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On thin ice – a review of multi-level governance regarding Chemicals of Emerging Arctic Concern (CEAC)

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The Arctic is a vital and unique ecosystem facing significant threats from climate change, biodiversity loss, and pollution. Recently, Chemicals of Emerging Arctic Concern (CEAC) have been identified as an area that requires further study by the Arctic Monitoring and Assessment Programme. Understanding and improving existing regulatory systems is crucial to preventing the adverse effects of CEAC. This review concentrates on chemical pollution and the Arctic's vulnerability to long-range chemical transport and local pollution sources, as well as existing national, regional, and global measures to regulate and mitigate these pollution sources. Our review underscores three challenges to effective chemical governance in the Arctic. First, there is a lack of a holistic approach in this area. Second, global and national governance fragmentation means many CEAC fall through regulatory cracks. Third, very few global or national regulations or rules consider the unique vulnerabilities and socioeconomic conditions of the Arctic and its Indigenous Peoples.

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Environmental significance

The Arctic ecosystem, one of the most vulnerable and unique regions on the planet, is under increasing threat from chemical pollution, intensified by both local sources and long-range transport of chemicals. Arctic Indigenous Peoples continue to be one of the most affected populations globally by multiple stressors, including pollution and climate change. Chemicals of Emerging Arctic Concern (CEAC) present a regulatory challenge, as many fall outside the scope of existing global frameworks. Addressing this issue is critical to protecting human health and the environment, Arctic biodiversity, human rights (including the right to a healthy environment and Indigenous culture and self-determination) and mitigating the far-reaching impacts of pollution on climate-sensitive regions. This review identifies regulatory gaps and highlights the need for improved national and regional measures, emphasizing the importance of a holistic approach, and integrating the precautionary principle into chemical regulations to protect the Arctic and its Indigenous Peoples from further environmental harm. Addressing CEAC is essential for safeguarding this vital ecosystem and Arctic Indigenous Peoples from the growing pressures of climate change and pollution.

1. Introduction

The Arctic is characterised by its unique social, political, and environmental vulnerabilities and global significance stemming from its remote geographic area. Each of the Arctic states and its peoples face challenges specific to the region, including reliance on imported goods and services and susceptibility to the economic and cultural impacts of ecosystem damage, biodiversity loss, and climate change.[1] Socioeconomic challenges, coupled with the properties of a growing number of chemicals, disproportionately affect the Arctic and its inhabitants. The Arctic, once perceived as a remote wilderness with little impact on the rest of the world, is now at the forefront of polluted regions.[2] This has particularly impacted Arctic Indigenous Peoples, who continue to suffer from the effects of colonisation and are additionally under severe threats from climate change and pollution.[3,4]

In this review, we turn to efforts to grapple with these challenges and to protect people and the environment in the Arctic through regulation. It is a fragmented picture of regulatory and voluntary approaches, at local, national, and global levels. There is no overarching chemicals treaty or authority to harmonise approaches. The Arctic Council lacks the authority to establish legally binding regulations and agreements. Instead, its approach relies on consensus, employing soft law mechanisms through non-binding agreements and cooperative frameworks.[5] As a forum, the Arctic Council promotes cooperation and dialogue among Arctic states and Arctic Indigenous Peoples

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(represented by the Permanent Participants organisations in the Arctic Council). It addresses concerns related to sustainable development and environmental protection. Despite contributing significantly to policy development and collaboration, decisions within the Council are non-binding, ensuring member states retain sovereignty over Arctic affairs.

Many of the problematic pollutants in the Arctic originate from areas outside the Arctic Council's jurisdiction. Whether chemicals travel to the Arctic through their long-range environmental transport (LRET) or arrive through products and articles in use, there is a clear need for global and national-level regulation to protect the Arctic. Here, we find a constellation of partially overlapping global rules and voluntary initiatives, in addition to national regulations that are often developed and enforced by different government agencies. Arctic chemical pollution is anticipated to be even more challenging in the future.[6] For example, climate change can be expected to increase the likelihood and rate of pollutant release.[7,8] Generally speaking, governance arrangements can be slow to evolve to these types of rapid external changes. In the Arctic Council, there is a need to consider the interplay between the various issues, from shipping to ecosystem protection.[9] Due to national interests taking a leading role and the so-called lack of strategy within the AC,[10] such synergies may be difficult to identify. In this context, we review the current state of chemical regulation in some Arctic states, the EU, and global cooperative efforts to minimise, manage, and mitigate Chemicals of Emerging Arctic Concern (CEAC).

We base this review on available documents related to the governance instruments that we reviewed. We considered the chemicals under regulation at various levels and cross-referenced these against CEAC. We also interviewed eight officials for background information working at regional and national levels. These interviews were necessary because few studies focus on the design, inclusivity, and efficacy of chemical regulations. We identified studies on the effects of pollution on Indigenous Peoples and pointed to the need to include Indigenous Peoples in decision-making on pollution control and how social and economic histories can shape exposure.[3,11] The social science literature on chemical governance usefully explains the evolution of global instruments[12,13] and scientific committees.[14] Yet, compared to other environmental issues, notably climate change, chemical pollution tends to be overlooked by social sciences. This study is a first step to connecting the broad literature on chemical governance to the unique realities of the Arctic. We take an Arctic perspective on global, regional, and national governance. Yet, there is a clear need to connect these silos by encouraging more comprehensive studies, which include Indigenous Knowledge and worldviews and social science perspectives. Such comprehensive approaches could include innovative research methodologies, prioritising Indigenous Knowledge sharing, and acting in response to Indigenous concerns.[15] We can learn much from Indigenous Peoples as they have much experience and knowledge with Arctic conditions and change and now must adapt to many combined stressors, including climate change and rising pollution in the Arctic.

2. Background

Arctic ecosystems and human health are intertwined with global economic and environmental trends. Historically, local chemical pollution was not a significant issue in the region, because of its remoteness, extremely cold climate, and low population density, which resulted in less industrial activity compared to other regions in the northern hemisphere. This is fast changing due to the warming climate. Over the last 50 years, the Arctic has warmed three to four times as fast as the rest of the planet, with estimates suggesting a largely ice-free September in the Arctic Ocean before 2050.[16] This reduction in sea ice cover allows for increased human activities such as the exploration of natural resources for food, feed, biotechnology and minerals, as well as shipping and tourism, in this vulnerable region.[6,17–20]

Regulation falls behind the speed with which new chemicals are devised, produced, and used. Chemicals are regulated at the international, regional, national, and, to some extent, subnational levels, which complicates lines of accountability and can create overlapping mandates or gaps between regulatory systems.[21] The primary problem is one of time. Policy making requires information and data, negotiation (among countries, national parties, and lobby groups), and legislative procedures. Global treaties in particular are slow to be negotiated, adopted, and entered into force. It is a slow process, while innovation in the sector is relatively much more rapid. The sheer rate of chemical production, particularly novel entity chemicals—those that have not yet been studied, monitored, or regulated—has far outpaced governments' ability to assess and control their risks. This situation raises concerns that the production and proliferation of novel chemicals may have exceeded planetary boundaries, a concept introduced by scholars[22,23] to highlight the point at which human activity pushes Earth's systems beyond safe ecological limits. As new chemicals continue to be introduced at an accelerating pace, the associated risks and impacts, including those from transformation products and chemical mixtures, may be significantly underestimated, compounding the challenges of chemical management globally.

At the national level, regulations are typically based on risk assessment, where each country has its approach and evaluates the risk from the expected uses based on the predicted exposure and adverse effects.[24] However, this regulatory process is often slow and complex, made even more challenging by the vast number of chemicals in circulation and the time required to evaluate each one individually. This is particularly challenging due to the lengthy processes and large numbers of chemicals that need to be addressed. There are approximately 350 000 chemicals registered for use by national governments (350 000+).[21] Countries take different approaches to handle the backlog. Countries shortlist chemicals to undergo risk assessments. EU REACH places the burden on the industry to provide data to the regulatory body. Regardless of the regulatory approach, there are still considerable uncertainties. For example, an assessment factor is often used to compensate for a lack of data or to cover especially sensitive environments or

species, and currently, regulatory approaches do not cover chemical mixtures.[25]

Due to the knowledge gaps around chemical monitoring in the Arctic, research efforts over the past decades focus on the best practices for identifying and monitoring chemical pollution in the region. Such data could be helpful to inform persistence, bioaccumulation, and toxicity (PBT) assessments used in some national-level regulatory processes. This information is already used in the Stockholm Convention on Persistent Organic Pollutants (POPs), due to the importance of LRET as one of the criteria for identifying a POP.[14] The interactions between science and policy in chemical management are often understudied. As we better understand the presence of these chemicals, we still lack holistic approaches to understanding governance dynamics, gaps, and influences on chemical regulation in the Arctic.

Chemicals are regulated nationally, regionally, and/or globally, often, we find, with little consideration for the prevailing conditions of use in the Arctic. The AMAP Assessment on Chemicals of Emerging Arctic Concern (CEAC)[19] identified numerous groups of chemicals in the Arctic environment. The mere presence of a chemical does not necessarily constitute a risk, but for many of these chemicals, the risk is very difficult to assess due to the limited information on their properties, such as persistence, accumulation, and toxic effects.

Here, we outline the multi-level governance of chemicals, as it relates to the Arctic. Other reviews have focused on one level, such as Selin's (2010) overview of global treaties as well as Selin's (2012) review of hazardous chemicals. To our knowledge, no review has taken Arctic vulnerability as its lens to review chemical regulation nationally, in the EU, and globally. This is a first attempt to better understand the instruments in place and their shortcomings and achievements, followed by an examination of how the regulatory landscape in the Arctic could be improved. It is to act as an initial overview of the progress in place towards multi-level governance of chemicals in the Arctic. The paper is therefore divided into three subsections. First, a review of risk assessments associated with determining CEAC, how they are calculated by nations and if they are set up to mitigate or restrict chemicals in the Arctic. Second, a multi-level review of the international, regional, and national policy landscape to govern CEAC. Finally, the key findings and recommendations for further research and action.

3. Multi-level governance review of chemical regulation in the Arctic

There are several global, national, and local-level efforts, plus those of the EU, that are relevant to chemical pollution in the Arctic. This review has not found substantial evidence that specific vulnerabilities associated with the Arctic environment are considered during risk assessments at any level of governance. However, we have identified opportunities to address CEAC in the future.

Regulating CEAC in the Arctic requires multi-level governance. No one level of governance, not even global, legally binding rules, can address all of the problems. Indeed, despite existing instruments, there are several barriers and challenges to preventing chemical pollution in the Arctic specifically. The transboundary nature of some chemicals and pollution makes it nearly impossible for regional and national regulations and controls to address production and pollution issues. It requires cooperation at the global level. For example, PFAS is known for its ability to travel long distances *via* the atmosphere, ocean currents, rain and snow.[26,27] There are also growing local sources of some PFAS, as products are brought into the Arctic region. In such cases, national legislation can help protect local communities from the import of harmful products and clean up local pollution. Regulatory levels can, in theory, work in concert. Even if regulations are in place, enforcement and monitoring are continued challenges. The Arctic region can be difficult to monitor due to its vast and remote areas and very cold climate, posing significant logistical challenges. Nevertheless, very successful national monitoring programs are in place, which produce a significant amount of data. Examples include the Canadian Northern Contaminants Program, which works in partnership with Canadian Arctic Indigenous Peoples and feeds into AMAP assessments. This information has been extensively used in the negotiations and implementation of global treaties, such as the Stockholm Convention.

When examining CEAC, risk assessments can be important tools to understand the potential impacts these substances can have on Arctic ecosystems, Indigenous Peoples, and local communities. Environmental risk assessments are a process that evaluates the potential adverse effects of a chemical in this case and identifies potential hazards, exposure levels and the likelihood of adverse effects.[28] Risk assessments aim to provide decision-makers with information to manage and mitigate risks. This process may include hazard identification, exposure and effect assessment, uncertainty analysis and communication to decision-makers on the way forward. Risk assessments have limitations, such as addressing chemical mixtures,[25] and they usually do not consider cultural differences in, for example, food consumption. Special concerns for CEAC in the Arctic must be taken into consideration, such as the remote location and ecosystem sensitivity due to cold conditions and extended food webs, as well as Arctic Indigenous Peoples, who are interictally connected to and dependent on their vulnerable ecosystem.[2,3]

3.1 Global chemical regulations

Most global treaties with the potential to tackle CEAC focus on POPs and hazardous substances. This constitutes a narrower but critical scope but also overlooks CEAC in plastics and pharmaceutical pollution. These treaties have distinct mandates and manage different aspects of chemicals, from production to trade. We find that only a few, notably the Stockholm Convention, presently address some CEAC.

3.1.1 Stockholm Convention on POPs. The Stockholm Convention[29] screening criteria define POPs as having four characteristics: persistence, adverse effects, bioaccumulation, and LRET. LRET sparked much of the concern about POPs and

catalysed a global response to protect remote communities, particularly Indigenous Peoples in the Arctic.[30] The Convention has three annexes to list POPs: Annex A for eliminating production and use, Annex B for restricting production and use, and Annex C for unintentional production.

The Stockholm Convention originally focused on a group of 12 POPs, the infamous 'Dirty Dozen', predominantly agricultural pesticides, alongside some industrial chemicals.[31] The Convention includes a mechanism to identify, screen, and list additional POPs in the treaty. Since 2005, the Convention has reviewed and listed over twenty industrial and agricultural chemicals and unintentionally formed POPs, increasing the total number of globally restricted chemicals or groups of chemicals to 34 as of 2024. History has shown the Convention to be responsive to new research findings and able to add additional POPs to its Annexes.

There is a mechanism to add new chemicals to the Convention. The POPs Review Committee (POPRC) is a subsidiary body of the Stockholm Convention, which was established to review chemicals nominated for addition to the Convention and to make recommendations on listing chemicals in the Stockholm Convention. Arctic data have been very important to the POPRC's reviews because it provides evidence of LRET of POPs to remote regions, indicates persistence, and in several cases demonstrates adverse effects, for example, to the health of Arctic Indigenous Peoples. It was often straightforward: presence in the Arctic was evidence of LRET because (for example, in the case of agricultural pesticides) the POP was generally not used or produced in the region. More recently, POPRC has reviewed widely produced and used chemicals, including chemicals used in imported products or industrial chemicals that have been used in the Arctic (such as PFOS in firefighting foams). Therefore, in limited cases, a POP's presence in the Arctic could also reflect some local contamination sources, which is addressed in the review process.

The review process begins with a party to the Stockholm Convention nominating a chemical for the POPRC's consideration. The review takes a minimum of three years. This party-driven process may miss some POPs. Breivik *et al.* (2023)[32] found in their screening of 12 615 high production volume (HPV) chemicals for the potential to accumulate in remote regions that 1693 chemicals have properties that would suggest they accumulate in remote regions. Although LRET as a single criterion is insufficient to enable listing in the Stockholm Convention, potentially a large number of chemicals could meet all four screening criteria.

It is important to note that the chemicals listed in the Stockholm Convention annexes include both individual substances and, increasingly, groups of related chemicals and/or their precursors, like in the cases of PFOS and PFOA. Its scope is limited to chemicals that have been identified as POPs. Some complex particles associated with, or resulting from products themselves, such as micro- and nanoplastics, may fit all the criteria of a POP chemical in that they have been found to undergo long-range environmental transport, bioaccumulate, are persistent, and have adverse effects. But, because they are not chemicals themselves and cannot be regulated in the same way, they fall outside the Stockholm Convention's scope.

Besides limits in scope, there are some gaps in the Convention. For example, parties can either "opt-in" or "opt-out" of listed chemicals; not all of the Convention's 180+ parties will eliminate or restrict all the listed POPs. In addition, several POPs listed have use exemptions, which is a provision to allow some continued uses where parties have claimed that there are no viable alternatives. Even some of the POPs that have been listed since 2004 (as part of the initial dirty dozen) continue to be used in some countries that registered for the exemption (for example, DDT) or are still present in old equipment or stockpiles (for example, PCBs). Many countries cite capacity-building constraints to eliminate POPs' uses, stockpiles, and products. Such ongoing use can lead to continued contamination globally and in the Arctic.

3.1.2 Basel Convention on the transboundary movement of certain hazardous wastes. The Basel Convention[33] governs trade in hazardous wastes, as well as other wastes such as plastics and household waste. Similar to the Rotterdam Convention discussed below, its central mechanism involves a prior informed consent (PIC) procedure. Countries importing wastes are provided with technical guidelines to help inform their environmentally sound management and disposal. These technical guidelines address several waste streams that may likely contain CEAC. The Basel Convention also develops technical guidelines for managing articles containing or contaminated with POPs. These guidelines include setting low-POP content for the wastes.

In recent years, the Basel Convention has shown the ability to increase the scope of wastes subject to the PIC procedure. Countries have used the "other wastes" annex (Annex II) to list governed waste streams that are of concern but may not be toxic. In 2019, parties added plastic wastes to Annex II and in 2023, they agreed to add non-hazardous electronic and electrical wastes (the hazardous counterparts are listed in the appropriate annex in the Convention).

3.1.3 Rotterdam Convention on the prior informed consent procedure for certain hazardous chemicals and pesticides in international trade. The Rotterdam Convention[34] addresses chemical trade by promoting shared responsibilities and cooperative efforts in the international trade of certain hazardous chemicals and pesticides. The Convention facilitates information exchange about hazards related to chemicals to inform countries' import decisions. This PIC procedure in international trade is the core mechanism of the treaty. Countries provide their import responses, which indicate if they are willing to import a chemical. It indirectly contributes to mitigating chemical pollution by regulating the movement of dangerous chemicals globally.

Like the Stockholm Convention, there is a mechanism to add new chemicals to the Rotterdam Convention. The subsidiary body, the Chemical Review Committee, considers the final regulatory actions that countries take to ban or restrict a chemical. If two countries, from two different PIC regions (defined in the Convention), act, it could lead to a listing in the Rotterdam Convention. The Committee also prepares information for

countries on the chemical's risks and management options. Unlike the Stockholm Convention's POPRC, the CRC does not evaluate a chemical's properties. It considers countries' regulations to inform decisions on whether the chemical's international trade should be part of the PIC procedure.

3.1.4 International Maritime Organization (IMO). The IMO[35] has several international treaties related to international shipping. The MARPOL Convention is vital in addressing concerns related to cruise ship activities. The IMO recently agreed to phase out PFAS from fire-fighting foams in ships by 2026. Additionally, the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (commonly known as the London Convention (1972)) and its 1996 Protocol prohibit the dumping of several materials. The Protocol restricts marine dumping, permitting only a shortlist of materials, including sewage sludge and dredged material. However, there has not yet been an assessment of the extent to which CEAC may be present in the materials permitted for dumping under the London Protocol.

More relevant to the Arctic, the IMO's Polar Code aims to enhance the environmental safety of the polar regions concerning pollution from marine operations. The IMO's regulatory framework, including the Polar Code, MARPOL, and other related instruments, provides adaptive mechanisms that could potentially address CEAC. MARPOL and the London Convention have mechanisms to update the treaties in the light of new scientific or economic realities. For example, the London Convention took steps *via* an amendment to regulate carbon dioxide storage in sub-sea geological formations.[36] Through these mechanisms, the IMO aims to prevent the release of harmful chemicals into Arctic waters, ensure proper emergency preparedness, and promote regional cooperation to protect the Arctic environment from chemical pollution.

3.1.5 Strategic Approach to International Chemicals Management (SAICM) and the global framework on chemicals. SAICM is a multi-stakeholder platform that fosters voluntary actions to achieve the sound management of chemicals throughout their life cycle. SAICM adopted resolutions related to emerging policy issues. Relevant to the Arctic, these include chemicals in products, hazardous substances in electrical and electronic products, environmentally persistent pharmaceutical pollutants, perfluorinated chemicals, and highly hazardous pesticides. These resolutions led to projects focused on capacity building or governance strengthening, to name a few. Its goal was for chemicals to be produced and used in ways that minimize significant adverse impacts on the environment and human health by 2020. This goal was not met, prompting negotiations for a post-2020 framework. The result was the Global Framework for Chemicals, which sets out targets for chemical management. Some targets, such as phasing out highly hazardous pesticides or working on perfluorinated chemicals, may be relevant to CEAC. Adopted only in 2023, much work remains to identify and enact strategies and projects to realize these targets. It will also use a multi-stakeholder approach, and decisions are not legally binding. It is expected that the Global Framework on Chemicals[37] will be able to respond to emerging issues.

3.2 Regional chemical regulations

Beyond the Arctic Council and the work of AMAP, we highlight three regional efforts. Here too, we find that several do not (yet) address pollution from CEAC specifically. But, like the global mechanisms above, there is potential for these bodies to consider these pollutants. Although not exclusively for the Arctic, the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) covers parts of the Arctic Ocean and addresses pollution prevention and elimination from land-based and offshore sources and dumping and incineration. Relevant work is conducted by OSPAR's Hazardous Substances & Eutrophication Committee (HASEC) along with its subsidiary working groups, including Monitoring and Trends and Effects of Substances in the Marine Environment (MIME) and Inputs to the Marine Environment (INPUT). OSPAR aims to minimize, supported by HASEC's monitoring, some chemicals of concern in the Arctic, including PCBs, PBDEs, and organotins.

3.2.1 European chemical regulation. In the EU, as in many other countries, there are regulatory frameworks for different uses of chemicals. The REACH Regulation ((EU) 1907/2006) acts as an overarching regime in the EU and applies to all chemical substances, industrial and others. It requires companies to identify and manage risks linked to substances they manufacture and place on the market in the EU. EU member state authorities and ECHA's scientific committees assess whether the risks of substances can be managed and can take action in case the intended use causes risk. In the REACH assessments, Arctic environmental conditions are not specifically considered, although the EU geographic area also covers Arctic territories.

One of the many CEAC found in the Arctic, agricultural pesticides, can only be approved for use in plant protection products if they fulfil the approval criteria that are laid down in Regulation (EC) 1107/2009. The member states, the European Food Safety Authority (EFSA) and the Commission evaluate active substances and synergists for safety before they can be placed on the market and used in plant protection products. Pesticide formulations, *i.e.*, the ingredients added to enhance the end product, are approved at the national level, and it is thus possible for a member state to not approve the use of pesticide formulations due to the risks identified.[38] The fate assessment under pesticide regulation is based on the use of models and five different scenarios, none of which reflect the environmental conditions in the Arctic. On the other hand, biocidal products, such as non-agricultural pesticides, also need to be authorised before they can be placed on the market. Under Biocidal Products Directive (EC) 98/8 (BPD), state-level restrictions (non-approvals) are possible, *e.g.*, based on Article 37 of the Regulation. It is not possible to restrict the use of a pesticide or biocide sub-nationally.

Pollution caused by pharmaceuticals has been identified as an emerging problem in the EU, as demonstrated in the EU Strategic Approach to Pharmaceuticals in the Environment.[39] Pharmaceuticals as products are exempt from most provisions under the Union's general chemicals legislation, though not from restriction provisions. EU legislation on veterinary

medicinal products (Regulation (EU) 2019/6) and Directive 2001/83/EC on the Community code relating to medicinal products for human use are the primary means for ensuring the safety of pharmaceuticals for the environment. The legislation is relatively recent and (EU) 2019/6 stresses the decisions to be made on the Union level based on overall benefit-risk assessment. The Arctic environmental conditions are not specifically considered in any EU chemical assessments. Sensitive environments are considered with assessment factors. Although chemicals are generally regulated on the EU level to harmonize the EU market, individual member states can set tighter restrictions where necessary. For example, Denmark has prohibited the use of a specific type of PFAS in food packaging (in 2020) as well as in fire-fighting foams (in 2024), which goes further than the existing REACH restrictions.[40] Yet, there is no experience in regulating chemicals at sub-national levels such as the Arctic regions. It is worth noting that although they are not EU member states, Iceland and Norway also follow the EU legislation. Meanwhile, Greenland and the Faroe Islands have not formally adopted EU REACH regulations; however, they may be considered to voluntarily follow them under other global conventions such as the Stockholm Agreement.[41]

3.2.2 The Convention on Long-range Transboundary Air Pollution (CLRTAP). The CLRTAP is a regional treaty that plays a role in addressing air pollutants across most Arctic states. The Convention has several protocols, including a POPs protocol, which aims to eliminate or restrict the international production and use of POPs. The protocol addresses similar POPs to the Stockholm Convention, creating regulatory overlap for the states that are a party to both. While all Arctic Council member states are signatories, except for Russia, not all have ratified the agreement, which leaves gaps in regulatory enforcement and highlights the need for improved collaboration.

3.3 National chemical regulations

Regulating chemicals at both the national and sub-national levels presents distinct challenges and opportunities. National-level governance typically oversees chemical management, concentrating expertise and resources within federal agencies. This more centralised role can lead to effective risk assessments and regulatory frameworks that work uniformly across the country. However, sub-national governance, including local or municipal regulations, too plays a critical role in addressing environmental concerns such as CEAC. Local authorities can not only monitor pollution, but are also in general responsible for waste management, which is critical to help reduce chemical releases into local environments. The interplay between these two levels of governance and more so the inclusion of regional and global governance can increase complications in risk assessments. When our multiple levels of governance arrangements diverge, they create inconsistencies that typically are first taken up at the national level. The integration between both levels is essential for effective chemical management, yet it requires careful coordination to enhance how they are done in practice. This includes the communication of an identified risk to vulnerable populations, in particular Arctic Indigenous Peoples AMAP Human Health Assessment (2021) and ref. 42. The section below presents national level Arctic chemical regulation, followed by a summary of the main gaps throughout the entire multi-level governance of CEAC.

3.3.1 US chemical regulations. The first chemical regulations, called the Toxic Substances Control Act (TSCA), were adopted in 1976. The Act was the result of pressure from a coalition of more than 450 organizations ranging from NGOs, health professionals, businesses and local communities. In 2016, TSCA was updated to create the Lautenberg Chemical Safety for the 21st Century Act (LCSA), which received wide bipartisan acceptance. The new law was created to evaluate chemical risks in commerce and mitigate those risks; however, some studies find this is an ineffective way and underestimates health risks by not considering exposure and accumulation.[43] It is important to note that the TSCA does not include pesticides, food additives or pharmaceuticals and only applies to industrial chemicals. Within the TSCA, the Environmental Protection Agency (EPA) evaluates the safety of new and existing chemicals under the TSCA through a three-step process: prioritisation, risk evaluation, and risk management. First, chemicals are categorised as either high-priority or low-priority. High-priority chemicals move forward to risk evaluation, where their hazards and exposure potential are analysed without considering non-risk factors, such as costs. This stage involves gathering data from manufacturers, processors, importers, users, and end-of-life stakeholders and can take up to three years. Finally, if a chemical is found to present unreasonable risks, the EPA implements risk management measures. These measures may include labeling requirements, use restrictions, phase-outs, or bans to eliminate the identified risks. The responsibility for assessing and mitigating these risks rests on the government.

Like the Canadian system described below, chemicals are first prioritised, and further evaluation is conducted on those determined to be a high priority. The risk evaluation includes hazard and exposure information and does not consider non-risk factors such as costs. The evaluation process can take up to three years to gather data from all sectors (*i.e.*, manufacturers, processors, importers, users, and end-of-life). In the management process, the EPA is required to undertake a management process that could include several regulatory options to reduce the risk (*i.e.*, labelling, restrictions, phase-outs, and bans). The burden falls upon the government to evaluate, manage, and regulate risks associated with hazardous chemicals. Since the last AMAP report on CEAC was released, there have been several new requirements from the EPA with a focus on pollution from PFAS. The concentrations of PFAS in Alaska are a cause for concern, with numerous known contaminated sites across 16 lakes near Anchorage and Fairbanks.[44] A recent study tested the two largest cities of Anchorage and Fairbanks waterways and found extremely high and toxic levels of PFAS pollution over previous thresholds.[45] Although the United States has begun to strengthen its regulations regarding many CEAC, there is no evidence that the Arctic is specifically taken into consideration when setting chemical restrictions.

3.3.2 Russian chemical regulations. As recently as 2021, Russia has established and implemented a regulatory framework for its chemical management through the adoption of the Technical Regulation on the safety of chemical projects.[46] Although it has proven difficult to access information on how it works in practice, this regulation requires manufacturers and importers of chemicals to comply with strict requirements on registration, labelling, and conformity assessment of chemical products. This aims to strengthen the existing regulations and environmental protection in handling chemicals of concern. However, when it comes to the implementation of chemical regulations, there are concerns around compliance and effectiveness in the Russian Arctic. Due to the increasing challenges and expansion of industrial activities from oil and gas extraction, the new chemicals regulation in Russia has a lack of specific mitigation efforts. Targeting the Arctic region should be included in future updates to the regulation.[47] Moreover, Russia is not a signatory to the protocol on POPs under the CLRTAP, and under the Stockholm Convention has limited itself to eliminating or restricting production and use of the original dirty dozen. Additionally, the non-existing cooperation within the Arctic Council further exacerbates its isolation from collaborative initiatives that could enhance chemical regulation and environmental protection of the Russian Arctic.

3.3.3 Canadian chemical regulations. Traditionally, protecting the Arctic and Indigenous Peoples has been a motivating factor in Canadian chemical regulation.[12] The economic costs of chemical pollution in Canada can be significant, exceeding CAD 30 billion.[48] There are various laws in Canada related to chemicals management, which are administered by various government departments, notably Health Canada and Environment and Climate Change Canada. These include the Pest Control Products Act (2002), the Canada Consumer Products Safety Act (2010), the Food and Drugs Act (1985), and the Controlled Drugs and Substances Act (1996). Below, we focus on the Canadian Environmental Protection Act, 1999 (CEPA), as the main legislation governing chemicals management. Neither of these instruments has specific requirements to consider Arctic conditions or specifically look at LRET in their assessments. They consider available information, which may include information related to the Arctic.

The assessment and management of chemical substances under CEPA relies on a risk-based approach. It does not specifically outline a requirement to consider the Arctic regions in the assessment of chemicals, although a recent amendment highlighted a need to consider vulnerable environments. CEPA has several key elements that may be relevant for assessing the impacts of chemicals in the Arctic environment. The Act includes the application of the precautionary principle, interpreted as the lack of full scientific certainty should not preclude cost-effective measures to prevent environmental degradation. Yet some argue that, in practice, the principle is interpreted to mean that chemicals are safe until they are proven unsafe due to the lengthy timelines for assessing and regulating substances.[49]

New provisions in CEPA may be useful to raise the inclusion of the Arctic region, including the consideration of vulnerable populations and cumulative effects, but only when data are available. CEPA also requires setting priorities for assessing chemicals and establishing a watch list of chemicals that are considered capable of becoming toxic under CEPA. Recent proposals for setting priorities under CEPA consider a list of factors, including "substances with the potential to contribute to cumulative risks; very hazardous substances that are capable of long-range transport (VH-LRT)". These criteria may be relevant for the Canadian Arctic regions, but more details on what this data will capture are needed. For example, LRET is not a criterion under CEPA. Canadian regulation has long taken an approach to shortlisting the many substances of potential concern. The Domestic Substances List (DSL) was initially compiled under the original CEPA in 1988. The 1999 CEPA required the federal government to complete the categorization of the 23 000 substances in the DSL by 2006. The categorization process required that the Departments of Health and Environment identify those substances that were persistent and/or bioaccumulative and inherently toxic, and also substances that have the greatest potential for exposure. The 2006 categorization identified 4300 substances for further evaluation to determine if they posed a risk to human health or the environment. The Chemical Management Plan (CMP) was introduced in 2006 to outline Canada's strategy to assess and manage, where needed, 4300 substances identified for further evaluation from the 2006 categorization of the 23 000 substances listed on Canada's Domestic Substances List. It has taken almost 20 years to complete the assessment of those 4300 substances identified from the categorization.

In addition to creating a framework to conduct screening assessment of the high-priority substances from categorization, the CMP also establishes a biomonitoring program and supports assessments of active ingredients used in pesticides and coordinates management approaches under the different legislation for those substances found to be toxic under the CEPA. It too refers to the precautionary principle and uses safety factors to address unknowns and uncertainties for assessments.

In practice, information specific to the Arctic has been considered in assessments, notably around flame retardants. CMP Monitoring and Surveillance works with the Northern Contaminants Program and uses its data when assessing substances, when available. Environmental and biomonitoring data from Arctic species, while not explicitly required by legislation, are frequently used in ecological assessments as evidence of long-range transport potential. Again, these data are considered when they are available, although modelling can be used. The CMP has played a key role in the chemicals management regime in Canada, especially in coordinating the various pieces of legislation and monitoring efforts in Canada's fragmented governance framework for chemicals.

The Canadian chemicals management focuses on regulating substances that are assessed as toxic, rather than products. This approach can create differences from other countries. For example, in pharmaceuticals management, Canada's substance-based approach differs from the EU and the US, which regulate the products.[37] Under CEPA, research has focused on endocrine-disrupting chemicals and contributed to innovations in considering the impacts of endocrine-disrupting

chemicals. Canada is part of a global network working to build confidence in New Approach methodologies that can identify, prioritize, and assess potential risks using more efficient methodologies and tools.[38]

Implementation of recent CEPA amendments is ongoing and a new commitment to support the CMP is in place. This offers some opportunities to consider the data that should be collected or required to consider the impacts of chemicals in the Arctic regions. In particular, the new requirement to consider available information on "vulnerable environments" at present is not defined in CEPA.† To take these steps, further consideration should be given to how the government implements the amendments to CEPA and what priority considerations are given to the Arctic environment and the Indigenous Peoples living in these regions.

4. Multi-level gaps

The above overview provides a cursory look at the various regulations that exist at global, regional, and national levels. It shows that many countries and global bodies are making considerable efforts, but these regulations also leave gaps, particularly related to CEAC.

At the global level, there is no overarching chemicals treaty (unlike the climate change or biodiversity governance regimes). There is the new, untested and voluntary Global Framework for Chemicals. But otherwise, only the Stockholm Convention, through the implementation of its parties, regulates the production and use of POPs (not all chemicals). Other major global treaties address specific issues, such as trade in hazardous chemicals or wastes. Regionally, there are sporadic efforts related to the Arctic. Many of these involve marine dumping, except for CLRTAP's focus on air pollutants. While global treaties have shown the ability to add new chemicals to their, rather niche, mandates, it is unclear how often regional agreements will do so. The CLRTAP does indeed have a protocol for adding new pollutants; however, the frequency of this mechanism's use as well as those in other regional agreements varies, and many parties have switched their focus to global treaties instead.

There is a transatlantic divide between the EU and North American countries regarding chemical regulation. While the EU puts the onus on producers, the US and Canada face the uphill battle of conducting risk assessments after chemicals are in use. There are two additional challenges that we identify to effectively manage CEAC in the Arctic. Both relate to activities or their legacies within the region itself. The transboundary nature of many chemicals requires multi-level efforts to avoid, for example, a POP released in one part of the globe to end up in the Arctic.[50] The increased industrial activity of the Arctic in and of itself is posing additional problems that national and regional governments may need to further attend to.

Products and articles currently fall into a regulatory gap at the global level. The Basel Convention involves prior informed consent from developed countries to developing countries. Therefore, it would not apply to products imported to Arctic countries. The World Customs Organization's Harmonized System codes may not apply to many products and can be slow to respond to products and articles of concern. It can take up to seven years for a code to be assigned. Ongoing negotiations for the legally binding plastics treaty may be able to address this gap, but this would be valid for plastics only.

The Arctic Council has actively engaged in waste management initiatives in the Arctic, including the Sustainable Development Working Group (SDWG) and Arctic Contaminants Action Program (ACAP) project focusing on waste management in remote communities in Alaska, Canada, and Finland[51,52] and an Aleut International Association (AIA) study focusing on 24 remote communities.[53] Efforts to enhance wastewater treatment are crucial in reducing releases by promoting degradation and binding contaminants in the sludge. However, it is noted that many Arctic communities lack adequate wastewater treatment, leading to potentially significant impacts on the local marine environment.[19] Additionally, in regions where wastewater treatment processes do exist, the management of sludge presents its own challenges, especially in the Arctic. Incineration can lead to air deposition of contaminants while land disposal may introduce further risks. More details on wastewater treatment in the Arctic are explored by Jensen *et al.*, 2025.[17]

There are potential resources that could assist with clean-up and remediation, but none were designed with the Arctic in mind. The Basel Convention prepared technical guidelines for a wide range of wastes. These technical guidelines represent global consensus on how to manage wastes in an environmentally sound manner. BAT/BEP guidance, including for contaminated sites, is developed for the Stockholm Convention POPs. All these resources are widely available, but the extent to which they are useful in Arctic conditions may be largely untested and understudied.

5. Governing a changing Arctic region

This first-of-its-kind review examines chemical regulations in, and pertaining to, the Arctic to prevent pollution from long-range and local sources. There are three key takeaways. First, there is a need for a more holistic and proactive approach, involvement of vulnerable populations (particularly Indigenous Peoples), and further holistic research on chemicals governance.[3] There is a lack of peer-reviewed studies on chemical regulatory regimes, including their design, development, and effectiveness. This holds at international and national levels. Comparative studies could help identify the benefits and dynamics apparent across national systems that may hinder effective regulation. There is an increasing need for detailed, holistic studies conducted through a co-production approach that integrates both scientific research and Indigenous Knowledge, while considering the local Arctic conditions, including multiple stressors, socioeconomic pressures, cultural heritage and knowledge, and efforts to cope with climate change and rising pollution. Political ecology, for example, could be a useful framework to help understand how marginalization, cultural

† Approaches are under development at the time of publication.

practices, and other socioeconomic realities shape pollution trends in the Arctic and *vice versa*.

Second, global and national governance is extremely fragmented, and many chemicals of concern in the Arctic fall between the cracks. Current approaches have so far been unable to address existing problems, pointing to the need for additional and multifaceted approaches. Global treaties and voluntary initiatives do not address the full scope of chemical pollution. Most have narrow mandates that largely ignore production (except the Stockholm Convention, which only addresses POPs). The ongoing UN global plastic treaty negotiations highlight this gap, as some countries argue against addressing chemicals separately within the plastics treaty, claiming that other MEAs cover chemicals, despite this not being the case. This reflects a broader unwillingness by certain nations to address chemical management proactively.[54]

At the national level, our review often required researching numerous different pieces of legislation. These spanned health and consumer safety, agriculture, industrial planning, and other discrete areas of government control. Information was often fragmented across these government departments. In some cases, such as Canada and the US, subnational territories and states assume some limited responsibilities that could influence chemical use and disposal.

Third, this review finds that few, if any, global or national-level regulatory or voluntary efforts consider the Arctic's unique vulnerabilities. The Stockholm Convention may be an outlier, in that it considers the presence of chemicals in remote regions, which include the Arctic, as a key criterion for determining whether a chemical is a POP. National-level legislation was often construed to consider risks to the population or environment, broadly construed, without particular attention to Arctic conditions and the unique vulnerabilities of the Indigenous Peoples living there.

The Arctic's unique geographic and socioeconomic status further complicates the challenges associated with regulating and managing these substances effectively. The Arctic is undergoing rapid changes. Changing industrial and consumption patterns complicate efforts to discern what chemicals originate from the Arctic. It is likely to become increasingly difficult to discern whether a chemical's presence in the Arctic is due to local sources, LRET, or both. The varied picture of environmental releases will require cooperation between all levels. National levels will have to work with regional and global efforts to address local and transboundary sources.

Finally, while this review primarily focuses on CEAC and POPs, we recognise the broader scope of chemical risks in the Arctic, including the transformation of products and chemical mixtures resulting from known pollutants. Given the complexity and significance of these emerging concerns, future reviews could benefit from a more in-depth exploration of the impacts of transformation products and the challenges they pose to chemical management and ecosystem protection in the Arctic.

Dynamics specific to the Arctic further illustrate the limitations of national and local efforts. The persistent issue of products in use serving as long-term sources of unknown or "old" chemicals poses significant regulatory challenges, emphasising the limitations in controlling substances caught in ice formations. Waste and wastewater management emerge as crucial focal points, with local initiatives playing a significant role, as exemplified by the dedicated review of wastewater in the Arctic.[17,55]

Moving forward, a holistic understanding of Arctic conditions, coupled with innovative solutions and effective governance, is crucial for mitigating the impact of chemical pollution in this unique and vulnerable ecosystem. It is not too late to adapt our regulations to the changing climate; however, we must start with the precautionary principle and a proactive approach, both of which are not yet sufficiently used in global chemical regulation.

Data availability

No primary research results, software or code have been included and no new data were generated or analysed as part of this review.

Author contributions

Conceptualisation (T. S. and E. C.); formal analysis (E. C., J. A., and T. S.); funding acquisition (E. C.); investigation (E. C., J. A., T. S., E. K., F. L., and T. M.); writing – original draft (E. C., J. A., T. S., E. K., and T. M.); writing – review & editing (E. C., J. A., T. S., E. K., F. L., and T. M.).

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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