

Visions of the Arctic Future: Blending Computational Text Analysis and Structured Futuring to Create Story-based Scenarios

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Key Points:

- Imaginative scenarios are an essential approach for designing futures in an accelerating era of social and environmental change in the Arctic.
- Story-based scenarios blended with computational text analysis provide an entirely new method for envisioning the future.
- Our scenario methods mirror other work on Arctic futures, though with important idiosyncrasies related to divergent regional changes.

Abstract

The future of Arctic social systems and natural environments is highly uncertain. Climate change will lead to unprecedented phenomena in the pan-Arctic region, such as regular shipping traffic through the Arctic Ocean, urban growth, military activity, expanding agricultural frontiers, and transformed Indigenous societies. While intergovernmental to local organizations have produced numerous synthesis-based visions of the future, a challenge in any scenario exercise is capturing the ‘possibility’ space of change. In this work, we employ a computational text analysis to generate unique thematic input for novel, story-based visions of the Arctic. Specifically, we develop a corpus of more than 2,000 articles in publicly accessible, English-language Arctic newspapers that discuss the future in the Arctic. We then perform a latent Dirichlet allocation, resulting in ten distinct topics and sets of associated keywords. From these topics and keywords, we design ten story-based scenarios employing the Mānoa mashup, science fiction prototyping, and other methods. Our results demonstrate that computational text analysis can feed directly into a creative futuring process, whereby the output stories can be traced clearly back to the original topics and keywords. We discuss our findings in the context of the broader field of Arctic scenarios and show that the results of this computational text analysis produce complementary stories to the existing scenario literature. We conclude that story-based scenarios can provide vital texture toward understanding the myriad possible Arctic futures.

Plain Language Summary

The Arctic will profoundly change in the 21st century. Climate changes and other increasing human pressures will transform many parts of the region beyond contemporary recognition. We need ways to capture the current, Arctic-based perspectives of this future change and to provide engaging visions of where it might be headed. First, we use a computer-assisted analysis of more than 2000 news articles that all discuss the future of the Arctic. Second, we take the insights from this analysis and produce a set of story-based scenarios. We do this by blending science fiction prototyping, the Mānoa method, and others to produce speculative fiction scenarios. In our results, we produce ten new, creative scenarios of the Arctic future. We find that our story-

48 based results have themes that are consistent with some existing Arctic scenarios. Moving
49 forward, we think that the methods we use will improve the accessibility future scenarios.

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Introduction

The future of Arctic social systems and natural environments is highly uncertain (Arctic Council, 2016; Fresco & Timm, 2016). Future climate change will lead to unprecedented phenomena in the pan-Arctic region, such as regular shipping traffic through the Arctic Ocean, urban growth, military activity, and expanding agricultural frontiers (Arctic Council, 2009; Cameron, 2012). Such impacts will challenge centuries of local and traditional knowledge (Ford et al., 2016; Krupnik & Jolly, 2002). Moreover, the unprecedented pace and character of Arctic social and environmental change reveals the limitations of traditional, quantitative scenario methods that privilege model-based projections inherently rooted in past observational data (Petrov et al., 2016). These knowledge and research gaps suggest an opportunity for novel tools providing comprehensive and, perhaps more importantly, imaginative scenarios of the future. Equipped with such scenarios, the Earth system science community could be better positioned to anticipate the social, economic, ecological, and technological changes that may unfold in the near future.

1.1 A rapidly changing Arctic may require new approaches

Underpinned by complex desires related to acquiring geopolitical hegemony, resource control, and urban growth, the Arctic is often viewed as a key focal point for cultural, economic, and military power in the 21st century (Arctic Research Consortium of the U. S, 2018; Brigham, 2007; Corbett et al., 2010; Mazurier et al., 2020; Network, 2008; Young, 2010, 2011). In parallel to these expansionist ambitions, the Arctic is experiencing the fastest geophysical changes taking place on the planet related to climate change, as noted in the accelerated loss of sea ice, changes in freeze thaw cycles of permafrost, and the expansion of boreal ecological systems into the Arctic region (Crate & Fedorov, 2013; Dodds, 2010; Post et al., 2009; Steiner et al., 2019; Stroeve et al., 2012). These efforts to understand the future have led to a surfeit of models, projections, and forecasts for the Arctic (Proshutinsky et al., 2016, 2020). In contrast, the local and regional experiences of those who dwell in the Arctic tend to receive considerably less attention (Cost, 2015; Falardeau et al., 2019; N. Wormbs et al., 2018).

1.2 Computational text analysis complements existing methods

It is a staggering challenge to collect, interpret, and prioritize the vast literature on Arctic system change - and then synthesize this information into scenarios about the future. Systematic meta-analysis of Arctic futures work (Arbo et al., 2013) has revealed the utility of synthetic review, but such meta-analysis may also be too narrowly focused on relatively small sample sizes (e.g., less than 100 articles). Others have argued that there is simply too much content to consume, and, as a result, pre-existing knowledge and biases are employed to filter content (Schatzmann et al., 2013). Thus, there is a need for complimentary approaches that can scan the information across hundreds or thousands of documents and across a broad range of disciplines to accurately understand the trajectory of where the world is heading (Kwon et al., 2017).

In thinking about the future Arctic, it is necessary to think well outside-the-box regarding nonlinear changes in technology and global change (Dator, 1993, 2019; Johnson, 2011). One method for addressing biased selection of evidence can be to develop a large corpus of literature that captures a very broad range of content related to the future Arctic. However, human cognitive biases actively disregard information that seems outlandish or strange (Schoemaker, 2004), making unbiased interpretation a persistent challenge.

Computational text analysis can assist in addressing this bias by providing a complimentary means of thematic identification and analysis of a corpus of literature. In other words, a computer program can be used to potentially reduce human selection bias by 'reading' the thousands of texts and 'interpreting' different patterns than a human might see. Specifically, machine learning-based latent Dirichlet allocation can enable the rapid analysis of large, text-based datasets to reveal thematically distinct clusters of information (Asmussen & Møller, 2019).

This approach has been used in a limited way for scenarios related to drone technology (Kwon et al., 2017) and electric cars (Kim et al., 2016). Considerable opportunity exists to leverage these methods and fully incorporate them into detailed visions of the future Arctic (Kayser & Blind, 2017; Kayser & Shala, 2016).

1.3 Storytelling can convey compelling scenario worlds

Scenarios of the future vary widely in terms of approach, style, and depth of detail (Kishita et al., 2016), yet often only describe a possible future world, based on projections and interpretations of large amounts of data. While descriptive scenarios can be creative, these approaches often fail to inspire action, engage the public, or interest policymakers (Milkoreit, 2017). Story-based scenarios with characters and plot development have emerged as successful vehicles for impactful sustainability scenarios (Calvert, 2019; Johnson & Winkelman, 2017; Merrie et al., 2018; Spijkers et al., 2021). Story-based methods can be understood as *narrative, fictional depictions of future worlds*. Storytelling methods are meaningfully different from narrative approaches, since they represent a deeper exploration of future worlds (Carbonell et al., 2017), and they allow participants to explore how their daily lives, values, and habits can be mapped onto different contexts (Raven & Elahi, 2015).

The purpose of the present work is to demonstrate how a latent Dirichlet allocation (LDA) analysis may input directly into a creative, structured futuring process (Fig 1). We define structured futuring as a *systematic, multi-step approach for creatively developing a story setting, set of characters, and plot that interrogates a particular topic or set of topics*. We are explicitly not aiming to provide a definitive new set of comprehensive scenarios, especially given the absence of participation with Indigenous and local communities in the Arctic. On the contrary, we are piloting this approach in the Arctic region both because of the extensive, existing scenario work available for comparison, as well as the diversity of challenges that are being faced by Arctic societies (Akiwenzie-Damm et al., 2019).

However, this does not mean that we ignore the context or the place where the text data originated. While our project is not participatory, we have endeavored to situate each story thoughtfully and critically in a specific future context, by telling multiple stories that reflect the diversity of the Arctic population, including ethnicities, gender identities, ages, and Indigeneity. Moreover, we aim to provide a “multiplicity of voices” through the eventual stories that are told (D’ignazio and Klein, 2020), while acknowledging the partiality of the perspectives that we can bring to bear given the limits that our perspectives permit (Weinberger, 2009). Finally, our scenarios aim to engage the humanities via the transformation of a computational text analysis into stories (and later artwork) that embrace open-interpretation, ambiguity and complexity (Drucker, 2011). We reflect more on the future of these methods in the Discussion section.

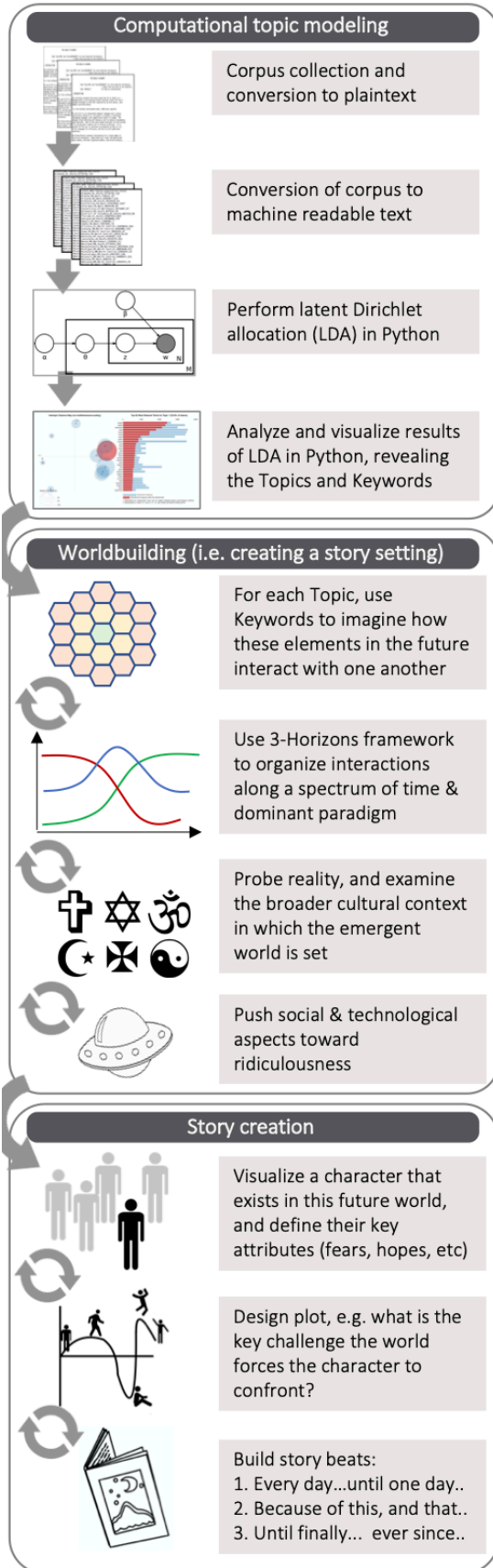


Figure 1. Conceptual overview of how the topic modeling analysis feeds into the structured futuring process, including worldbuilding and story creation.

2 Data and Methods

2.1 News article corpus on the future of the Arctic

We collected news articles from multiple Arctic regional news sources. These articles were available in publicly accessible, English-language Arctic newspapers, specifically: The Arctic Sounder, Arctic Today, The Barents Observer, CBC North, The Moscow Times, Nunatsiaq News, and Radio Canada International. These sources were selected based on a set of preliminary conversations with community leaders, scientific experts and public officials from throughout the Arctic. We use the Google Search engine as a method of discovery, and a temporal window of search of 2010-2020. These dates do not correspond to any specific event, but rather capture a recent, contemporary set of published perspectives on the future Arctic.

For most sources, we simply used the search term ‘future’ as a filter of the articles, given the publication itself was an ‘arctic’ publication. For Radio Canada International and The Moscow Times, we used both ‘arctic’ and ‘future’ as a filter. While the language of the sources was restricted to English-language texts, there are news resources coming from the entire pan-Arctic region, including Russia, Finland, Sweden, Norway, Iceland, Canada, Greenland, and Alaska. The purpose for this broad collection is to ensure that the information from the regional (i.e. spatially extensive, less granular, more general) and the local (i.e. spatially specific, more detailed, deeper knowledge), spans the possibility space of a large fraction of the Arctic discourse about the future, available in English-language newspapers. While additional words could have been used, such as ‘projection’, ‘forecast’, or ‘scenario’, we were intentional about using a simple, straightforward — and hopefully repeatable — procedure. We rely on the word ‘future’ as our primary search term, for multiple reasons. First, ‘future’ is commonly used as both a noun and an adjective. As a noun, ‘future’ is defined as “the time that will come after the present or the events that will happen then” (OED Online, 2021). Likewise, as an adjective, ‘future’ is defined as “That is to be, or will be, hereafter.” These definitions are precisely the meaning we are after. Second, there are very few nouns in the English language that are commonly used to convey this definition, with less commonly used words including “hereafter”

and "tomorrow". There are some synonyms of 'future' as an adjective, though these tend to be less precise (words include: anticipate, expected). Thus, the simple choice of 'future' in this case allows us to target the definition of the word future, with a straightforward approach.

While the Google Search algorithm often displays tens of thousands of search returns, a user only has access to approximately 300 entries. Thus, we limit the collection of articles to the top 300 articles returned from each source. The order of entries from a Google search employs the proprietary PageRank algorithm that sorts and orders webpages based on the number of other links to them on the internet. This will inevitably lead to some skew in the types of articles that are listed at the top, and we anticipate that future work could use alternative search approaches that would potentially yield different sets of articles. That is, however, beyond the scope of this work. Ultimately, by using Google Search we ensure the method is free and generally easy for others to use, without any fee-based licenses.

The potential for biases exists in multiple aspects of this corpus. First, we only use English-language texts (or texts that were translated into English). As a result, there is an *anglophone* bias that may include implicit or tacit perspectives that are difficult to surface, not least related to the legacy of settler colonialism in Indigenous communities in the Arctic. Along with this, we note that the LDA implicitly absorbs biases of the corpus itself, including: the vocabulary of the news article authors, the political biases of the article authors themselves, and the editorial biases of the news sources and their publishers. In acknowledging the various contexts that constrain the creation of these source articles (D'ignazio and Klein, 2020), we aim to definitively underline that this machine learning method contains its own variety of bias.

Second, we are implicitly adopting the biases of the search algorithm that was used — in this case a Google-based search. While this is certainly a bias, we intend for this method to be theoretically accessible to anyone, which would exclude many scholarly search products, which often require paid subscriptions or memberships to specialized organizations. While other forms of written information about the future of the Arctic region exist (such as journal articles, reports, or other forms of information), we wanted to collect publicly-available and currently discussed

ideas about the future. Freely available news articles serve this aim by providing publicly available information.

Finally, we note that the composition of the research team is not local or Indigenous to the Arctic, and is only capable of interpreting English-language texts. Moreover, since the goal was to generate written stories from computational text analysis, both the input and the output needed to be in English. Also, while a future goal of this type of work could include engagement of local and Indigenous communities in the Arctic, this work aims to demonstrate the method's potential, by using publicly available documents written for and by an audience that exists in, or is concerned with, the Arctic. That being said, the data should be interpreted as originating from texts that were written from specific positions of cultural power throughout the Arctic and near-Arctic, rather than representative of a reality devoid of these power dynamics (D'ignazio and Klein, 2020).

2.2 Text preparation and conversion

Each document was saved in a plaintext file, and manually stripped of erroneous material that did not pertain to the article itself, including strings of characters associated with unrelated website HTML (i.e., Hypertext Markup Language), unrelated publication text, or advertisements. Once the corpus of texts was identified, we generated a machine-readable corpus using Python-based scripts that can batch-convert documents to text strings. It is important to note that the corpus is being used for educational and research purposes only, and that the corpus itself is not publicly distributed.

2.3 Latent Dirichlet allocation (LDA)

Using the GENSIM package, in addition to several other Python-based tools, we performed the tasks of converting the strings of text into a vectorized set of inputs for analysis, including tokenization, lemmatization, and stop-word filtering (Řehůřek & Sojka, 2010; Sarkar, 2019). Next, we performed the latent Dirichlet allocation (LDA). LDA is a machine-learning based approach for taking a large corpus of texts, and revealing the latent (i.e., hidden), patterns of keywords and topics that occur across the corpus. Below, is a more detailed explanation of the process, including the corresponding versions of each software package used. We note that

multiple methods of text analysis could be suitable for identifying semantically distinct topics from a large corpus, such as latent semantic analysis (LSA) or latent semantic indexing (LSI). We employ LDA primarily because it produces highly interpretable topics (Kayser and Shala, 2014) with intuitive topic visualization options (Sievert and Shirley, 2014).

We use Python version 3.7.7 for this entire analysis. The initial step for the LDA is to pre-process each document using the Python-based Natural Language Toolkit (NLTK) version 3.4.4. Tokenization is the initial step of breaking the text within each document in the corpus into the individual units of meaning, in this case, individual words. Stopwords are then removed, including frequently used words such as “the”, “and”, “as”, etc. As a note we used both Gensim and NLTK since the tokenization process in Gensim led to spurious words that persistently passed through the tokenization filters that we implemented using Gensim. NLTK was used as a substitute since it was more effective at the tokenization procedure, for our specific task.

Lemmatization is the final step in the corpus preparation, which helps reduce the remaining words to their basic form, e.g., changing past tense versions of a word to a common form. These steps result in a tokenized corpus of texts. It is possible that lemmatization eliminates potentially valuable temporal context for articles, specifically signaling past, present, and future tenses. However, in this analysis we wanted to maximize the set of distinct words to characterize the future, rather than find (potentially) multiple words with the same root albeit with different tenses. Future work could explore this question, though it is outside the scope of this work.

Next, the Gensim Python package (version 3.8.0) is used for the LDA, which is a method that iteratively identifies the latent topic structure across the corpus. This is completed by repeatedly evaluating sets of words, and learning which clusterings lead to coherent, distinct, topics. There are several parameters that can be adjusted, but the most consequential for our work is the number of topics that are being sought in the analysis. We performed a sensitivity analysis, varying the number of topics for which the corpus was clustered, and calculated the resulting Coherence scores for all analyzed numbers of clusters. Coherence measures the degree of semantic similarity, which helps distinguish between statistical artefacts and actual semantic relatedness. So, a better Coherence score implies greater semantic similarity among the terms in

each topic cluster. There are several metrics for Coherence, and based on a systematic review of various coherence metrics, we employ the C_v metric (Röder et al., 2015). For our purposes, we aimed for each topic to be internally, semantically, similar enough to support a coherent storytelling process. Thus, we aimed for the highest Coherence score.

2.4 Visualize LDA results and identify scenario seeds

Using the pyLDAvis package in Gensim (Sievert and Shirley, 2014), we visualized the Intertopic Distance Map, based on a principal component analysis calculated within pyLDAvis. Additionally, we show the 30 most relevant terms for each topic. The Intertopic Distance Map was leveraged as a quadrant space (i.e., the four sections created by the two axes) and we labeled the axes to provide scenario context based on exogenous drivers; this is further elaborated in Section 3.3 below. The process of creating a quadrant space to construct scenarios is a central feature of many scenario analyses (Raven, 2014; Raven and Elahi, 2015; Merrie et al., 2018).

2.5 Employ structured futuring methods to take the LDA to a story-based scenario

We develop a process for creatively blending the topic's keywords and the topic's context, to construct a novel scenario world (i.e., the setting of the story), produce characters who inhabit this scenario world, and develop a brief plot. The first step is the same for all scenarios:

1. *Define the axes of the Intertopic distance map:* Label the axes of the principal component quadrants to define overarching context for each scenario, to ensure that themes which are close to one another in the principal component quadrant space are similar in some

way, while those far apart are dissimilar. Build from existing work that employs similar scenario quadrants (Raven, 2014; Raven and Elahi, 2015; Merrie et al., 2018).

The subsequent steps are repeated for each scenario, though the details of each diverge according to the topics and keywords identified for each scenario (a full example of these steps are given in Section 3.5). Relevant references corresponding to each step are provided below:

2. *Summarize keywords*: Examine the set of 30 keywords for the topic, and manually summarize into a core topic. If there is a specific location(s), use this to provide a setting for the world.
3. *Distill core topic*: Based on the keyword summary, identify a suitable core topic (Kwon et al., 2017).
4. *Explore topic and keywords with futures wheels*: Based on the core topic, the keywords, and the intertopic context, brainstorm how the ideas might be connected to one another in the future. Look for both logical and contradictory connections (Pereira et al., 2018).
5. *Use 3-horizons framework to build a future history*: Placing the futures wheels brainstorm at the end of the third horizon, begin to identify how the world has transformed from the present day to the hypothetical future world. Identify key events or changes that had to unfold to get from the present to the future (Sharpe et al., 2016).
6. *Probe reality and cultural change*: Zoom-out from the specific scenario world that is emerging, and explore what changes exist in governance, education, culture, the arts, economy, and more (Hamann et al., 2020).
7. *Push toward ridiculousness*: Select several of the keywords or other ideas and identify the most radical technological or social changes that could unfold in the future. Include some of these in the scenario (Dator, 1993; Merrie et al., 2018).
8. *Visualize character(s)*: Take the nascent future world and visualize a scene from the world. Explore the type of character that is revealed in this scene and articulate what the character is doing in the visualization. Based on this, define relevant attributes for

understanding this character (internal and external motivations; fears and hopes; past experiences; etc.).

9. *Design plot based on world and character*: Based on the character and the world, identify a challenge that could emerge that would allow the character to change or adapt in some way. Then, identify how a character might deal with such a challenge (Johnson, 2011).

10. *Build story beats*: Use the character and the basic plot to articulate the story-beats that will form the scaffold of the story. Story beats include: *Every day...*, *Until one day...*, *Because of this...*, *Because of that...*, *Until finally...*, and *Ever since then...*

11. *Write story*: Using the story-beat scaffold, begin writing the creative story of the character moving through the world, responding to a challenge, and navigating the consequences of these actions.

12. *Test story for fidelity*: Ensure that the resultant story contains key elements from the LDA analysis, including the intertopic context, the topic keywords, and the core topic.

In an effort to critically participate in the representation of diverse situations in the Arctic, we intentionally and explicitly represent storylines that take place in different social, cultural, and national contexts. We also intentionally represent characters of different ages, classes, and genders to provide a critical lens through which to view issues of social power. By exposing these goals, we hope to clarify the importance of situating stories thoughtfully, particularly in parts of the world populated by people who have been historically marginalized or harmed.

3 Results

3.1 Corpus construction

We collected 2,058 articles from our set of Arctic news sources. Each source provided 300 news articles, except for Arctic Today, in which we found a total of 258 articles in our search. More articles were returned that were published toward the end of the decade, than toward the beginning, which is possibly a result of the Google Search algorithm (Fig S11). Each article was saved in a plaintext format, and its metadata was recorded, which is available in Supplemental

Table 1. The 2,058 articles were then batch-converted from plaintext files to machine-readable strings. Other methods exist for characterizing corpus composition, including bi- and tri-gram frequency (the frequency of certain sequences of word pairs, or triads). In our work, however, we employ the term frequencies that are specifically related to each of the LDA-derived topics.

3.2 Computational topic modeling

We iteratively performed the LDA by varying the number of topics, and measuring the corresponding Coherence score (discussed in Section 2.3; see Fig S12). The highest Coherence score in our analysis was 0.54, and was achieved with eleven clusters. It is worth noting that Coherence is a relative metric related to the corpus itself. Additional information on the statistical optimization of latent Dirichlet allocation (LDA) methods is discussed in depth in other work (Chang et al., 2009; Hecking & Leydesdorff, 2018; Röder et al. 2015). Thus, the result of our LDA analysis was eleven semantically different topic clusters.

Topic coherence is one way to quantitatively assess how well the topic model is able to capture distinct topics with distinct sets of meaning, i.e., semantic similarity. Given that the purpose of the LDA in this research is to feed directly into a semantically meaningful task, i.e., creative storytelling, the qualitative process we employ serves as a second, though informal, metric of whether the identified topics are semantically meaningful. Indeed, topic eleven was ignored in this analysis given its clear lack of meaning, despite being identified by the LDA as a distinct topic. Other methods exist for detecting meaningfulness in a corpus, including word or topic intrusion (Chang et al., 2009). While beyond the scope of this research, since the authors themselves served as the human test of whether a topic was semantically meaningful or not, these methods could be a useful complement in research where there is no subsequent step that assesses topic meaning.

The LDA produced a variety of results, including a set of overall term frequencies across the entire corpus (Fig 2, right side), a set of latent topics composed of keywords, as well as various measures of ‘intertopic’ distance in a set of principal component axes (Fig 2, left side). The spread of the topics is not uniform across the distance map, which highlights that some of the topics may be more related to one another than not. This is not a problem and will be leveraged, as discussed in the next section. The Intertopic Distance Map shows that the first ten

topics represent substantial portions of the corpus, while the eleventh topic (while quantitatively unique), contains text that is two orders of magnitude lower in frequency across the corpus. Thus, we ignored the eleventh topic, and are left with ten distinct topics.

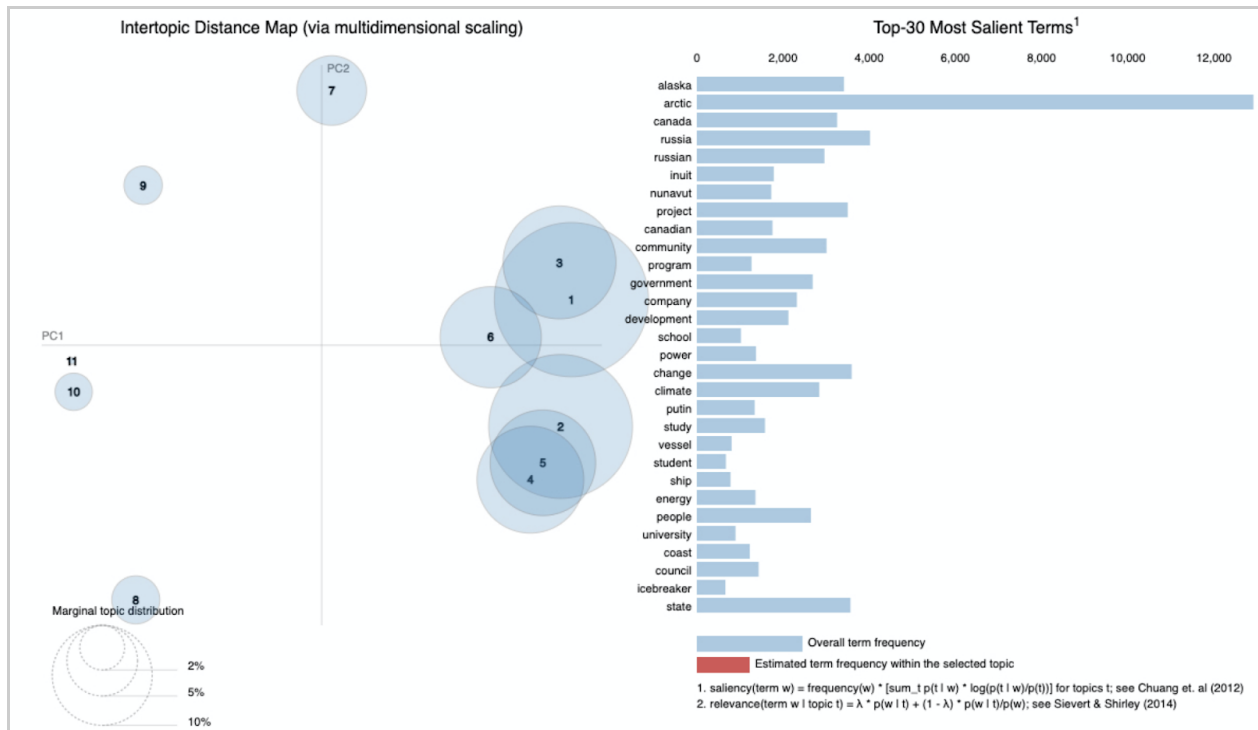


Fig 2. Results of the latent Dirichlet allocation, with thematic dominance and clustering visualized on the left, and the baseline frequency of keywords across the entire corpus depicted on the right. This was generated using the freely available pyLDAvis software in the GENSIM Python package.

3.3 LDA topic quadrants

We labeled the axes of the principal component quadrants to define overarching context for the scenarios, to ensure that topics which are close to one another in the quadrant space are similar in some way, while those far apart are dissimilar. To be clear, this step is entirely user-defined, and relies on human interpretation of the text analysis. For the purposes of our scenarios, which aim

to explore the *future* of the Arctic, we use two broad features that would serve as exogenous drivers for the entire region: climate change severity and regional levels of cooperation.

The x-axis describes the relative severity of climate change in the Arctic region, with the right side representing anticipated climate changes, and the left side representing extreme climate changes. Given the overwhelming evidence to date of how the Arctic is disproportionately sensitive to climate change (Dodds, 2010; Post et al., 2009; Steiner et al., 2019; Stroeve et al., 2012), the concentration of most of the scenarios in that domain is supported empirically. The left side of the x-axis represents more extreme climate changes, which we acknowledge are possible in the range of climate projections, as well as being exceptionally consequential to the region.

The y-axis describes whether the Arctic region is characterized by conflict or cooperation. The top of this axis represents high cooperation, including economically, politically, socially, and militarily. The bottom of this axis represents low cooperation. In this way, the bulk of the thematic clusters are somewhat neutral, and this is broadly reflected in the patchy history of Arctic cooperation (Osherenko & Young, 2005). There have been periods of peace and international cooperation, exemplified, for example, by the effectiveness of the Arctic Council (Young, 2010). Likewise, there have been profound periods of conflict (Keil, 2014; Rahbek-Clemmensen, 2017; Young, 2011), as well as targeted violence toward Indigenous peoples (Crawford, 2014; Salusky et al., 2021).

To be clear — the position of the topic clusters in this quadrant space does not determine the content of the scenario but helps to frame the *context* of the scenario. Thus, when the scenarios produced in this analysis are compared with one another, those that were identified computationally as more tightly clustered exist in similar types of geopolitical and climatic contexts (i.e., topics 1, 2, 3, 4, 5, 6), whereas those that were distributed throughout the intertopic space will be more idiosyncratic (i.e., topics 7, 8, 9, 10).

3.4 Distribution of topic clusters in the Intertopic Distance Map

We can clearly interpret the current dominance of each topic relative to the others, with topics 1-6 being quite dominant and topics 7-10 being less so. This information provides additional

context of how representative a given theme is for the entire corpus. Here we provide a summary showing each topic with its corresponding keywords (Table 1).

Table 1. Summary of topic clusters with corresponding top 30 keywords in that cluster with terms listed in descending order of relevance within the topic (i.e., the first term is the most salient to the topic)

| Topic # | Top 30 Keywords in each topic |
|-------------------------------|--|
| Overall corpus term frequency | alaska, arctic, canada, russia, russian, inuit, nunavut, project, canadian, community, program, government, company, development, school, power, change, climate, putin, study, vessel, student, ship, energy, people, university, coast, council, icebreaker, state |
| 1 | people, alaska, community, state, future, would, years, public, project, local, think, issue, right, group, friend, working, member, really, support, first, going, continue, alaskan, family, provide, need, important, program, place, opportunity |
| 2 | arctic, change, climate, research, study, ocean, polar, water, years, could, bear, north, future, researcher, population, report, temperature, summer, fishery, scientist, found, increase, university, marine, impact, permafrost, warming, island, region, species |
| 3 | arctic, council, region, norway, country, state, barents, international, norwegian, china, climate, meeting, finland, agreement, policy, greenland, chinese, include, minister, north, issue, change, russia, observer, security, northern, development, cooperation, nation, unite |
| 4 | arctic, first, north, building, guard, would, winter, include, plan, future, build, photo, service, yukon, northwest, three, search, system, coast, base, northern, place, n.w.t., mission, could, rescue, design, technology, space, station |
| 5 | project, company, energy, million, development, industry, investment, infrastructure, production, government, arctic, percent, mining, shipping, natural, billion, build, economic, increase, would, could future, resource, region, construction, price, accord, route, pipeline, plan |
| 6 | russia, russian, putin, state, moscow, country, military, headline, president, gazprom, power, political, vladimir, defense, rosneft, would, authorities, ukraine, report, foreign, sanction, minister, force, soviet, ministry, ruble, china, kremlin, control, government |
| 7 | canada, inuit, nunavut, canadian, government, community, iqaluit, indigenous, territory, federal, minister, protect, ottawa, trudeau, marine, northwest, arctic, national, tuktoyatuk, agreement, organization, report, northern, sahar, conservation, quebec, baffin, inlet, nunavik, president |
| 8 | vessel, ship, icebreaker, nuclear, power, cruise, expedition, murmansk, coast, route, fleet, voyage, waters, northern, svalbard, submarine, class, rosatom, passage, sailing, meter, shipyard, sail, plant, floating, hurtigruten, josef, pevek, tanker, reactor |
| 9 | alaska, caribou, lease, refuge, development, wildlife, national, coastal, administration, trump, plain, hilcorp, drilling, environmental, protect, statement, yereth, bureau, management, porcupine, slope, gwich'in, corps, murkowski, protection, comment, prudhoe, nation, decision, sullivan |

| | |
|----|--|
| 10 | student, school, program, college, education, youth, university, graduate, award, skill, collection, learning, career, secondary, science, degree, course, grade, offer, prize, study, mother, academic, dawson, contest, class, robot, adult, training, mcconnell |
|----|--|

3.5 Creating story scenarios from the LDA topics

While the creation of each of the ten stories was inherently unique, we nonetheless detail the process for one of the stories (Topic #5, “Concession 60”) to illustrate what the structured futuring process looks like in practice (Fig 3). The full creative processes for all the stories are documented in the Supplement. While the LDA objectively revealed the keywords for this approach, every other step was a structured, imaginative endeavor. As such, a very large number of stories could conceivably emerge from the starting point of the topic model. However, a key goal of this method is to maintain fidelity in the eventual story concepts and ideas to the original LDA topic context and keywords (Steps 1 and 2).

While each step is described in the Methods section of this text, we examine here the step-by-step approach displayed in Fig 3, corresponding to the steps for constructing the story for Topic #5, entitled ‘Concession 60’:

1. For Topic #5, the two-quadrant context was *expected climate change* and *low cooperation*.
2. The keywords for Topic #5 were clustered around the concepts of ‘industrial development’, ‘finance’, ‘extraction’, and ‘agreements’.
3. Based on these keywords, the core topic was labeled ‘Extractive, industrial Arctic’.
4. Next, using Futures Wheels we brainstormed interconnections that might emerge in the future among these keywords in Topic #5, in the context of the labeled quadrants.
5. Then, we used the ideas from Step 4 in a Three Horizons exercise and explored the changing paradigms that would wax and wane over time, leading to a future characterized as an ‘Extractive, industrial Arctic.’
6. Next, we took our ideas and keywords from Steps 2-5, and reflected on the broader regional and global aspects of how the world in Topic #5 may interact with this idea of a future Arctic.
7. In ‘pushing toward ridiculousness’ and given the topic of extraction and industrialization in the Arctic, we considered what aspects of society, economy, and technology could be dramatically different from the present. In this way, we explored ideas of labor, drone monitoring, and nano-mining that are, at present, not socially, economically, or technologically in existence.

8. Equipped with a mature setting in which a story might unfold, we develop a character named *Misha Park*, a climate migrant from the United States who had migrated north, to an undisclosed Arctic location.
9. Based on the extractive, industrial Arctic and the climate migrant, Misha, we developed a plot that explored how a climate migrant might be entrapped in exploitative labor practices to satiate ongoing global demand for rare earth metals.
10. Using the story beats method, we identified the major turning points of the narrative for the character, focusing on a day in the life of an indentured laborer in future rare earth mining operations, who also suffers from the trauma that she experienced as a climate migrant.
11. Using all this preparatory work, the story was drafted around each story beat, ensuring that Misha had a satisfying character arc, and that the story adequately explored the future world of an extractive, industrial Arctic.
12. Qualitative review was employed to check whether the eventual story could reflect back to the original keywords from the LDA, with prominent themes in the story related to 'infrastructure', 'investment', 'mining', 'resource', and 'production'.

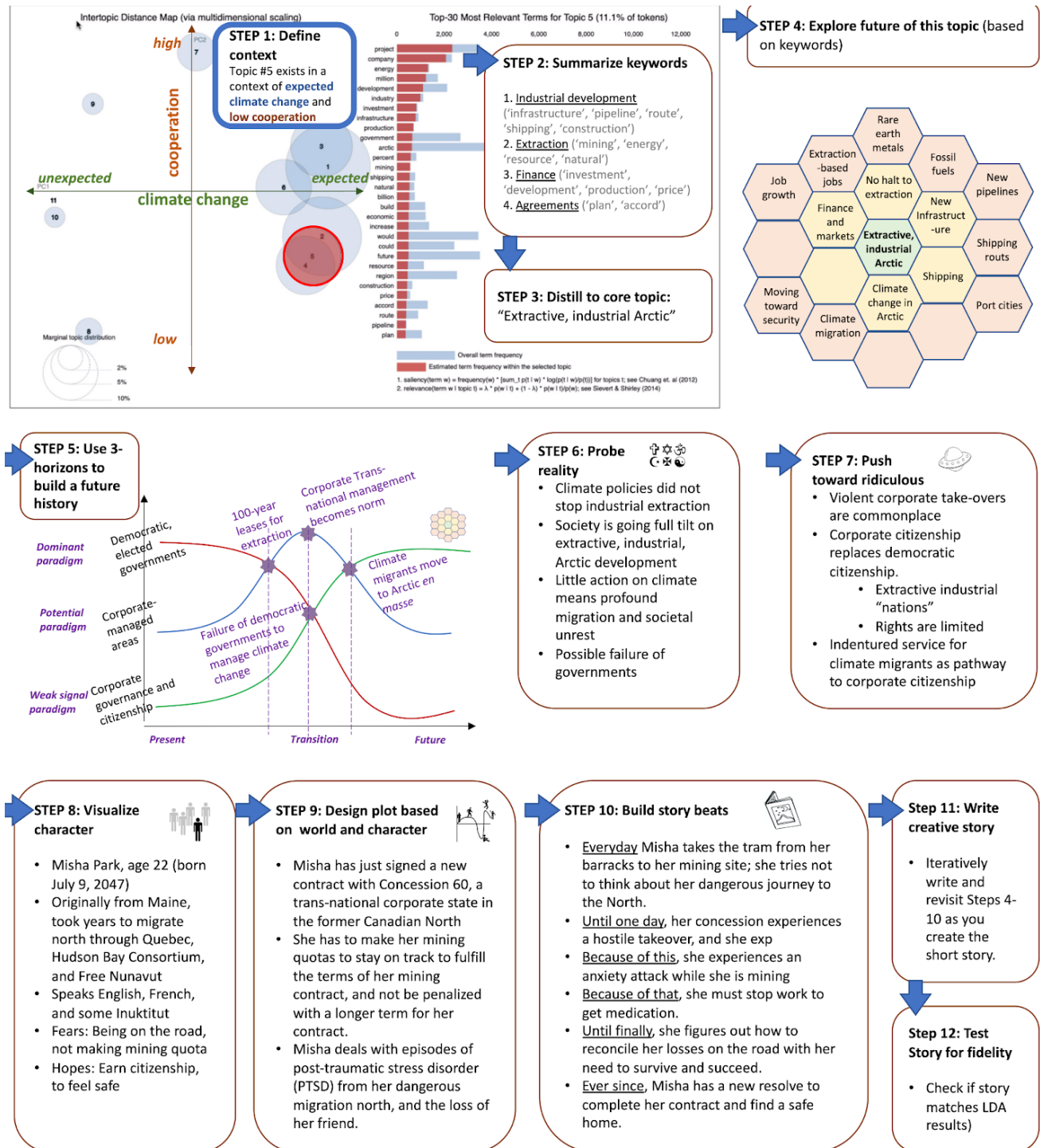


Fig 3. Summary of the story-based scenario creation procedure for Topic #5 'Concession 60'. Steps begin at the top left, and can be read left-to-right, and top-to-bottom.

3.6 Description of stories from LDA themes

We briefly share an overview of all ten stories in Table 2, and the full stories are included in the Supplement. The important result presented in this manuscript is not the collection of scenarios per se, but rather the method for feeding the LDA approach into a structured futuring process. Thus, while the ten scenarios are valid in their own right, we emphasize that the purpose of these scenarios is to illustrate the outcome of the blended LDA and structured futuring approach.

Table 2. Overview of stories, including theme, title, and brief description of the world and story.

| Topic #: Title of Story | Synopsis of World and Story |
|----------------------------|---|
| 1: Campus Utqiagvik | <p>World: Among Arctic communities, universities and colleges have merged with municipal governments. In this case, Iḷisaḡvik College has merged with the city of Utqiagvik, and is a key government entity in North Slope, Alaska.</p> <p>Story: The outgoing civic leader in Campus Utqiagvik is visiting the grocery store, and is experiencing nostalgia and a sense of time passing as she steps down from her civic responsibilities.</p> |
| 2: Nanook Station | <p>World: Climate change has driven significant changes in polar bear ecology and salmon fisheries, and in which both are intensely studied and actively manipulated by academic scientists. Corporate espionage of genetic manipulation techniques takes place against a conflicted Canadian Arctic.</p> <p>Story: A corporate spy is secretly monitoring scientific advancements at a scientific outpost on Devon Island near Baffin Bay, in Nunavut, Canada.</p> |
| 3: Security Detail | <p>World: The Arctic region has seen dramatic and positive changes in socio-economic progress, largely driven by China's continuous investment in infrastructure via its ever expanding 'Belt and Road Initiative'.</p> <p>Story: Else Larsen, the security detail for the Norwegian delegates to an Arctic Council meeting, compares the public and private comments regarding China's potential joining of the international diplomatic body.</p> |
| 4: The Last Preserve | <p>World: The world has sought to conserve a handful of ecosystems in the Arctic, as a forward-thinking act of preservation for the future. While these preserves are hyper-secure, students are permitted to make annual visits to learn about the past.</p> <p>Story: A student group is on an ocean-going ship visiting a preserved island environment in the Yukon, Canada, where they learn about the decisions that led to this conservation effort.</p> |
| 5: Concession 60 | <p>World: A climate-changed world has seen Arctic governance collapse and subsumed by trans-national corporations, which each offer their own brand of corporate citizenship. Climate migrants are a source of indentured labor for dangerous, resource extraction work, e.g., mining of rare earth metals.</p> <p>Story: A person begins a work contract with a mining conglomerate, and experiences traumatic memories of her migration North.</p> |

| | |
|-----------------------------|--|
| 6: Putin's Gambit | <p>World: A world where the Russian government collapsed following a disastrous gamble on the prospect that fossil fuel extraction would continue during the 21st century, despite global progress reducing carbon emissions.</p> <p>Story: A future history in the style of a popular podcast, where a story unfolds of how Russian political leadership miscalculated in how to handle changing fossil fuel extraction.</p> |
| 7: Voice from the Past | <p>World: First nations formerly in the Canadian North have separated from Canada, and unified in the Indigenous nation of Inuit Nunangat. This sovereign nation is a successful, trusted member of the global community</p> <p>Story: During a meeting among trade representatives from Inuit Nunangat and Canada, an off-hand prejudiced comment leads to a history lesson about Indigenous life before, during, and after Canadian control of Inuit Nunangat.</p> |
| 8: Icebreaker | <p>World: A world that has been dramatically changed from the present climate, with regular periods of ice-free oceans in the Russian Arctic. International Conflict in the Arctic is common.</p> <p>Story: Two individuals on a permanent Russian icebreaking station near the Kara Sea must decide how to deal with a potential geopolitical incident.</p> |
| 9: Assisted Migration | <p>World: Despite global coordination to deal with climate change, and a broadly cooperative Arctic region, widespread ecological change has led to the need for ecological stewardship to actively support wildlife migrations.</p> <p>Story: A group of biologists, tasked with monitoring and guiding the Porcupine Caribou herd northward encounters a technological and ecological challenge.</p> |
| 10: School's Out Forever | <p>World: Following extreme climate change, and major disruption to global economic systems, including 20th century notions of education, communities are fragmented and focused internally on local, rather than global, lifestyles.</p> <p>Story: A family on a homestead in the Sakha region of the former Russian Federation shares stories about what the world used to be like and the way the world is now.</p> |

4 Discussion

4.1 Scenarios connect back to the LDA analysis

Following the structured futuring approach, and the creation of the story-based scenarios, we examined whether the resultant stories bore a resemblance to the original LDA topics. Each of the narratives was iteratively reviewed to ensure both that (a) the story content reflected the corresponding topic clustering and the topic keywords, and (b) that each story did not too-closely resemble the content of another set of topic keywords. This review process helped to ensure that each scenario depicted relatively unique elements of the future. While outside the scope of the present analysis, future work could endeavor to explicitly determine whether the keywords

present in a resultant scenario are quantitatively distinct from other scenarios. However, this would be challenging due to the short word count of the story scenarios, which are each between 1,500 and 2,500 words.

4.2 Comparison with narrative scenarios across the global Arctic

We find notable thematic overlap among various other narrative scenario efforts, sampled from research conducted around the global Arctic. In Table 3, we highlight some of these other scenarios, with corresponding descriptions of thematic overlap. The narrative scenarios highlighted in Table 3 provide a sample of the existing literature on the topic of the future of the Arctic region. While it is interesting that some of the scenarios that we have produced are thematically well-represented in the Arctic scenario literature (e.g., “Concession 60”, “Assisted Migration”), there is one that notably has no apparent representation in the existing literature.

“Putin’s Gambit” describes a world that has made tremendous global progress on climate change action and emissions reductions, except for Russia, where its politics have fostered continued fossil fuel exploration. From a scenario perspective, this is in large part due to Russia’s continued and projected reliance on fossil fuels as a major part of its economy (Ilinova et al., 2020; Keil, 2014). Thus, a contradiction emerges where despite global progress being made on the topic of emissions reduction, there is a significant aberration in the Russian economy. The brief thematic review in Table 3 suggests that this combination of themes may be under-represented in the existing scenario literature.

Table 3. Comparison of a sample of existing Arctic scenario narratives with the ten scenarios produced in this analysis

| Topic #: Title of Story | Scenario literature featuring similar ideas | Thematic overlap |
|--------------------------------|---|---|
| 1: Campus Utqiagvik | Lovecraft (2019), "Scenario #5"; Falardeau et al. (2019) "Havakatigiit" | Environmental progress; regional isolation with cooperation |
| 2: Nanook Station | Lovecraft (2019), "Scenario #2"; Nilsson et al. (2017), "Inequality" | Changed arctic ecosystems; wide gaps in level of privilege |
| 3: Security Detail | Lovecraft (2019), "Scenario #4"; Global Business Network (2008), "Arctic Saga"; Brigham (2007b), "Adaptive Frontier"; Falardeau et al. (2019) "Indigenuity Informs Science" | Cooperative Arctic; Global environmental progress; Indigenous communities ascendant |
| 4: The Last Preserve | Global Business Network (2008), "Polar Preserve" | Stable governance; Emptying Arctic |
| 5: Concession 60 | Global Business Network (2008), "Arctic Race"; Brigham (2007b), "Globalized Frontier"; Nilsson et al. (2017), "Inequality"; Merrie et al. (2018), "FISH INC." | Unstable governance; High resource extraction; Environmental strain |
| 6: Putin's Gambit | --- | --- |
| 7: Voice from the Past | Lovecraft (2019), "Scenario #7"; Falardeau et al. (2019) "Kablonak" | Global cooperation; Adaptation to climate change; Indigenous leadership |
| 8: Icebreaker | Lovecraft (2019), "Scenario #1"; Global Business Network (2008), "Arctic Race"; Brigham (2007b), "Fortress Frontier"; Nilsson et al. (2017), "Regional rivalry"; Spijkers et al. (2021), "Scramble for the Atlantic" | Insecure Arctic; High resource demand; Militarized coastal areas; Intensive consumption |
| 9: Assisted Migration | Lovecraft (2019), "Scenario #3"; Global Business Network (2008), "Arctic Saga"; Brigham (2007b), "Equitable Frontier"; Nilsson et al. (2017), "Sustainability" | Lowered emissions; Regional social harmony; Stewardship of ecosystems |
| 10: School's Out Forever | Lovecraft (2019), "Scenario #6"; Global Business Network (2008), "Polar Lows" | Reduced emissions; Local isolation and reliance on subsistence |

4.3 Stories permit creative visions of the future

An advantage of combining a distant time-horizon (e.g., the end of the 21st century) with a creative approach to scenario generation (e.g. science fiction prototyping), is the ability to play with themes that are outlandish or perhaps ridiculous, at least compared to the present day (Dator, 1993; Johnson, 2011). In the context of the Arctic, there are a significant number of factors that will lead to diverse and wide-ranging outcomes, in particular the roles of Indigenous identities in the future (e.g., Latulippe & Klenk, 2020), pronounced ecological change (Post et al., 2009), and radical technological advances (Akiwenzie-Damm et al., 2019; Asinnajaq, 2017).

The process of developing a story-based future inherently requires creativity, which is neither easy to quantify nor easy to train. Moreover, narrative scenarios can prove to be tremendously engaging to readers of scenarios, by immersing a reader in a story rather than providing only a description (Burnam-Fink, 2015). With this demonstration of blending computational text analysis with storytelling, a next step could be to engage Arctic participants directly in both the curation of a novel corpus of literature on the future, and to participate in the imagining of new visions of the future. Stepping back, this work can be seen as examining how human creativity can productively collaborate with machine learning methods. Indeed, in an era where algorithms dominate discourse about what to expect from and of the future, there is an urgency for demonstrations of the critical role of humanistic perspectives.

Artwork is an additional mode of contending with the complex content and questions embedded in scenarios, and can include visual art, spoken word, musical interpretation, or theatrical production (Grimberg et al., 2019; Jacobs et al., 2017; Merrie et al., 2018). As such, art can be leveraged to meaningfully engage a much broader audience that otherwise would not have a clear way to participate in the process of envisioning Arctic futures. Art can tap into deep-seated human experience, and it can be leveraged to connect wide-ranging audiences with important, worthwhile topics, with which they might not otherwise engage (Akiwenzie-Damm et al., 2019; Ramachandran & Hirstein, 1999). While full discussion is beyond the scope of this article, visual concept art has been developed to accompany the ten visions of the Arctic

presented in this article. This artwork provides an engaging and immersive complement for the stories themselves. An example is shown in Fig 4.



Figure 4. Examples of visual art for two of the story-based scenarios. The top panel is an image inspired by ‘Concession 60’ (i.e., Topic #5), and the bottom panel is an image inspired by ‘Assisted Migration’ (i.e., Topic #9). Artwork is used with permission by Patrick W. Keys and Fabio Comin. All rights reserved by the creators.

4.4 Positionality and interpretation

The authors of this work emphasize that the analysis, particularly the subjective interpretation of the LDA results and the development of stories, reflects individual positionality (i.e., Western, non-Indigenous), perspective (i.e., external to the Arctic), and social privilege (i.e., scientists from a research university). Awareness of this is critical to appropriately situate and contextualize the scenarios themselves, both as readers and writers. A story-based scenario process is inevitably subjective, which is in fact part of the motivation, given that stories can be an accessible format for engaging broad audiences on complex topics. Nonetheless, we clarify our own positionality above to provide additional context for those engaging with these stories.

4.5 Future work

This work is intended to be a starting point for those interested in expanding the scope of Arctic scenarios, by blending computational methods with imaginative, story-based approaches. While the present analysis is limited to two authors who are not currently located in the Arctic, we hope that this pilot demonstration can serve as a launchpad for engaging new partners. Specifically, we hope that communities that are local and Indigenous to the Arctic will find the scenarios engaging and explore the story-based methodology to develop future scenarios tailored to their own communities.

A next step of this work could be to identify communities in the Arctic that might specifically be a good fit for this type of scenario process. Potential partners could include colleges and universities, particularly those with a focus on educating local populations, for example Iḷisaḡvik College located in Utqiagvik, Alaska. Such a partnership could include a combination of scenario-based learning, as well as collaborative research, both among students and faculty. Eventually, if such a scenario approach were successful in an Arctic academic context, a broader effort could be made to work with communities beyond academia, including tribal organizations and local governments. Many other examples of structured futuring exist in Arctic contexts including with Indigenous communities (e.g., Falardeau et al., 2019), though few explicitly link the methods we discuss in this article (specifically computational text analysis and story-based futures). All efforts in the Arctic, however, are characterized by a need for deep

engagement with local communities, which require time, communication, and honest partnership.

Some complexities exist for this work to be relevant for Arctic communities, not least the technical barriers that exist for collecting relevant texts, developing multi-lingual analytical capacity, the provision of computing hardware, as well as technical training for personnel. At the same time the entire method presented here does not need to be adopted in its entirety. It is conceivable that a user of this work could take our LDA analysis, and use it as a jumping off point, such that other scenarios could be created following our story-based approach yet based on the same LDA output. This would sidestep the barriers to computational text analysis and would permit new interpretation of the LDA results in a way that reflected the perspective of the new users.

There are numerous possibilities for future expansion of the computational text analysis. First, exploration of non-English corpuses is a frontier for this work, not least because of the linguistic diversity present in the Arctic. While it is well beyond the scope of this analysis, collaborative research teams, possibly leveraging circumpolar research networks, could leverage considerable local capacity. Groups such as the Inuit Circumpolar Council, International Arctic Science Committee and others could serve as valuable partners for such an effort. In a similar context, several types of corpuses could be collaboratively constructed, that explore differences among distinct aspects of Arctic identity. This could include Indigenous and non-Indigenous identities, as well as other cultural, national, and ethnic groupings. To that end, methods such as word or topic intrusion could be explicitly co-developed with stakeholders or partners to strengthen topic model analyses, with local, on-the-ground perspectives and knowledge. Finally, additional approaches could be employed to connect any resultant scenarios further back to the original corpus composition. First, information about the topic distribution across documents could help test whether the scenarios reflect the document composition more directly. Second, bi- and tri-gram frequency across the corpus could be used to examine whether and how the eventual scenarios relate to the raw, unanalyzed corpus.

As with the non-English analysis discussed above, such a comparative approach would require broad collaboration among diverse groups throughout the Arctic region. A central

concern of work that engages Indigenous and local people in the collection and interpretation of perspectives on the future, is that of appropriately situating this knowledge. Likewise, it would be necessary to carefully evaluate the biases of the research questions that are asked. Substantial effort would be required to detail the context of perspectives on the future, and likewise to understand the cultural dynamics from which these perspectives originate (D'ignazio and Klein, 2020).

This hybrid method of blending computational text analysis with story-based approaches is not intended to be stand-alone. Rather, it can serve as a complement to existing scenario development practices, including conventional geophysical and Earth system science projections of Arctic change. Moreover, this method provides a broad perspective on locally driven, place-based initiatives. In this way, the methods and results presented in this article can serve as a platform for interweaving regional and circumpolar themes into local scenario efforts.

5 Conclusions

The future Arctic will be profoundly different from that observed in the present. We contribute a new approach toward creating scenarios of the future Arctic, by blending computational text analysis with structured futuring. The topic modeling yielded a set of distinct thematic clusters of keywords, which were directly employed in the creation of story-based visions of the future Arctic. The stories that were created permit a visit to ten different, textured, and vital visions of the future. While the stories are interesting, the major contribution of this work is to demonstrate a method of how topic modeling can be used directly in an imaginative scenario process. In the future, we anticipate that computational text analysis could be incorporated as a component of general scenario methods, to simultaneously provide an unsupervised scan of existing literature, as well as to provide orthogonal insight that might not be present in the existing worldview of the scenario creators. Similarly, we anticipate that creative story-based methods will become

increasingly important for making sense of a world experiencing accelerating and surprising change.

Acknowledgments, Samples, and Data

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Figure 1. Conceptual overview of how the topic modeling analysis feeds into the structured futuring process, including worldbuilding and story creation

Figure 2. Results of the latent Dirichlet allocation, with thematic dominance and clustering visualized on the left, and the baseline frequency of keywords across the entire corpus depicted on the right. This was generated using the freely available pyLDAvis software in the GENSIM Python package.

Figure 3. Summary of the story-based scenario creation procedure for Topic #5 ‘Concession 60’. Steps begin at the top left, and can be read left-to-right, and top-to-bottom.

Figure 4. Examples of visual art for two of the story-based scenarios. The top panel is an image inspired by ‘Concession 60’ (i.e., Topic #5), and the bottom panel is an image inspired by ‘Assisted Migration’ (i.e., Topic #9). Artwork is used with permission by Patrick W. Keys and Fabio Comin. All rights reserved.

Table 1. Summary of topic clusters with corresponding top 30 keywords in that cluster with terms listed in descending order of relevance within the topic (i.e., the first term is the most salient to the topic).

Table 2. Overview of stories, including theme, title, and brief description of the world and story.

Table 3. Comparison of a sample of existing Arctic scenario narratives with the ten scenarios produced in this analysis