The Extractive Industries and Society 10 (2022) 101094

Contents lists available at ScienceDirect

The Extractive Industries and Society

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

Original article

Examining impact and benefit agreements in mineral extraction using game theory and multiple-criteria decision making

Benjamin C. Collins *, Mustafa Kumral

Department of Mining and Materials Engineering, McGill University, 3450 University Street, Montreal, Quebec H3A 0E8, Canada

ARTICLE INFO

Keywords:
Impact and benefit agreements
Game theory
Bargaining
Multiple-criteria decision making
Mining
Indigenous communities

ABSTRACT

This research takes a novel approach to analyzing impact and benefit agreements (IBA) using multiple-criteria decision making (MCDM) and game theory. Local communities, which are often Indigenous communities, face with difficult decisions regarding the trade-offs of impacts vs. benefits from mineral resource development. Analyses of IBAs typically focus on their economic benefits but fail to consider environmental, socio-cultural, and other sustainability criteria. By not considering these criteria, current methods struggle to predict if an IBA is adequate or if it will be accepted. This research develops a model with MCDM that balances complex sustainability trade-offs for communities during mineral development negotiations. Bargaining positions of companies or impacted communities are also an essential, yet understudied factor in IBA analyses. Game theory is employed to show how bargaining positions can affect the compensation included in an IBA. In all, this research develops a model that can consider different criteria, value systems, and the implications of cooperation or competition to predict if an IBA will be accepted. This study provides recommendations, which can be applied other resource development projects which impact communities. The model shows the importance of flexibility in design, power dynamics in bargaining, cooperation, and knowledge sharing.

1. Introduction

The mining industry is at a crossroads. Society's growing demand for minerals continues to push for more mines, but many projects struggle to secure permits due to opposition from impacted Indigenous communities and other stakeholders. The continued growth of the mining industry impacts communities on countless socio-environmental levels, which are not easily accounted for during project evaluation. Impact and benefit agreements (IBAs) were developed to create collaborative solutions to balance the impacts and benefits of mineral development for communities. IBAs are contracts between impacted groups and project proponents that typically outline the benefits the community will receive, in terms of compensation and economic opportunities, as well as the strategies for impact mitigation (Gibson and O'Faircheallaigh, 2015). IBAs formalize a company-community partnership with the goal of reducing project delays and disruptions from protests, blockades, or legal opposition (Ali, 2003). The issue is that it is not well understood what exactly should be included in IBAs to balance the impacts vs. benefits of a project (Cascadden et al., 2021). There are several guidelines created for IBAs, e.g., Gibson and O'Faircheallaigh (2015), but there is a critical lack of formalized methods that can incorporate community values and predict if IBAs will be accepted and successful. The main questions of this research are: How can we predict if an IBA will be accepted? What are the main factors for a successful IBA? How can IBAs be better aligned to the wants, needs, and values of communities? And, what are the sustainability challenges with IBAs for mineral development projects? To better understand these questions, this research's goal is to create a new method to analyze IBAs.

This research creates a formalized method using bargaining game theory and multiple-criteria decision analysis (MCDM) to investigate IBAs. Analyses of sustainability focused decision making methods for the mining industry, as seen in Collins and Kumral (2020a, 2020c), showed the need in selecting these two methods. The use of MCDM and game theory can help investigate mineral developments' trade-offs between economic, social, and environmental indicators. Incorporating bargaining game theory allows this research to explore the implications of how two or more groups interact. While MCDM brings a method to incorporate multiple-criteria and differing value systems to rank alternatives (Liang et al., 2019; Sitorus et al., 2019). These two methods were selected because of their strong potential to aide in holistic sustainability

* Corresponding author.
E-mail address: Benjamin.collins2@mail.mcgill.ca (B.C. Collins).

https://doi.org/10.1016/j.exis.2022.101094
Received 22 September 2021; Received in revised form 9 May 2022; Accepted 9 May 2022
Available online 15 May 2022
2214-790X/

assessments that factor in different stakeholders and criteria. Both bargaining game theory and MCDM individually, and especially in combination, are rarely applied to the mining industry, and have never been applied to IBAs. MCDM and bargaining game theory are well-developed fields of study with many applications. This study provides a novel approach to IBA analyses by combining game theory and MCDM. There is no agreed upon method for this combination, which rarely occurs, therefore a strong emphasis on MCDM and game theory methods is needed and is conducted.

Typically, mineral economics and sustainability guides are often employed by the mining industry to guide socioeconomic and environmental considerations for IBAs (Collins and Kumral, 2020a). Mineral economics and sustainability guides unfortunately provide too narrow of an analysis. Mineral economics can lack the ability to consider non-market aspects of ecosystems, account for our lack of understanding of ecosystems, and respect differences in values of decision makers (Daly and Farley, 2011). Sustainability guides present numerous important sustainability criteria to consider but do not provide any direction on how to prioritize or trade-off between the sustainability criteria (Eisenmenger et al., 2020). Bargaining game theory and MCDM are used in this study to help bring a more holistic approach to IBA strategies originally based on mineral economics and sustainability guides.

IBAs are often developed between Indigenous communities and development proponents. MCDM and game theory are selected to consider better impacted groups, like Indigenous communities. IBA requirements are constantly morphing depending on the community's needs, the type of development taking place, environmental sensitivities of the area, and the political conditions. As mining continues to push into more remote regions and expands to meet demand, the impacts seen by Indigenous communities will continue to grow as well. IBA negotiations are opportunities to find collaborative solutions to a historically non-collaborative situation. To protect Indigenous communities, it is imperative analysis methods for IBAs are inclusive and can consider different value systems, wants, needs, and cultures.

The next section outlines the methods and applications used in this research. Section 3 will introduce, discuss, and glean the relevant literature from IBAs (Section 3.1), MCDM (Section 3.2) and bargaining game theory (3.3). Section 4 brings together the findings in Section 3 to develop a method to investigate and predict IBA requirements. Section 5 and 6 analyze the model's assumptions and discuss its persistent complexities, limitations, and next steps. Finally, Section 7 distills the key recommendations from this research.

2. Methods and materials

This research investigated and applied MCDM methods and game theory to inspect IBAs. Literature over the past twenty years was examined for relations between bargaining theory, non-cooperative game theory, sustainability decision making, MCDM, Monte-Carlo simulation, and resource development decisions. McGill's University Library Database, Scopus, Web of Science, and Google Scholar Databases were used for finding journal articles, conference proceedings, and books. Mendeley citation software was used to organize and analyze literature.

Drawing on examples from Nunavut, the IBAs signed by the communities in Nunavut have provided economic opportunities, investment, training, and involvement in environmental negotiations. In the Appendix there is information collected from several IBAs in Nunavut. This was used to inform how to build the model. The main benefits and considerations from these documents, along with NI 43–101 feasibility studies, provided the background information for the base case scenarios. This model however, stayed general to allow the different perspectives from communities that exist in mineral development and IBAs. The authors of this paper did not want to make any assumptions for the values, wants, and needs of Indigenous communities. Indigenous communities should have their own voices heard and incorporated, which requires open and respectful collaboration. This paper focusses on the development of this new method, which is needed at this stage of research.

To synthesize the analysis, a model was developed using Python3 and several software packages. With Python 3 and the packages MCDM 1.2 and Nashpy 0.0.20, a program was written to investigate IBAs. TOPSIS, which is an MCDM, was selected because it is well suited to clearly present trade-offs between criteria, specifically sustainability criteria (Papathanasiou and Ploskas, 2018). To consider unknown weightings of the value functions, Monte-Carlo simulation-based analysis is used. For a more detailed discussion on the developed model please see Section 5. Sections 3.2 and 3.3 will further outline MCDM and Game theory, and distill applicable applications for this research.

3. Literature review

This section first analyzes recent literature on IBAs and describes how this study's model adds to this field. This section then presents the findings used for this study's model from relevant applications of MCDM and bargaining game theory.

3.1. Impact and benefit agreements review

IBAs outline the benefits to be shared from a development project with impacted communities. As seen in IBAs from the Mary River (2018), Meliadine (2017) and Meadowbank mines (2017), these benefits can include preferential employment, training, joint venture agreements, compensation, environmental protection, cultural protection, and participation in decisions. This section reviews some key IBA literature for their main findings and specifically how they incorporate multiple-criteria trade-offs into best-practices and decision making.

IBAs are independent contracts with impacted Indigenous nations, communities, or stakeholders. They are also known as benefit-sharing agreements but go by many other names (Gunton and Markey 2021). Depending on the region, they can be required by regulators (Fidler and Hitch, 2007; Galbraith et al., 2007; O'Faircheallaigh, 2021). IBAs are a relatively recent instrument for company-community relations. As noted by Gunton and Markey (2021), IBA are context dependent instruments which are dependent on the community, mine, local environment. They unfortunately stem from a failure of government to ensure impacted communities receive the necessary benefits from a project (Peterson St-Laurent and Billon, 2015). In theory, and in Canada, processes like environmental assessments, socioeconomic assessments, and project permitting should assess the impacts of a project. Regulators should then ensure adequate resources are given back to the impacted communities from the mine's taxes and royalties. This scheme is successful for some communities, but many, for example, Indigenous communities, who are typically more impacted by resource development projects, have a history of receiving little to no benefits from both regulators and project owners.

The IBA bargaining process, which is most advanced in Australia and Canada, has both its merits and challenges. Research over the past ten years, such as Bradshaw et al. (2018), Craik et al. (2017), and Papillon and Rodon (2017), have analyzed the current state of IBAs, and what it adds to Indigenous law and consultation requirements. Bradshaw et al. (2018) notes the many questions that remain for IBAs around the variability of negotiations, the governance issues, and if IBAs are benefiting both communities and companies. In terms of governance, Craik et al. (2017) argue IBAs as a type of private governance but require accounting the additional procedural and legitimacy demands. Papillon and Rodon (2017) on the other hand, see proponent led IBAs as a "*truncated version of FPIC* [Free Prior and Informed Consent]", which undermines the FPIC process.

Some scholars argue that EA and IBA negotiations can overlap, and even that IBAs should be a part of the EA process (Gibson and

O'Faircheallaigh, 2010). Lukas-Amulung (2009) found that they overlap during the scoping, deliberation, and resolution stage. She proposes that IBA and EAs be coordinated at the beginning stage of a project to improve information sharing and monitoring. It is also argued by scholars such as Bradshaw et al. (2018), St-Laurent and Le Billon (2015), and Caine and Krogman (2010), that power imbalances will continue to be an issue in IBA negotiations.

Cascadden et al. (2021) create a best practice framework for IBAs and discuss success depends on "*the quality of the agreement, the context within which the IBA exists, and the dedication with which the agreement is implemented.*" Based on best practices, it provides an overview of the types of criteria to be considered. The criteria, although imperative for an inclusive IBA, does not consider the environmental implications of the mine plan. A mine's impact can vary greatly depending on its mining methods, size, processing methods, and the proximity to environmental features (e.g., lakes, rivers, forests, and sensitive ecosystems). To determine if an IBA is successful, there must be some consideration of what the actual mine plan is. Understanding the mine plan can lead to understanding the total impacts of the mine. A mine plan with more impacts should potentially have a lower chance of being accepted. Using an MCDM with different mine plan scenarios, this research's model can investigate this aspect of IBAs. It can better present the relationship between community values and the environmental impacts of the mine.

Adebayo and Werker (2021) calculate the economic benefits that can be received in terms of financial transfers, jobs, and contracting opportunities. As they note in their paper, through taking an economic perspective solely, essential socio-environmental benefits are not considered. Ecosystem health is an imperative requirement of many communities. By not including environmental criteria for benefit calculations, the trade-offs of environmental impacts versus economic opportunities that communities make are not considered. It is therefore impossible to tell if the mine provides adequate benefits for its impacts. This study adds to this by developing a method which considers the environmental criteria and trade-offs communities make when deciding to accept or reject an IBA.

An IBA can enhance a community through project revenues and protocols for monitoring project impacts. However, it is unclear how successful, in terms of helping communities over the long-term, these IBAs truly are (O'Faircheallaigh, 2020, 2018). O'Faircheallaigh (2018) argues for more systemic analyses of the positive outcomes of IBAs to truly conclude they are positive instruments. O'Faircheallaigh (2020) also finds IBAs do not often realize their potential to be able to monitor projects. Finally, these agreements do have the potential to protect the community's cultural heritage, but as O'Faircheallaigh (2008) discusses, bargaining positions need to be addressed. This research uses bargaining game theory to analyze these bargaining positions.

A key reference, O'Faircheallaigh (2016), evaluates 45 IBAs across Australia and develops several criteria to evaluate negotiation outcomes. He notes that the aggregation of outcomes in criteria such as—environmental management, cultural heritage protection, rights and interests in land, financial payments, employment and training, business development, and implementation measures—will show if a negotiation is successful or not. He ranks the agreements based on environmental performance and finds that the "*agreements that display strongly positive outcomes in one area tend to be strong in others; weaker agreements tend to be weaker across the board*" (O'Faircheallaigh, 2016). His-research brings a quantitative approach for which this paper is also attempting to achieve, however the difference is that this paper develops a method from MCDM, to aggregate the indicators based on a community's values function. O'Faircheallaigh (2016) only uses environmental criteria to define the IBAs as "*strong*". Even though he finds that strong environmental performance is linked to strong socio-cultural performance, he ignores that a community may value one criterion over the environment, and deems the IBA as being strong across all criteria regardless.

The incorporation of environmental criteria takes place in O'Faircheallaigh and Corbett (2005) and O'Faircheallaigh (2016). The issues with O'Faircheallaigh and Corbett (2005) and O'Faircheallaigh (2016) is their methods of putting values on to the environmental criteria. From O'Faircheallaigh and Corbett (2005), going from "*Joint decision making on some or all environmental management issues*" to "*Indigenous parties have the capacity to act unilaterally to deal with environmental concerns or problems associated with a project*" is worth a score increase of one. Why one? Why not two? The community being impacted should be able to make this judgement on the scoring differences between criteria. MCDM brings this into the analysis by incorporating a value-function for a community.

Peterson St-Laurent and Billon (2015) discuss how IBAs take away from the state's responsibility towards communities. Cameron and Levitan (2014) also discuss the creation of IBAs is in fact the privatizing of government's duty to consult. This can lead to limiting access to political and legal systems and creating market-based solutions to community impacts. IBAs exist within an already flawed neoliberal governance system but provide some recourse for communities. Caine and Krogman (2019) show IBAs can help create engagement and benefits, but provisions need to allow transparency and dialog between communities, companies, and regulators. Benefits need to be shared throughout the community; however, power dynamics within the community and with the proponents need to be considered.

Many IBAs are confidential, which has issues and merits. Confidentiality can prevent other communities from understanding how projects typically affect and benefit communities. When an IBA is confidential, communities cannot learn what is typically included. On the other side, mining companies can take advantage of their experience on previous properties (Caine and Krogman, 2010). Hummel (2019) argues IBAs should be transparent because they resemble public law and have an increasing role in a company's duty to consult. In Nunavut, Hummel (2019) shows the transparency of IBAs has created opportunities for constructive scrutiny. Some communities prefer IBA confidentiality because it protects them from the Federal Government potentially reducing their support in proportion to how much the IBA is providing (Hummel, 2019). In addition, given each project is unique and has regional specific impacts, it is possible referencing other IBAs would be extraneous and could impact their bargaining positions. Bargaining game theory, which this study presents, can show the implications of confidentiality.

As shown in the literature, the current calculation of benefits of IBAs is inconsistent. Some studies incorporate environmental indicators, some do not, and none of them are able to bring together all sustainability criteria with a community-focused approach of incorporating how communities value criteria. Additionally, the bargaining positions of each group is an essential piece that dictates what is included in an IBAs, but there is a lack of methods to include bargaining positions. To fill these gaps, this study uses MCDM and game theory, which are described in the next two sections.

3.2. Multiple-criteria decision making: trade-offs with TOPSIS

MCDM, also known as multiple-criteria decision analysis, helps structure decisions between alternatives using conflicting or corresponding criteria (Zopounidis and Doumpos, 2017). Different MCDM techniques, such as PROMETHEE, AHP, ELECTRA, VIKOR, COPRAS, ARAS, MOORA, MULTIMOORA and TOPSIS vary with how they calculate trade-offs between criteria and rank alternatives (Sitorus et al., 2019). There are countless applications of MCDMs for sustainability focused decisions, unfortunately there is a critical lack of MCDM applications in the mining industry (Collins and Kumral, 2020a). Some applications of MCDM in the mining industry include Štirbanović et al. (2019) for flotation machine selection, Rahimdel and Noferesti (2020) mined material investement, and Naghadehi et al. (2009) for underground mining method selection. This section will now briefly introduce TOPSIS and present how it is applied to this research.

Originally developed by Hwang and Yoon (1981), the TOPSIS procedure selects the best alternative by having the shortest distance associated with the positive ideal solution and the farthest distance from the negative-ideal solution (Behzadian et al., 2012; Zavadskas et al., 2016). This allows criteria to be either minimized or maximized. Crucially, attribute values must be numeric, monotonically increasing or decreasing, and have commensurable units (Hwang and Yoon, 1981; Papathanasiou and Ploskas, 2018).

This study selected TOPSIS because it provides a clear approach to dealing with criteria trade-offs in decision making (Savun-Hekimoğlu et al., 2021). As discussed by Zavadskas et al. (2016), TOPSIS does not exclude alternatives based on pre-defined thresholds, which corresponds well to this research's IBA application: maximizing sustainability in mineral development requires trade-offs of different sustainability criteria. TOPSIS is relatively easy to structure for both negative and positive criteria, and is flexible when using both quantitative and qualitative data. This is key for working with stakeholders that use different analysis methods.

The TOPSIS process used in this research is briefly summarized below.

First, a decision matrix with *m* alternatives, $A_1, \ldots, A_m$, and n criteria, $C_{1,\ldots}, C_n$, needs to be created. These two matrices are evaluated with respect to the other to create the matrix:

$$X = (x_{ij})_{m\times n}$$

A vector for criteria weighting also needs to be created. Let $W = (w_1, \ldots.., w_n)$ such that $\sum_{j=1}^{n} w_j = 1$. This research explores situations with unknown criteria functions.

Normalization of the decision matrix is conducted for creating dimensionless criteria. There are several methods for normalization; this study uses vector normalization as shown in the following equation:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}\ ,\ i = 1, \ldots, m, \quad j = 1, \ldots, n$$

Using the weights, the normalized weighted values are calculated with:

$$v_{ij} = w_j r_{ij}\ ,\ \ i = 1, \ldots, m, \quad j = 1, \ldots, n$$

Assumptions are made for the ideal (A*) and negative solutions (A^-). They are calculated as follows:

$$A^* = \{v_1^*, v_2^*, \ldots, v_n^*\} = \left\{\left(\max_j v_{ij} |\ i \in I'\right), \left(\min_j v_{ij} |\ i \in I''\right)\right\},\ i = 1, \ldots, m, \quad j = 1, \ldots, n$$

$$A^- = \{v_1^-, v_2^-, \ldots, v_n^-\} = \left\{\left(\min_j v_{ij} |\ i \in I'\right), \left(\max_j v_{ij} |\ i \in I''\right)\right\},\ i = 1, \ldots, m, \quad j = 1, \ldots, n$$

Calculation of the Euclidian distances to the ideal (D_i*) and anti-ideal solutions (D_i^-) then take place.

$$D_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2},\ i = 1, \ldots, m, \quad j = 1, \ldots, n$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2},\ i = 1, \ldots, m, \quad j = 1, \ldots, n$$

Finally, the relative closeness (C^*_i) is calculated for each alternative. The closer to 1, the higher the rank.

$$C_i^* = \frac{D_i^-}{D_i^* + D_i^-}\ i = 1, \ldots, m$$

There are some drawbacks of the TOPSIS method. The normalized decision matrix is often derived from a narrow gap between the criteria performances. This can at times not show the true dominance of alternatives. In addition, like other MCDM methods, when adding in non-optimal alternatives, or more alternatives, a ranking reversal can occur or contradictions in the model. In Section 4, this method will be applied to incorporate unknown weighting of values using Monte-Carlo simulation-based analysis.

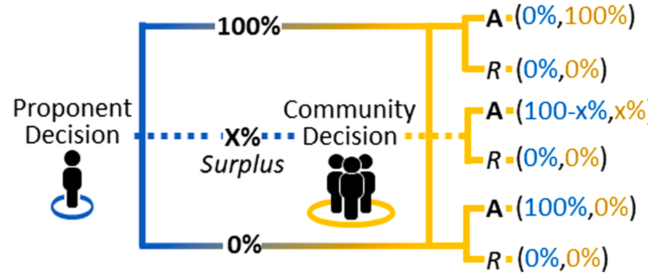

Fig. 1. Simple Bargaining Game (payoffs in blue for the proponent, payoffs in yellow for the community).

3.3. Game theory for bargaining

Modern game theory, discussed by von Neumann and Morgenstern (1944), investigates how two or more players interact, compete, or cooperate. Nash (1950a) discussed equilibrium cases where no player would be better off changing their strategy. This led to Nash (1950b) branching into bargaining theory. Bargaining theory, which this study considers, is a branch of game theory which explores how players divide a surplus of goods (Binmore, 2007; Harsanyi, 1961; Spaniel, 2014; Sutton, 1986). Game theory and bargaining have been applied extensively. (Binmore, 2007). This research uses bargaining game theory and game theory in general to analyze how benefits are shared and how impacts are managed during IBA negotiations. It can provide a framework to investigate what influences how parties divide a resource or a surplus.

Different game assumptions provide different outcomes and insights. Insights from simple games such as the ultimatum game and the Rubinstein bargaining model can provide a base for analyzing real life scenarios. For an ultimatum game there is a proposer and a responder. The proposer decides how much money they want to split with the responder, and the responder decides to accept or reject (Harsanyi, 1961). This is further described below and shown in Fig. 1.

If, $V_1 =$ the maximum the proposer is willing to share, and $V_2 =$ the minimum the proposer is willing to accept, then surplus (S) will be: $\frac{V_1 - V_2}{V_1}$. For an ultimatum game to take place $S \geq 0$; all other scenarios will be rejected.

Fig. 1 presents a simple two stage bargaining model based on this ultimatum game. In this figure, *x* denotes the proposed split of surplus, or for this research, the percent the community will receive. The community can either accept or reject the offer. The payoffs, which are in terms of percent surplus, for the proponent are at the bottom of the figure in blue, the payoffs for the community are in yellow. In this ultimatum game, the equilibrium state, which occurs when no player is better off deviating from their strategy, occurs when the offered surplus (x) is as close as possible to, or equal to V_2.

If S_i is the strategy set for player "*i*", where $i = 1, 2\ldots N$. Let $s^* = (s_i^*, s_{(-i)}^*)$ be a strategy set, where each player has one strategy. s_{-i}^* means the set of all strategies for every player except *i*. The equilibrium state occurs if for any player altering the strategy is not profitable. That is if, $u_i(s_i^*, s_{-i}^*)\ u_i(s_i^*, s_{-i}^*)$ for all $s_i \in S_i$, and where $u_i(s_i^*, s_{-i}^*)$ is the player's payoff as a function of their strategies.

For a Rubinstein bargaining model, the game has alternating offers over an infinite time horizon. Both players have complete information,

Table 1
Bargaining Factors (Adapted from Binmore (2007), Harsanyi (1961), Spaniel (2014), and Sutton (1986)).

Factor	Description
Control over proposals	Whoever makes proposals has an advantage. Whoever has the last say in making proposals has an advantage. Generally, mining companies control proposals, but this could change if communities are better supported, and their capacities improve.
Patience	Whoever has the most patience has better outcomes. Conversely, the player who is desperate for a deal has a disadvantage. This can apply to either player. Communities, like Canada's northern communities, who have little economic opportunities, and are in dire socioeconomic conditions, can potentially be less patient, or cannot afford to be less patient. Companies can be less patient due to the increasing costs of development and delays from permitting.
Outside options	Having credible and competitive outside options gives the player an advantage. Depending on the mining company, some companies have a large portfolio of development properties to choose from, and some have only one property. Companies with a larger portfolio could potentially have better outside options to invest their money. For communities, they could have different types of development opportunities in their territory.
Monopoly	Having a unique quality other players want is an advantage. This could apply to a mining company that has a strong reputation, but more likely to the mineral development property and community. Viable mineral development properties are rare and can even be unique in specific economic climates.
Reputation	A strong reputation, where you typically get better deals than average, will provide a player with an advantage. This can be applied to either player.
Credible commitments/ threats	If a player can be credible to select a strategy in certain situations, then this can be an advantage. The threat could be many things such as a rejection, protest, or legal action.
Knowledge or information asymmetry	If a player knows the other player's preferences, bottom line, or cost-benefit criteria, they can use it to their advantage.
Uncertainty	Uncertainty can sometimes lead to negotiation breakdowns and inefficient outcomes. But also, uncertainty can potentially help players with less bargaining power.

meaning they know the options of each player, and delays in the game are costly (Rubinstein, 1982). The discount factor "d" of each bargaining stage then plays an important role for the equilibrium calculation. In this game, the first player gets a surplus payoff of $\frac{1}{1+d}$ and the second player gets a surplus of $\frac{d}{1+d}$.

This study focussed on game theory and bargaining in relation to sustainability trade-offs. Some examples include Carraro et al. (2007) and Hemati and Abrishamchi (2020) for water management, Carraro and Sgobbi (2008) for natural resource management, Stranlund (1999) for forestry management, Sauer et al. (2003) pollution reduction, Lennox et al. (2013) for conservation agreements, Caparrós (2016) for international environmental agreements, and Schopf and Voss (2019) for a three-person game over natural resources.

The simple games and the applications in sustainability trade-offs present key factors affecting bargaining positions and outcomes. Table 1 presents the many factors that influence how the surplus is divided or what "x" is in Fig. 1. This has been adapted from research previously mentioned such as: Binmore (2007), Harsanyi (1961), Spaniel (2014), and Sutton (1986). Table 1 discusses the roles they potentially play in IBA negotiations. Seeing how IBA processes can be different from case to case, the factors outlined in Table 1 can either help or impact either of the players depending on the situation. These factors will be further discussed in relation to IBAs in the next sections.

4. Game theory and MCDM model for IBAs

This section combines the findings of Section 3 to provide a novel and structured analysis of IBAs. This research takes the MCDMs from a community's perspective, where the alternatives are different IBA proposals and a rejection alternative. This study considers IBA proposals in terms of the following criteria: (1) their environmental impact using the life of mine's total tonnes, (2) compensation to the community in dollars, and (3) a rating for socioeconomic activities. The rating for socioeconomic activities would be developed through a collaborative process with the community. Other criteria could be easily incorporated such as employment, wildlife compensation, contracting opportunities, but for this model three criteria are used. With IBA negotiations occurring near the beginning of the mine life-cycle, these criteria will be predicted criteria. This will be further discussed in the next section.

Reviewing literature that mixes Monte-Carlo simulation, game theory, and MCDM for sustainability based decisions, shows their integration is not common. Some notable examples include Madani and Lund (2011), Madani et al. (2015), Debnath et al. (2018), and Collins and Kumral (2020b). Madani and Lund (2011) and Madani et al. (2015) specifically use game theory to model MCDM problems and Monte-Carlo to analyze uncertainty in the performance of alternatives. Instead, this paper assumes values for the performance of alternatives and uses the Monte-Carlo simulation for preferences.

The criteria weightings (W) are a key unknown for this study and IBAs in general. Accepting impacts from one criterion should bring benefits from another. The amount of benefit/utility gained per impact however is unknown and depends on the W functions, which was introduced in Section 3.2. To determine the W function, MCDM methods like the Analytical Hierarchy Process (AHP) can be used. AHP for example, uses pair-wise comparisons to determine the relative importance of each criterion (Saaty, 1987). Methods like AHP bring together opinions from numerous members of a community or experts with often different values and opinions on trade-offs.

This study uses a Monte-Carlo simulation-based analysis to model the unknown criteria weightings, as discussed in Mosadeghi et al. (2013). The Monte-Carlo simulation investigates how randomized criteria values affect alternative selection. With three criteria for the W function, their sum needs to equal one. The Monte Carlo simulation selects three random integers between one and a thousand, then finds the relative weight of each criterion. This is conducted by dividing each random variable by the sum of the three integers. These three variables are put through the MCDM program and this process is repeated one thousand times. Other distributions could be used for this process such as the normal, skewed, or triangle distributions, however when normalizing their sum to equal one, the original distribution characteristics are lost.

The MCDM process shows how a community looks at trade-offs. Bargaining game theory dictates how the surplus will be divided.

Table 2
IBA Cases.

All values in% change from base Scenario Name\Alternatives	High Payments (HP)	Mid Payments (MP)	Low Payments (LP)	High Impacts (HI)	Mid Impacts (MI)	Low Impacts (LI)
Least Variability	+10%	+5%	0%	0%	-5%	-10%
Base Case	+30%	+15%	0%	0%	-15%	-30%
Mid Variability	+100%	+50%	0%	0%	-33%	-50%
High Variability	+300%	+100%	0%	0%	-50%	-75%

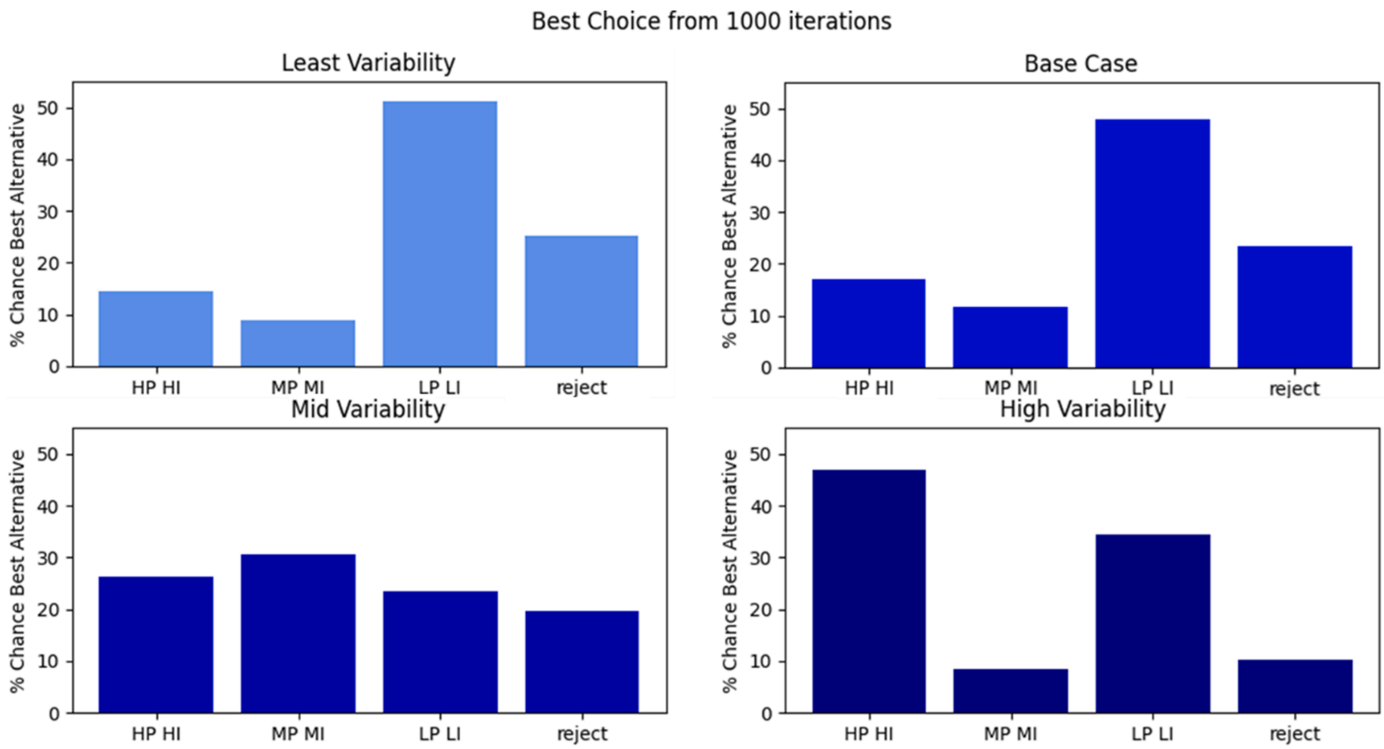

Fig. 2. Monte-Carlo simulations between alternatives with different variabilities.

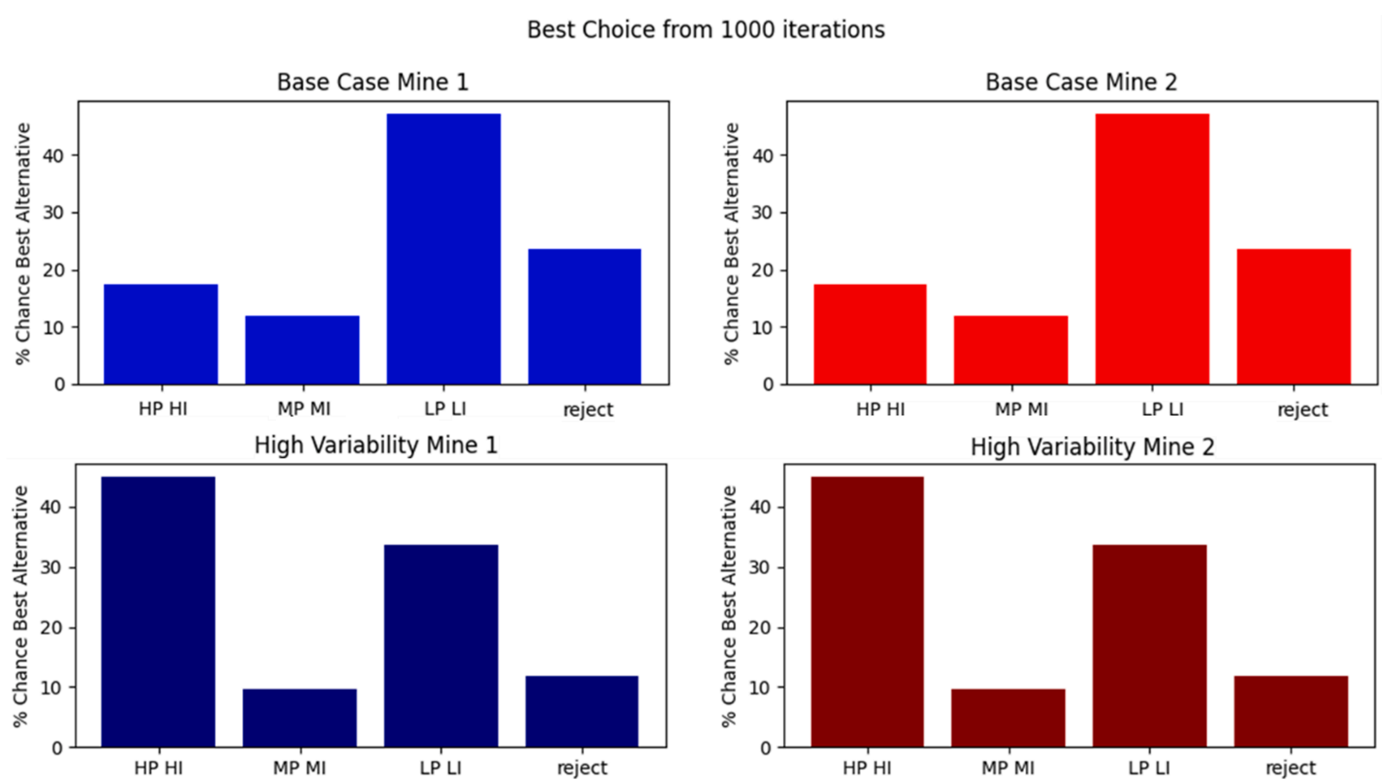

Fig. 3. Monte-carlo simulation between two mines.

Table 1 as previously discussed shows some of the key factors influencing how a surplus is divided. Exactly how much the factors affect the players' bargaining positions, and the division of the surplus is difficult to estimate. The goal of this study is not to provide exact figures but to provide an idea of which main factors affect the outcomes.

This model ranks alternatives with different relative levels of payments and environmental impacts. Using the scenarios shown in Table 2, this research developed a base case to model the relationship between benefits and impacts. The model then varies the environmental impacts and level of payments from the base case according to the increases or decreases outlined in Table 2. The socioeconomic rating does not vary between IBAs; it is kept at a fixed value. All criteria go to zero

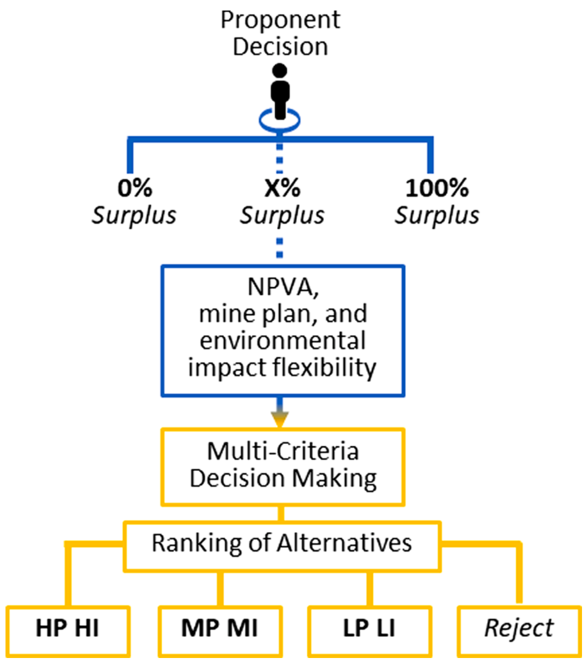

Fig. 4. Relationship between Bargaining and MCDM.

for the reject scenario. Using the different relative levels of payments and impacts, this research provides an investigation on how relative trade-offs of sustainability criteria affect IBA negotiations. Short form codes of the scenarios are shown in the table, to present how impacts vs. payments vary from the base case.

Figs. 2 and 3 show the IBA output for this TOPSIS MCDM model with unknown criteria weights. In Fig. 2, the graphs become darker blue when variability between payments and impacts increases. In Fig. 3, again the darker the color means higher variability; but instead with two different mines (one in blue and one in red). The variability term is used in this model to indicate the amount of criteria change that exists from the base case.

For example, the base case scenario in Fig. 2 shows the community has the option to: (1) select high payment (HP) and high impact (HI), which is "HP HI" in the figure, (2) mid payment, mid impact, "MP MI", (3) low payment low impact "LP LI", or (4) they can reject the proposal. Again, Table 2 shows the percent changes between the high, mid, and low for impacts and payments for the base case scenario. The Monte Carlo Simulation picks random criteria weights then using the TOPSIS MCDM the best alternative is selected. This is done one thousand times and Fig. 2 (top right for base case) shows the percent chance each alternative is the highest ranked. Other scenarios look at different variabilities between alternatives. Fig. 3 uses the same variabilities as Fig. 1 but looks at two different mines with base case and high variability cases.

Fig. 4 shows how MCDM and bargaining interact in this research. The factors outlined in Table 1 dictate the amount of surplus that will be shared (the x% in Figs. 1 and 4). Depending on the mine plan, this surplus could provide community compensation, or it could be put into reducing the environmental impacts. Reducing environmental impacts could be through technology investment or even reducing the mine's total tonnage. The amount of compensation that is available to use in a bargaining situation, which this study calls "NPVA", is dictated by the mine's NPV and the company's financial goals for the project. Their financial goals could include a minimum NPV, maximum payback period, or minimum internal rate of return. The MCDM process in this Fig. 4 shows the community's ranking for how the surplus of the mine should be used. In this case it communicates the importance of environmental protection and the relative amount of compensation necessary. In addition, if the preferred option is to not have any development, this is shown as "reject".

Table 3
MCDM Output Example: Base Case.

Base Case Name	Company	Community
HP HI	2	2
MP MI	2	1
LP LI	2	4
Reject	1	3

Table 4
Game Theory Conversion Table: Base Case.

	Company				
Community		**HP HI**	**MP MI**	**LP LI**	**Reject**
	HP HI	(2,2)	(1,3)	(1,3)	(1,3)
	MP MI	(1,3)	(2,1)	(1,3)	(1,3)
	LP LI	(1,3)	(1,3)	(2,4)	(1,3)
	Reject	(1,3)	(1,3)	(1,3)	(1,3)

Table 5
MCDM Output Example: Reject Case.

Reject Case Name	Company	Community
HP HI	2	2
MP MI	2	1
LP LI	2	3
Reject	1	4

Table 6
Game Theory Conversion Table: Reject Case.

	Company				
Community		**HP HI**	**MP MI**	**LP LI**	**Reject**
	HP HI	(2,2)	(1,4)	(1,4)	(1,4)
	MP MI	(1,4)	(2,1)	(1,4)	(1,4)
	LP LI	(1,4)	(1,4)	(2,3)	(1,4)
	Reject	(1,4)	(1,4)	(1,4)	(1,4)

The outputs of Fig. 4 can be analyzed as a strategic game as discussed in Madani and Lund (2011). To continue with the same example, the output of the base case scenario in Fig. 2 is used. The output of the MCDM provides an ordinal ranking of the alternatives. The community ranking of ordinal preferences is summarized in the second column of Table 3. This study assumes the company for this case will rank the "Reject" scenario as the worst, but it is unknown how they prefer ratios between payments vs. environmental impacts. For this case, this model assumes the company is indifferent as the surplus was already decided in the bargaining step of this research.

Table 4 is the conversion of the ordinal ranking into a strategic game that shows scenarios of both cooperation and non-cooperation. When the two parties disagree the default scenario is the reject, as the mine will not be allowed to proceed. The highlighted cell in Table 4 shows the highest payoff which is achieved under cooperation where both players agree to the "LI LP" alternative. With the company indifferent, the maximum utility will be the preferred alternative of the community unless the community's top alternative is the reject, as shown in Tables 5 and 6. In this case there will be two situations with the highest total payoffs; the reject alternative and the community's next preferred alternative. The highlighted cells show the highest total payoffs situation which include all situations where they disagree.

An assumption this research makes is that if the community rejects the mine, the mine does not occur. This is not necessarily true and depends on how much importance a regulator puts on the relationship between a community and a company. This importance continues to grow for many nations. Regardless, the reject scenario will be damaging for a company. If a mine continues development without approval, major conflicts can arise which greatly affect the mine's profitability and the company's reputation (Ali, 2003).

5. Analysis and discussion

IBAs are major hurdles for resource development projects; however, they greatly lack advanced analysis tools and methods. This section discusses some of the issues and important considerations when applying this paper's MCDM and game theory approach.

To implement these methods, data needs to be collected collaboratively from all stakeholders. The impacts of mining can be collected from mining companies and the criteria preferences is collected from of impacted communities. Some impact data can be found in National Instrument (NI) 43 101 feasibility reports, company reports, and sustainability reports but these documents do not provide adequate data for this analysis (Collins and Kumral 2020b). To test this research's model, this study developed impact and benefit data from the Mary River (2018), Meliadine (2017) and Meadowbank mines (2017) in Nunavut. For a community, their preferences will be what dictates if the IBA is accepted, and how they make trade-offs. The issue is that determining their exact preferences is challenging, if not impossible. For many mining communities in Canada, there can be a distinct lack of trust with resource development industries. For Indigenous communities specifically, this stems from generations of cultural genocide from colonial policies and companies. Meaningful collaboration requires trust. If a strong relationship can be developed between company and community, MCDM preference determination methods such as an Analytical Hierarchy Process (AHP), which uses pairwise comparisons between criteria, could be employed to understand how the community makes trade-offs. But, even if trust is established and an AHP can be conducted, it is very difficult to consider all concerns of a group. Individuals have their own wants, needs, and values which influence how they make trade-offs in sustainability. This research uses the Monte-Carlo simulation to investigate unknown criteria preferences for an alternative selection.

The exact values for the criteria used in this model may be difficult to quantify exactly due to the inherent uncertainty of a mine. At the beginning of IBA negotiations, there is considerable uncertainty with how the mine will develop, achieve profits, and impact the environment. NI 43–101 feasibility studies provide a qualified prediction for these numbers for the IBAs, but in the end it is still a prediction. Even though these are predicted values and not exact figures, the potential payments and impacts can be used, and probabilities can be implemented if desired. It is important to note however, that the indicators used in this paper are just some of the many indicators that could be used for this model. The key contribution from this research, is to create a model that can incorporate this type (or any other type) of data, and compare it to other indicator data types.

Regarding the application of MCDM, it provides a structured approach to analyze and communicate trade-offs between impacts and benefits. However, implementing it for resource development decisions, which have a reject alternative, can provide results that are overly sensitive to values. Using TOPSIS, the vastly different outcomes of having a mine and receiving benefits, or having no mine and receiving no benefits, creates few opportunities to compromise when criteria preferences are unknown. With vastly different alternatives, the decision becomes very sensitive to criteria preferences and insensitive to the scale of benefits. See Fig. 2, which models two different mines, but the MCDM output is very similar. According to this model's MCDM, the chances of a community rejecting an IBA are independent of how profitable the mine. This is arguably seen in practice too; the relative profitability of a mine does not seem to have a correlation to community-company conflict risk (Andrews et al., 2017; Hilson, 2002). Contradictorily and according to assumptions in mainstream economics, the more profitable the mine, the better chance the mine should be accepted. A more profitable mine should provide more resources for communities to be prosperous and healthy. However, mainstream economics often fails to adequately value ecosystems' intrinsic values as shown by ecological economics scholars; it should not be utilized without more holistic methods like MCDM (Daly and Farley, 2011; Shmelev, 2012).

It is imperative to discuss a possible conflicting view to this study's assumptions in O'Faircheallaigh (2016), who found that trade-offs between his developed criteria in fact do not occur in a major way, but they do occur at the margin. He finds that IBAs that are most positive on economic criteria also are strongest on environmental and cultural heritage indicators. This paper, by contrast, as shown in Table 2, creates alternatives that trade-off between criteria. When O'Faircheallaigh (2016) discusses criteria trade-offs, he examines the trade-offs between different types of IBAs, but not necessarily between having a mine versus not having a mine. A mine decision is inherently a trade-off. It trades the environmental health of a region for economic opportunities. The major trade-off occurs between the "reject" alternative and the non reject alternatives (i.e., the remaining alternatives). The differences between the non-reject alternatives may not be too dissimilar as shown by O'Faircheallaigh (2016). In Table 2 we have the alternatives trading off significantly, but this is selected to show differences in non-reject alternatives. In the end, the mix of impacts vs. benefits will be established based on factors outlined in Table 1, and these will dominate the decision space of non-reject alternatives. For the community, the trade-off of criteria will then occur between the dominant non-reject alternative and the reject alternative."

Another important consideration regarding the MCDM of this model, is how variability in terms of options changes alternative rankings. The higher the variability, which is the ability to have more trade-offs between environmental impacts and benefits, the lower chance the community will reject the mine (see Table 3). With these scenarios, they show a higher chance the mine will be accepted as is but requiring more payments. Providing flexibility to alter impacts or increase payments creates fewer rejections. The main takeaway is a flexibility provides more cooperative outcomes.

This paper uses the term flexibility for the propensity of companies to provide more varied alternatives. Flexibility in alternatives can provide better results but providing alternatives to mine plans is not common. Mine plans and methods are generally selected by the mining company. They are selected to maximize net present value (NPV) first and foremost, but also to follow regulations and maintain safety. There is typically limited flexibility in the design of the mine plan at the IBA negotiation stage. The only flexibility is in the amount of compensation, local employment, local contracts, general economic opportunities, and communication protocols. This research's model shows the benefit of providing flexibility in a mine plans' environmental impact as it reduces the chance of IBAs being rejected. For example, mining companies should communicate the alternative mining method options for more destructive mining methods like underground caving and large-scale open pit mining. In addition, more flexible alternative options for mine closure, mine waste management, mineral processing, and water treatment can provide a sustainability focussed and accepted project.

The term mining methods used in this paper is more holistic. It does not just consider open pit vs. underground vs. open-cast type operations, but the staging of the operation, the tonnes per day, and the scheduling as well. How the mine is mined on every level is part of the mining methods. Currently, many mining methods (and many mining processes) are unfortunately inflexible. The mining method for a property is selected by the mining company to consider the geology and the maximization of NPV, but it is rarely altered. There are strong constraints on mining methods by the site's geology, mineralogy, and local site conditions, but engineers and innovation must be pushed to make mining methods more flexible to the wants and needs of local communities, and to the uncertainties of mineral development. Different mining alternatives need to be seriously considered and discussed with community members during negotiations.

For the bargaining process, the factors outlined in Table 1 can either help or impact either of the players. If it helps the proponent, then the options to the community will most likely become less variable. If it helps the community, the option to the community will be more variable. If the community has bargaining power the company has to convert more NPV to NPVA. Relating this to the previous paragraph, the more variable the lower chance the community will reject the mine. Meaning, the more the community has power in the bargaining process the more likely they will accept the mine. This makes intuitive sense, the party with more say in the proposal will more likely accept the offer.

Several of the factors affecting bargaining power shown in Table 1, such as control over proposals, patience, outside options, and knowledge, are generally in favor of mining companies, and typically give mining companies advantages in IBA negotiations as also discussed in Bradshaw et al. (2018), St-Laurent and Le Billon (2015), and Caine and Krogman (2010). The unique qualities factor, however, which in this case is the mineral resource, would be an advantage to the community depending on the global state of exploration and project development of the specific commodity. If many projects are available around the world for mining companies, they could have more options if bargaining breaks down, giving them an advantage. Conversely, if there are few sites then the community's site has less competition and they would have the advantage. Uncertainty and reputation can also alter bargaining outcomes for either party, but in countless ways. The definitions of these bargaining factors in the end can be interpreted for numerous criteria and situations, and could be an advantage or disadvantage for either party. However, the factors that are typically an advantage for mining companies need to be understood by regulators, and a bargaining process needs to be established where communities can receive fair deal during negotiations.

Scholars in ecological economics argue using money to value nature, as is often done by society's current economic and legal systems, is extremely problematic (Brown and Timmerman, 2015; Daly and Farley, 2011; Shmelev, 2012). Ecosystems can be infinitely complex; the planet's current understanding continues to improve but significant knowledge gaps remain (Vasseur et al., 2017). When reviewing the state of our planet's ecosystems, working within western economic growth paradigms has proved to be highly damaging (Gray, 2015). With the addition of MCDM, this research's goal is to provide a more pluralistic analysis of how different groups can value nature and its complexity. Unfortunately, this method still focusses on a human-centric viewpoint, where nature provides to society rather than the planet being a symbiotic system. In the end, for mineral development decisions, decision makers must make trade-offs to ensure better sustainability outcomes. This method provides a structure to understand and communicate these trade-offs.

6. Limitations and next steps

The limitations of this model and paper occur due to the nascence and limited integration of MCDM and game theory for the mining industry. The model developed in this paper is informed by data shown in the appendix, but for further applications a significant data collection endeavor would have to occur. Taking this paper's more theoretical model to a more applied level would require data from communities and mining companies on mine design parameters, criteria selection, criteria values, traditional knowledge, traditional economies, socio-environmental relationships, ecosystem parameters, biodiversity, and many more site specific considerations. Collecting that data requires strong local partnerships and is best done collaboratively with all players. At this point, this data collection undertaking is outside of the scope of this research. At this stage, this research's proposed model provides the first step for the integration of game theory and MCDM for IBAs and shows users the main considerations when making complex sustainability focused decisions. The data used in appendix provides an adequate framing for the model's development and for aligning it for future work.

The variables used in the model–1. environmental impact using the life of mine's total tonnes, 2. compensation to the community in dollars, and 3. a rating for socioeconomic activities—present a simplistic representation of real-world considerations in IBA negotiations. More criteria should be implemented, which can easily be done with this model. At this stage, the key was to use criteria that represented different areas of sustainability and that could be valued in very different ways. With the goal of developing MCDM and game theory methods for IBAs adding more criteria at this stage would not provide create a better discussion. The next steps will be to engage directly with communities to understand and develop more criteria for project development.

Modeling MCDMs without value functions is not common and can make this model look more complex and less user-friendly than it is. Further data collection and the incorporation of value functions would simplify the models for easier use. At this stage, by keeping the value functions unknown, the model provides an ability to incorporate uncertainty of another party's strategy, which is common during negotiations. The model at this stage provides a way of analyzing often incommensurable criteria which is not easily done during negotiations.

This model developed provides new tools and methods to analyze IBAs, which can be used for future data collection steps when looking at specific sites. In all, this paper provides a structured approach for dealing with multiple criteria and multiple stakeholders with different value systems. The next steps will be to engage directly with mining companies and communities to collect the necessary data to understand the ideal trade-offs between criteria. These trade-offs will take place through agreeing to the mine plan, compensation schedule, and environmental impacts.

7. Conclusion and recommendations

To summarize, the following list provides several key recommendations uncovered from this research for individuals looking to develop IBAs or predict if it will be accepted:

- A project which provides alternatives which can trade-off between all important criteria, can make a project more likely to be accepted.
- Before negotiations, bargaining factors should be analyzed to understand which group will potentially be at an advantage. The main factors–patience, knowledge, uncertainty, and power to make proposals–should be discussed and mediated.
- Mineral policies should require proponents to provide flexible alternatives for all important criteria to communities.
- Alternatives designs should be included for mine plans, mine closure plans, waste management plans, hiring policies, contracting policies, environmental monitoring plans, research and development initiatives, mine ownership, and compensation.
- Transparent alternative assessments should be conducted to bring understanding to the economic-environmental trade-offs that exist between project benefits and impacts.
- The model developed in this study can provide a method to organize and communicate the complex sustainability trade-offs that exist within mineral development.

IBA negotiations raise a lot of questions, uncertainties, expectations, and conflicts regarding resource development projects. This research's unique contribution was in its analysis and application of tools like bargaining theory, strategic games, and MCDM to help mineral development push towards sustainability focussed outcomes for society. To keep up with demand, mining's impacts are continuing to grow despite efficiency gains in many environmental mining technologies for water treatment, green-house-gas emissions, and waste management. With mining projecting to grow as society pushes towards lower carbon technologies, IBAs will continue to be key steps for resource development projects. IBAs must evolve to consider the increasing impacts of mining and the growing expectations and bargaining power of communities. To push for sustainability focused outcomes and informed decisions, IBAs should use methods like MCDM and game theory to better communicate the inherent and complex sustainability trade-offs in mineral and resource extraction.

Declaration of Competing Interest

None

Acknowledgments

This work was supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) (NSERC ID: 461234); and the Economics for the Anthropocene (E4A) research partnership.

Appendix – Impact and benefit agreements in Nunavut

The Nunavut mining industry in Canada was analyzed to provide an applied scenario to better understand IBAs. Nunavut was selected as the analysis area because it is one of the few regions where several IBAs are public. The following data in Table A.1 helped guide the development of this study's model.

Table A.1
Mines and IBAs in Nunavut.

Mine	Company	Community Association	Proven and Probable Reserves	Life of Mine	After-tax NPV ($ millions)	Internal rate od return	Incentives	Cash incentives	References
Mary River (Iron ore)	Baffinland	Qikiqtani Inuit Association	60.7 M tonnes Ore	20 years	$1030 (8% discount rate)	30.6%	• Financial Participation • Royalties • Contracting Opportunities • Employment • Inuit Education and Training • Community support • Wildlife compensation • Inuit Engagement • Project Monitoring and Mitigation	20 million (M) + 1.25 M per construction quarter. $75 million max. If mine keeps operating. Royalty of 1.25% or percent of net revenue.	(Baffinalnd Iron Mines Corporation, 2011; "The Mary River Project Inuit Impact Benefit Agreement," 2018)
Meadowbank (Gold)	Agnico Eagle	Kivalliq Inuit Association	24.771 M tonnes Ore	7 years	$202.0 (5% discount rate)	25.7%	• Contracting opportunities • Training • Employment • Promotes social and cultural wellness • Financial Compensation • Wildlife compensation	$2.5 M + 6.5 + 1.4% Net Smelter Return)	(Agnico Eagle Mines Limited, 2017; "Meadowbank Mine Inuit Impact and Benefit Agreement between Agnico-Eagle Mines Limited and Kivalliq Inuit Association," 2017, "The Whale Tail Project Inuit Impact and Benefit Agreement," 2017)
Meliadine (Gold)	Agnico Eagle	Kivalliq Inuit Association	13.944 M tonnes Ore (10.048 Mt underground)	14 years	$267 (5% discount rate)	10.3%	• Business Opportunities • Preferred Contracts • Training and Employment • Advancement of Women, Youth, and Challenged Workers • Education • Social and Cultural Wellness • Financial Compensation • Training. • Contracts • Community support • Wildlife compensation • Monitoring and Mitigation	$3 M + 1.2% Net Smelter Return	("Meliadine Project Inuit Impact and Benefit Agreement between the Kivalliq Inuit Association and Agnico Eagle Mine Limited," 2017)
Hope Bay (Gold)	Agnico Eagle	Kitikmeot Inuit Association	16.782 Ore (Mt)	15 years	$486 (5% discount rate)	19.7%	Details not public. • Employment • Training • Business Opportunities • Compensation for traditional, social and cultural matters, and effects on Inuit water rights	Information not public	("IMPACT/BENEFIT AGREEMENT Miramar, KIA Concur on Hope Bay Project," 2004)

References

Adebayo, E., Werker, E., 2021. How much are benefit-sharing agreements worth to communities affected by mining? Resour. Policy 71, 101970. https://doi.org/10.1016/j.resourpol.2020.101970.

Zopounidis, C., Doumpos, M., 2017. Multiple Criteria Decision Making - Applications in Management and Engineering. Springer. https://doi.org/10.1007/978-3-319-39292-9.

Agnico Eagle Mines Limited, 2017. Technical Report on the Mineral Resources and Mineral Reserves At Meadowbank Gold Complex. URL https://s21.q4cdn.com/374334112/files/doc_downloads/operations/meadowbank/Meadowbank-Technical-Report-Feb-14-2018-Final-poasted-on-Sedar.pdf (accessed 3.31.21).

Ali, S.H., 2003. Mining the Environment and Indigenous Development Conflicts. Mining the Environment and Indigenous Development Conflicts. The University of Arizona Press, Tucson.

Andrews, T., Elizalde, B., Billon, P. Le, Hoon Oh, C., Reyes, D., Thomson, I., 2017. The rise in conflict associated with mining operations: what lies beneath?. Canadian International Resources and Development Institute URL https://cirdi.ca/wp-content/uploads/2017/06/Conflict-Full-Layout-060817.pdf (accessed 4.30.21).

Baffinalnd Iron Mines Corporation, 2011. Mary river iron ore trucking NI 43-101 technical report. URL https://www.miningdataonline.com/reports/MaryRiver_Technical_012011.pdf (accessed 4.1.19).

Behzadian, M., Khanmohammadi Otaghsara, S., Yazdani, M., Ignatius, J., 2012. A state-of the-art survey of TOPSIS applications. Expert Syst. Appl. 39, 13051–13069. https://doi.org/10.1016/j.eswa.2012.05.056.

Binmore, K., 2007. Does Game Theory Work? : The Bargaining Challenge. Does Game Theory Work? : the Bargaining Challenge. MIT Press, Cambridge, Mass.

Bradshaw, B., Fidler, C., Wright, A., 2018. Impact and benefit agreements and northern resource governance: what we know and what we still need to figure out, in: Gap Analysis Report #9. pp. 204–218. 10.4324/9781351019101.

Brown, P.G., Timmerman, P., 2015. Ecological Economics for the Anthropocene: An Emerging Paradigm. Ecological Economics for the Anthropocene: an Emerging Paradigm. Columbia University Press, New York. https://doi.org/10.7312/brow17342.

Caine, K.J., Krogman, N., 2010. Powerful or just plain power-full? a power analysis of impact and benefit agreements in Canada's North. Organ. Environ. 23, 76–98. https://doi.org/10.1177/1086026609358969.

Cameron, E., Levitan, T., 2014. Impact and benefit agreements and the neoliberalization of resource governance and indigenous - State relations in Northern Canada. Stud. Political Econ. 93, 25–52. https://doi.org/10.1080/19187033.2014.11674963.

Caparrós, A., 2016. Bargaining and international environmental agreements. Environ. Resour. Econ. 65, 5–31. https://doi.org/10.1007/s10640-016-9999-0.

Carraro, C., Marchiori, C., Sgobbi, A., 2007. Negotiating on water: insights from non-cooperative bargaining theory. Environ. Dev. Econ. 12, 329–349. https://doi.org/10.1017/S1355770X06003536.

Carraro, C., Sgobbi, A., 2008. Modelling negotiated decision making in environmental and natural resource management. A multilateral, multiple issues, non-cooperative bargaining model with uncertainty. Automatica 44, 1488–1503. https://doi.org/10.1016/j.automatica.2007.12.021.

Cascadden, M., Gunton, T., Rutherford, M., 2021. Best practices for impact benefit agreements. Resour. Policy 70, 101921. https://doi.org/10.1016/j.resourpol.2020.101921.

Collins, B., Kumral, M., 2020a. Environmental sustainability, decision-making, and management for mineral development in the Canadian Arctic. Int. J. Sustain. Dev. World Ecol. 27, 297–309. https://doi.org/10.1080/13504509.2019.1684397.

Collins, B., Kumral, M., 2020b. A critical perspective on social license to operate terminology for Canada's most vulnerable mining communities. Extr. Ind. Soc. In Press. https://doi.org/10.1016/j.exis.2020.11.002.

Collins, B., Kumral, M., 2020c. Game theory for analyzing and improving environmental management in the mining industry. Resour. Policy 69, 101860. https://doi.org/10.1016/j.resourpol.2020.101860.

Craik, N., Gardner, H., McCarthy, D., 2017. Indigenous – corporate private governance and legitimacy: lessons learned from impact and benefit agreements. Resour. Policy 52, 379–388. https://doi.org/10.1016/j.resourpol.2017.05.002.

Daly, H.E., Farley, J.C., 2011. Ecological economics: Principles and Applications. Ecological Economics: Principles and Applications, 2nd ed. Island Press, Washington, DC.

Debnath, A., Bandyopadhyay, A., Roy, J., Kar, S., 2018. Game theory based multi criteria decision making problem under uncertainty: a case study on Indian tea industry. J. Bus. Econ. Manag. 19, 154–175. https://doi.org/10.3846/16111699.2017.1401553.

Eisenmenger, N., Pichler, M., Krenmayr, N., Noll, D., Plank, B., Schalmann, E., Wandl, M. T., Gingrich, S., 2020. The sustainable development goals prioritize economic growth over sustainable resource use: a critical reflection on the SDGs from a socio-ecological perspective. Sustain. Sci. 15, 1101–1110. https://doi.org/10.1007/s11625-020-00813-x.

Fidler, C., Hitch, M., 2007. Impact and benefit agreements: a contentious issue for environmental and aboriginal justice. Environments 35, 49–70.

Galbraith, L., Bradshaw, B., Rutherford, M.B., 2007. Towards a new supraregulatory approach to environmental assessment in Northern Canada. Impact Assess. Proj. Apprais. 25, 27–41. https://doi.org/10.3152/146155107X190596.

Gibson, G., O'Faircheallaigh, C., 2015. IBA Community Toolkit: Negotiation and Implementation of Impact and Benefit Agreements. Walter and Duncan Gordon Foundation.

Gray, N.F., 2015. The Planet's Health, in: Facing Up to Global Warming: What Is Going on and How you can Make a Difference? Springer International Publishing, Cham, pp. 333–356. https://doi.org/10.1007/978-3-319-20146-7_13.

Gunton, C., Markey, S., 2021. The role of community benefit agreements in natural resource governance and community development: issues and prospects. Resour. Policy. 73, 102152 https://doi.org/10.1016/j.resourpol.2021.102152. Available from:

Harsanyi, J.C., 1961. On the rationality postulates underlying the theory of cooperative games. Confl. Resolut. 5, 179–196. https://doi.org/10.1177/002200276100500205.

Hemati, H., Abrishamchi, A., 2020. Water allocation using game theory under climate change impact (case study: zarinehrood). J. Water Clim. Chang. 1–13. 10.2166/wcc.2020.153.

Hilson, G., 2002. An overview of land use conflicts in mining communities. Land Use policy 19, 65–73. https://doi.org/10.1016/S0264-8377(01)00043-6.

Hummel, C., 2019. Behind the curtain, impact benefit agreement transparency in Nunavut. Les Cah. Droit 60, 367. https://doi.org/10.7202/1060981ar.

Hwang, C.L., Yoon, K., 1981. Multiple Attribute Decision making: Methods and Applications. Multiple Attribute Decision Making: Methods and Applications. Springer-Verlag, New York.

Lennox, G.D., Gaston, K.J., Acs, S., Dallimer, M., Hanley, N., Armsworth, P.R., 2013. Conservation when landowners have bargaining power: continuous conservation investments and cost uncertainty. Ecol. Econ. 93, 69–78. https://doi.org/10.1016/j.ecolecon.2013.04.016.

Liang, Q., Hu, H., Wang, Z., Hou, F., 2019. A game theory approach for the renegotiation of public-private partnership projects in Chinese environmental and urban governance industry. J. Clean. Prod. 238, 117952 https://doi.org/10.1016/j.jclepro.2019.117952.

Lukas-Amulung, S., 2009. The rules of engagement? Negotiated agreements and environmental assessment in the Northwest Territories. Canada. Royal Roads University.

Madani, K., Darch, G., Parra, F., Workman, M., 2015. Using game theory to address modern resource management problems. Grantham Institute, Imperial College London 6.

Madani, K., Lund, J.R., 2011. A Monte-Carlo game theoretic approach for multi-criteria decision making under uncertainty. Adv. Water Resour. 34, 607–616. https://doi.org/10.1016/j.advwatres.2011.02.009.

Mary River Project Inuit Impact Benefit Agreement, 2018. URL https://www.qia.ca/wp-content/uploads/2018/10/Mary-River-IIBA-Signed.-October-22-2018.pdf (accessed 4.29.21).

Meadowbank Mine Inuit Impact and benefit agreement between agnico-eagle mines limited and Kivalliq Inuit association, 2017. URL http://kivalliqinuit.ca/ (accessed 9.2.20).

Meliadine Project Inuit Impact and benefit agreement between the Kivalliq Inuit association and agnico eagle mine limited, 2017.

Mosadeghi, R., Warnken, J., Tomlinson, R., Mirfenderesk, H., 2013. Uncertainty analysis in the application of multi-criteria decision-making methods in Australian strategic environmental decisions. J. Environ. Plan. Manag. 56, 1097–1124. https://doi.org/10.1080/09640568.2012.717886.

Naghadehi, M.Z., Mikaeil, R., Ataei, M., 2009. The application of fuzzy analytic hierarchy process (FAHP) approach to selection of optimum underground mining method for Jajarm Bauxite Mine, Iran. Expert Syst. Appl. 36, 8218–8226. https://doi.org/10.1016/j.eswa.2008.10.006.

Nash, J.F., 1950a. Equilibrium points in N-person games. Proc. Natl. Acad. Sci. United States Am. 36, 48–49. https://doi.org/10.1073/pnas.36.1.48.

Nash, J.F., 1950b. The bargaining problem. Econometrica 18, 155–162.

O'Faircheallaigh, C., 2021. Explaining outcomes from negotiated agreements in Australia and Canada. Resour. Policy 70. https://doi.org/10.1016/j.resourpol.2020.101922.

O'Faircheallaigh, C., 2020. Impact and benefit agreements as monitoring instruments in the minerals and energy industries. Extr. Ind. Soc. 7, 1338–1346. https://doi.org/10.1016/j.exis.2020.05.016.

O'Faircheallaigh, C., 2018. Using revenues from Indigenous impact and benefit agreements: building theoretical insights. Can. J. Dev. Stud. 39, 101–118. https://doi.org/10.1080/02255189.2017.1391068.

O'Faircheallaigh, C., 2016. Negotiations in the Indigenous World: Aboriginal Peoples and Extractive Industry in Australia and Canada. Negotiations in the Indigenous World: Aboriginal Peoples and Extractive Industry in Australia and Canada. Routledge, New York, p. 2016.

O'Faircheallaigh, C., Corbett, T., 2005. Indigenous participation in environmental management of mining projects: the role of negotiated agreements. Environ. Politics 14 (5), 629–647.

Papathanasiou, J., Ploskas, N., 2018. Chapter 1 TOPSIS, in: Multiple Criteria Decision Aid In: Springer Optimization and Its Applications. Springer, Cham, pp. 1–30. https://doi.org/10.1007/978-3-319-91648-4_1.

Papillon, M., Rodon, T., 2017. Proponent-Indigenous agreements and the implementation of the right to free, prior, and informed consent in Canada. Environ. Impact Assess. Rev. 62, 216–224. https://doi.org/10.1016/j.eiar.2016.06.009.

Peterson St-Laurent, G., Billon, P.Le, 2015. Staking claims and shaking hands: impact and benefit agreements as a technology of government in the mining sector. Extr. Ind. Soc. 2, 590–602. https://doi.org/10.1016/j.exis.2015.06.001.

Rahimdel, M.J., Noferesti, H., 2020. Investment preferences of Iran's mineral extraction sector with a focus on the productivity of the energy consumption, water and labor force. Resour. Policy 67, 101695. https://doi.org/10.1016/j.resourpol.2020.101695.

Rubinstein, A., 1982. Perfect equilibrium in a bargaining model. Econometrica 50, 97–109.

Saaty, R.W., 1987. The analytic hierarchy process - what it is and how it is used. Math. Model. 9, 161–176. https://doi.org/10.1016/0270-0255(87)90473-8.

Šauer, P., Dvořák, A., Lisa, A., Fiala, P., 2003. A procedure for negotiating pollution reduction under information asymmetry. Environ. Resour. Econ. 24, 103–119. https://doi.org/10.1023/A:1022886831892.

Savun-Hekimoğlu, B., Erbay, B., Hekimoğlu, M., Burak, S., 2021. Evaluation of water supply alternatives for Istanbul using forecasting and multi-criteria decision making methods. J. Clean. Prod. 287 https://doi.org/10.1016/j.jclepro.2020.125080.

Schopf, M., Voss, A., 2019. Bargaining over natural resources: governments between environmental organizations and extraction firms. J. Environ. Econ. Manag. 97, 208–240. https://doi.org/10.1016/j.jeem.2017.12.002.

Shmelev, S.E., 2012. Ecological Economics - Sustainability in Practice. Ecological Economics - Sustainability in Practice. Springer, Oxford, UK.

Sitorus, F., Cilliers, J.J., Brito-Parada, P.R., 2019. Multi-criteria decision making for the choice problem in mining and mineral processing: applications and trends. Expert Syst. Appl. 121, 393–417. https://doi.org/10.1016/j.eswa.2018.12.001.

Spaniel, W., 2014. Game Theory 101 - Bargaining. Bolton, ON.

Štirbanović, Z., Stanujkić, D., Miljanović, I., Milanović, D., 2019. Application of MCDM methods for flotation machine selection. Miner. Eng. 137, 140–146. https://doi.org/10.1016/j.mineng.2019.04.014.

Stranlund, J.K., 1999. Bargaining to preserve a unique ecosystem: the role of anticipatory investments to establish stronger bargaining positions. Ecol. Econ. 31, 425–437. https://doi.org/10.1016/S0921-8009(99)00065-8.

Sutton, J., 1986. Non-cooperative bargaining theory: an introduction. Rev. Econ. Stud. 53, 709–724. https://doi.org/10.2307/2297715.

The Whale Tail Project Inuit Impact & Benefit Agreement, 2017. URL http://kivalliqinuit.ca/wp-content/uploads/2019/02/Whale-Tail-IIBA-2017-06-15.pdf (accessed 4.29.21).

Vasseur, L., Horning, D., Thornbush, M., Cohen-shacham, E., Andrade, A., Barrow, E., Edwards, S.R., Wit, P., Jones, M., 2017. Complex problems and unchallenged solutions : bringing ecosystem governance to the forefront of the UN sustainable development goals. Ambio 46, 731–742. https://doi.org/10.1007/s13280-017-0918-6.

von Neumann, J., Morgenstern, O., 1944. Theory of Games and Economic Behavior. Theory of Games and Economic Behavior. Princeton University Press, Princeton, NJ.

Zavadskas, E.K., Mardani, A., Turskis, Z., Jusoh, A., Nor, K.M., 2016. Development of TOPSIS method to solve complicated decision-making problems: an overview on developments from 2000 to 2015. Int. J. Inf. Technol. Decis. Mak. 15, 645–682. https://doi.org/10.1142/s0219622016500176.