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

P. W. Keys[1] and A. E. Meyer[1]

[1] School of Global Environmental Sustainability, Colorado State University, Fort Collins, CO, USA

Corresponding author: Patrick Keys (patrick.keys@colostate.edu)

Key Points:

- Creative scenarios are an essential approach for designing futures in an accelerating era of social and environmental change in the Arctic.
- Story-based scenario creation blended with computational text analysis provides 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 objectively 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 objectively identified 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 developing some new ways for systematically writing speculative, fiction scenarios. In our results, we produce ten new, creative scenarios of the Arctic future. We find that our story-based results have themes

that are consistent with some existing Arctic scenarios. Moving forward, we think that the methods we use will allow new audiences to learn, discuss, and engage with future scenarios.**1**

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 a need for novel, cutting edge tools for comprehensive and, perhaps more importantly, creative scenarios of the future.

1.1 Rapidly changing Arctic region requires new approaches

Understanding the future of the Arctic has been a focus of concerted effort for many decades (Young, 2010, 2011). 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). 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 experiences of those who have dwelled in the Arctic, currently dwell in the Arctic, and will continue to dwell in the Arctic receive considerably less attention (Cost, 2015; Falardeau et al., 2019; N. Wormbs et al., 2018). These local and indigenous communities - and particularly their visions of the future (Akiwenzie-Damm et al., 2019; Asinnajaq, 2017) - are often missing from the regional scale projections and scenario exercises, though recent work has acknowledged this problematic legacy (Cameron, 2012; Wexler, 2009).

1.2 Computational text analysis can improve scenarios

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 objectively harvesting information across many hundreds 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 with regard to 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 help address human selection bias by 'reading' the thousands of texts and 'interpreting' different patterns than a human might see. Specifically, machine learning-based natural language processing methods 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). 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 an LDA analysis may input directly into a creative process (Fig 1). We are explicitly not aiming to provide a definitive new set of comprehensive scenarios, especially given the absence of clear participation with indigenous and local communities in the Arctic. Nonetheless, the Arctic is an ideal location for piloting this approach, 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).

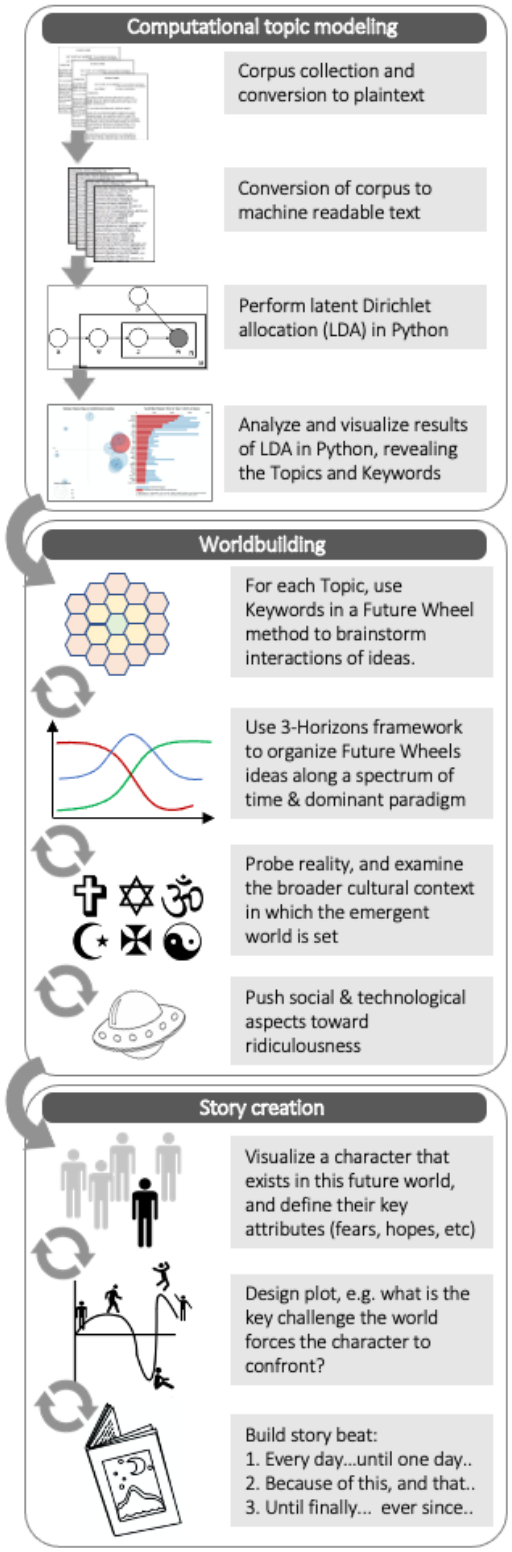

Figure 1. Conceptual overview of how the topic modeling analysis feeds into the structured futuring process, including worldbuilding and story creation.

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. We use the Google Search engine as a method of discovery, and a window of search of 2010-2020. Given that Google's Search algorithm has a maximum search return of 300 entries, we limit the collection of articles to the top 300 articles returned from each source.

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 the entire Arctic's discourse about the future.

2.2 Text preparation and conversion

Once the corpus of texts is identified, we generate a machine-readable corpus using Python-based scripts that can batch-convert documents to text strings. It is also important to note that the corpus is 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, 2018; 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, or 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 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 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. 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.

Next, the GENSIM Python package (version 3.8.0) is used for the LDA. This machine-learning method 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 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 is 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 higher Coherence score implies greater semantic similarity among the terms in each topic cluster. 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. The statistical optimization of LDA methods is discussed in depth, in other

work (Chang et al., 2009; Hecking & Leydesdorff, 2018). The result of our LDA analysis was eleven semantically different topic clusters.

2.4 Visualize LDA results and identify scenario seeds

Using the visualization package in GENSIM (pyLDAvis), we show the Intertopic Distance Map, based on a principal component analysis, calculated within the pyLDAvis Python software. Additionally, we show the 30 most relevant terms for each topic.

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 location in the PC quadrant space, 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 scenarios, as a way to ensurehat themes which are close to one another in the principal component quadrant space are similar in some way, while those far apart are dissimilar.

The subsequent steps are unique for each story-based scenario with relevant references identified for each step:

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 as a way 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 future wheels*: Based on the core topic, the keywords, and the context provided by 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 future wheel 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

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

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

225 10. *Build story beats*: Use the character and the basic plot to articulate the story-beats that
226 will form the scaffold of the story.

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

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

232

233 # 3 Results

234 ## 3.1 Corpus construction

235 We collected 2,058 articles from our set of Arctic news sources, using Google Search, and from
236 the time period 2010-2020. Each news source provided 300 news articles, except for Arctic
237 Today, in which we found a total of 258 articles in our search timeframe (2010-2020) and using
238 our search term ('future'). Each article was saved in a plaintext format, and its metadata was
239 recorded, which is available in Supplemental Table 1. The 2,058 articles were then batch-
240 converted from plaintext files to machine-readable strings using Python-based programs,
241 including the freely available GENSIM python package.

242 ## 3.2 Computational topic modeling

243 The latent Dirichlet allocation produced a variety of results, including a set of overall term
244 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). Inspection of 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 discarded the eleventh topic, and are left with ten distinct topics.

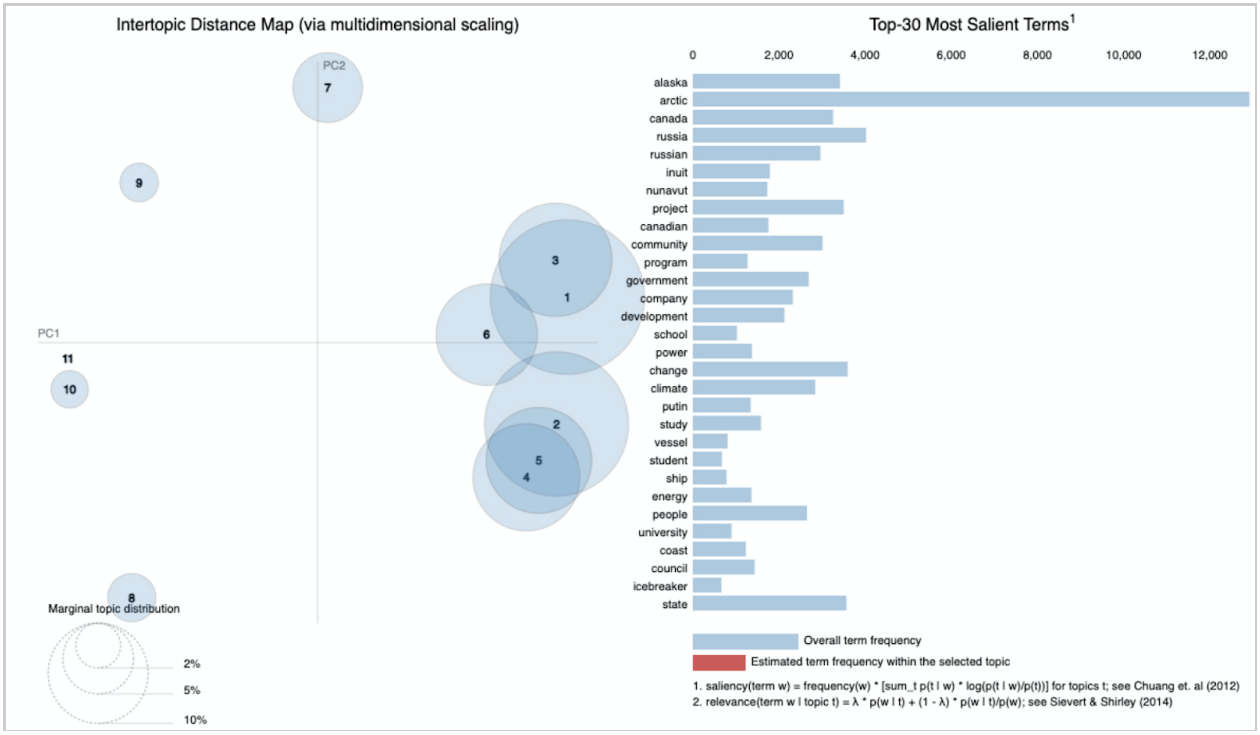

Fig 2. Results of the latent Dirichlet allocation, with thematic dominance and clustering visualized on the left, and the baseline frequency of keywords across the entire corpus depicted on the right. This was generated using the freely available pyLDAvis software in the GENSIM Python package.

3.3 LDA topic quadrants

We labeled the axes of the principal component quadrants to define overarching context for the scenarios, as a way 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. For the purposes of our scenarios, which aim to explore the *future* of the Arctic, we use two broad features that would likely define 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

286 contexts (i.e. topics 1, 2, 3, 4, 5, 6), whereas those that were distributed throughout the intertopic
287 space will be more idiosyncratic (i.e. topics 7, 8, 9, 10, 11).

288 **3.4 Distribution of topic clusters in the Intertopic Distance Map**

289 We can clearly interpret the current dominance of each topic relative to the others, with topics 1-
290 6 being quite dominant and topics 7-10 being less so. This information provides additional
291 context of how representative a given theme is for the entire corpus. Here we provide a summary
292 showing each topic with its corresponding keywords (Table 1).

293

294 **Table 1. Summary of topic clusters with corresponding top 30 keywords in that cluster with terms**
295 **listed in descending order of relevance within the topic (i.e. the first term is the most salient to the**
296 **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

297

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 reveals the keywords for this approach, every other step is a structured, creative endeavor. As such, an infinite 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).

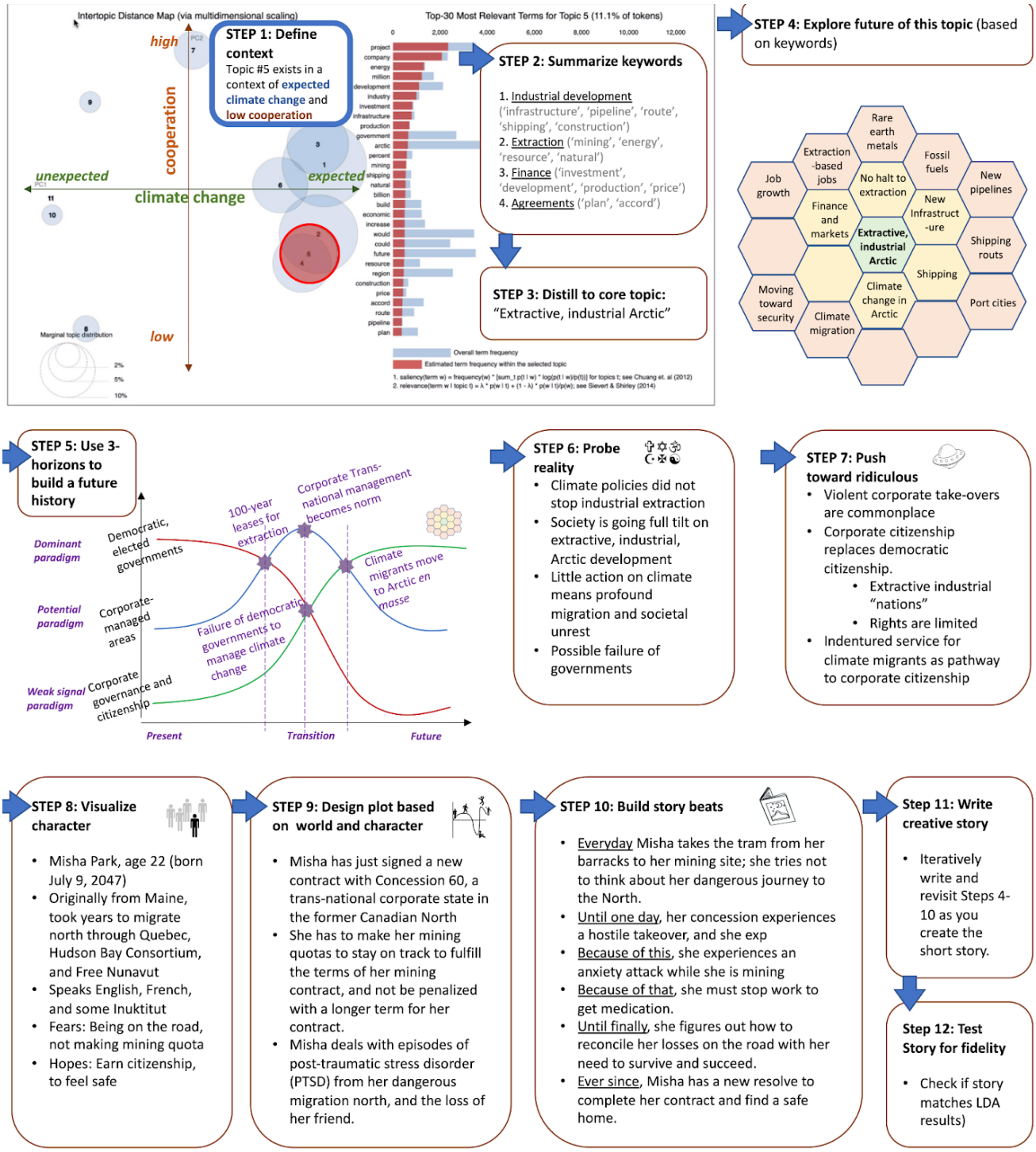

Fig 3. Summary of the story-based scenario creation procedure for Topic #5 "Concession 60". Steps begin at the top left, and can be read left-to-right, and top-to-bottom.

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 process 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 Utqiaġvik	***World**: Among Arctic communities, universities and colleges have merged with municipal governments. In this case, Iḷisaġvik College has merged with the city of Utqiaġvik, and is a key government entity in North Slope, Alaska.* ***Story**: The outgoing civic leader in Campus Utqiaġvik is visiting the grocery store, and is experiencing nostalgia and a sense of time passing as she steps down from her civic responsibilities.*
2: Nanook Station	***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.* ***Story**: A corporate spy is secretly monitoring scientific advancements at a scientific outpost on Devon Island near Baffin Bay, in Nunavut, Canada.*
3: Security Detail	***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'.* ***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.*
4: The Last Preserve	***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.* ***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.*
5: Concession 60	***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.* ***Story**: A person begins a work contract with a mining conglomerate, and experiences traumatic memories of her migration North.*
6: Putin's Gambit	***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.* ***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.*
7: Voice from the Past	***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* ***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.*
8: Icebreaker	***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.* ***Story**: Two individuals on a permanent Russian icebreaking station near the Kara Sea must decide how to deal with a potential geopolitical incident.*
9: Assisted Migration	***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.* ***Story**: A group of biologists, tasked with monitoring and guiding the Porcupine Caribou herd northward encounters a technological and ecological challenge.*
10: School's Out Forever	***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.* ***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.*

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 description 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 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 Utqiaġvik	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) "Kabolonak"	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

identity 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. Yet, the creative process is itself uniquely valuable for participatory scenario practice and can yield tremendous insight on the part of the creator (Pereira et al., 2018). Moreover, narrative scenarios can prove to be tremendously engaging to readers of scenarios, by immersing a reader in a scenario rather than providing only a description (Burnam-Fink, 2015).

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 beyond the scope of this manuscript, visual concept art has been developed to accompany these ten visions of the Arctic presented in this article, to provide an engaging and immersive complement for the stories themselves. The art is available at the following website: *>>URL available upon publication<<*

4.4 Future work

This work is intended to be a starting point for additional creative scenario work in the Arctic. While the present analysis is limited to two authors who are not currently located in the Arctic, we hope that this pilot demonstration of how to blend computational text analysis with creative story-based scenarios 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 also explore the story-based methodology to develop future scenarios tailored to their own communities.

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 topic modeling 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 in their own right, the major contribution of this work is to demonstrate a method of how computational topic modeling can be used directly in a creative scenario process. In the future, we anticipate that computational topic modeling could be incorporated as a component of general scenario analysis methodologies, to simultaneously provide a method for an unsupervised scan of the source 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 as Arctic systems continue to change in accelerating and surprising ways, that creative story-based methods will become increasingly important for making sense of a profoundly changing world.

Acknowledgments, Samples, and Data

The authors thank Nathaniel Barnes and Nicholas Barnes for feedback on the scenario stories. The authors acknowledge no conflicts of interest. All data used in this analysis is available in the Supplementary Materials of this article, entitled Table S1: Visions of the Arctic Future _ Metadata for Arctic news corpus (Keys and Meyer, 2021).

411 **References**

412 Akiwenzie-Damm, K., Assu, S., Mitchell, B., Qitsualik-Tinsley, R., Qitsualik-Tinsley, S.,
413 Robertson, D. A., et al. (2019). This Place: 150 Years Retold. Portage & Main Press.

414 Arbo, P., Iversen, A., Knol, M., Ringholm, T., & Sander, G. (2013). Arctic futures:
415 conceptualizations and images of a changing Arctic. Polar Geography, 36(3), 163–182.
416 https://doi.org/10.1080/1088937X.2012.724462

417 Arctic Council. (2009). Arctic Marine Shipping Assessment 2009 Report. researchgate.net.

418 Arctic Council. (2016). Arctic resilience report. (G. P. M. Carson, Ed.). Stockholm: Stockholm
419 Environment Institute and Stockholm Resilience Centre.

420 Arctic Research Consortium of the U. S. (2018, March 26). Quantitative Scenarios Can Help
421 Identify Arctic Research Needs.

422 Asinnajaq. (2017). Three Thousand. Canada: {National Film Board of Canada}.

423 Asmussen, C. B., & Møller, C. (2019). Smart literature review: a practical topic modelling
424 approach to exploratory literature review. Journal of Big Data, 6(1), 93.
425 https://doi.org/10.1186/s40537-019-0255-7

426 Brigham, L. W. (2007). Thinking about the Arctic's Future. Futur Sept--Oct, 27–34.

427 Burnam-Fink, M. (2015). Creating narrative scenarios: Science fiction prototyping at Emerge.
428 Futures, 70, 48–55. https://doi.org/10.1016/j.futures.2014.12.005

429 Calvert, B. (Ed.). (2019). 2068 The Speculative Journalism Issue. High Country News. Retrieved
430 from http://www.hcn.org/external_files/digitaledition/51-14.pdf

431 Cameron, E. S. (2012). Securing Indigenous politics: A critique of the vulnerability and
432 adaptation approach to the human dimensions of climate change in the Canadian Arctic.
433 Global Environmental Change: Human and Policy Dimensions, 22(1), 103–114.
434 https://doi.org/10.1016/j.gloenvcha.2011.11.004

435 Carbonell, J., Sánchez-Esguevillas, A., & Carro, B. (2017). From data analysis to storytelling in
436 scenario building. A semiotic approach to purpose-dependent writing of stories. Futures,
437 88, 15–29. https://doi.org/10.1016/j.futures.2017.03.002

Chang, J., Gerrish, S., Wang, C., Boyd-graber, J. L., & Blei, D. M. (2009). Reading Tea Leaves: How Humans Interpret Topic Models. In Y. Bengio, D. Schuurmans, J. D. Lafferty, C. K. I. Williams, & A. Culotta (Eds.), Advances in Neural Information Processing Systems 22 (pp. 288–296). Curran Associates, Inc. Retrieved from http://papers.nips.cc/paper/3700-reading-tea-leaves-how-humans-interpret-topic-models.pdf

Corbett, J. J., Lack, D. A., Winebrake, J. J., Harder, S., Silberman, J. A., & Gold, M. (2010). Arctic shipping emissions inventories and future scenarios. Atmospheric Chemistry and Physics, 10(19), 9689–9704. https://acp.copernicus.org/articles/10/9689/2010/

Cost, D. S. (2015). The role of public education in governance for resilience in a rapidly changing Arctic. Ecology and Society, 20(3). https://doi.org/10.5751/ES-07757-200329

Crate, S. A., & Fedorov, A. N. (2013). A Methodological Model for Exchanging Local and Scientific Climate Change Knowledge in Northeastern Siberia. Arctic, 66(3), 338–350.

Crawford, A. (2014). "The trauma experienced by generations past having an effect in their descendants": Narrative and historical trauma among Inuit in Nunavut, Canada. Transcultural Psychiatry, 51(3), 339–369. https://doi.org/10.1177/1363461512467161

Dator, J. (1993). From future workshops to envisioning alternative futures. Futures Research Quarterly, 9(3), 108–112.

Dator, J. (2019). Alternative Futures at the Manoa School. In J. Dator (Ed.), Jim Dator: A Noticer in Time: Selected work, 1967-2018 (pp. 37–54). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-17387-6_5

Dodds, K. (2010). A polar Mediterranean? Accessibility, resources and sovereignty in the arctic ocean. Global Policy, 1(3), 303–311. https://doi.org/10.1111/j.1758-5899.2010.00038.x

Falardeau, M., Raudsepp-Hearne, C., & Bennett, E. M. (2019). Our Future-Hivunikhavut. McGill University. https://doi.org/10.13140/RG.2.2.32556.51847

Ford, J. D., Stephenson, E., Cunsolo Willox, A., Edge, V., Farahbakhsh, K., Furgal, C., et al. (2016). Community-based adaptation research in the Canadian Arctic. Wiley Interdisciplinary Reviews. Climate Change, 7(2), 175–191. https://doi.org/10.1002/wcc.376

466 Fresco, N., & Timm, K. (2016). Fostering Resilience in the Face of an Uncertain Future: Using
467 Scenario Planning to Communicate Climate Change Risks and Collaboratively Develop
468 Adaptation Strategies. In J. L. Drake, Y. Y. Kontar, J. C. Eichelberger, T. S. Rupp, & K.
469 M. Taylor (Eds.), Communicating Climate-Change and Natural Hazard Risk and
470 Cultivating Resilience: Case Studies for a Multi-disciplinary Approach (pp. 79–94).
471 Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-20161-0_6

472 Grimberg, B. I., Williamson, K., & Key, J. S. (2019). Facilitating scientific engagement through
473 a science-art festival. International Journal of Science Education, Part B, 9(2), 114–127.
474 https://doi.org/10.1080/21548455.2019.1571648

475 Hamann, M., Biggs, R., Pereira, L., Preiser, R., Hichert, T., Blanchard, R., et al. (2020).
476 Scenarios of Good Anthropocenes in southern Africa. Futures, 118, 102526.
477 https://doi.org/10.1016/j.futures.2020.102526

478 Hecking, T., & Leydesdorff, L. (2018, June 4). Topic Modelling of Empirical Text Corpora:
479 Validity, Reliability, and Reproducibility in Comparison to Semantic Maps. arXiv
480 [cs.CL]. Retrieved from http://arxiv.org/abs/1806.01045

481 Ilinova, A., Solovyova, V., & Yudin, S. (2020). Scenario-based forecasting of Russian Arctic
482 energy shelf development. Energy Reports, 6, 1349–1355.
483 https://doi.org/10.1016/j.egyr.2020.11.022

484 Jacobs, R., Howarth, C., Coulton, P., & Others. (2017). Artist-Scientist Collaborations:
485 Maximising Impact of Climate Research and Increasing Public Engagement.
486 International Journal of Climate Change: Impacts and Responses, 9(3), 1–9.

487 Johnson, B. D. (2011). Science Fiction Prototyping: Designing the Future with Science Fiction
488 (Vol. 3, pp. 1–190). Morgan & Claypool Publishers.
489 https://doi.org/10.2200/S00336ED1V01Y201102CSL003

490 Johnson, B. D., & Winkelman, S. (2017). Two Days After Tuesday. Arizona State University.

491 V., & Blind, K. (2017). Extending the knowledge base of foresight: The contribution of text
492 mining. Technological Forecasting and Social Change, 116, 208–215.
493 https://doi.org/10.1016/j.techfore.2016.10.017

494 Kayser, V., & Shala, E. (2016). Generating Futures from Text—Scenario Development Using
495 Text Mining. In T. U. Daim, D. Chiavetta, A. L. Porter, & O. Saritas (Eds.), Anticipating
496 Future Innovation Pathways Through Large Data Analysis (pp. 229–245). Cham:
497 Springer International Publishing. https://doi.org/10.1007/978-3-319-39056-7_13

498 Keil, K. (2014). The Arctic: A new region of conflict? The case of oil and gas. Cooperation and
499 Conflict, 49(2), 162–190. https://doi.org/10.1177/0010836713482555

500 Kim, J., Han, M., Lee, Y., & Park, Y. (2016). Futuristic data-driven scenario building:
501 Incorporating text mining and fuzzy association rule mining into fuzzy cognitive map.
502 Expert Systems with Applications, 57, 311–323.
503 https://doi.org/10.1016/j.eswa.2016.03.043

504 Kishita, Y., Hara, K., Uwasu, M., & Umeda, Y. (2016). Research needs and challenges faced in
505 supporting scenario design in sustainability science: a literature review. Sustainability
506 Science, 11(2), 331–347. https://doi.org/10.1007/s11625-015-0340-6

507 Krupnik, I., & Jolly, D. (2002). The Earth is Faster Now: Indigenous Observations of Arctic
508 Environment Change. Arctic Research Consortium of the United States.

509 Kwon, H., Kim, J., & Park, Y. (2017). Applying LSA text mining technique in envisioning social
510 impacts of emerging technologies: The case of drone technology. Technovation, 60-61,
511 15–28. https://doi.org/10.1016/j.technovation.2017.01.001

512 Latulippe, N., & Klenk, N. (2020). Making room and moving over: knowledge co-production,
513 Indigenous knowledge sovereignty and the politics of global environmental change
514 decision-making. Current Opinion in Environmental Sustainability, 42, 7–14.
515 https://doi.org/10.1016/j.cosust.2019.10.010

516 Mazurier, P. A., Jose Delgado-Moran, J., & Paya-Santos, C. A. (2020). The Meta-Tragedy of the
517 Commons. Climate Change and the Securitization of the Arctic Region. Security and
518 Defence in Europe, 63–74. https://doi.org/10.1007/978-3-030-12293-5_5

519 Merrie, A., Keys, P. W., Metian, M., & Österblom, H. (2018). Radical ocean futures-scenario
520 development using science fiction prototyping. Futures, 95, 22–32.
521 https://doi.org/10.1016/j.futures.2017.09.005

522 Milkoreit, M. (2017). Imaginary politics: Climate change and making the future [Data set].
523 https://doi.org/10.1525/elementa.249

524 Network, G. B. (2008). The Future of Arctic Marine Navigation in Mid-Century. Scenario
525 Narratives Produced for the Protection of the Arctic Marine Environment (PAME)
526 Working Group.

527 Osherenko, G., & Young, O. R. (2005). The Age of the Arctic: Hot Conflicts and Cold Realities.
528 Cambridge University Press.

529 Pereira, L., Hichert, T., Hamann, M., Preiser, R., & Biggs, R. (2018). Using futures methods to
530 create transformative spaces: visions of a good Anthropocene in southern Africa. Ecology
531 and Society, 23(1), 19. https://doi.org/10.5751/ES-09907-230119

532 Petrov, A. N., BurnSilver, S., Chapin, F. S., Fondahl, G., Graybill, J., Keil, K., et al. (2016).
533 Arctic sustainability research: toward a new agenda. Polar Geography, 39(3), 165–178.
534 https://doi.org/10.1080/1088937X.2016.1217095

535 Post, E., Forchhammer, M. C., Bret-Harte, M. S., Callaghan, T. V., Christensen, T. R., Elberling,
536 B., et al. (2009). Ecological dynamics across the Arctic associated with recent climate
537 change. Science, 325(5946), 1355–1358. https://doi.org/10.1126/science.1173113

538 Proshutinsky, A., Steele, M., & Timmermans, M.-L. (2016). Forum for Arctic Modeling and
539 Observational Synthesis (FAMOS): Past, current, and future activities: FAMOS
540 PROJECT RESULTS. Journal of Geophysical Research, C: Oceans, 121(6), 3803–3819.
541 https://doi.org/10.1002/2016JC011898

542 Proshutinsky, A., Krishfield, R., & Timmermans, M. -L. (2020). Introduction to Special
543 Collection on Arctic Ocean Modeling and Observational Synthesis (FAMOS) 2: Beaufort
544 Gyre Phenomenon. Journal of Geophysical Research, C: Oceans, 125(2), 997.
545 https://doi.org/10.1029/2019JC015400

546 Rahbek-Clemmensen, J. (2017). The Ukraine crisis moves north. Is Arctic conflict spill-over
547 driven by material interests? The Polar Record, 53(1), 1–15.
548 https://doi.org/10.1017/S0032247416000735

549 Ramachandran, V. S., & Hirstein, W. (1999). The science of art: a neurological theory of
550 aesthetic experience. Journal of Consciousness Studies, 6(6-7), 15–51.

551 Raven, P. G., & Elahi, S. (2015). The New Narrative: Applying narratology to the shaping of
552 futures outputs. Futures, 74, 49–61. https://doi.org/10.1016/j.futures.2015.09.003

553 Řehůřek, R., & Sojka, P. (2018). Gensim: Topic Modelling for Humans.

554 Salusky, I. R., Kral, M., Amarok, B., & Wexler, L. M. (2021). Navigating between two the
555 worlds of school and "being on the land": Arctic Indigenous young people, structural
556 violence, cultural continuity and selfhood. Journal of Youth Studies, 1–23.
557 https://doi.org/10.1080/13676261.2020.1858040

558 Sarkar, D. (2019). Python for Natural Language Processing. In D. Sarkar (Ed.), Text Analytics
559 with Python: A Practitioner's Guide to Natural Language Processing (pp. 69–114).
560 Berkeley, CA: Apress. https://doi.org/10.1007/978-1-4842-4354-1_2

561 Schatzmann, J., Schäfer, R., & Eichelbaum, F. (2013). Foresight 2.0 - Definition, overview &
562 evaluation. European Journal of Futures Research, 1(1), 1–15.
563 https://doi.org/10.1007/s40309-013-0015-4

564 Schoemaker, P. J. H. (2004). Forecasting and scenario planning: the challenges of uncertainty
565 and complexity. Handbook of Judgment and Decision-Making, Eds. , DJ Koehler and N.
566 Harvey. Oxford, UK: Blackwell, 274–296.

567 Sharpe, B., Hodgson, A., Leicester, G., Lyon, A., & Fazey, I. (2016). Three horizons: a pathways
568 practice for transformation. Ecology and Society, 21(2).
569 https://www.jstor.org/stable/26270405

570 Spijkers, J., Merrie, A., Wabnitz, C. C. C., Osborne, M., Mobjörk, M., Bodin, Ö., et al. (2021).
571 Exploring the future of fishery conflict through narrative scenarios. One Earth, 4(3), 386–
572 396. https://doi.org/10.1016/j.oneear.2021.02.004

573 Steiner, N. S., Cheung, W. W. L., Cisneros-Montemayor, A. M., Drost, H., Hayashida, H.,
574 Hoover, C., et al. (2019). Impacts of the Changing Ocean-Sea Ice System on the Key
575 Forage Fish Arctic Cod (Boreogadus Saida) and Subsistence Fisheries in the Western
576 Canadian Arctic-Evaluating Linked Climate, Ecosystem and Economic (CEE) Models.
577 Frontiers in Marine Science, 6. https://doi.org/10.3389/fmars.2019.00179

578 Stroeve, J. C., Serreze, M. C., Holland, M. M., & Kay, J. E. (2012). The Arctic's rapidly
579 shrinking sea ice cover: a research synthesis. Climatic Change.
580 https://doi.org/10.1007/s10584-011-0101-1

581 Wexler, L. (2009). Identifying colonial discourses in Inupiat young people's narratives as a way
582 to understand the no future of Inupiat youth suicide. American Indian and Alaska Native
583 Mental Health Research , 16(1), 1–24. https://doi.org/10.5820/aian.1601.2009.1

584 Wormbs, N., Wormbs, & Beck. (2018). Competing Arctic Futures: Historical and Contemporary
585 Perspectives. (N. Wormbs, Ed.). Palgrave Macmillan, Cham. https://doi.org/10.1007/978-
586 3-319-91617-0

587 Young, O. R. (2010). Arctic Governance - Pathways to the Future. Arctic Review, 1(2).

588 Young, O. R. (2011). The future of the Arctic: cauldron of conflict or zone of peace?
589 International Affairs, 87(1), 185–193. Retrieved from
590 https://academic.oup.com/ia/article-abstract/87/1/185/2326463

591

592

593

594

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

597

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

602

603 **Figure 3.** Summary of the story-based scenario creation procedure for Topic #5 "Concession
604 60". Steps begin at the top left, and can be read left-to-right, and top-to-bottom.

605

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

609

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

611

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

614