Behaviour

The respondents read the following sentences and selected the behaviour that best characterized the way they behave. The recoding is given in parentheses.

Attitude towards wood ash recycling:

• For you, to use ash in your forest during the next 10 years is:
Worthless _ _ _ _ _ _ _ Valuable
(+1) (+7)

• For you, to use ash in your forest during the next 10 years is:
Harmful _ _ _ _ _ _ _ Beneficial

(+1) (+7)
Social perception regarding wood ash recycling:
• The forest owners that I know whose opinions I value
Will not use ash _ _ _ _ _ _ _ Will use ash
in their forest during the 10 next years
(+1) (+7)
• Most forest owners I know will use ash in their forest during the next 10 years
Extremely unlikely _ _ _ _ _ _ _ Extremely likely
(+1) (+7)
Control regarding wood ash recycling:
• If I wanted to, I could use ash in my forest during the next 10 years
Definitely false _ _ _ _ _ _ _ Definitely true
(+1) (+7)
• It is mostly up to me whether or not I use ash in my forest during the next 10 years
Strongly disagree _ _ _ _ _ _ _ Strongly agree
(+1) (+7)

Appendix B. Environmental sensitivity questionnaire

• Industry should be required to use recycled materials even when this costs more than making the products from new raw materials.
☐ I totally disagree
☐ I disagree
☐ Neutral
☐ I agree
☐ I totally agree
• Governments should control the rate at which raw materials are used to ensure that they last as long as possible.
☐ I totally disagree
☐ I disagree
☐ Neutral
☐ I agree
☐ I totally agree
• Controls should be placed on industry to protect the environment from pollution, even if it means that things will cost more.
☐ I totally disagree
☐ I disagree
☐ Neutral
☐ I agree
☐ I totally agree
• People in developed societies are going to have to adopt a more energy-conserving life-style in the future.
☐ I totally disagree
☐ I disagree
☐ Neutral
☐ I agree
☐ I totally agree
• The government should give generous financial support to research related to the development of alternative energy sources such as solar energy.
☐ I totally disagree
☐ I disagree
☐ Neutral
☐ I agree
☐ I totally agree
• I don't think people in developed societies are going to have to adopt a more energy-conserving life-style in the future.
☐ I totally disagree
☐ I disagree
☐ Neutral
☐ I agree
☐ I totally agree
• Industries should be able to use raw materials rather than recycled ones if this leads to lower prices and costs, even if it means the raw materials will eventually be used up.
☐ I totally disagree
☐ I disagree
☐ Neutral
☐ I agree
☐ I totally agree
• It is wrong for governments to try to compel business and industry to put conservation before producing goods in the most efficient and cost-effective manner.
☐ I totally disagree

☐ I disagree
☐ Neutral
☐ I agree
☐ I totally agree

• I am completely opposed to measures that would force industry to use recycled materials if this would make products more expensive.

☐ I totally disagree
☐ I disagree
☐ Neutral
☐ I agree
☐ I totally agree

• I am opposed to governments controlling and regulating the way raw materials are used in order to try to make them last longer.

☐ I totally disagree
☐ I disagree
☐ Neutral
☐ I agree
☐ I totally agree

Appendix C. Latent class estimation with class membership function

	Class 1 – Low expressed control on wood ash recycling		Class 2 – High expressed control on wood ash recycling	
Attributes	Coefficient	(Stand. Err.)	Coefficient	(Stand. Err.)
One percent increase in productivity	0.276*	(0.152)	3.436***	(0.124)
Technical help	0.048*	(0.027)	0.282***	(0.021)
Cost (in hundreds of euros)	−0.002*	(0.001)	−0.019***	(0.001)
SQ	0.920***	(0.022)	0.206***	(0.017)
Fixed effects in the class membership model				
Sensitivity	−0.048	(0.033)		
Control	−0.317***	(0.100)		
89 forest owners, 712 choices				
LL	−862.28			
AIC	1748.56			
BIC	1778.42			

Significance levels: *$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

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