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From white to green gold: Digging into public expectations and preferences for ecological restoration of asbestos mines in southeastern Quebec, Canada

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ABSTRACT

The asbestos mining industry in Canada shut down in 2012, leading to several decommissioned and some abandoned sites. In southeastern Quebec, asbestos mining residues cover an area of 2308 hectares. About 800 million tonnes of tailings are vestiges of this mining industry, along with socio-economic and environmental impacts resulting from mine closure. Ecological restoration of asbestos tailings and waste rock involves many considerations, including afforestation challenges, high costs and health risks related to asbestos dust exposure during the process. This study documented social demands for asbestos mine restoration in southeastern Quebec (Canada) by local community members. Choice-based conjoint analysis assessed public expectations and preferences for various key attributes related to ecological restoration (i.e., types of vegetation cover, desired uses, total area to be restored, and payment conditions) of former asbestos mining sites. Results highlight public interest regarding ecological restoration projects in these areas, show various landscape preferences and a positive willingness to financially support land reclamation scenarios. In addition to heterogeneity in the choice of attributes and levels associated to the proposed scenarios, the results of this study reveal that the surveyed community members possess a strong sense of belonging to their mining heritage, but low risk perceptions regarding exposure to asbestos fibres. By adopting a cross-disciplinary perspective of social and natural sciences, this study suggests possible avenues for integrating social dimensions that shape these communities toward a post-mining future fostering consensus and cohesion.

1. Introduction

For many years, asbestos was perceived as a "magic mineral" due to its resistance to heat, fire, tension and chemicals. This mineral was used widely in various industries and has been referred to as "white gold," alluding to the immensely valuable and vast deposits of white asbestos or chrysotile (a serpentine phyllosilicate mineral) that were mined in Quebec since the 1870s. Indeed, many open-pit mines were established around the globe to meet industrial demands; the most representative of these industrial-scale operations have been found in Canada, Russia, South Africa, Australia, Zimbabwe and Italy (Lysaniuk, 2013). Despite the advantages of this fibrous mineral (actually, six naturally occurring serpentine or amphibole minerals), asbestos is a recognized human carcinogen and can also cause various non-cancerous respiratory disorders (Brofy et al., 2007; Goldberg and Luce, 2009). Since the 1980s, many countries have introduced bans or tight restrictions on the production, importation and use of asbestos due to public health and environmental concerns (Lin et al., 2019).

Until recently, Canada was the largest producer of asbestos in the world. Asbestos mining of this country has been conducted in Quebec, Newfoundland and Labrador, British Columbia, and the Yukon Territory (Kuyek, 2003). In 2018, Canada joined a dozen other countries in banning the use and production of products containing asbestos (Canada, 2018). Therefore, regulations banning asbestos and products containing asbestos were added to the Canadian Environmental Protection Act (Canada, 1999). The implementation of these regulations would not have taken place without international solidarity and support of the scientific community, activists and asbestos victims (Ruff, 2017).

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Canada's legacy of asbestos mining, which was once a prosperous industry, has been reduced to mountains of tailings and decommissioned mine lands. In addition, the permanent closure of open-pit asbestos mines has generated further health, environmental, economic and social consequences, such as asbestos exposure-related diseases, environmental contamination and unemployment (van Horssen, 2016; Allen et al., 2018). In Canada, the provincial governments are responsible for the mining sectors within their respective jurisdictions (Rabbi et al., 2015). In Quebec, mine land rehabilitation and restoration is compulsory; since 1995, costs that are associated with the restoration process are to be assumed by the owners under the Mining Act (RSQ, c. M-13.1). Yet, most asbestos mining operations had already ceased their operations when these legal provisions came into force and, therefore, closed mines were not covered by these new obligations (BAPE, 2020). If owners go bankrupt, this can lead to site abandonment, which in turn places the financial burden of restoration of these orphan sites on the government (Simard, 2019).

The socio-economic challenges of mine closure are present for most extractive industries around the world, and require greater research attention (Bainton and Holcombe, 2018). Over the past few decades, numerous studies have provided comprehensive information regarding stakeholder perceptions regarding mine closure and ecological restoration (Vodouche and Khasa, 2015; Khadija et al., 2016; Unger et al., 2020). There is also a growing literature on the perspectives of citizens' preferences and concerns toward the post-mining futures of their communities (Sklenicka and Molnarova, 2010; Burton et al., 2012; Svobodova et al., 2012; Rixen and Blangy, 2013; Sinnett and Sardo, 2020). Yet, few studies have examined the social dimensions of the Canadian asbestos post-mining context (van Horssen, 2013; Carney, 2016). Despite the growing academic interest in the social aspects that are related to mine closure and restoration, such as social expectation, economic transition and stakeholder engagement, their integration still remains challenging for the extractive industries and the government (Bainton and Holcombe, 2018).

Ecological restoration in the presence of asbestos residues differs from other mining restoration projects due to the controversial nature of the mineral itself. Indeed, asbestos raises human health-risk challenges, which in turn, necessitates taking special precautions during such projects. This situation requires further special considerations when determining possible future uses of post-mining sites that are practicable. The present study explores the perceptions of local communities regarding ecological restoration of post-mining sites in three southeastern Quebec municipalities. More precisely, the objectives of this study were: (1) to assess peoples' expectations regarding ecological restoration of asbestos mine sites; (2) to analyze respondents' preferences for plant species that are being tested for ecological restoration in the area and potential future uses for such land; (3) to explore mechanisms that financially support such restoration scenarios; and (4) to suggest possible avenues for incorporating social dimensions into a post-mining future.

It should be noted that this current study complements an ongoing afforestation study that is taking place across mine sites in the study area. The current study forms part of this ecological restoration project, the details of which are summarized in Section 2.2. By adopting cross-disciplinary perspectives that drawn upon both the social and natural sciences, these two studies form a comprehensive assessment of the social and ecological challenges that are associated with asbestos mine restoration. Thus, greater integration of these two disciplines would allow local communities to express their preferences and expectations that are related to the ongoing afforestation research project and potential land uses after restoration.

The rest of the paper is structured in five sections. Section 2 provides an overview of the study areas and describes a complementary, ongoing ecological restoration research project in mine sites in these areas. Section 3 describes the social experimental design and data collection methods for surveying the communities, while Section 4 reports the results of preferences for ecological restoration scenarios. Section 4 also includes a simulation among four ecological restoration scenarios that explores the willingness to pay. Section 5 provides a full discussion on findings as well as implications of carrying out ecological restoration of mine sites at a larger scale in southeastern Quebec. Finally, Section 6 provides concluding remarks.

2. Materials and methods

2.1. The case study areas: The towns of Thetford Mines, Black Lake and Asbestos

In Canada, the mining of asbestos has mostly occurred in the Province of Quebec. At the peak of the industry, Quebec had 10 of the 13 mines in Canada (Kuyek, 2013). Most asbestos mining sites in the province were found in its southeast administrative regions, i.e., Chaudière-Appalaches (Thetford Mines and Black Lake) and the Eastern Townships (Asbestos). Chrysotile mining in this area began in 1877; by 1895, it had produced 10,000 tonnes of asbestos per year and employed 700 people (Faucher, 1971). Thereafter, the asbestos industry developed slowly. It was only after 1910 that exploitation of asbestos in Quebec developed at a larger scale, eventually reaching 29% of worldwide production (Savard, 2017). In 1956, its production reached 1,014,229 tonnes, equivalent to 80% of the asbestos world market at that point in time (Grenier, 1959). In the mid-1970s, the asbestos industry was in turmoil due to falling global demand for the ore, which led to overproduction and an increase in the regional unemployment rate. It was also a time when the onset of international studies began that linked human health problems to asbestos exposure (Savard, 2017).

In 2012, the last asbestos mine in Quebec shut down (Marier, 2016). The large-scale open-pit mining operations have led to a marked transformation of the landscape surrounding the towns of Thetford Mines, Black Lake and Asbestos. This landscape is now dotted with dozens of deserted mining sites that are characterized by tailings piles and waste rock (overburden). It is estimated that 800 million tonnes of material have been accumulated over time, covering a total area of 2308 hectares (BAPE, 2020). Encroachment of the overburden (waste rock) dumps by nearby forests is limited, due to the hostile nature of the material. The landscape of these former mining communities is comparable to other places in the world where mining activities occurred. Worldwide estimates of orphaned, abandoned or decommissioned mine lands are not well documented, but millions of them are likely to exist (Worrall et al., 2009).

Since the closure of the asbestos mines, there have been substantial efforts at some sites in Quebec to reconstruct the soil profile over the waste rock and tailing piles using residual wastes, such as municipal biosolids and deinking sludge. When mixed in adequate proportions, these materials provide a substrate that can support plant growth. As such, some decommissioned asbestos mines in Quebec have favoured this fast and reliable approach for revegetation using grasses (Fig. 1). Thus far, this has been a very successful solution and there have been no indications of phytotoxicity. Until very recently, however, there were very few attempts of afforestation. This is due to the many challenges of growing trees on the shallow and very well drained reconstructed soils, which have a low capacity to supply water and nutrients in adequate amounts for tree survival and growth (Macdonald et al., 2015).

2.2. Ecological restoration research project

An ongoing afforestation study, which is led by a co-author of this paper (N. Bélanger), is investigating technological solutions for reconstructing more suitable (deeper and more stable) soils for afforestation on asbestos tailings piles at the Black Lake mining site in the Thetford Mines region (Figs. 2, 3 and 4). Serpentine asbestos (chrysotile) is rich in magnesium [$(Mg)_3Si_2O_5(OH)_4$], which can create nutritional imbalances and deficiencies due to antagonistic effects of magnesium on the uptake of other nutrients, such as calcium. Two field experiments were

Fig. 1. Ecological restoration of a waste rock pile in Black Lake with grass. Grasses were seeded on a mixture of municipal biosolids and deinking sludge.

Fig. 2. Open-pit asbestos mine with the municipality of Black Lake in the background.

Fig.. 3. Waste rock piles that are ready for ecological restoration in Black Lake.

developed as a means of identifying the best possible soil-plant combination for afforestation. These experiments included the testing of three main soil mixtures: (1) municipal biosolids (300 Mg ha^{-1}) and deinking sludge (900 Mg ha^{-1}); (2) mixture 1 with slightly contaminated soils; and (3) mixture 1 with wood ash, wood shavings or mycorrhizae, which were applied at the soil surface as nested soil amendments. In spring 2017, tree seedlings were planted at sites where grasses had been seeded on mixture 1 one to four years prior. Oats (*Avena sativa*) were applied at a rate of 80 kg ha^{-1} and were used as a nurse plant, whereas a mixture composed 55% Timothy grass (*Phleum pretense*), 30% red clover (*Trifolium pretense*), and 15% alsike clover (*Trifolium hybridum*) was applied at a rate of 20 kg ha^{-1}. Trees were either planted directly into the grass cover (control), or on small mounds (maximum height of ~20 cm, diameter of ~60 cm) that had been formed by a backhoe, or a microsite

Fig. 4. Side-slope image of an asbestos tailings barrow in Black Lake. Note how its maximum elevation approaches the height of the nearest natural peak (background, right hand side).

where grasses were eliminated after application of glyphosate. A complete randomized block design was used to test 5 tree species, totalling 3024 individuals (4 blocks × 21 plots of 100 m^2/block × 36 trees/plot). The species include green alder (*Alnus viridus* ssp. *crispa*), three hybrid poplar clones (915,302, 915,303 and 915,311), one willow species (*Salix miyabeana*), white spruce (*Picea glauca*), and tamarack (*Larix laricina*). The three hybrid poplar clones were developed by the *Ministère des forêts, de la faune et des parcs du Québec* (MFFPQ) and are all the result of a crossbreeding between a female parent originating from Japan (*Populus maximowiczii*) and a native male parent of balsam poplar (*Populus balsamifera*) with a northern spatial distribution. They are thus well adapted to the bioclimatic and edaphic conditions of the region. Results suggest a greater potential (survival and growth rates) of the poplar clones, followed by tamarack and then white spruce planted on mounds. When planted directly into grasses or on microsites with glyphosate, these species showed poor survival and growth. *Salix miyabeana* and green alder had low survival and growth rates for all site preparation treatments.

Overall, this study confirmed low tree survival and growth due to an incapacity of their roots to develop deeper than the artificial soil (depth of reconstructed soils is generally ~15 cm for grass restoration) and a significant lodging effect (i.e., the displacement of stems/roots from their proper vertical placement) associated with the high winds on top of the barrows and the poor stability of the artificial soil, leads. This led to a second study in 2018, where three soil mixtures that were identified above were tested. To provide a greater rooting depth and a larger water and nutrient reservoir, the soil mixture was applied in windrows, which were about 50 cm high and 75 cm wide (Fig. 5). No grasses were seeded. The complete randomized block design included 2 sites, 3 blocks/site, 3 planting preparations/block, and 8 species/block. These treatment combinations were repeated three times, for a total of 144 plots. Each contained 49 trees at a constant spacing (or 7056 trees in total). Species that were tested included two white spruce provenances (i.e., southern and northern provenances), three hybrid poplar clones (102,216, 103,125 and 915,508), tamarack, red pine (*Pinus resinosa*) and jack pine (*P. banksiana*). The three hybrid poplar clones were also developed by the MFFPQ. Clone 102,216 originates from crossbreeding of a female parent of *Populus maximowiczii* and a male parent of *Populus balsamifera*. Clone 103,124 is the result of crossbreeding between a female parent of *Populus maximowiczii* and a male parent of black poplar (*Populus nigra*) from southern Europe. Finally, clone 915,508 comes from a female hybrid parent of eastern cottonwood (*Populus deltoides*) x *Populus nigra*, and a male parent of *Populus maximowiczii*. Eastern cottonwood is native to the eastern United States and southern Quebec. Again, results suggest that hybrid poplar offers the greatest potential for afforestation at the site and that windrowing results in lower mortality rates and higher growth rates than when the same poplar clones are planted on mounds. This practice further favours substantial encroachment of native poplars from the surrounding forests (Fig. 6) . In addition, the researchers are evaluating the potential of these systems to sequester carbon in soils and vegetation.

2.3. Choice-based conjoint (CBC) analysis

In conducting a CBC analysis, this study investigated public expectations and preferences toward different scenarios of ecological

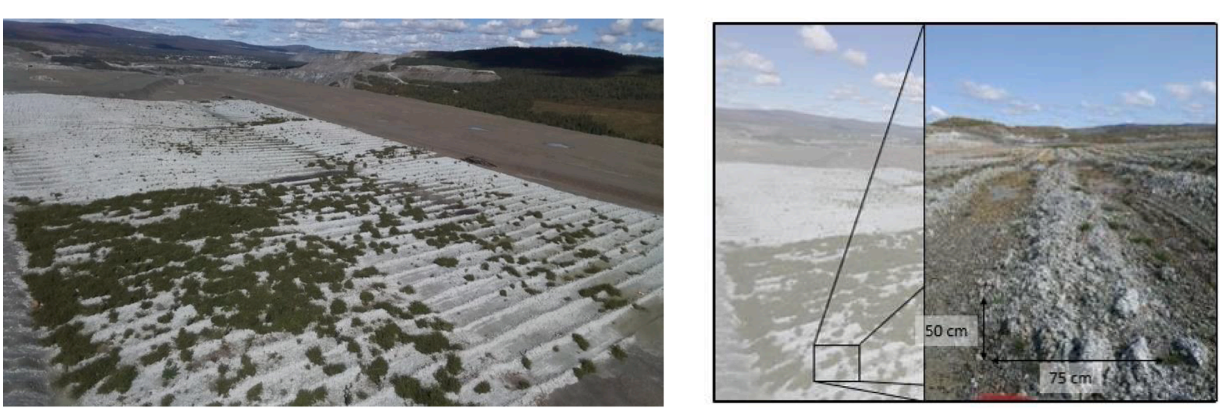

Fig. 5. New windrows (prior to tree planting) on top of an asbestos tailings barrow in Black Lake (left) and a close-up view of a fresh windrow (right).

Fig. 6. Hybrid poplar in their third year of growth at Black Lake (background), together with encroachment of native poplars (foreground). Note that native poplars are not achieving the same height growth as hybrid poplars.

restoration of asbestos mines in three former asbestos mining towns. CBC experiments emerge from the desire to have ex-ante (i.e., forecasting) and multidimensional evaluation methods to assess the relevance of decisions regarding human choice (Dachary-Bernard and Rambonilaza, 2012). CBC is a market-based research model that has been used by businesses for product development and predicting consumer preferences (Scherer et al., 2018). This method has gained attention in other research fields, such as the environmental and health sciences (Veitch et al., 2017; Zipursky et al., 2017; Hille et al., 2019).

Within a survey, individuals are confronted with alternative scenarios, which are constructed by combining different attributes and levels. Attributes are defined as the qualitative or quantitative components that are to be considered by the respondent when making a decision (Raghavarao et al., 2011). For example, in the case of the choice of a weekly meal plan, one might wish to consider preparation time, number of calories, and price, among other possibilities. In CBC analysis, the researcher typically defines the attributes. Yet, prior consultations with the population to be surveyed can be useful to identify the attributes that are most likely to influence choice. Each attribute is assigned a set of possible values, which are referred to as "attribute levels." In the weekly meal plan example, the attribute "preparation time" could have three levels, such as 10, 15 and 25 min. For this attribute, these three levels are representative of real possibilities that the respondent must face during decision-making.

These scenarios are presented within sets of choices. In each set, respondents are asked to choose their preferred option. The multiplication of these choice experiences by the different individuals makes it possible to take into account the relationships of substitution and complementarity between the attributes. CBC analysis therefore permits utilities to be estimated that individuals derive from any choice alternatives based on estimates of their preferences.

2.3.1. Experiment

The questionnaire prepared for the CBC experiment consisted of four parts. The first part dealt with the mining history of the respondents. Questions determined how many years they resided in the area, whether they had already worked in the asbestos mining industry, and whether relatives or friends have worked in the mining industry. Questions also assessed their appreciation of the current mining landscape. The second part consisted of the choice-based conjoint analysis itself, which is presented in detail in Section 2.3.1. The third part assessed how their choices were made for the different scenarios. What was of interest were the number of attributes that were considered when making their decision, their order of preference among attributes, and whether the respondents believed that this type of project could be carried out, expressed in terms of probability. This part also served to assess their acceptance with respect to ecological restoration of asbestos mines as a whole, and their level of agreement with regard to specific advantages of ecological restoration. The last part portrayed the socio-demographic characteristics of the participants.

The questionnaire was conducted using Lighthouse Studio (version 9.8.0, Sawtooth Software Inc., Provo, UT). In addition to a dual-response none-option, the CBC experiment incorporated 12 random choice sets with three scenarios of ecological restoration for each task. The dual-response non-option allowed the respondent to confirm whether he or she agreed with the alternative that they selected in the first place. A total of 30 versions of the questionnaire were generated from an overall choice design by the software's algorithms. We applied the "balance overlaps design" option in the Sawtooth software to enable minimal level overlap within individual tasks. This option allowed us to maximize statistical precision for estimating the main effects (Orme and Chrzan, 2017). Minimal overlap allows the probability that an attribute level repeats itself in each choice set to decrease to as low a value as possible (Huber and Zwerina, 1996). By doing so, it improves the precision of interaction effects between the attributes.

2.3.2. Selected attributes for the experiment

To define the attributes and levels of ecological restoration, a focus group discussion was conducted with the research team (with expertise including soil and forestry sciences, geography, agronomy and ecological economics), together with individual interviews with personnel (i.e., mining industry and environmental consulting) who were involved in the current ecological restoration project at the Black Lake site. In addition, two semi-structured interviews were conducted with workers at the Black Lake mine to gain a better grasp on restoration constraints and history of the mine. Based upon the information that was gathered from these interviews and a literature review, an exhaustive list was developed of attributes related to ecological restoration.

Four attributes were selected from the complete list to maximize information while maintaining simplicity of the choice sets. The first attribute refers to the "types of vegetation cover" that could be used for restoration. The types of vegetation cover that were presented in the CBC experiment were those being tested at the Black Lake site. The second attribute explored the public preferences of "desired uses" once restoration was completed. Desired uses attribute levels included two uses where people could access the mining sites once they were restored (i.e., park and motorized tails), and two others where human access was not a central focus (i.e., carbon storage and wildlife habitats). The third attribute sought to better understand public preference in terms of the area to be restored. Given strong emotional attachment to the mining heritage of the region and demands for mine tailings (new technologies are available for reuse with potential commercial gains), the attribute choice was set to determine whether the general public in the study area preferred that 30%, 60% or 100% of the mine barrows would undergo ecological restoration. It also tested whether respondents had other preferences in terms of use of asbestos mine tailings, which could influence their preference regarding the percentage of the total area that would undergo ecological restoration. Finally, a monetary attribute ($10, $25, $50 or $150) was added to determine respondent preference to contribute financially to ecological restoration projects, thereby assessing their willingness-to-pay (WTP). In this CBC experiment, it was stipulated that the amount would be included in the municipal tax accounts and amortized over five years.

Once the selection of attributes and levels was completed, a pre-test was carried out with three researchers who were familiar with CBC analyses, together with two practitioners working in the ecological restoration sector and three citizens living in the study area. The resulting set of attributes and levels is summarized in Table 1.

2.4. Data collection

Data collection took place from the end of November 2019 to the beginning of January 2020, in the three former asbestos mining towns in southeastern Quebec. This study took place while the Quebec Government was holding a full investigation and public audiences regarding the presence of asbestos in the province, its current uses, ways to recycle/reuse/eliminate it, and its repercussions for human health. To minimize bias in the study results, community surveys were conducted prior to the debut of sectorial meetings for public consultations.

The total population of the towns is 24,673 (Statistics Canada, 2016), i.e., Thetford Mines (16,170), Black Lake (3298) and Asbestos (5205). Data were collected using an online questionnaire that was hosted by Sawtooth Software. Fig. 7 shows an example of a choice set from which respondents had to choose from the scenarios that were generated by Lighthouse Studio 9.8.0. Before beginning the questionnaire, the context of the current afforestation study was briefly presented. Furthermore, the short text emphasized that the current study on public expectations and preferences for ecological restoration was intimately linked to the afforestation study and presented the goal of this study. For each of the proposed scenarios, the respondents were invited to compare each scenario according to the attributes and levels presented, and choose the one that they preferred.

The participants completed the in-person questionnaire with the help of the research team. To do this, the team used direct solicitation from the general public in these three communities. Solicitations were made in different places with high concentrations of people, such as grocery stores, hardware stores, big-box stores, shopping centres, and on a college campus and seniors residences. Each time a respondent completed the survey, the person nearest to the interviewer was solicited to avoid selection bias. Collected data were analyzed by using a Hierarchical Bayesian approach and a latent class model (Orme and Chrzan, 2017). The following sub-sections describe these two analyses.

One hundred sixty-one people completed the questionnaire, thereby providing a robust dataset to conduct the analyses following model pretesting using Test Design options (Lighthouse Studio v.9.8.0) on the CBC Exercise Setting (with a 95% confidence interval). The total number of respondents who were encountered during this survey is appropriate for a multivariate statistical model, according to a rule-of-thumb formula that was suggested by Orme (2014):

$$\frac{nta}{c} \geq 500$$

Table 1
Restoration attributes of the CBC experiment.

Attribute Name	Attribute Level
Types of vegetation cover	
	Commercial plantation
	Natural forest
	Meadow
Desired uses	
	Motorized trails (ATV, snowmobile)
	Carbon storage
	Wildlife habitats
	Park (walking, biking, cross-country skiing)
Total area to be restored	
	100%
	60%
	30%
Payment conditions	
	$5
	$25
	$50
	$150

where n is the number of respondents, t is the number of choice sets, a is the number of alternatives per set, and c is the maximum number of levels in any attributes.

$$n(12)(3)/4 \geq 500 \text{ or } n \geq 56$$

2.4.1. Specifics of CBC analysis and the Hierarchical Bayesian approach

In the past few decades, CBC analysis has gained in popularity in preference research (Raghavarao et al., 2011). The basic assumption of this approach is that humans gain utility from specific combinations of attributes, rather than from the attribute itself. CBC analysis creates a part-worth utility for the different attribute levels and the relative importance of attributes.

During data collection, strong heterogeneity was detected within our group of respondents. Thus, a Hierarchical Bayes (HB) approach was used to calculate part-worth utilities and the relative importance of attributes. It is a statistical estimation method that is suited to highlighting of preference heterogeneity. The HB method can estimate individual-level utilities (Orme, 2000). The 'hierarchical' nature of the method nests one level within the other. The higher level assumes that an individual's part-worth is described by a multivariate normal distribution, while the lower level claims that given an individual's part-worth, human probabilities of choosing particular alternatives are controlled

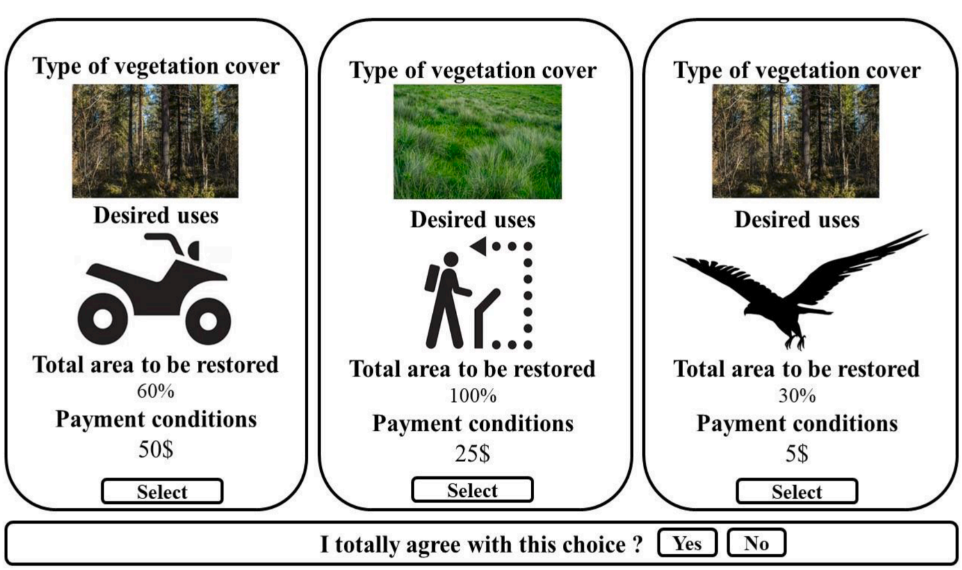

Fig. 7. Example of a choice set from which respondents had to choose.

by a multinomial logit model. In this study, HB estimates were performed using a Monte Carlo Markov Chain algorithm implemented in Lighthouse Studio 9.8.0 (Orme and Chrzan, 2017). Goodness-of-fit indicators for the model in this study were the average root likelihood (RLH) and average percent certainty.

2.4.2. Specifics of latent class analysis

Latent class (LC) Analysis allows different segments of a population to be studied to know precisely what their preferences are in relation to a study subject (Boxall and Adamowicz, 2002). LC analysis allows individuals to be grouped into homogeneous preference classes. This analysis simultaneously groups of individuals into classes and then estimates the different parameters of the utility function conditionally, based upon their group membership (Bonnieux and Carpentier, 2007). Unlike cluster analysis, respondents are not ultimately assigned to exclusive groups; rather, they have probabilities of membership for each class (Orme, 2010). In this study, LC analysis (Lighthouse Studio 9.8.0) identified general public segments, each with widely homogeneous preferences.

2.4.3. Preference simulation

Simulation can allow utility to be increase by taking into consideration the interaction among attributes. There are many tools to perform preference simulations (Train and Weeks, 2005). In this study, we used the Choice Simulator (Sawtooth Software). Based upon respondent-level CBC results, the simulator can define hypothetical scenarios, which then compete against each other (Orme, 2010). The simulator estimates the choice shares by means of Randomized First Choice (RFC, Orme, 2010), which is an advanced technique that is quite suited to CBC. It allows the incorporation of heterogeneity among segments. The choice simulator requires the input of the estimated part-worth that represents public preferences. In this study, the attributes and levels that are related to asbestos mine restoration were the same as those used in the CBC experiment. Therefore, the simulation used HB draws from the CBC analysis. The goals of this simulation were (1) to quantify and weigh the decision criteria and preferences of citizens in the asbestos mine region of Quebec for ecological restoration scenarios and (2) to derive implications for a socially accepted ecological restoration strategy in the area.

3. Results

Table 2 provides a portrait of the socio-economic profile of the respondents (Statistics Canada, 2016). The random selection of respondents led to a stronger representation of males than females. Overall, there was a reasonable allocation of respondents with regard to levels of household income and education. Certain age groups were not well represented by the sampling scheme, namely, the class of individuals who were aged between 30 and 59 years. Although sampling was performed in various public spaces and at different times during the week, which should have encouraged individuals to participate, the age class was not interested in participating in the study (mainly due to a lack of time). The small sample of this age group is a limitation of the study, especially since it represents most workers in the study case areas. Contact with many elders was highly valuable and enriching given that a number of them had a mining history that went back to several generations and many saw the ongoing ecological restoration project in Black Lake as the new leg of the journey for future generations.

Table 3 provides a portrait of the respondents' mining histories. For example, 66% of respondents indicated that relatives worked in the asbestos industry before mine closure. More than half (57%) of the respondents indicated they enjoyed living within the mine landscapes. When asked why they enjoyed these artificial landscapes, many respondents suggested that these features were linked to their history and living environment. For these respondents, the landscapes are perceived as a positive heritage, given that they were key to development of the municipalities in the region. Other respondents indicated an appreciation for the uniqueness of these mines from a landscape point-of-view. They appreciated the rugged topography of the overburden and tailings mounds that were a legacy of asbestos extraction and the green lakes that formed within the open-pit mines. For many respondents, especially the elderly, these sites remind them of past economic prosperity, and memories of children playing on waste rock piles and tailings before the health risks that are associated to the exposure of asbestos

Table 2
Socio-demographic structure of the respondents.

Sample characteristics	Respondents (n = 161)	Proportion (%)	Population of the case study areas(n = 24 673)	Population of Quebec(n = 8 164 361)
Gender				
Female	62	39	11 755	4 016 760
Male	99	61	12 915	4 147 605
Age				
18–29	43	27	2 210	995 950
30–39	10	6	2 410	1 066 045
40–49	16	10	2 335	1 025 950
50–59	22	14	3 800	1 255 910
60–69	38	24	4 385	1 050 845
70 +	32	20	5 420	1 007 015
Total household annual ($) gross income				
<10 k	17	11	2 005	789 595
10 k - 24 999	22	14	8 625	1 188 135
25 k - 49 999	34	21	5 535	800 365
50 k - 69 999	15	9	2 350	916 200
70 k - 99 999	15	9	1 000	598 125
100 *k* +	19	11	390	348 620
Not answered	39	24	–	–
Education				
Elementary diploma	7	4	5 145	1 323 070
High school diploma	43	27	4 635	1 426 980
Vocational studies diploma	25	16	9 595	3 884 235
College diploma	49	30	3 770	1 165 515
University diploma	36	22	920	1 361 730
Not answered	1	1	–	–

*Includes the communities of Thetford Mines, Black Lake and Asbestos.

Table 3
Mining history of the respondents.

Sample characteristics		Respondents ($n =$ 161)	Proportion (%)
Origin			
	Thetford Mines	122	76
	Black Lake	14	9
	Asbestos	14	9
	Other	11	7
Number of years in the area			
	<5	22	14
	6–10	7	4
	11–20	24	15
	21–30	18	11
	31–40	12	7
	41 +	70	43
	Not answered	8	5
Native of the area			
	yes	102	63
	no	59	37
If native, number of generations			
	1st	8	5
	2nd	22	14
	3rd	34	21
	4th +	37	23
Mining work history			
	Yes	23	14
	No	137	85
	Not answered	1	1
Mining family history			
	Yes	107	66
	No	53	33
	Not answered	1	1
Mining landscape attraction			
	Yes	92	57
	No	62	39
	Not answered	7	4

fibres were demonstrated.

3.1. Hierarchical Bayes analysis

Results from HB analysis of the CBC experiment are presented in Table 4. The average root-likelihood (RLH) and average percent certainty scores were respectively 0.523 and 0.524. The desired uses attribute was the most important factor for the choice decisions (40.03%) and was followed in hierarchical order by payment conditions (24.24%), type of vegetation cover (21.70%), and total area to be restored (14.03%) (Table 4).

Table 4 also summarizes the part-worth utility coefficients of each attribute level and overall importance of the attributes. HB analysis yielded results that were scaled to zero-centered differences for easier comparison. A negative part-worth value does not necessarily mean a negative preference, but it indicates that this level is generally less attractive than other levels relating to the same attribute. In regard to the type of vegetation cover attribute level, the highest part-worth utility was associated with natural forest, followed by meadow and commercial plantations. For the desired uses attribute level, park and wildlife habitats had positive values, whereas motorized trails had a negative part-worth utility (bounded by 95% CI). For the attribute of total area to be restored, a 100% recovery was favoured over the two other proposed levels (60% and 30%). For payment conditions, respondents were strongly opposed to the $150 5-year annual contribution. The $50 contribution was also a negative part-worth utility, whereas both $5 and $25 showed a significant positive part-worth utility. The dual-response none-option produced a very high utility value, which indicates that respondents agreed with the choice that they had made during the experiment.

Table 4
Average utility values (zero-centered differences) and average importance of attribute.

Attribute level	Utility value	SD	Lower 95% CL	Upper 95% CL
Types of vegetation cover: Commercial plantation	−16.55	42.44	−23.10	−9.99
Natural forest	14.90	40.87	8.58	21.21
Meadow	1.65	40.85	−4.66	7.96
Desired uses: Motorized trails (ATV, snowmobile)	−61.12	64.79	−71.13	−51.11
Carbon storage	0.86	49.99	−6.87	8.58
Wildlife habitats	23.78	51.82	15.78	31.79
Park (walking, biking, cross-country skiing)	36.49	50.31	28.71	44.26
Total area to be restored: 100%	16.21	26.47	12.13	20.30
60%	2.46	18.00	−0.32	5.24
30%	−18.67	23.81	−22.35	−14.99
Payment conditions: $ 5	30.72	34.98	25.32	36.13
$ 25	19.52	22.49	16.05	22.99
$ 50	−0.86	24.00	−4.56	2.85
$ 150	−49.39	31.64	−54.27	−44.50
Dual-response none-option	−199.52	180.60	−227.41	−171.62
Attribute	**Importance (%)**	**Std Deviation**	**Lower 95% CL**	**Upper 95% CL**
Types of vegetation cover	21.70	13.20	19.66	23.74
Desired uses	40.03	15.45	37.64	42.41
Total area to be restored	14.03	7.81	12.83	15.24
Payment conditions	24.24	12.42	22.32	26.16

SD is standard deviation and 95% CL is confidence limit.

3.2. Latent class analysis (LCA)

LCA was also performed using Lighthouse Studio 9.8.0 software. The class segmentation choice was made according to indicators, such as the log-likelihood, percent certainty, consistent Akaike Information Criterion (CAIC), Bayesian Information Criterion (BIC) and relative Chi-square, which are presented in Table 5. Complementary to the results that are presented in Table 5, we used qualitative data that were gathered during the choice experiment to choose the fourth segment solution. This segmentation provides the greatest interpretability and the best fit to field observations.

Table 6 shows the part-worth utilities of each class and the relative importance of their attributes. To calculate relative importance of attributes per class, the attribute importance of each respondent was estimated individually. We converted the ranges of attributes within each respondent that fit into each class to percentages (Orme and Chrzan, 2017). For the part-worth utility score, a negative utility value indicates that this level is generally less attractive than other levels relating to the same attribute. Based on our results, the four classes are: 1) park aficionados (13.7%, $n = 22$); 2) nature lovers (40.2%, $n = 65$); 3) wildlife enthusiasts (16.2%, $n = 26$); and 4) recreational adepts (29.3%,

Table 5
Model selection for latent class segmentation.

Segments	Log-likelihood	Percent certainty	CAIC	BIC	Relative Chi-Square
2	−2348.96	18.30	4896.97	4873.97	45.74
3	−2281.88	20.63	4866.67	4831.67	33.89
4	−2237.41	22.18	4881.60	4834.60	27.13
5	−2198.37	23.53	4907.38	4848.38	22.94

Table 6
Part-worth utilities and importance of attributes (zero-centered differences) per class.

	Classes **Class 1**(park aficionados) 13.7%	**Class 2** (nature lovers) 40.2%	**Class 3** (wildlife enthusiasts) 16.2%	**Class 4** (recreational adepts) 29.9%
Attribute level	**Utility value per class**			
Types of vegetation cover: Commercial plantation	−4.85	−26.60	−71.58	1.29
Natural forest	−3.72	42.27	31.98	−16.39
Meadow	8.57	−15.67	39.60	15.09
Desired uses: Motorized trails (ATV, snowmobile)	−50.48	−176.49	−68.11	56.86
Carbon storage	2.73	57.66	0.48	−107.17
Wildlife habitats	−30.74	68.27	69.07	−11.53
Park (walking, biking, cross-country skiing)	78.49	50.56	−1.44	61.84
Total area to be restored: 100%	6.72	21.76	28.99	27.52
60%	13.75	−3.61	20.56	−7.62
30%	−20.47	−18.15	−49.55	−19.90
Payment conditions: $ 5	98.48	18.63	34.85	12.62
$ 25	56.53	5.92	8.47	62.82
$ 50	−30.09	3.30	−5.06	13.83
$ 150	−124.92	−27.85	−38.25	−89.27
Dual-response none-option	−78.46	−306.93	154.85	−691.86
Attribute	**Relative importance per class (%)**			
Types of vegetation cover	3.35	17.22	27.80	7.87
Desired uses	32.24	61.19	34.29	42.25
Total area to be restored	8.55	9.98	19.63	11.85
Payment conditions	55.85	11.62	18.28	38.02

$n = 48$). The name denoting each class is figurative, which we assigned to best describe its uniqueness based upon the distinct attributes and levels revealed by LCA. These classes are described in sections 3.3.1 to 3.3.4.

3.2.1. *Class 1 – Park aficionados*

One characteristic feature of class 1 was the importance of the payment conditions attribute (55.85%). Further, this class expressed the lowest relevance for types of vegetation cover (3.35%), desired uses (32.24%) and total area to be restored (8.55%), compared to the other three segments. With respect to the part-worth utilities of the different attribute levels, this class yielded the highest score among classes for the lowest payment conditions (98.48) and the least desire for the entire area to be restored (6.72). Very low importance was given to the types of vegetation cover attribute, whereas the meadow option was preferred over natural forest and commercial plantation. Due to its strong positive evaluation regarding parks (78.49) as the desired uses, this class was denoted “park aficionados”.

3.2.2. *Class 2 – Nature lovers*

Class 2 showed greater affinity towards the desired uses attribute (61.19%) compared to the three other groups, whereas the importance of payment conditions (11.62%) was the lowest. This class exhibited the highest part-worth utility score among classes for natural forest (42.27) as the preferred type of vegetation cover. The group strongly rejected the motorized trails option (−176.49) as a desired use. Rather, the class preferred desired uses that exerted a low impact on the environment (i.e., parks) or uses that would enhance wildlife habitats (68.27) and carbon sequestration (57.66). In addition, this class was the only one with a high preference for carbon storage as a desired use. A very low utility for the dual-response none-option (−306.96) suggests that members of class 2 are hoping that their choice of scenario will become a reality. Given that the results of the part-worth values for the different levels of the total area to be restored attribute emphasized a high preference for natural forests, and desired uses with minimal impacts on the environment, this class was denoted “nature lovers”.

3.2.3. *Class 3 – Wildlife enthusiasts*

A main trait of class 3 is the importance of attributes that were related to types of vegetation cover (27.80%). Yet, the most important attribute was desired uses, with a value of 34.29%. Class 3 indicated very low importance should be given the payment conditions (3.3%). In accordance with the positive part-worth value for the dual-response none-option (154.85), class 3 appeared to strongly disagree with the idea of paying for ecological restoration projects. As indicated by the part-worth utilities of the different attribute levels, this class exhibited a high score for meadow (39.60) and natural forest (31.98) as the type of vegetation cover, with a negative utility for commercial plantation (−71.58). To finish, Class 3 preferred wildlife habitats (69.07) as the desired use. On this basis it was denoted “wildlife enthusiasts.”.

3.2.4. *Class 4 - Recreational adepts*

Class 4 showed greater alignment with the desired uses (42.25%) and payment conditions (38.02%) attributes, compared to the other classes. Types of vegetation cover were not an important attribute. In accordance to the positive part-worth value, class 4 was the sole class with a positive score for commercial plantations (1.29) as the type of vegetation cover. Likewise, this class was the only one with a positive score for motorized trails (56.86). This class preferred 100% of total area to be covered (27.52) relative to the other levels of this attribute. It had a strong preference toward parks (61.84) as the desired use. Yet, class 4 rejected desired uses that did not lead to direct utilities for humans, i.e., carbon storage and wildlife habitats (−107.17 and −11.53, respectively). Class 4 tended to prefer higher prices ($25 and $50) as payment conditions. It had the lowest utility for the dual-response none-option (−691.86), which suggests that members of this group were strongly hoping that their choice of scenario would become a reality. Due to their positive assessments of park and motorized trails as desired uses, this class was denoted “recreational adepts”.

3.3. *Public agreement towards asbestos mine ecological restoration benefits*

This study reveals that the majority (81%) of respondents have an interest in ecological restoration of asbestos mine sites (Table 7). Despite 53% (Table 3) of Thetford Mines, Black Lake and Asbestos residents valuing former asbestos mining sites and residues as a cultural landscape, they agree (85%) that mine reclamation would improve the overall landscape of their areas. Those who disagree with ecological restoration projects considered the costs to be too high because of the current work restrictions and necessary health precautions that have been imposed by the Government of Quebec. Finally, some residents simply appreciate the mining landscape, so ecological restoration may not be a desirable option for them. Indeed, this social phenomenon has been documented in mining communities elsewhere, where restoration would negatively impact mining heritage (Robertson, 2010).

Table 7 presents the degree of agreement that people have demonstrated for different benefits of mine ecological restoration, which has been reported in the literature or by experts who are involved in the restoration project at Black Lake. Almost half (43%) of the respondents

Table 7
Public approval on ecological restoration and degree of public agreement to various benefits from ecological restoration of asbestos mines.

Public consent on ecological restoration of asbestos mines	Agree (%)	Disagree (%)	Not answer (%)
In favor of current and future ecological restoration projects	81	19	–
Benefit of restoration	**Agree (%)**	**Partly agree (%)**	**Disagree (%)**
Return landscape to an acceptable visual	85	12	3
Reducing health risks related to asbestos dust exposure	57	21	22
Enlargement of natural environments	85	13	2
Carbon storage by plants	75	16	9
Recycling of residual materials, e.g., biosolids and slightly contaminated soils (circular economy)	79	17	4
Stabilize waste rock piles and tailings	67	24	9
Limit runoff of contaminants (water interception)	84	11	5

only partly agreed or had disagreed with the statement that restoration of asbestos mines would reduce the health risks associated with exposure to asbestos dust. The disagreement was not linked to the risk of exposure during the restoration process, but more to the fact that the levels of asbestos contained in the waste rocks and tailings were not, according to them, a public health concern. In fact, several respondents were visibly irritated by the declaration of this benefit. For them, the potential health risk that is associated with asbestos dust is greatly exaggerated. About one-third of respondents only partly agreed or disagreed with the fact that restoration would stabilize rock waste piles and tailings. For these respondents, the existing mounds do not pose a public safety threat. Many respondents favoured recycling options (e.g., chemical processes are available for extraction of other ores contained in the tailings) rather than ecological restoration of the tailings piles.

3.4. Simulation of the willingness-to-pay for ecological restoration scenarios of asbestos mines

A first simulation was carried out using the same attributes and levels that were used in the HB analysis. In the sensitivity analysis, we kept the types of vegetation cover constant, while varying the levels of the other three attributes: total area to be restored, desired uses and payment conditions. The sensitivity analysis was performed using the Randomized First Choice (RFC) model. RFC calculates preference shares, which is the percent of respondents in the sample who preferred each alternative (Orme, 2010). Results suggest that the natural forest was the preferred attribute of the respondents among the types of vegetation cover (Fig. 8). The natural forest attribute was followed by the meadow attribute and then by the commercial plantation attribute. These results are in agreement with results of the HB analysis.

In terms of total area to be restored, the share of preference for the three types of vegetation cover remained stable between 60% and 100%, and drastically decreases thereafter. For the desired uses attribute, the share of preference was the highest for wildlife habitats, followed by park and commercial plantation. This result differs from the HB analysis where the park attribute level had the largest utility value. Unlike the first two simulations, preference shares relating to payment conditions were very different between types of vegetation cover. For the natural forest attribute level, the preference share remained stable until around $12 and then gradually decreased. This pattern was not present for the two other attributes.

A second simulation was carried out by creating scenarios based on the four classes results that emerged from the LCA. The levels that were retained for each scenario were those with a high utility value in LCA. Therefore, each scenario roughly represents the segments/classes that were identified within the population surveyed according to their

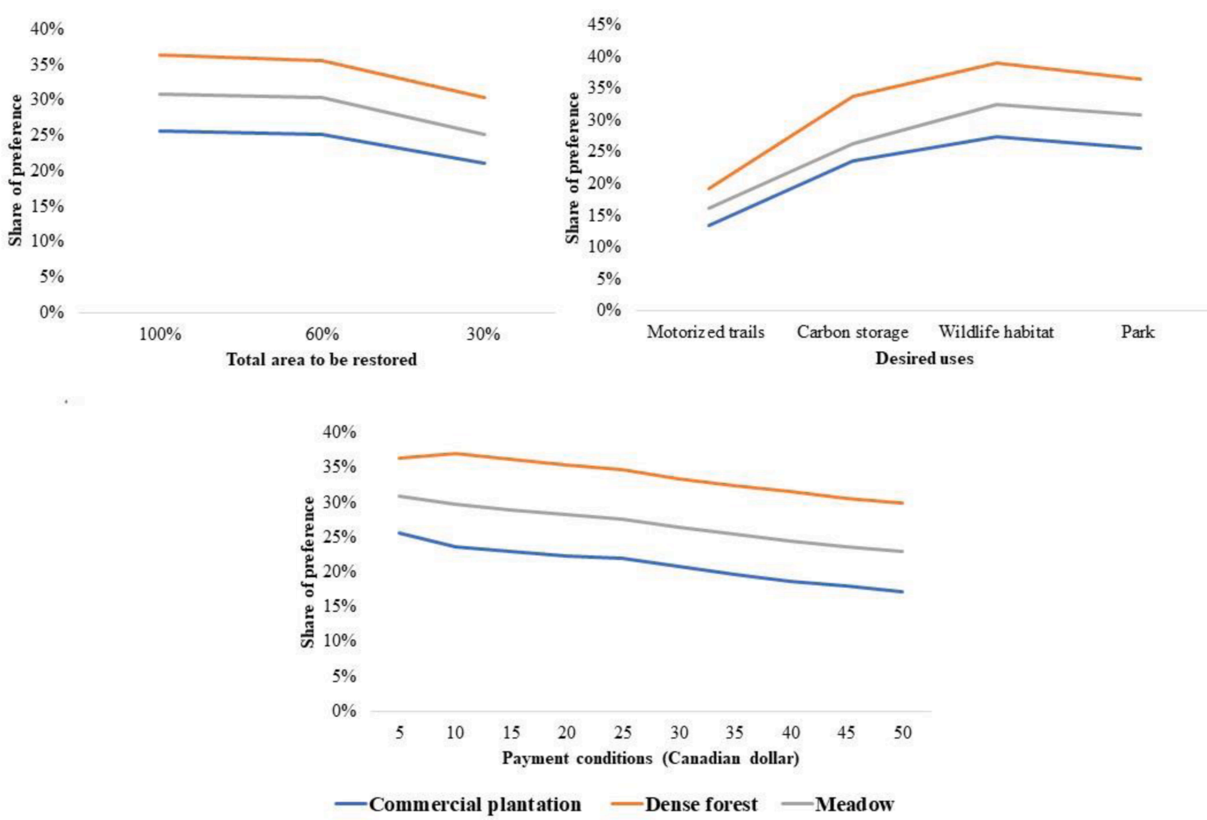

Fig. 8. Sensitivity analysis with constant type of cover levels ($n = 161$).

preferences. Since we wanted to know the willingness-to-pay for this type of restoration project, the payment conditions varied during the simulation for each of the four scenarios. The scenarios that were retained in the simulation are presented in Table 8. Simulation results of the four selected scenarios are presented in Fig. 9.. The "park aficionados" scenario has the highest share of preference relating to payment terms. This scenario also tends to have a greater tolerance for an increase in the payment conditions. This is the same case with the "wildlife enthusiasts." Despite their small preference share, this scenario seemed resilient to price fluctuations and accepted restoration costs of up to $25 per year.

4. Discussion

Given the proximity of households to the mining sites that are to be restored, this study assessed the pulse of the public expectations and preferences in terms of ecological restoration strategies. Study results show a broad consensus for ecological restoration. On one hand, HB analysis results show how preferences and expectations that are related to the land reclamation scenarios differ among the respondents. Despite this heterogeneity, some attributes and levels (e.g., natural forest as vegetation cover, or park and wildlife habitat for post-mining uses) seem more desirable than others. On the other hand, LCA allowed us to draw out four distinct respondent segments that highlight similarities and differences toward mine reclamation key attributes. This suggests that ecological restoration should employ multiple strategies to foster consensus and cohesion among community members who living around the closed mine sites.

The general enthusiasm shown by local residents for appropriating the former asbestos mining sites is partly demonstrated by the openness of the local community to provide partial financial support of the high costs associated with the restoration work. Several members of the community who had been surveyed lost hope that the government or former mine-site owners would pay for this type of restoration, but they were willing to contribute financially if this support would move work forward. Further, each potential use is associated with challenges both in terms of costs and the technical feasibility and public health risks. For example, restoration for the creation of parks and motorized trails could constitute a source of debate among stakeholders with regards to human health and safety. Most respondents who had selected these two uses did not seem aware of these implications. An educational program to train community members on the environmental and health benefits of afforestation could facilitate the work of stakeholders during the different restoration phases (Vimercati et al., 2018). Participatory scenario planning could also be a good strategy to employ in the design and implementation phases of the ecological restoration projects, both to increase public engagement and to draw a better portrait of their concerns and needs (Rixen and Blangy, 2016; Everingham et al., 2018).

The feeling or sense of belonging to a mining heritage, where the mining landscape is an integral part of the surroundings and history, is consistent with other studies (Robertson, 2010; van Horssen, 2016).

Table 8
Ecological restoration scenarios of asbestos mines used in the market simulator.

Scenarios	Types of vegetation cover	Desired uses	Total area to be restored	Payment conditions
Recreational adepts	Meadow	Motorized trails (ATV, snowmobile)	100%	$5–50
Nature lovers	Natural forest	Carbon storage	100%	$5–50
Wildlife enthusiasts	Natural forest	Wildlife habitats	100%	$5–50
Park aficionados	Meadow	Park (walking, biking, cross-country skiing)	100%	$5–50

Note: For all scenarios, $5 is the default payment condition.

Uses other than those that were proposed in the questionnaire were also discussed with respondents during fieldwork. In particular, respondents proposed the possibility of extracting magnesium from tailings (Innovation, Science and Economic Development Canada, 2018**)** and further enhancing the mining heritage of the sector as a tourist attraction. From this perspective, interesting reflections and possible designs have been proposed by architects, which would promote mining heritage and identity (Daigle-Croteau, 2013; Meijerink, 2013; Dubois, 2017). Given the emotional attachment that the respondents have towards their mining heritage, it would be relevant to learn how restored mines around the world have adopted new uses, while conserving their historical identity. In Thetford Mines, the project *centre historique de la mine King* is a ready example of using a "controversial heritage" to revitalize this former asbestos mining territory (Bélanger, 2016).

This study concurs with other studies that report low health risk perceptions regarding asbestos exposure (van Horssen, 2016; Mazzeo, 2018; Litvintseva, 2019). The Province of Quebec has the highest incidence rates of diseases that are related to asbestos exposure in Canada (INSPQ, 2007). The relatively low levels of public awareness regarding asbestos health risks are explained by three main factors: (1) the powerful asbestos industry and their campaign of misinformation with regard to the effects of asbestos on human health; (2) asbestos-related diseases affecting mostly industrializing/developing countries; and (3) the long latency period of the health risks of asbestos exposure (Douglas and Van den Borre, 2019). Future studies should investigate in greater detail the relationship between general public characteristics and health risk perceptions that are related to naturally occurring asbestos regions, which was not the focus of this study.

Modalities exist for the restoration of mining sites in Quebec (MERN, 2017), but establishment of specific standards for asbestos mine reclamation in Canada would facilitate further restoration work. Such guidelines exist for mine closure (Worrall et al., 2009; Stacey et al., 2010), including a socio-economic framework (Xavier et al., 2015). For example, the integration of social aspects of land reclamation and remediation should be included well before a mine closes (Bainton and Holcombe, 2018). It would allow trust to be built among local community members throughout the restoration and post-mining stages (Jardine et al., 2013). Perhaps, implementation of inclusive and participatory approaches could be a strategy that would give people an opportunity to address their opinions so that they are heard and taken into account during the decision-making process (Irvin and Stansbury, 2004; Jardine et al., 2013). The fact that the Quebec government has lunched an investigation and public consultations on the presence of asbestos in these communities is an important step toward that goal.

5. Conclusion

The present study provided comprehensive information regarding general public preferences for ecological restoration of former asbestos mines in Quebec (Canada). By exploring general public preferences, the findings of this study can be used to recommend actions on how to promote socially acceptable mine restoration projects. The feasibility of realizing the expectations of respondents regarding ecological restoration of asbestos mines is complex. The context and configuration of waste rock piles and tailings vary in terms of environment, public safety and costs associated with the restoration. However, southeastern Quebec is not the only place in the world in need of restoring former asbestos mines (Cornelissen et al., 2019; Unger et al., 2020). Examples of implementation that are elsewhere in the world (Been, 1990; O'Dell and Claassen, 2009; Zagas et al., 2010) could be used as examples to guide restoration projects, especially if they incorporated the emerging literature on stakeholder engagement in closure and reclamation (Bainton and Holcombe, 2018; Everingham et al., 2018)

Mining legacies reveal how values and understanding related to resource extraction, including chrysotile asbestos, can shift rapidly over time. Once a source of pride and prosperity, this "white gold" has

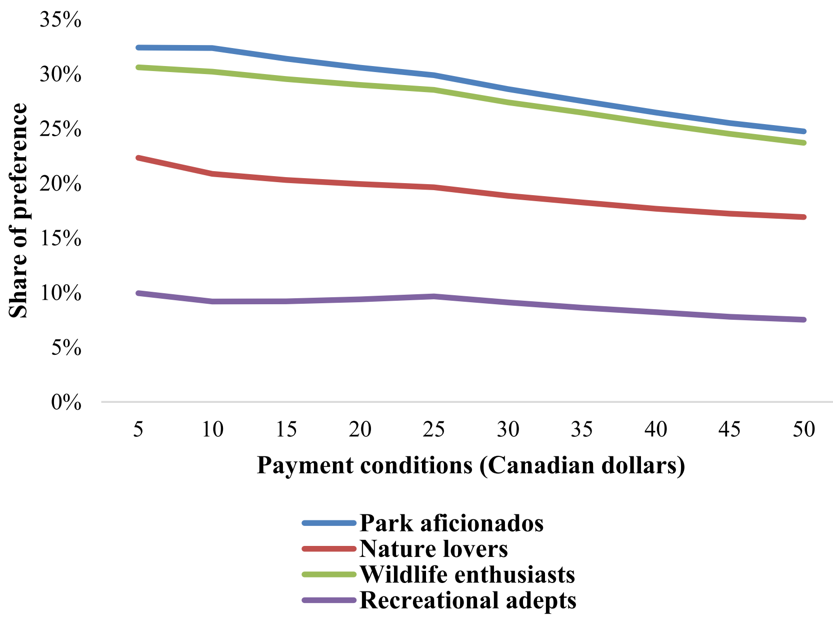

Fig. 9. Payment condition sensitivity analysis of four ecological restoration scenarios of asbestos mines.

gradually transformed into a socio-economic and environmental dilemma (van Horssen, 2016). Although they are strongly attached to their mining heritage, many members of the surveyed communities believe that the time has come to turn the page in their history. The afforestation of tailings piles and waste rocks presents an appealing path forward for their communities. The "green gold" emerging from successful ecological restorations could replace the "white gold" of the past.

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Declaration of Competing Interest

No potential conflicts of interest were reported by the authors.

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