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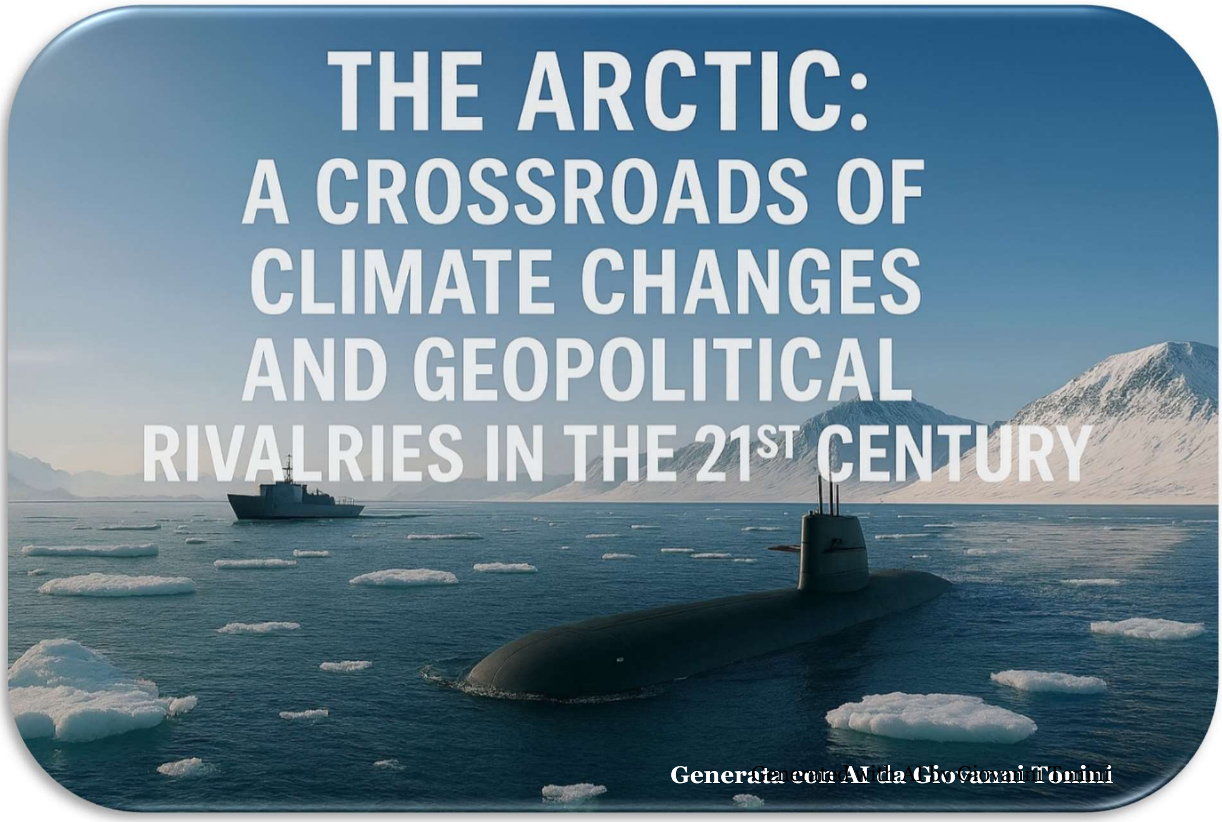

by Giovanni Tonini and Cecilia Sandroni


“We dedicate this essay to those who inspired us in its development, Emanuela Somalvico, founder and Director of the Arctic Intelligence Observatory of the Italian Intelligence Society (SOCINT), as well as to the distinguished Professor Mario Caligiuri, President.

We would like to thank Arturo Acanfora, Elisa Chiaffi and Marco Lin for their hard work in producing a synopsis and global press review on the Arctic during their internship at ItaliensPR; this document has been invaluable to us."

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Introduction

The Arctic of the 21st century is one of the most dynamic and complex theatres of contemporary global change. Once considered a remote and marginal frontier, this region is now at the centre of unprecedented environmental transformations and growing geopolitical rivalries that are redefining the global balance of power. The rapid melting of ice, accelerated by global warming, is not only radically altering polar ecosystems, but also opening up new economic opportunities and creating unprecedented strategic tensions between the major global powers.

The Arctic region, which encompasses the waters and lands within the Arctic Circle, spans eight sovereign nations: Canada, Denmark (through Greenland), Finland, Iceland, Norway, Russia, Sweden and the United States. However, its influence extends far beyond these geographical boundaries, with implications for global climate patterns, international supply chains and the global balance of power. This essay aims to analyse this complex reality through a multidisciplinary perspective, examining how environmental changes are creating new opportunities and challenges, and how these intersect with emerging geopolitical dynamics involving traditional actors and new global players.

Chapter 1

The Arctic climate crisis - Unprecedented acceleration

1.1 Climate feedback mechanisms

The Arctic is warming at a rate four times higher than the global average: this phenomenon is known as 'Arctic amplification', which produces chain reactions with global implications. Recent scientific studies from 2024-2025 have revealed that this process is more complex and accelerated than previously thought.
One of the most alarming discoveries concerns the transformation of Arctic permafrost from a reservoir to a net source of greenhouse gases. The permanently frozen soil, which for millennia has stored enormous amounts of organic carbon, is now releasing CO_2 and methane at increasing rates, triggering a positive feedback loop that intensifies global warming.
A further cause for concern is the release of ancient methane from small Arctic glaciers, as documented in Svalbard, where meltwater is releasing potentially immense buried carbon reserves.
Recent studies have also highlighted how Arctic afforestation, proposed in some geoengineering strategies, may paradoxically accelerate warming in some areas by reducing the albedo of the tundra and altering natural habitats, suggesting the need for more balanced approaches to safeguarding the Arctic ecosystem.

1.2 Revised climate projections

The most up-to-date estimates anticipate the total disappearance of Arctic ice in summer by about two decades, now possible as early as 2027, an acceleration explained by the better integration of numerous underestimated feedback mechanisms into climate models.
The so-called 'Last Ice Area', once considered a refuge for ice-dependent species, is likely to disappear by 2035, with devastating consequences for wildlife and indigenous populations.

1.3 The phenomenon of 'Atlantification'

The "Atlanticisation" of the Arctic is one of the most dramatic and irreversible oceanographic processes of contemporary climate change. This phenomenon describes the massive and accelerated influx of warmer, saltier Atlantic waters into the Arctic oceans, mainly through the Barents Sea and the Fram Sea.

The mechanism behind this process is complex and self-perpetuating. Atlantic waters, which are 2-4 °C warmer than traditional Arctic water masses, penetrate the subsurface layers of the ocean through deep currents that follow the underwater ridges. Once penetrated, these warmer water masses accelerate the melting of sea ice from below, in a process called 'basal melting', which has been found to be up to ten times more effective than surface melting caused by warm air.

The 'Atlantification' of the Barents Sea is particularly advanced, with average temperatures rising by more than 1.5 °C over the last decade. This has led to the almost complete disappearance of winter sea ice in vast areas that historically remained covered all year round. The phenomenon is now spreading eastwards, affecting the Kara Sea and the Laptev Sea, threatening to transform the entire Siberian Arctic into a temperate oceanic environment.

The biological impacts are devastating and reverberate throughout the entire food chain. Arctic phytoplankton communities, adapted to cold waters and long periods of darkness, are being replaced by Atlantic species that alter the primary productivity of the ecosystem. This change is propagating through zooplankton, fish and marine mammals, with dramatic h l consequences for iconic species such as polar bears, walruses and various species of seals.

The phenomenon of Arctic 'greening', closely linked to Atlanticification, is transforming the tundra into grasslands and boreal forests. Rising ocean temperatures create milder climatic conditions on the coasts, allowing denser vegetation to grow. Paradoxically, this 'greening' further accelerates warming by reducing surface albedo: while tundra reflects up to 80% of solar radiation, vegetation reflects only 10-20%.

Marine algae growth has exploded in some Atlantic-influenced regions, creating massive blooms that alter ocean chemistry and produce hypoxic zones. These marine 'dead zones' threaten traditional fisheries and benthic ecosystems that have sustained indigenous communities for millennia.

From a global climate perspective, the Atlanticification of the Arctic is altering global ocean circulation patterns. The warming of Arctic waters reduces deep water formation, a key mechanism for global thermohaline circulation. This could lead to a slowdown or collapse of the Atlantic Meridional Overturning Circulation (AMOC), with catastrophic consequences for the European and global climate.

Chapter 2

New economic opportunities and trade routes

2.1 New sea routes: the 'Suez Canals' of the future

The gradual melting of Arctic ice is opening up new shipping routes that promise to revolutionise global trade.

By 2050, many of these routes are expected to be navigable for most of the year.

The ***Northern Sea Route***, which runs along the coast of Russia connecting the Atlantic and Pacific oceans, is the most strategic. It reduces the distance between Asia and Europe by approximately 4,000 nautical miles compared to the Suez Canal, lowering travel time between Shanghai and Hamburg from 34 to just 23 days.
Russia has invested heavily in this route with nuclear icebreakers and port infrastructure.
It is seeing an extension of the navigable season thanks to the melting of the ice. The route is increasingly frequented by a growing fleet of Chinese container ships, with which Moscow is collaborating to develop joint logistics hubs and increase the volume of goods transported.
The NSR (Northern Sea Route) has reduced travel times and costs compared to the Suez Canal, but it also poses new challenges for navigation in areas with unpredictable residual ice, particularly in the Canadian route, which has proven to be more dangerous.

Another crucial route is the ***Northwest Passage***, which crosses the Canadian archipelago and connects the Atlantic to the Pacific. This route is at the centre of an international legal dispute, as Canada considers it to be internal waters while other countries see it as an international corridor.

The ***Transpolar Route***, still hypothetical, would be the shortest route connecting Europe and Asia, crossing the central Arctic Ocean.

The opening of these routes could save around $91 billion a year in transport costs, but would redistribute global trade flows, with significant impacts on historic hubs such as Egypt and Singapore.

2.2 The mineral wealth of the Arctic: a new geopolitical frontier

The Arctic represents one of the last frontiers for the extraction of natural resources, harbouring enormous deposits of strategic minerals and hydrocarbons that are redrawing the global geopolitical balance.

2.2.1 Rare earths: Greenland takes centre stage

Greenland is emerging as a key player in the market for rare earths, elements that are essential for the technology industry and the energy transition. The Kvanefjeld deposit, in particular, represents a resource of global significance: according to geological estimates, it could meet up to 15% of global demand for these critical minerals, which are used in the production of electronic components, wind turbines and electric vehicles.

Rare earth elements (REE) are a group of 17 chemical elements that have unique metallurgical, catalytic, nuclear, electrical, magnetic and optical properties.

Despite their name, they are not particularly rare in the Earth's crust, but are usually found in low concentrations, making their extraction uneconomical.

Among these elements, the most important for technology and digital transition include the following.

- Lanthanides:
  - Neodymium (Nd), essential for the production of extremely powerful permanent magnets used in electric motors, wind turbines and electronic devices such as smartphones;
  - Dysprosium (Dy) and praseodymium (Pr), often used in alloy with neodymium to improve the resistance of magnets to high temperatures; they are essential for electric cars and wind turbines;
  - Europium (Eu) and terbium (Tb), used as red and green phosphors in displays, from televisions to computer screens.

- Other elements include scandium (Sc) and yttrium (Y), used in light metal alloys for the aerospace industry, electronics and high-power lasers.

Demand for rare earths is growing rapidly due to their indispensability for green technologies and high technology. Currently, global production is dominated by China, which has made Western countries vulnerable.
The Arctic, with its vast deposits, could represent an alternative source for these strategic resources, reducing dependence on a single supplier and redefining the global geopolitical balance.

2.2.2 Hydrocarbons: the race between Russia and Norway

The Arctic oil sector is undergoing a phase of intense expansion:

- recent discoveries of oil fields in the Barents Sea have reignited interest in this region, with significant investments by Norwegian and Russian companies;

- the Russian megaproject 'Vostok Oil' is one of the most ambitious investments in the Arctic, aimed at exploiting the vast Siberian reserves.

2.2.3 The international dimension

Competition for Arctic resources does not only involve countries in the region:

- China has stepped up its investments in Arctic mining, focusing on strategic resources such as lithium in the Murmansk region;
- the United States is paying increasing attention to antimony deposits in Alaska, a mineral that is crucial for various industrial applications.

2.2.4 Future implications

This wealth of natural resources is transforming the Arctic from a peripheral region into a theatre of geopolitical competition, where environmental, economic and international security issues intertwine.

2.3 Logistical and environmental challenges

Despite the resources, extraction in extreme environmental conditions remains complex and costly. The lack of adequate infrastructure and regulatory and climatic issues limit development, as in Greenland.

The ban on the use of heavy fuel oil in Arctic waters, introduced to protect the environment, still has operational loopholes until 2029, only partially mitigating the environmental impact.

Chapter 3

The redefinition of geopolitical balances

3.1 The main players and their strategies - Russian supremacy

- ***Russia***: controls half of the coastline and leads the race with the world's most powerful icebreaker fleet, military bases, advanced missile systems and ambitions to control routes and resources through LNG projects and strategic deterrence. It maintains a key role with 32 permanent military bases, the world's most advanced fleet of nuclear icebreakers and investments in military and scientific infrastructure, such as the research platform at the North Pole and the Ivan Papanin combat icebreakers, equipped with advanced weaponry. It is also studying the development of strategic centres such as the one in Khatanga, to support its logistical presence.

- ***United States***: after years of disinterest, it has relaunched its Arctic presence from its base in Alaska, upgrading icebreakers, air bases and satellites, focusing on deterrence and NATO cooperation rather than direct control.

- ***Canada***: dominant in the western Arctic, it claims the Northwest Passage but struggles to control it completely, investing in patrol ships, indigenous sovereignty and international cooperation.

- ***Nordic countries***: Norway, Denmark (Greenland), Sweden and Finland play key roles thanks to modern infrastructure and military bases and, with Sweden and Finland joining NATO, are fundamental to Nordic strategic control.

China: not an Arctic state, it defines itself as a 'quasi-Arctic state' and aims to gain access to resources, polar trade routes and scientific cooperation, exploiting 'wallet diplomacy' and avoiding direct confrontation.

3.2 The expansion of Chinese influence

Although not an Arctic nation, China is active with a comprehensive strategy that combines scientific cooperation (Yellow River Station in Svalbard), energy partnerships with Moscow and joint coastguard patrols.
The China-Nordic Arctic Research Centre (CNARC) is a pillar of this strategy, using research as geopolitical leverage under the rhetoric of sustainability.

3.3 The Western response

In recent years, NATO has recognised the Arctic as an area of growing strategic importance and has stepped up its activities in the region to ensure the collective security of its member countries. The expansion of the Alliance, with the entry of Sweden and Finland in 2023-24, has strengthened NATO's presence in the Arctic, closing a geopolitical gap and consolidating a compact northern front.

It has strengthened its military presence with large-scale exercises such as 'Nordic Response' and 'Joint Viking'. The trilateral 'ICE Pact' (US, Canada, Finland) aims to support icebreaker capacity and polar shipbuilding to bridge the technological gap with Russia.

British initiatives include the use of artificial intelligence to monitor state activities in the Arctic, in collaboration with Iceland and Norway.

NATO pursues a multilateral strategy combining deterrence, cooperation and technological monitoring.

Key projects include:

- enhancing surveillance and intelligence capabilities through satellites and advanced communication systems to monitor military and civilian activities in the region;

- training courses and joint exercises specific to operations in extreme Arctic conditions, aimed at improving interoperability between member countries;

- investments in military and logistical infrastructure in key Nordic countries, such as bases in Norway, Iceland and US Alaska;

- the promotion of an integrated approach to security, which also includes cooperation with non-NATO partners and the management of environmental and humanitarian challenges related to climate change.

NATO's overall objective in the Arctic is to prevent conflicts, ensure freedom of navigation and protect strategic trade routes, while maintaining a balance between deterrence and diplomatic dialogue in the context of growing geopolitical tensions.

The region represents a crucial test bed for the Alliance's ability to adapt to new global security scenarios.

3.4 Trump's ambitions for Greenland

Donald Trump's re-election in 2024 has reignited American ambitions for Greenland with unprecedented force, transforming what began as a media provocation during his first term into a structured and persistent geopolitical strategy. Trump's statements on the acquisition of Greenland are no longer isolated incidents, but reflect an American strategic vision that considers the island crucial to national security and Arctic supremacy in the 21st century.

The strategic motivations behind American interest are manifold and deeply rooted in Arctic geopolitical dynamics. Greenland is home to Thule Air Base, one of the northernmost American military installations, which is crucial for missile defence and Arctic surveillance. The island also controls the passage between the Atlantic and the Arctic, a strategic position that could become crucial with the opening of new polar trade routes.

From a resource perspective, Greenland is a real geopolitical treasure trove. Its rare earth deposits could cover up to 25% of global demand, drastically reducing Western dependence on China. Offshore uranium, iron, zinc and oil deposits complete a picture of natural riches that could transform the global economic balance. Direct American control over these resources would guarantee the US a dominant position in the energy transition and technological competition with China.

The Greenlandic population has reacted firmly to American pressure, developing a strong identity-based resistance that has crystallised in the 'Greenland for Greenlanders' movement. The March 2025 parliamentary elections saw a landslide victory for the Demokraatit party, which made gradual independence its flagship policy but categorically rejected any suggestion of ceding the country to the United States.

The campaign to boycott American products launched by Greenlandic youth movements reached unexpected proportions, involving Inuit communities in Canada and Alaska in a pan-Arctic solidarity front. Social media such as TikTok and Instagram became platforms for mobilisation, with hashtags such as #GreenlandIsNotForSale reaching millions of views globally.

Denmark finds itself in an extremely delicate position, torn between its Atlantic loyalty to the US and its constitutional responsibility towards Greenland. The Danish government has categorically rejected

American advances, but internally, pressure is growing from groups that see a sale as a solution to the enormous costs of Greenlandic subsidies. Greenland receives approximately 3.4 billion Danish kroner ($500 million) in transfers annually, a significant burden on the Danish economy.

Trump has intensified the pressure through a multifaceted strategy combining economic diplomacy and media pressure. The United States has increased infrastructure investment in Greenland, financing telecommunications and transport projects that create economic dependence. At the same time, American officials have initiated direct contacts with local leaders, often bypassing official Danish diplomatic channels.

The European Union has responded with the Arctic Partnership Initiative, a €2 billion investment package aimed at strengthening Europe's presence in the Arctic and supporting Greenlandic self-determination. This has turned the Greenland issue into a showdown between geopolitical blocs, with implications that transcend Arctic borders.

Trump's strategy also includes elements of soft power, with scholarship programmes for Greenlandic students at American universities and investments in scientific research projects. This 'wallet diplomacy' aims to create a Greenlandic ruling class with strong ties to the United States, a long-term strategy that could bear fruit in future generations.

The legal implications of a possible acquisition are complex and controversial. International law guarantees the right of peoples to self-determination, but Greenland remains formally Danish territory with limited autonomy. A unilateral declaration of independence followed by accession to the US would set dangerous precedents for the international order, potentially legitimising other territorial annexations.

3.5 The Danish reaction: institutional firmness

Minister Løkke Rasmussen has adopted unusually harsh diplomatic language, describing American activities as 'unacceptable interference' in Danish territorial sovereignty. The summoning of the chargé d'affaires is a particularly serious diplomatic tool in international protocol, second only to the recall of the ambassador for consultations.
The Danish position is based on three main points

- **Violation of constitutional sovereignty**: Denmark emphasises that, despite Greenland's autonomy, foreign policy and defence remain the exclusive prerogatives of the Kingdom of Denmark. Any negotiations concerning the future status of Greenland must necessarily involve Copenhagen.
- **Worrying precedent**: The Danish authorities fear that American operations could set a precedent for other powers interested in influencing autonomous European territories, threatening the stability of the European constitutional order.
- **Threat to the unity of the Kingdom**: American interference is interpreted as an attempt to disrupt the constitutional unity of the Kingdom of Denmark, which includes mainland Denmark, Greenland and the Faroe Islands.

3.5.1 Escalating Atlantic tensions

This diplomatic incident comes amid growing tensions between the Trump administration and European allies, taking on particularly significant characteristics for several reasons:

- **Implications for NATO cohesion**: Greenland is home to military installations crucial to Western defence, including the Thule base. Tensions between the US and Denmark could undermine the cohesion of the Atlantic Alliance at a time when Western solidarity is particularly needed.
- **Challenges to international law**: American influence operations call into question fundamental principles of international law regarding respect for the territorial sovereignty and constitutional integrity of allied states.
- **European domino effect**: Other European countries with autonomous territories are watching the Greenland precedent with growing concern, fearing that similar strategies could be applied to their own territories.

3.5.2 The Greenlandic dimension of the crisis

The Greenlandic population finds itself at the centre of this diplomatic battle, torn between

American economic perspectives and Danish constitutional ties. Greenlandic Prime Minister Múte Bourup Egede has maintained a cautious stance, publicly rejecting the idea of a transfer to the United States but avoiding explicitly condemning American economic overtures.
Internal dynamics in Greenland include:

- **Political polarisation**: The American issue has created divisions in Greenland's political landscape, with some factions seeing American interest as an opportunity for greater economic autonomy from Denmark.
- **Economic dilemmas**: The proposed American investments could alleviate some of Greenland's structural economic problems, but they would create new forms of dependency that could be more restrictive than the current ones.
- **Identity balance**: The Greenlandic community must balance aspirations for greater autonomy with the risk of losing elements of its cultural identity in a broader and more competitive geopolitical context.

3.5.3 Implications for transatlantic relations

The summoning of the American chargé d'affaires represents a moment of particular tension in US-Denmark relations, with implications that transcend the Greenland issue:

- **Credibility of the alliance**: The strength of Western alliances is tested when one partner uses methods of influence typical of geopolitical rivalries towards other members of the alliance.
- **Arctic governance**: The incident further complicates the already fragile mechanisms of Arctic cooperation, making it more difficult to manage the region's environmental and economic challenges multilaterally.
- **Strategic precedent**: American influence operations could be interpreted as legitimising similar tactics by other powers such as China and Russia, opening new chapters of competition for influence over Western autonomous territories.

This diplomatic episode represents a significant evolution in American strategy on Greenland, showing how ambitions have shifted from provocative statements to concrete operations of political influence. The firmness of the Danish reaction indicates Copenhagen's determination to resist American pressure, foreshadowing a confrontation that could redefine not only the future of Greenland, but the very balance of Western alliances in the era of Arctic competition.

3.6 Strategic advantages for control of the Arctic

- ***Trade routes***: power to influence trade between Europe, Asia and North America, creating a new control similar to historic strategic straits.
- ***Critical resources***: access to oil, gas and minerals essential for renewable energy, advanced technology and the space industry.
- ***Military supremacy***: shorter routes for nuclear missiles, forward bases, deterrence and naval projection capabilities.
- ***Climate leadership***: the opportunity to lead global adaptation and energy transition policies.
- ***Scientific innovation***: natural laboratory for extreme technologies applicable in space, communications and marine engineering.

3.7 Advantages, risks and challenges

- ***Environmental***: climate acceleration, destruction of unique ecosystems, oil spills, impacts on indigenous populations.
- ***Geopolitical***: military escalation, fragmentation of cooperation, territorial disputes, military accidents.
- ***Economic***: high operating costs, volatile climatic conditions, dependence on specialised technology.

Chapter 4

Innovative technologies and geoengineering solutions

4.1 Refreezing projects

Arctic geoengineering represents one of the most controversial and daring frontiers of contemporary climate science, with refreezing projects that could literally reverse the course of climate change in the polar region. These planetary-scale technological interventions stem from the realisation that traditional emission reduction measures may come too late to save Arctic ecosystems.

The 'Real Ice' project by Finnish start-up Arctic Reflections represents the most advanced and funded approach in the field of artificial refreezing. The technology is based on wind-powered underwater pumps that bring cold deep water (at -1.8°C) to the surface, where it can freeze naturally during the Arctic winter. Each Real Ice unit can produce up to 1 square metre of additional ice per day, with plans to deploy thousands of these units across the Arctic.

Initial pilot tests in the waters of Svalbard in 2024 showed encouraging results, with ice thickening by up to 30% in the areas of intervention. However, the project requires colossal investments: it is estimated that significant refreezing of the Arctic would require approximately £400 billion and the deployment of over 10 million pump units.

Parallel to the 'Real Ice' project is the development of 'bright ice' technologies that use silicon dioxide microspheres to increase the albedo of existing ice. These microspheres, dispersed on the ice surface by specialised aeroplanes, can increase solar reflectance by up to 90%, drastically slowing down melting. The technology, developed by the University of Cambridge in collaboration with US companies, has proven effective in laboratory tests and small field trials.

The 'Marine Cloud Brightening' project proposed by the University of Washington represents an even more ambitious approach. Using specialised ships equipped with marine aerosol generators, the project aims to increase the reflectivity of Arctic clouds by spraying sea salt particles into the atmosphere. These particles act as condensation nuclei, creating denser, more reflective clouds that could reduce the solar radiation reaching the ice surface.

A more controversial approach is Arctic Solar Radiation Management (SRM), which involves injecting sulphate aerosols into the polar stratosphere to create an artificial 'sunshade'. This method, inspired by the cooling effects of large volcanic eruptions, could reduce Arctic temperatures by 2-3 °C within a few years. However, the side effects could be catastrophic, altering global precipitation patterns and potentially causing droughts in Africa and Asia.

The indigenous scientific community has raised fundamental objections to these projects, not only because of the environmental risks but also because of deeper issues of sovereignty and cultural respect. Inuit elders describe ice as a living entity with its own spirituality, and consider attempts at technological manipulation to be sacrilegious violations of the natural order. The Inuit Circumpolar Council has formally condemned geoengineering projects, demanding their prior consent for any intervention in their ancestral territories.

The technical challenges remain enormous. Climate models struggle to predict the long-term effects of such large-scale interventions. There is a real risk of 'termination shock': if geoengineering projects were to be abruptly halted, for political or economic reasons, the accumulated warming would manifest itself within a few years, causing an even more rapid and devastating climate collapse than the current one.

The energy costs of refreezing projects are colossal. The 'Real Ice' project would require the equivalent of the energy production of several dozen nuclear power plants operating continuously, raising paradoxical questions about the sustainability of technologies that consume enormous amounts of energy to combat climate change caused precisely by excessive energy use.

4.2 Innovations in monitoring

Autonomous research stations, capable of operating without human supervision in extreme conditions, collect data on temperature, humidity and greenhouse gases.
Advanced satellite integration, such as the Copernicus programme and ESA systems, provides unrivalled real-time coverage.

4.3 Drones and Arctic robotics

The use of drones and robots to explore otherwise inaccessible areas has made it possible to obtain very high-definition 2D and 3D bathymetry, revolutionising our understanding of ice structure, ocean currents and marine ecosystems.

Chapter 5

Implications for global security

5.1 The militarisation of the Arctic

The militarisation of the Arctic in the 21st century represents one of the most significant and dangerous geopolitical transformations in the global strategic landscape. What was traditionally considered an 'ocean of peace' is rapidly turning into a theatre of high-intensity military confrontation, where the world's major powers are deploying increasingly sophisticated weapon systems in an unprecedented arms race in the polar region.

Russia has assumed an undisputed leadership role in this militarisation, transforming the Arctic into a strategic fortress through military investments estimated at over $100 billion over the last decade. Russia's fleet of militarised icebreakers, led by the colossal Ivan Papanin and Nikolai Zubov, is much more than just support vessels: they are veritable floating weapon platforms, equipped with advanced missile systems, state-of-the-art radar and electronic warfare capabilities.

The deployment of Kinzhal and Zircon hypersonic missiles at Russian Arctic bases has radically altered the global strategic balance. These systems, capable of reaching speeds in excess of Mach 9 and equipped with evasive manoeuvring capabilities, can strike targets in Western Europe and North America in timescales that make any traditional defence virtually impossible. The Nagurskoye base, located just 900 kilometres from the North Pole, is home to Tu-95 strategic bombers and MiG-31 interceptor fighters modified for extreme Arctic operations.

Nuclear submarines are perhaps the most dangerous element of this militarisation. Russia has deployed new-generation submarines such as the Knyaz Pozharsky to the Arctic, capable of carrying up to 64 nuclear warheads and operating under the Arctic ice for months without detection. These submarines use silent propulsion technologies and ice-penetrating communication systems that make them virtually invisible to Western detection technologies.

The United States has responded with a massive programme to modernise its Arctic capabilities, after decades of relative disinterest in the region. The new American military doctrine, Arctic Strategy 2024, calls for investments of over $80 billion over the next five years, focused on military icebreakers, satellite surveillance systems and advanced air bases in Alaska.

The THAAD ballistic missile defence system has been upgraded with installations specifically designed to intercept threats from the polar route, the traditional flight corridor for intercontinental ballistic missiles. The Thule Air Base in Greenland has been transformed into a command and control hub, equipped with the most advanced phased array radar systems capable of tracking objects the size of a baseball from thousands of kilometres away.

Canada has launched the 'NORAD Modernisation' programme with investments of 18.4 billion Canadian dollars, focused on surveillance of the Arctic Archipelago and control of the Northwest Passage. The new Harry DeWolf-class Arctic patrol ships are equipped with modular weapon systems and the ability to operate in ice up to 1 metre thick, representing a revolution in Canada's Arctic power projection capabilities.

European militarisation of the Arctic has intensified dramatically with the entry of Sweden and Finland into NATO. These countries bring unique Arctic expertise to the Atlantic Alliance, developed through decades of active neutrality during the Cold War. Finland, in particular, maintains one of the world's most sophisticated Arctic defence doctrines, with underground bunkers, distributed weapons depots and rapid mobilisation systems specifically designed for waging war in extreme conditions.

Hybrid warfare technologies are taking on particular importance in the Arctic. Russia has demonstrated advanced electronic warfare capabilities through systems such as 'Murmansk-BN', capable of disrupting satellite and GPS communications over areas of thousands of square kilometres. These systems can render civilian and military navigation technologies unusable, creating electronic 'dead zones' that isolate entire Arctic regions.

The spatial militarisation of the Arctic represents a new frontier of strategic confrontation. Surveillance and communication satellites have become primary targets, with all Arctic powers developing anti-satellite capabilities. Russia has tested ground-based laser systems capable of 'blinding' reconnaissance satellites, while the US has responded with constellations of 'micro-satellites' that are more difficult to neutralise.

The implications of this militarisation transcend regional boundaries. The Arctic has become the 'third pole' of global strategic confrontation, after Europe and the Indo-Pacific, but with unique characteristics that make it potentially more dangerous. The lack of de-escalation mechanisms, extreme environmental conditions that limit communication, and the proximity of nuclear weapons systems create an explosive cocktail for incidents that could trigger global conflicts.

Militarisation also has devastating impacts on the Arctic environment and local populations. Large-scale military exercises disrupt animal migration routes, while radar and missile installations alter delicate polar ecosystems. Indigenous communities suddenly find themselves surrounded by military installations that transform their ancestral territories into potential battlefields.

5.2 Hybrid warfare and asymmetric threats

The Arctic is the scene of new hybrid conflicts, including cyber attacks on energy infrastructure and espionage.

Russia uses a 'shadow fleet' of oil tankers to circumvent sanctions, turning the region into a laboratory for economic and logistical confrontation.

5.3 The extension of the Ukrainian conflict

Ukrainian military operations extend into the Arctic, with drone attacks on Russian air bases such as Olenya, demonstrating how the Arctic is transforming from a zone of stability into a potential theatre of war.

5.4 Case study: the Kola Peninsula – Land-based downsizing and naval reinforcement

The Kola Peninsula is the epicentre of Russian maritime and nuclear capabilities in the High North. Historically conceived as a hub for the Northern Fleet and a centre of protection for strategic submarines, Kola has played a crucial role as a bastion for maintaining second-strike nuclear capabilities.

With the outbreak of the conflict in Ukraine, the region has undergone a significant reorganisation of operational priorities. Land units stationed on the peninsula have been transferred to the Ukrainian front, suffering significant losses in the early stages of the conflict and contributing to a noticeable weakening of the local land component. Intelligence sources report significant losses by the 200th Separate Brigade and an overall reduction in regional land forces.
At the same time, Russia's response has focused on strengthening its maritime profile: the Northern Fleet has maintained a high level of activity, receiving new-generation naval units and submarines and enhancing the area's air and missile capabilities. The result is a paradoxical strategic configuration: local land capabilities are declining, while maritime and strategic capabilities are further strengthened. This arrangement increases the strategic value of Kola as a crucial node of Russian deterrence, but also accentuates certain vulnerabilities, in particular dependence on the maintenance of port infrastructure and repair yards, and increasing exposure to surveillance and anti-submarine warfare (ASW) activities.
For the West, the operational implications are clear: the need to strengthen maritime and underwater surveillance, improve ASW interoperability with Nordic partners, and protect critical infrastructure (submarine cables, ports, logistics bases). From a political perspective, the presence of strategic assets

in Kola makes the region sensitive to any escalation, requiring de-escalation practices and technical communication channels to reduce the risk of high-intensity incidents.

5.5 The Russian fleet of nuclear icebreakers: Arctic supremacy

Russia maintains undisputed supremacy in the field of nuclear icebreakers, with a fleet that is unrivalled anywhere in the world. Moscow currently has seven nuclear vessels in service - Taymyr, Vaygach, Yamal, 50 Let Pobedy, Arktika, Sibir and Ural - supplemented by several conventional icebreakers. This unique arsenal guarantees the Federation the ability to navigate the Arctic throughout the year, keeping routes operational even in extreme ice conditions.

5.5.1 Future projects and developments

President Vladimir Putin has announced that by 2035, Russia intends to have 13 icebreakers, including nine nuclear ones, as part of its 'Strategy for the Development of the Arctic Zone until 2035'. The programme aims both to exploit Arctic energy and mineral resources and to transform the Northern Sea Route (NSR) into a globally significant trade corridor.
Particular attention is being paid to the construction of three LK-120YA Leader class vessels, equipped with unprecedented power and autonomy, designed to operate even in ice thicker than four metres.

5.5.2 The modern Arktika class

The latest generation is represented by Project 22220, inaugurated with the Arktika unit (which entered service in 2020) and followed by Sibir and Ural. With over 33,000 gross tonnes and a power output of around 60 MW, these universal icebreakers are considered the largest and most powerful in the world. Their 'universal' design allows them to operate both in deep waters and along the shallow coasts of Siberia, significantly increasing the operational versatility of the fleet.

5.5.3 Strategic relevance

Nuclear icebreakers are much more than just civilian tools; they are a real geopolitical asset of threefold importance:

- **Permanent navigation**: They keep Arctic routes open throughout the year, ensuring both commercial and military transit.
- **Access to resources**: They enable the systematic exploitation of the Arctic's energy and mineral wealth, strengthening Russia's energy security and its position in global markets.
- **Projection of influence**: They ensure Russian control over vast swathes of Arctic waters, giving it a lasting competitive advantage over all other international players.

Russia currently remains the only country in the world to systematically operate nuclear-powered icebreakers. This technical and industrial supremacy gives it a long-term strategic advantage both economically and in terms of security, as icebreakers also serve as logistical support platforms for military presence in the Arctic and contribute to control of the Northern Sea Route, transforming a technological resource into an instrument of geopolitical influence.

Chapter 6

The crisis in international cooperation

6.1 The collapse of the Arctic Council

The collapse of the Arctic Council represents one of the most dramatic geopolitical casualties of the war in Ukraine, marking the end of more than three decades of multilateral cooperation that had made the Arctic a unique model of constructive regional diplomacy. Founded in 1996 as a forum for collaboration between the eight Arctic states, the Council had managed to maintain dialogue even during the most tense periods of the Cold War and subsequent post-Soviet crises, but it did not survive Russia's invasion of Ukraine on 24 February 2022.

The suspension of the Council's activities was immediate and total. On 3 March 2022, just one week after the invasion, the seven Western member states (Canada, Denmark, Finland, Iceland, Norway, Sweden and the United States) jointly announced the suspension of all Council activities involving Russia, effectively paralysing the entire organisation, given that Moscow holds about 53% of the Arctic territory and controls the region's most significant resources.

The scientific consequences of this collapse have been catastrophic. Over 150 collaborative research projects were immediately halted, including crucial programmes for climate monitoring, biodiversity protection and maritime safety. The Arctic Climate Impact Assessment, considered the gold standard for polar climate research, can no longer be updated without Russian participation, as Russia controls access to approximately 60% of Arctic weather stations.

The loss of access to Russian research bases has created huge gaps in global climate datasets. Crucial stations such as the one on Wrangel Island, which monitors sea ice in the Chukchi Sea, or the Barentsburg research complex in Svalbard, run by the Russian Arctic and Antarctic Institute, have become inaccessible to Western researchers. These 'black holes' in the data compromise scientists' ability to understand and predict Arctic climate change at a time when such information is most urgently needed.

The Arctic Search and Rescue system, one of the Arctic Council's most concrete achievements, has entered a deep operational crisis. The 2011 SAR agreement had created a coordinated rescue network covering the entire Arctic, but the suspension of cooperation with Russia has left huge "grey" areas where international coordination is impossible. This is particularly dangerous given the increase in Arctic shipping traffic: in 2024, there were over 300 commercial transits through the Northern Sea Route, but without effective SAR coordination.

Research on the protection of Arctic wildlife has suffered dramatic setbacks. Monitoring programmes for migratory species such as polar bears, caribou and various species of seabirds require cross-border cooperation to be effective, as these animals regularly cross Arctic national borders. The 1973 Polar Bear Agreement, one of the first international conservation treaties, is effectively unenforceable without Russian participation.

The economic impacts extend far beyond scientific research. The Arctic Economic Council, an advisory body to the Arctic Council that brought together businesses from all Arctic states, has seen the suspension of energy, mining and logistics projects worth billions of dollars. Established partnerships between Western and Russian companies in natural gas extraction, Arctic technology development and maritime services have been abruptly severed, causing economic losses estimated at over £50 billion.

The paralysis of the Council also hit Arctic indigenous peoples hard, who, through the six 'Permanent Organisations of Indigenous Peoples', had found in the Council a unique platform to make their voices heard internationally. The 'Circumpolar Inuit Council', representing Inuit communities scattered across Alaska, Canada, Greenland and Siberia, suddenly found itself unable to maintain links with Siberian communities, interrupting decades-long cultural exchanges and language preservation programmes.

Attempts to rebuild Arctic cooperation without Russia have proved problematic and incomplete. The "Western Arctic Council," informally constituted by the seven non-Russian members, lacks the legitimacy and geographical representativeness necessary to address challenges that are inherently Arctic and therefore transnational. Initiatives such as the "Arctic Partnership" between the US and Canada and the "Nordic Defence Cooperation" represent partial efforts that cannot replace pan-Arctic cooperation.

Iceland, which holds the rotating chairmanship of the suspended Arctic Council for the period 2023-2025, has attempted to maintain some channels of technical communication with Russia, but under enormous political pressure from its NATO partners. Reykjavik has promoted "track-two diplomacy" through academic and scientific institutions, but with limited results given the climate of geopolitical tension.

The loss of institutional trust goes beyond the simple suspension of formal activities. Thirty years of trust-building among Arctic officials, scientists and economic operators have been wiped out, creating scars that could take generations to heal. The Arctic's reputation as a 'low-tension zone' has been permanently compromised, with implications extending to the governance of other polar regions such as Antarctica.

6.2 Attempts at reconciliation

Under the Norwegian presidency, the Council is slowly reviewing some activities, with Norway at the forefront of maintaining channels of communication with Moscow for environmental monitoring, aware that Russian isolation would undermine indispensable efforts.

6.3 New alliances and partnerships

New coalitions emerge, such as the 'new Hanseatic League' or the Germany-Canada-Norway trilateral for security in Atlantic communications. The European Union intensifies its Arctic strategies, balancing sustainability with geopolitical ambitions.

Chapter 7

The impact on indigenous populations


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Four million people, including Inuit, Sami, Nenets and other communities, live in the Arctic.

Geopolitical transformation is an opportunity for autonomy and development, but also a source of environmental, cultural and health risks.

Their inclusion in decision-making is crucial, thanks to their wealth of ecological knowledge accumulated over thousands of years.

7.1 The mosaic of Arctic populations

The Arctic is home to over 40 distinct indigenous groups, with a total population of around 4 million people spread across eight nations. Each community brings with it millennia of cultural, social and ecological adaptation to one of the most extreme environments on the planet.

7.2 The main indigenous groups

- The ***Inuit*** are the largest and most geographically distributed indigenous population in the Arctic, with approximately 180,000 people spread across Alaska, northern Canada, Greenland and eastern Siberia. Their traditional society is based on hunting seals, caribou and whales, with a system of ecological knowledge that enables survival in extreme conditions.
- The ***Sami***, with approximately 100,000 individuals spread across Norway, Sweden, Finland and Russia, are the only officially recognised indigenous people in the European Union. Their

traditional economy revolves around reindeer herding, fishing and handicrafts, with a strong spiritual component linked to nature.

- The ***Nenets*** of Russian Siberia, numbering around 45,000, maintain a nomadic lifestyle based on reindeer herding. They are considered among the northernmost nomadic herders in the world, with seasonal migrations covering distances of over 1,000 kilometres.
- Other significant groups include the ***Chukchi***, ***Evenk***, and ***Yakut*** in Russia, the ***Gwich'in*** in Alaska and Canada, and numerous other communities, each with specific cultural traditions and systems of territorial governance.

7.3 Positions and concerns of indigenous communities

- Territorial sovereignty and ancestral rights

  Arctic indigenous peoples claim a relationship of sovereignty over their ancestral territories that goes beyond Western concepts of land ownership. For these communities, land is not simply an economic resource, but forms the basis of their cultural, spiritual and social identity.

  The Inuit Circumpolar Council (ICC) has stated: 'We are not stakeholders in our territory, we are rights holders'. This position reflects a view that considers Arctic lands not as national territories to be exploited, but as ancestral homelands with inalienable rights.

  Sami communities have developed the concept of 'Sápmi', the traditional homeland that crosses modern national borders, claiming rights to self-government and natural resource management based on historical treaties and customary practices.

- Opposition to predatory extractivism

  Indigenous peoples express deep concern about extractive projects that threaten their traditional ecosystems. The 2018 'Utqiagvik Declaration', signed by Inuit representatives from across the Arctic, explicitly condemns offshore oil activities that endanger the marine wildlife on which coastal communities depend.

  The Gwich'in of Alaska and Canada have launched an international campaign against drilling in the Arctic National Wildlife Refuge, an area sacred to their culture and vital for caribou migration. Their position is: "The Porcupine Caribou Herd is our food, our culture, our life. Without it, we cease to exist as a people."

  The Nenets communities of the Yamal Peninsula have documented the devastating impacts of the natural gas industry on their traditional pastures, with significant losses of reindeer and alterations to millennia-old migration routes.

- Climate change: primary victims and privileged witnesses

  Arctic indigenous peoples are among the first victims of climate change, but they are also the most qualified witnesses to the environmental transformations underway. Their empirical observations often precede official scientific data by years.

  For decades, Inuit elders have documented changes in sea ice patterns, animal migrations and weather phenomena that are now confirmed by climate science. Sheila Watt-Cloutier, an Inuit activist and Nobel Prize nominee, has called climate change 'a violation of fundamental human rights' for Arctic peoples.

  The Sami observe dramatic changes in freeze-thaw cycles that make traditional reindeer feeding impossible, with devastating economic and cultural impacts. Rain-on-snow phenomena create impenetrable ice crusts that prevent reindeer from reaching their food.

- Governance and decision-making participation

  Indigenous peoples claim the right to 'free, prior and informed consultation' on all projects affecting their territories, as established by the 2007 UN Declaration on the Rights of Indigenous Peoples.

The Arctic Council, the only international forum dedicated to the region, recognises six indigenous organisations as 'permanent participants' with special status. However, many communities complain that this role remains largely advisory, with no binding decision-making power.

Indigenous organisations are demanding:
- 'veto power' over extractive projects in their territories;
- 'co-management' of protected areas and natural resources;
- 'direct representation' in international negotiations on the Arctic;
- 'legal recognition' of their traditional governance institutions.

7.4 Traditional ecological knowledge: a strategic asset

Millennial knowledge systems

Arctic indigenous peoples have developed some of the most sophisticated ecological knowledge systems in the world, based on empirical observations accumulated over millennia. This knowledge includes:
- “traditional weather forecasting”: the Inuit use over 100 different terms to describe sea ice conditions, enabling safe navigation in conditions that would be deadly for outside observers;
- 'sustainable resource management': traditional hunting systems include self-regulating mechanisms that have maintained ecological balance for millennia. The Sami practise grazing rotations that prevent overgrazing;
- “traditional medicine”: Arctic peoples have identified the medicinal properties of hundreds of plants and natural substances, many of which are now being studied by modern pharmacology;
- “astronomy and navigation”: traditional orientation systems use stars, winds, currents and ice patterns for precise navigation over thousands of kilometres.

7.5 Integration with modern science

Numerous scientific projects are demonstrating the value of traditional knowledge for understanding Arctic environmental change:
- the SIKU Project integrates Inuit observations with GPS and satellite technologies to monitor sea ice conditions in real time;
- Reindeer Husbandry Climate Research combines Sami knowledge with climate models to predict the impact of environmental changes on pastures;
- Community-Based Monitoring involves indigenous hunters and herders in collecting scientific data on Arctic wildlife, producing more accurate and continuous datasets than those obtainable by conventional methods.

7.6 Resilience and adaptation strategies

▪ International mobilisation

  Arctic indigenous peoples have developed sophisticated international advocacy strategies, using multilateral forums to amplify their voices:
  - *participation in climate COPs*: Arctic indigenous representatives have become key players in international climate negotiations, bringing direct testimony of the impacts of climate change;
  - *transnational alliances*: the Arctic indigenous movement has created solidarity networks that transcend national borders, coordinating common resistance strategies;
  - *global media campaigns*: strategic use of social media and international channels to raise global public awareness of indigenous rights in the Arctic.

▪ Alternative economic initiatives

  Many communities are developing sustainable economic models that value their traditional knowledge:
  - *Responsible cultural tourism*: programmes that allow visitors to experience indigenous culture while respecting community protocols;

- *certification of traditional products*: quality labels for traditional indigenous crafts and food products;
- *environmental consulting services*: use of traditional ecological knowledge for environmental research and monitoring projects;
- *community renewable energy*: community-managed wind and solar energy projects to reduce dependence on expensive fossil fuels.

▪ Cultural revitalisation

Indigenous peoples are investing heavily in the preservation and revitalisation of their cultures:
- *language programmes*: initiatives to keep indigenous languages alive, many of which are at risk of extinction;
- *traditional education*: schools that integrate Western and traditional knowledge, training new generations capable of navigating both worlds;
- *ceremonial practices*: revitalisation of traditional ceremonies and spiritual practices as a tool for community cohesion.

7.7 Multidimensional impacts of geopolitical pressures

▪ Health impacts

The industrialisation of the Arctic has had dramatic health consequences for indigenous populations:
- *food contamination*: high levels of mercury, PCBs and other persistent contaminants in marine mammals, the basis of the traditional Inuit diet;
- *respiratory problems*: air pollution from industrial and shipping activities causes increases in asthma and other respiratory diseases;
- *mental health*: the erosion of traditional cultural practices and the loss of connection with the land cause high rates of depression and suicide, particularly among young people;
- *Food security*: climate change and restrictions on traditional hunting activities threaten the food security of remote communities.

▪ Cultural impacts

Geopolitical pressure on the Arctic threatens the cultural continuity of indigenous peoples:
- *loss of traditional knowledge*: the death of elders and the interruption of intergenerational transmission cause the irreversible loss of millennia-old knowledge;
- *Cultural homogenisation*: assimilationist pressures from national governments and globalisation are eroding local cultural distinctiveness.
- *Territorial sacredness*: the desacralisation of spiritually significant sites through industrial activities represents a profound violation of indigenous identity.

▪ Socio-economic impacts

Economic transformations in the Arctic are creating new forms of marginalisation:
- *dual economy*: the creation of capital-intensive extractive economies that exclude local populations from the benefits;
- *local inflation*: the arrival of high-wage industrial workers causes inflation that makes basic necessities unaffordable for local populations;
- *external dependence*: erosion of traditional food and economic self-sufficiency, creating dependence on vulnerable external economic systems.

7.8 Proposals and demands of indigenous peoples

▪ International legal framework

Arctic indigenous organisations are calling for:
- an *international treaty on indigenous rights in the Arctic*: a binding agreement recognising the territorial and self-government rights of indigenous peoples;

- an *international tribunal for indigenous rights*: a specialised international justice mechanism for violations of indigenous rights;
- *binding consultation protocols*: mandatory procedures for prior consultation on all projects affecting indigenous territories.

- Co-management models

  Indigenous communities propose models of territorial management that combine indigenous sovereignty and state governance:
  - *indigenous protected areas*: territories managed exclusively by indigenous peoples according to their traditional governance systems;
  - *co-management zones*: areas where the government and indigenous communities share decision-making authority on an equal basis;
  - *protected migration corridors*: legal protection of traditional animal migration routes that are essential for indigenous livelihoods.

- Sustainable indigenous economy

  Proposals include:
  - *indigenous development funds*: financial resources dedicated exclusively to development projects defined and managed by indigenous communities;
  - *markets for traditional products*: certification and marketing systems that promote products from the traditional indigenous economy;
  - *payments for ecosystem services*: economic recognition of the role of indigenous peoples in environmental conservation;
  - *appropriate technologies*: development of technologies that respect indigenous cultural values and strengthen the traditional economy.

Communities in Alaska combine tradition and technology to develop resilient infrastructure and new agricultural practices. However, risks remain related to permafrost thaw, sea level rise and emerging diseases.

7.9 Towards a fair and sustainable Arctic

The indigenous peoples of the Arctic are not simply "stakeholders" to be consulted in geopolitical decisions about the region, but are the legitimate custodians of ancestral territories with inalienable rights. Their meaningful inclusion in decision-making processes is not only a matter of social justice, but a strategic necessity for any sustainable governance of the Arctic.

Their millennia-old ecological knowledge, their experience in sustainable resource management and their deep understanding of Arctic ecosystems are indispensable strategic resources for addressing the environmental challenges of the 21st century.

The future of the Arctic will depend on the international community's ability to recognise and respect the rights of indigenous peoples, transforming the current extractive model into a paradigm of sustainable development based on environmental justice and partnership with the true custodians of the Arctic.

Only through this approach will it be possible to prevent the Arctic's 'new strategic frontier' from becoming yet another area of colonial plunder, instead building a model of regional governance that can serve as an example for a more just and sustainable world.

Chapter 8

Technological innovations and scientific research

8.1 Advanced monitoring systems

Floating laboratories such as the Tara Polar Station collect data in the most remote areas.

Artificial intelligence analyses millions of satellite images, revealing record retreats of sea ice.

8.2 Arctic biotechnology

Arctic biotechnology represents one of the most promising and unexplored scientific frontiers of the 21st century, where the extreme conditions of the polar environment have selected organisms with extraordinary biological capabilities that are revolutionising sectors ranging from medicine to food technology, from conservation to industrial production.

Arctic organisms have developed unique survival strategies that challenge the traditional limits of life on Earth. Antifreeze proteins (AFP) are perhaps the most revolutionary discovery in this field. These molecules, found in Arctic fish such as polar cod, psychrophilic bacteria and ice algae, can lower the freezing point of body fluids to -1.9 °C without significantly altering their boiling point, a phenomenon that violates the traditional laws of thermodynamics.

The molecular structure of AFPs is astonishingly elegant: they use hydrogen bonds to selectively bind water molecules in ice formation, preventing the growth of crystals that would damage cells. This technology has revolutionary applications in the preservation of organs for transplantation: while organs can currently be stored for only a few hours, the integration of AFPs could extend this period to days or weeks, saving thousands of lives through a completely redesigned transplant logistics system.

The food industry is experimenting with the use of AFP to create ice creams that do not form ice crystals even after months of storage, maintaining their creamy texture and flavour. Companies such as Unilever have invested over £150 million in the development of these technologies, which could revolutionise the global cold chain by reducing food waste estimated at £30 billion annually.

Arctic psychrophilic bacteria, organisms that thrive at sub-zero temperatures, are providing revolutionary enzymes for the biotechnology industry. 'Cold lipases' extracted from Antarctic bacteria maintain their enzymatic activity at temperatures that would completely inactivate conventional enzymes. This enables low-energy industrial processes for the production of biodiesel, eco-friendly detergents and pharmaceuticals.

Research on *Arctic tardigrades*, microorganisms capable of surviving in space and lethal radiation, is opening up incredible perspectives for regenerative medicine. These organisms, nicknamed "water bears," can enter a state of "cryptobiosis" where all metabolic processes stop, only to "resurrect" completely when conditions improve. The molecular mechanisms that enable this 'resurrection' are the subject of intense research for applications in human tissue preservation and the fight against ageing.

Arctic archaea, primitive microorganisms that represent one of the three major divisions of life on Earth, produce chemical compounds that cannot be synthesised artificially. Some species produce "living metals," biologically active metal nanoparticles that could revolutionise organic electronics and drug delivery systems. Other archaea generate "natural l polymerisers" capable of creating biodegradable plastic at room temperature using only CO_2 and water as raw materials.

The discovery of *giant viruses* in Arctic subglacial lakes is redefining our understanding of microbial life. These viruses, which are as large as bacteria and have complex genomes, appear to play crucial roles in the Arctic microbial ecosystem. Some species of giant viruses produce self-assembling "structural proteins" that could be used to create biological building materials, smart fabrics or organic data storage systems.

Arctic algae represent a biological goldmine for the sustainable production of fuels, food and materials. Species such as Chlamydomonas nivalis can grow on snow and ice, producing oils rich in omega-3 fatty acids without requiring arable land or fresh water. A single tonne of these algae can produce up to 300 litres of biofuel while absorbing 2 tonnes of CO_2 from the atmosphere.

Arctic *cryoprotecogenomics* is identifying genes responsible for cold resistance that could be transferred to agricultural crops, allowing cultivation in regions previously unsuitable for agriculture. Russian researchers have isolated genes from Siberian bacteria that, when inserted into tomato plants, allow them to survive temperatures of -6°C, opening up possibilities for expanding agriculture to polar regions.

Arctic pharmacogenomics has identified bioactive compounds in polar organisms that exhibit extraordinary anti-tumour, antiviral and neuroprotective properties. 'Arctic bryostatin', extracted from bryozoans that grow on frozen seabeds, has shown efficacy against Alzheimer's disease in preliminary clinical trials, opening up new hope for neurodegenerative diseases considered incurable.

8.3 Archives for the future

The Svalbard Global Seed Vault stores agricultural seeds from around the world as a safeguard against future crises; the Arctic World Archive protects digitised cultural works, including manuscripts and historical monuments.

Chapter 9

Emerging health and environmental challenges

9.1 New health threats to the environment

The thawing of Arctic permafrost is releasing a 'biological Pandora's box' of ancient pathogens, viruses, bacteria and parasites that have been frozen for millennia and now threaten unprepared ecosystems and global populations lacking natural immunity. This health threat is one of the most disturbing and unpredictable consequences of climate change, transforming the Arctic from a remote region into a potential epicentre of global health crises.

'Zombie viruses' represent the most spectacular and media-friendly threat, but also the most potentially devastating. In 2024, French researchers reactivated 13 different viruses extracted from Siberian permafrost, some of which had been dormant for over 48,000 years. These 'giant amoeba viruses', although currently only capable of infecting single-celled organisms, demonstrate an extraordinary capacity for survival and adaptation that is deeply worrying to the scientific community.

The risk lies not so much in the viruses currently identified, but in the possibility that thawing could release pathogens completely unknown to modern medicine. The contemporary human immune system has never encountered these pathogens, leaving humanity potentially vulnerable to pandemics for which there are no vaccines, treatments or even simple scientific understanding.

More concrete and immediate is the threat posed by pathogenic bacteria preserved in the permafrost. In 2016, an anthrax outbreak in Siberia was caused by the release of bacterial spores from a reindeer carcass that had been frozen for over 70 years. The episode resulted in the death of over 2,000 reindeer, the hospitalisation of 13 people and required the emergency vaccination of 63,000 domestic animals. This event demonstrated that the threat is not theoretical, but real and present.

Climate change is also dramatically altering the distribution patterns of vector-borne diseases in the Arctic. Mosquitoes, ticks and other arthropods are expanding their range northwards at astonishing speeds, bringing tropical diseases to regions that were historically immune to them. Lyme disease, previously confined to temperate regions, was diagnosed for the first time in Inuit communities in northern Alaska in 2023, signalling an unprecedented geographical expansion.

Arctic wildlife is experiencing devastating health impacts that reflect the vulnerability of polar ecosystems to new biological pressures. Polar bears are showing increasing rates of trichinella and other parasites previously rare in their diet, a direct consequence of changes in prey populations and the marine ecosystem. Arctic seals are exhibiting previously undocumented skin lesions and respiratory infections, likely linked to exposure to pathogens released from thawing permafrost.

Caribou and reindeer are experiencing recurrent outbreaks of diseases previously controlled by extreme climatic conditions. Brucellosis and other bacterial infections, once limited by harsh winters that eliminated vectors, now persist year-round, causing massive mortality that threatens the livelihoods of indigenous communities that depend on these animals.

Of particular concern is the emergence of fungal infections in the Arctic, an environment historically hostile to most pathogenic fungi. White-nose syndrome, a bat-killing fungus that has decimated North American populations, is spreading to Arctic regions, where migratory bats could serve as vectors for completely vulnerable animal communities.

Indigenous Arctic populations are on the front line of this emerging health crisis. Their traditional diet, based on subsistence hunting and fishing, exposes them directly to pathogens concentrated in the local fauna. In addition, geographical isolation and limited health infrastructure make these communities particularly vulnerable to epidemics that could be managed more effectively in urban settings.

Rising temperatures are promoting the proliferation of toxic algae in Arctic waters that were previously too cold to support these species. Blue-green algae blooms produce toxins that accumulate in the food chain, causing poisoning in marine mammals and potentially in humans who consume local fish and shellfish.

Arctic epidemiological surveillance systems are dramatically inadequate to address these emerging threats. The vastness of the territory, extreme climatic conditions and scarcity of specialised medical personnel create 'blind spots' where epidemics could develop and spread before being detected. The lack of diagnostic laboratories equipped to identify unknown pathogens further exacerbates the risk.

'Climate-related emerging diseases' are affecting previously resistant Arctic species. The 'seal pox virus' has caused massive epidemics among Bering Sea seals, while new strains of 'avian influenza' are spreading through Arctic seabird colonies, threatening to make a species jump to mammals and potentially humans.

9.2 Pollution and contamination

Despite its remote geographical location, the Arctic has become the final destination for global pollutants, through atmospheric and oceanic processes that transport contaminants from all over the planet to the poles. This phenomenon, known as the 'cold condensation effect', concentrates persistent pollutants in the Arctic that evaporate in warm regions and condense in cold ones, creating an environmental paradox where the most uncontaminated regions of the planet host the highest concentrations of toxic substances.

Microplastics are one of the most pervasive and disturbing contaminants in the contemporary Arctic. Studies in 2024 found concentrations of microplastics in Arctic sea ice of up to 12,000 particles per litre, levels higher than those found in many coastal urban areas. These particles, mainly derived from industrial and domestic activities around the world, reach the Arctic through ocean currents and atmospheric deposition.

The process of microplastic contamination is particularly insidious in the Arctic because sea ice acts as a 'concentrating trap'. During ice formation, microplastics become trapped in the crystalline matrix and concentrated in brine pockets. When the ice melts, these concentrations are released in massive bursts into the marine ecosystem, creating contamination spikes that can be lethal to small marine organisms.

The Arctic food chain is accumulating microplastics at alarming levels. Arctic copepods, the basis of the marine food chain, ingest microplastics, mistaking them for phytoplankton, and accumulate particles in their digestive system that they cannot expel. These contaminated copepods are consumed by Arctic fish, which in turn are preyed upon by seals, polar bears and humans, creating a process of biomagnification that concentrates microplastics at the upper levels of the food chain.

Mercury is perhaps the most studied and dramatic contaminant in the Arctic. This heavy metal reaches the polar regions mainly through atmospheric deposition from global industrial activities, particularly coal combustion. Once deposited in the Arctic environment, mercury undergoes chemical transformations that make it highly bioaccumulative.

Methylmercury, the most toxic form of this element, is formed through bacterial processes in permafrost and marine sediments. The methylmercury produced accumulates dramatically in the Arctic food chain: while seawater contains mercury concentrations in the order of nanograms per litre, polar bear tissue can contain millions of times more, reaching levels that are toxic for reproduction and neurological development.

Arctic indigenous populations, who depend on a traditional diet based on marine mammals and fish, have some of the highest levels of mercury in their blood documented globally. Studies conducted on Inuit communities in Greenland have found mercury concentrations in blood 10-20 times higher than the levels considered safe by the World Health Organisation, with documented consequences on child cognitive development and adult cardiovascular health.

The phenomenon of 'mercury depletion events' in the Arctic is one of the most spectacular and worrying contamination processes. During the Arctic spring, photochemical reactions catalysed by ice crystals convert atmospheric mercury into highly reactive forms that are deposited heavily on the snow surface. In a matter of hours, entire Arctic regions can receive mercury deposits equivalent to months of normal accumulation, creating hotspots of extreme contamination.

Persistent organic pollutants (POPs) are another critical category of Arctic contaminants. Substances such as PCBs (polychlorinated biphenyls), DDT and the more modern PFAS (per- and polyfluoroalkyl substances) reach the Arctic through long-range atmospheric transport and accumulate in the fatty tissues of Arctic organisms.

Polar bears, at the top of the Arctic food chain, have some of the highest concentrations of POPs ever documented in wildlife. Female polar bears in Svalbard have PCB levels in their fatty tissue exceeding 50 mg/kg, concentrations that cause endocrine disruption, immunosuppression and reproductive problems. These contaminants are transferred to cubs through breast milk, perpetuating contamination across generations.

The release of contaminants from thawing permafrost is an emerging and poorly understood threat. For millennia, permafrost has acted as a natural freezer, preserving not only organic carbon but also industrial pollutants deposited in the Arctic during decades of human activity. The melting of permafrost is now releasing these 'legacy' contaminants, including heavy metals, POPs and even radioactive substances generated by nuclear testing in the 1950s and 1960s.

The Arctic shipping industry is introducing new forms of pollution through the release of contaminated ballast water, black carbon emissions from ship engines, and accidental fuel spills. Black carbon is particularly dangerous in the Arctic because the dark particles settle on snow and ice, reducing albedo and accelerating melting. A single ship transiting the Northern Sea Route can deposit black carbon over hundreds of square kilometres of ice surface.

Noise pollution is an often overlooked but increasingly significant form of pollution in the Arctic. Growing shipping traffic, oil exploration activities using seismic air guns, and military installations are creating underwater 'background noise' that interferes with the communication of Arctic marine mammals. Whales, seals and narwhals depend on acoustic communication for navigation, feeding and reproduction, and noise pollution can alter behaviours that are crucial to their survival.

Chapter 10

Future perspectives and possible scenarios

10.1 Climate scenarios

By 2050, the Arctic ecosystem will undergo irreversible changes of such magnitude that they will completely transform the polar region, with traditional species being replaced by different biological communities in what scientists describe as a 'regime shift' unprecedented in recent climate history.

The most up-to-date climate projections outline three main scenarios that depend on global emission trajectories and the effectiveness of mitigation measures implemented over the coming decades. In *the most optimistic scenario* (RCP 2.6), which envisages a drastic reduction in global emissions by 2030, the Arctic would still lose about 60% of its summer sea ice by 2050, with average temperatures rising by 3-4 °C above pre-industrial levels. Even in this 'best' scenario, the transformation of Arctic ecosystems would be dramatic and largely irreversible.

The *intermediate scenario* (RCP 4.5) envisages a completely ice-free Arctic summer by 2040, with warming of 5-6 °C leading to the complete transformation of the tundra into boreal forests over vast areas of northern Canada, Alaska and Siberia. The Arctic treeline would shift 500-700 kilometres northwards, eliminating the traditional habitats of caribou, reindeer and numerous species of Arctic birds.

The *worst-case scenario* (RCP 8.5), which reflects the current global emissions trajectory, envisages a systemic collapse of the Arctic ecosystem by 2045. In this catastrophic scenario, Arctic warming would reach 7-9 °C, triggering massive carbon release from permafrost, which would further amplify global warming through uncontrollable positive feedbacks.

The possible collapse of *the Atlantic Meridional Overturning Circulation* (AMOC) is perhaps the most serious climate risk associated with Arctic change. The AMOC, which transports around 15 million cubic metres of warm water per second to Europe, is already slowing by 15% compared to 1950 levels. Climate models suggest a 40-60% probability of partial collapse by 2060, which could cause catastrophic climate disruption in Europe and Asia.

A collapse of the AMOC would result in a 3-5 °C cooling in north-western Europe, paradoxically in the context of accelerated global warming. This would create a 'climate dipole' with a colder, drier Europe and a warmer, wetter South Asia, destabilising the monsoons that impact the food and water balance of over 2 billion people. Rainfall in Europe would be reduced by 20-30%, turning vast agricultural areas into semi-deserts.

The *accelerated desalination* of the Arctic Ocean, caused by the massive melting of land and sea ice, is altering the density of ocean water in ways that could trigger irreversible changes in global ocean circulation. Recent models suggest that by 2040, the influx of approximately 10,000 cubic kilometres of fresh water per year into the Arctic oceans could create a 'lens' of fresh water up to 200 metres thick that would block deep water formation, a key mechanism of thermohaline circulation.

Arctic acidification is proceeding at twice the global average rate, with ocean pH already decreasing by 0.3 units compared to pre-industrial levels. By 2050, a further reduction of 0.4 units is expected, which would make the Arctic Ocean corrosive to the shells of molluscs and crustaceans, causing the collapse of entire marine food chains. This phenomenon would hit indigenous populations who depend on these species for their livelihoods particularly hard.

Arctic storms are increasing in frequency and intensity, with extreme events now reaching intensities comparable to tropical hurricanes. The phenomenon of 'Arctic cyclones' could become regular by 2040, with storm systems generating 15-20 metre waves that would devastate coastal and naval infrastructure. These extreme events would make new Arctic trade routes increasingly dangerous, paradoxically limiting the economic benefits of ice melt.

The northward *migration of species* is accelerating at a rate of 6-8 kilometres per year, twice the speed recorded in the 1990s. Sub-Arctic species are colonising Arctic ecosystems, bringing with them diseases and parasites against which native species have no defences. This 'biological invasion' could lead to the extinction of iconic species such as polar bears, narwhals and numerous species of Arctic seals by 2070.

Arctic climate *tipping points* show dangerous interconnections that could trigger cascades of systemic collapse. Exceeding the critical threshold of 2°C of Arctic warming, now inevitable by 2030, could trigger the collapse of the Thwaites Glacier in Antarctica through ocean teleconnection mechanisms, causing a sea level rise of 60 centimetres by 2100.

10.2 Geopolitical developments

The geopolitical evolution of the Arctic in the coming decades will see the emergence of new global players that will completely redraw the balance of power in the region, transforming it from the exclusive domain of the eight Arctic nations to a theatre of multipolar competition involving emerging powers, international organisations and non-state actors in a complex network of alliances, rivalries and interdependencies.

India is emerging as one of the most unexpected protagonists in Arctic geopolitics, motivated by the need to diversify its energy sources and access new polar trade routes that could drastically reduce transport costs with Europe. New Delhi has invested over $2 billion in Arctic projects over the past five years, including participation in Russia's Vostok Oil project and the acquisition of significant stakes in liquefied natural gas projects in the Barents Sea.

India's strategy combines scientific soft power and economic hard power. The Himadri research station in Svalbard was expanded in 2024 with investments of $150 million, transforming it into one of the most advanced climate research centres in the Arctic. At the same time, Indian companies such as ONGC Videsh and Reliance Industries have signed joint venture agreements with Russian companies for offshore Arctic oil exploration, positioning India as Moscow's strategic energy partner in the region.

South Korea is pursuing an ambitious 'Arctic Strategy 2050' that aims to position the country as a technology hub for sustainable Arctic development. Seoul has invested $5 billion in technologies for polar navigation, Arctic shipbuilding and cold-resistant smart cities. The South Korean programme includes the construction of 15 new-generation icebreakers by 2035 and the development of technologies for the sustainable extraction of Arctic resources.

The military dimension of South Korea's strategy is more subtle but significant: Seoul is developing polar satellite surveillance capabilities and quantum communication systems resistant to the electromagnetic interference typical of Arctic regions. These technological investments position South Korea as a potential strategic partner for both the United States and Russia, depending on future geopolitical configurations.

Japan has launched its 'Arctic Ocean Policy 2025', which combines scientific, economic and strategic interests. Tokyo has allocated $3 billion for Arctic marine research projects and the development of technologies for extracting methane gas from underwater hydrates. Japan's partnership with Norway for the development of carbon capture and storage technologies in the Arctic is a model of technological cooperation that could be replicated with other regional players.

The 'spatial dimension' of Arctic competition is becoming increasingly important. The European Union's Arctic Watch satellite constellation, launched in 2024 with 24 satellites dedicated to polar monitoring, competes directly with similar Chinese, Russian and American systems. This ' ' Arctic space race includes the development of quantum satellite communication systems, hyperspectral observation technologies and nanosatellite networks for real-time environmental monitoring.

The possibility of *limited cooperation* between the US and Russia in the Arctic remains one of the most uncertain but potentially transformative scenarios. Sectors such as search and rescue, environmental monitoring and scientific research could offer opportunities for collaboration even in the context of broader geopolitical tensions. The Arctic Science Diplomacy Initiative proposed by some think tanks envisages the creation of 'scientific cooperation zones' where researchers from both countries could collaborate on specific projects despite bilateral sanctions.

Transnational cooperation scenarios could emerge around specific crises, such as environmental disasters, humanitarian emergencies or maritime accidents that would require immediate operational coordination. Joint management of shipping traffic through Arctic routes, which is essential for preventing accidents and pollution, could be an area of common interest that transcends political divisions.

The European Union's growing role in the Arctic is taking shape through the Arctic Partnership Policy, which combines green diplomacy, infrastructure investment and cultural soft power. Brussels has allocated €7 billion for the period 2025-2030 for Arctic energy transition projects, sustainable development and support for indigenous peoples. The European strategy aims to position the EU as a 'regulatory power' in the Arctic, promoting environmental standards and human rights that could become global benchmarks.

Arctic city diplomacy is an emerging phenomenon through which Arctic urban centres such as Reykjavik, Tromsø, Fairbanks and Murmansk are developing direct cooperation networks that bypass national governments. These 'sister cities networks' facilitate technological, cultural and economic exchanges that could create bottom-up interdependencies, influencing national policies.

The emergence of transnational *Arctic economic corridors* is redefining regional economic geographies. China's 'Polar Silk Road' is integrating with Russian, Scandinavian and North American infrastructure projects, creating an integrated network of transport, communications and energy flows that could make the Arctic the 'Mediterranean of the 21st century' for global trade.

Indigenous organisations are gaining increasing geopolitical influence, acting as 'soft power' for their respective nation states but also developing autonomous agendas that transcend state borders. The 'Circumpolar Indigenous Forum 2025' has proposed the creation of an 'Indigenous Arctic Passport' that would facilitate the cross-border mobility of native populations, challenging traditional concepts of state sovereignty.

Fragmentation scenarios could emerge if global geopolitical tensions intensify further. The regionalisation of the Arctic into distinct "spheres of influence" – a Russian-Chinese bloc in the east, a NATO-EU bloc in the west, and grey zones of competition in the centre – could create new dividing lines that would make integrated governance of transnational challenges such as climate change and environmental conservation impossible.

However, scenarios of *competitive cooperation* seem more likely, where strategic competition and functional cooperation coexist in different sectors. This form of hybrid governance could see military and economic rivalries accompanied by collaboration in technical areas such as meteorology, oceanography, and marine biology, which are essential for the safety and sustainability of all Arctic activities.

10.3 Technological challenges

The development of year-round navigation technologies in Arctic waters is crucial.
Russia and China are collaborating to build a new generation of ARC7 class container ships, with the first expected in 2027.

Arctic data centres, which exploit the natural cold for efficiency, are opening up new industrial perspectives.

10.4 Scenario: multilateral cooperation

Strengthened institutions, sustainable management, indigenous inclusion, economic sharing and environmental protection.

10.5 Scenario: controlled competition

Regional spheres of influence, regulated arms race, selective cooperation, intensive but limited exploitation.

10.5 Scenario: conflict and fragmentation

Military escalation, collapse of cooperation, unregulated exploitation, humanitarian crises.

Conclusions

The Arctic as a mirror of the global future

The Arctic is emerging as a living laboratory where global climate, technological and geopolitical changes are amplified. It is a region of extraordinary economic opportunities and growing strategic tensions.

The crisis in Arctic cooperation highlights profound limitations in international governance mechanisms, but also the possibility of new functional models that separate scientific dialogue from political disputes.

The paradox of 'green colonialism' raises ethical questions about climate justice and indigenous rights, given that the resources that could support the energy transition are being exploited thanks to climate change that threatens local communities.

The urgency for coordinated action is growing by the day, with windows of opportunity rapidly closing.

A new governance paradigm is needed that combines environmental sustainability, social justice and geopolitical stability, recognising the shared planetary responsibility in addressing this epochal transformation.

Decisions on the Arctic will shape the global climate and geopolitical destiny, with the whole of humanity called upon to respond to this crucial challenge.

Giovanni Tonini and Cecilia Sandroni
Florence, 31 August 2025

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Methodological notes

This bibliography has been compiled with a focus on:

1. Peer-reviewed academic sources published by recognised publishers
2. Reports from official international organisations
3. Primary source government documents
4. Research published in the last 15 years to ensure topicality
5. Geographical diversification of sources to avoid regional bias

All sources are verifiable and accessible through academic databases or institutional archives. The thematic breakdown facilitates consultation and allows for quick identification of the most appropriate sources for specific areas of research.