Navigating Collaborative Futures

Expert Panel on International Science, Technology, Innovation, and Knowledge Partnerships

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Council of Canadian Academies
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This project was undertaken with the approval of the Board of Directors of the Council of Canadian Academies (CCA). The members of the expert panel responsible for this report were selected by the CCA for their special competencies and with regard for appropriate balance.

This report responds to a request from Global Affairs Canada (GAC) for an independent assessment. GAC was not involved in either panel selection or report development; any opinions, findings, or conclusions expressed in this publication are those of the authors, the Expert Panel on International Science, Technology, Innovation, and Knowledge Partnerships, and do not necessarily represent the views of their organizations of affiliation or employment.

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The Expert Panel on International Science, Technology, Innovation, and Knowledge Partnerships would like to acknowledge the First Nations, Inuit, and Métis peoples who have stewarded the lands now known as Canada since time immemorial.

The Council of Canadian Academies (CCA) acknowledges that our Ottawa offices are located on the unceded, unsurrendered ancestral home of the Anishinaabe Algonquin Nation, who have cared for the environment of this territory for millennia. Though our offices are in a single location, our work to support evidence-informed decision-making has potentially broad impacts across Canada. We at the CCA recognize the importance of drawing on a wide range of knowledges and experiences to inform policies that will build a stronger, more equitable, and more just society.

The CCA

The CCA is a not-for-profit organization that supports independent, science-based, authoritative expert assessments to inform public policy development in Canada. Led by a Board of Directors and advised by a Scientific Advisory Committee, the CCA's work encompasses a broad definition of science, incorporating the natural, social, and health sciences as well as engineering and the humanities. CCA assessments are conducted by independent, multidisciplinary panels of experts from across Canada and abroad. Assessments strive to identify emerging issues, gaps in knowledge, Canadian strengths, and international trends and practices. Upon completion, assessments provide government decision-makers, researchers, and stakeholders with high-quality information required to develop informed and innovative public policy.

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Expert Panel on International Science, Technology, Innovation, and Knowledge Partnerships

Under the guidance of its Scientific Advisory Committee and Board of Directors, the CCA assembled the **Expert Panel on International Science, Technology, Innovation, and Knowledge Partnerships** to undertake this project. Each member was selected for their expertise, experience, and demonstrated leadership in fields relevant to this project.

Monica Gattinger (Chair), Director, Institute for Science, Society and Policy; Full Professor, University of Ottawa (Ottawa, ON)

Stewart Beck, Distinguished Fellow, Asia Pacific Foundation of Canada; Fellow, Canadian Global Affairs Institute (Vancouver, BC)

Paul A. Berkman, Founder and President, Science Diplomacy Center; Senior Fellow, United Nations Institute for Training and Research; Faculty Associate, Program on Negotiation, Harvard Law School; Associate Director of Science Diplomacy, Harvard-MIT Public Disputes Program (Falmouth, MA)

Karen Croteau, Partner, Goss Gilroy Inc. (Ottawa, ON)

Paul Dufour, Principal, PaulicyWorks (Gatineau, QC)

Meredith Lilly, Associate Professor and Simon Reisman Chair in International Economic Policy, Norman Paterson School of International Affairs, Carleton University (Ottawa, ON)

David Perry, President & Senior Analyst, Canadian Global Affairs Institute (Ottawa, ON)

Caroline S. Wagner, Professor, John Glenn College of Public Affairs, Ohio State University (Columbus, OH)

Jennifer Welsh, Canada 150 Research Chair in Global Governance and Security; Director of the Centre for International Peace and Security Studies; Professor, McGill University (Montréal, QC)

The CCA also recognizes the contributions of **David Audretsch,** Distinguished Professor; Ameritech Chair of Economic Development; Director, Institute for Development Strategies, Indiana University (Bloomington, IN) and **Peggy van de Plassche,** Founder and CEO, Roar Growth (Toronto, ON).

Workshop Participants and Guest Speakers

As part of the evidence-gathering process, the expert panel convened a workshop, which brought together its own members and an additional nine experts. Additionally, the panel engaged with a series of guest speakers.

Heather Chalmers, President and Chief Executive Officer, GE Canada

Mehrdad Hariri, Founder and CEO, Canadian Science Policy Centre

The Right Honourable David Johnston, P.C., C.C., C.M.M. C.O.M., C.D., FRSC, former Governor General of Canada and Chair of the Rideau Hall Foundation

John Knubley, former Deputy Minister, Innovation, Science and Economic Development Canada

Lisa Koperqualuk, President, Inuit Circumpolar Council Canada

Valérie La Traverse, Vice President, Corporate Affairs, Social Sciences and Humanities Research Council

Pooja Shree Mishra, Scientist and Senior Data Analyst, Public Health Agency of Canada

David Moorman, Senior Policy Advisor, U15 Group of Canadian Research Universities

Marie-Lucie Morin, P.C., O.C., former National Security Advisor

Chidi Oguamanam, Professor, Faculty of Law (Common Law Section), University of Ottawa

Rémi Quirion, O.C., C.Q., Chief Scientist of Québec

Nigel J.T. Smith, Executive Director, TRIUMF

Éliane Ubalijoro, Global Hub Director, Canada, Future Earth; Executive Director, Sustainability in the Digital Age

Robert (Bob) Walker, Senior Fellow, Institute for Science, Society and Policy, University of Ottawa

David B. Watters, President, Global Advantage Consulting Group

Robert (Bob) Watts, Vice President, Indigenous Relations and Strategic Programs, Nuclear Waste Management Organization

Carl Weatherell, Executive Director and CEO, Canada Mining Innovation Council; President, ReThink Mining Ventures

Interviewees

CCA staff also conducted interviews with officials at the following member organizations of the Interdepartmental Network for International Science and Technology (INIST):

Agriculture and Agri-Food Canada

Canada Foundation for Innovation

Canadian Food Inspection Agency

Canadian Institutes for Health Research

Canadian Space Agency

CIFAR

Defence Research and Development Canada

Environment and Climate Change Canada

Fisheries and Oceans Canada

Global Affairs Canada

Innovation, Science and Economic Development Canada

International Development Research Centre

Mitacs

National Research Council Canada

Natural Resources Canada

Natural Sciences and Engineering Research Council of Canada

Polar Knowledge Canada

Social Sciences and Humanities Research Council

Message from the Interim President and CEO

Three decades ago, a report from the National Advisory Board on Science and Technology heralded Canada as a "small but significant player in the world of science and technology," with a wealth of applicable domestic resources and considerable international connections. The same report called for "a more organized approach to planning and management of international science and technology activity ... based on a framework of national objectives and criteria."

In the years since, experts and committees tasked with assessing Canada's international science, technology, innovation, and knowledge production (STIK) issued similar calls. Today, Canada remains without a strategic framework for assessing our STIK partnerships. This absence is a serious impediment to powering our excellence in S&T, to enhancing our prosperity and resilience, and to maintaining our international standing.

Navigating Collaborative Futures offers a strategic approach to the prioritization and evaluation of international partnerships grounded in our national priorities. It provides a guide for decision-making about Canada's international STIK partnerships, informed by essential expertise from science diplomacy, global security, economics, trade, and innovation. It balances the need for stability with the flexibility required to support Canada's current priorities and partnerships and secure them for the future.

We navigate the route to the future from the vantage point of the present, recognizing the historical contributions of those who have faced these issues before. I am grateful to the members of the expert panel, chaired by Monica Gattinger, for moving through this complicated terrain with intelligence, care, and a profound belief in Canada's future.

Tijs Creutzberg
Interim President and CEO, Council of Canadian Academies

Message from the Chair

The landscape of global knowledge production is shifting dramatically. A growing number of emerging economies are making significant investments in science and innovation. The momentum towards open science has grown. And knowledge is increasingly co-produced with Indigenous peoples.

The opportunities for collaboration have never been greater. Nor have they been more critical. Vexing global challenges — pandemics, climate change, cybersecurity — extend beyond the abilities of any single nation to resolve. And Canada faces a fundamentally changed geopolitical context that is increasingly protectionist, volatile, and uncertain, and in which the international rules-based order is under stress.

In this context, Canada's international STIK partnerships are pivotal. They enable the country to advance its socioeconomic well-being, participate in complex value chains, strengthen its long-term prosperity, and improve national resiliency.

But we must do more to maximize their potential.

Canada's approach to international STIK partnerships is highly decentralized, reflecting the realities of our system but also the benefits of bottom-up, researcher-driven collaborations. However, Canada has long-struggled to effectively couple and leverage our domestic STIK activities with our national priorities within the global arena. Repeated calls for a strategic framework have gone unanswered. At this moment, the need for greater strategic coordination is increasingly urgent. So are the opportunities before us if greater coordination can be achieved.

In this report, the panel identifies the key elements of a strategic framework to guide the evaluation and prioritization of international STIK partnership opportunities. The framework is grounded in national priorities, leveraging value, and ensuring benefits to Canada. We offer criteria, indicators, and metrics to support rigorous, data-enabled decision-making. The panel also considers governance and other factors that contribute to successful implementation of such a framework.

It has been an honour to chair this panel. I warmly thank my panel colleagues, who gave generously of their time and expertise throughout the assessment. The diversity of disciplines, experiences, and perspectives around the panel table generated rich and stimulating dialogue. I commend panel members' deep engagement and commitment to the process, and their spirit of collaboration and collegiality.

Our evidence-gathering for this assessment was extensive; on behalf of my colleagues, I want to thank the CCA staff for their exceptional research and support. I also want to acknowledge and thank the workshop participants, guest speakers, interviewees, and peer reviewers for their invaluable insights and feedback that strengthened the report.

All involved in this assessment are dedicated to helping Canada advance a more strategic approach to international STIK partnerships. We hope this report provides timely and thoughtful input, and we stand ready to assist in translating our findings into action.

Monica Gattinger
Chair, Expert Panel on Science, Technology, Innovation, and Knowledge Partnerships

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Peer Review

This report was reviewed in draft form by reviewers selected by the CCA for their diverse perspectives and areas of expertise. The reviewers assessed the objectivity and quality of the report. Their confidential submissions were considered in full by the Panel, and many of their suggestions were incorporated into the report. They were not asked to endorse the conclusions, nor did they see the final draft of the report before its release. Responsibility for the final content of this report rests entirely with the authoring Panel and the CCA.

The CCA wishes to thank the following individuals for their review of this report:

Jeffrey M. Alexander, Director, Innovation Policy, RTI International (Washington, D.C.)

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Karen Dodds, Chair, Board of Trustees, Canadian Museum of Nature; Chair, Board of Directors, the Marine Environmental Observation, Prediction & Response network (MEOPAR) (Ottawa, ON)

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Meghna Ramaswamy, Director, International Office, University of Saskatchewan (Saskatoon, SK)

The peer review process was monitored on behalf of the CCA's Board of Directors and Scientific Advisory Committee by **Digvir S. Jayas, O.C., FRSC, FCAE,** Distinguished Professor and Vice-President (Research and International), University of Manitoba. The role of the peer review monitor is to ensure that the panel gives full and fair consideration to the submissions of the peer reviewers. The Board of the CCA authorizes public release of an expert panel report only after the peer review monitor confirms that the CCA's report review requirements have been satisfied. The CCA thanks Dr. Jayas for his diligent contribution as peer review monitor.

Acknowledgments

The Panel and CCA staff would like to express their sincere appreciation to the following individuals who provided information and perspectives:

David Golding, Interim Deputy Director, Innovate UK

Ömer Kaya, Chief Executive Officer, Global Advantage Consulting Group

Susie Kitchens, Deputy Director, Global Research & Innovation, Department of Science, Innovation and Technology, United Kingdom

Caroline Martin, Trade Commissioner, Science and Technology, High Commission of Canada, United Kingdom

Michael Rowell, Director, Policy and Research, Global Advantage Consulting Group

David B. Watters, President, Global Advantage Consulting Group

Executive Summary

Opportunities for international partnerships are expanding alongside the rapid pace and increasing complexity of new scientific discoveries and emerging innovations. More nations than ever are participating in the global enterprise of science, technology, innovation, and knowledge production (STIK). Severe realities such as the COVID-19 pandemic, supply chain issues, geopolitical tensions, and climate change further highlight the urgency of international STIK cooperation and collaboration. At the same time, concerns of security and other national interests impact the movement toward open science and transdisciplinary approaches.

Global challenges demand global responses. International STIK partnerships offer opportunities for accelerating collective solutions, while at the same time meeting national priorities. They also create a mechanism for consensus building within a complex and changing geopolitical context. Strategic and deliberate partnerships, coordinated at a national scale through a decision-making framework that supports national priorities, can help Canada seize opportunities, manage accompanying risks, and build successful responses to today's global challenges. By engaging in international STIK partnerships, Canada can be a world leader in open and inclusive approaches to collaboration that unlock prosperity, resilience, and a wide range of other benefits for the country. But the need for a strategic approach is acute.

Recognizing the opportunities and challenges created by the expanding global STIK system, Global Affairs Canada (GAC) and 10 supporting federal departments and agencies asked the Council of Canadian Academies (CCA) to convene an expert panel to provide an evidence-based and authoritative assessment on the following question and sub-questions:

In a post-COVID world, how can Canadian public, private, and academic organizations evaluate and prioritize science, technology, and innovation (STI) partnership opportunities with foreign countries to achieve key national objectives, using indicators supported by objective data where possible?

- How do federal and selected provincial and territorial science-based departments and agencies, the STI organizations they fund (e.g., the Canada Foundation for Innovation), and academic institutions (collectively, the Canadian STI ecosystem) currently evaluate international STI partnership opportunities and select priority foreign partners to achieve their objectives?
- Considering international best practices, what would be the key elements of a new framework to evaluate international STI partnership opportunities for Canada, including criteria, indicators, and objective metrics where possible?
- What are the necessary governance and other success factors to make effective use of a new federal framework for international STI collaboration on an ongoing basis?

To address the charge, the CCA convened a multidisciplinary and multi-sectoral panel of nine experts from Canada and the United States (the Expert Panel on International Science, Technology, Innovation, and Knowledge Partnerships, henceforth the panel). The final report reflects the panel's consensus based on its assessment of the evidence.

Elements of a Framework for Evaluating International STIK Partnerships

For this report, the panel considered science (S) and technology (T) to include all activities concerned with the generation, advancement, dissemination, and application of knowledge in all science and technology fields. Innovations (I) are new or improved products and processes that are implemented within a system and create value. In recognition of knowledge systems that exist outside the standard STI frame — notably Indigenous knowledge — the panel added knowledge production (K) to include both the practices of knowledge production and the body of knowledge beyond STI. STIK partnerships are formalized relationships among individual researchers, institutions, and governments with a focus on STIK activities and outcomes. The panel focuses its review of the evidence by examining international STIK partnerships as relationships that establish or support cooperative STIK activities at a national or organizational level.

The charge to the panel inquires about the key elements of a data-driven framework needed to evaluate and prioritize international STIK partnership opportunities. While the users of the framework elements discussed in this report are expected to be primarily from the federal government and associated entities, the panel anticipates that any public, private, or academic organization considering or participating in international STIK partnerships may find value in working through them. Thus, framework elements are presented in a way that offers sufficient flexibility to serve partnership agreements at all levels of STIK development — from a bottom-up, researcher-driven partnership to a top-down, mission-driven partnership — and to be inclusive of both government-supported and independent operators.

The panel discusses three key steps of the partnership evaluation process: i) articulating goals; ii) identifying, evaluating, and weighting appropriate indicators; and iii) making a decision whether to pursue or continue an international partnership. The first two steps are supported by the framework elements *National Priorities*, *Leveraging Value*, and *Benefits to Canada*. It is in the area of overlap among all three elements that the third step, decision-making, occurs. The successful implementation of framework elements will depend on the level of available supports, including those related to strategic foresight; data sources and analyses; governance; and the evaluation and adaptability of the framework itself to changing contexts and usages. These elements are foundational to framework success (Figure 1).

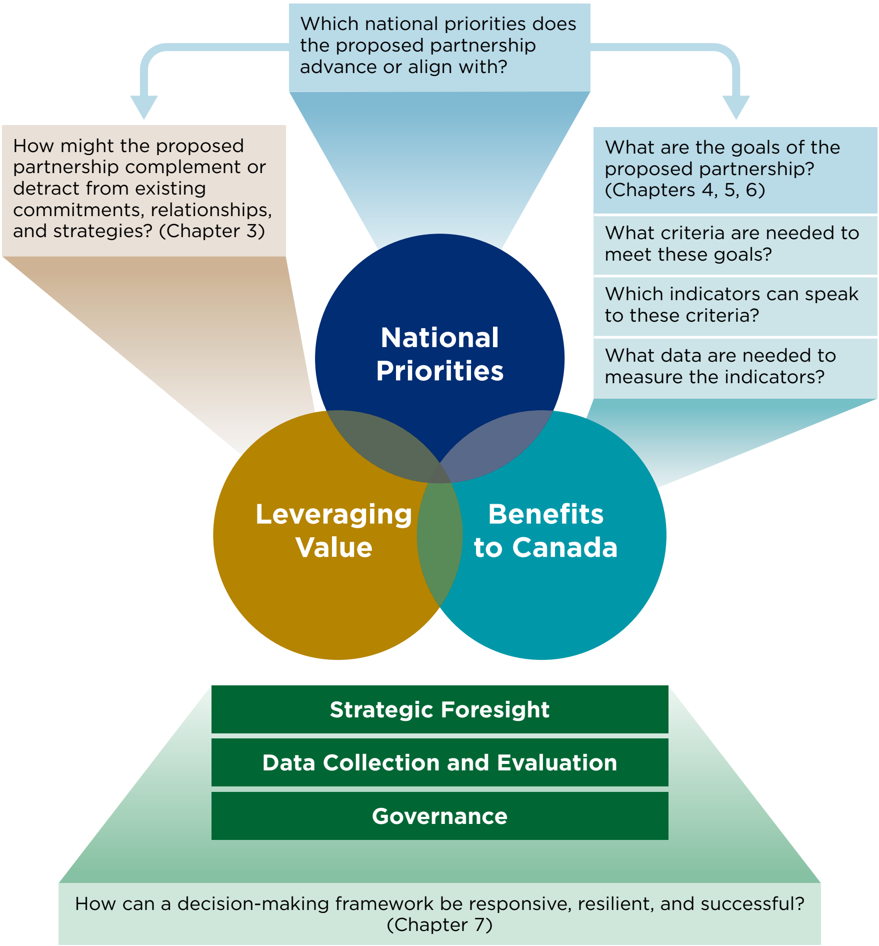

Figure 1 Elements of a Framework for Prioritizing International STIK Partnership Opportunities

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For international STIK partnership opportunities, evaluations are centred on meeting national priorities — though these will differ across contexts. Thus, an initial articulation of partnership goals is necessary to identify desired outcomes and their associated indicators and metrics. Partnership opportunities are also evaluated in the context of the existing and projected STIK landscapes, both domestic and international. Foundational to the success of a framework are considerations of flexibility and responsiveness, as well as the risks of both action and inaction in seizing partnership opportunities. These elements can be combined to create a decision-making framework adaptable to different contexts and situations.

National Priorities

Identifying the *National Priorities* that potential partnerships are meant to advance will help users articulate goals and desired outcomes (Figure 2). The goals and outcomes are used to identify indicators and data relevant to the other two main framework elements: *Leveraging Value* and *Benefits to Canada*.

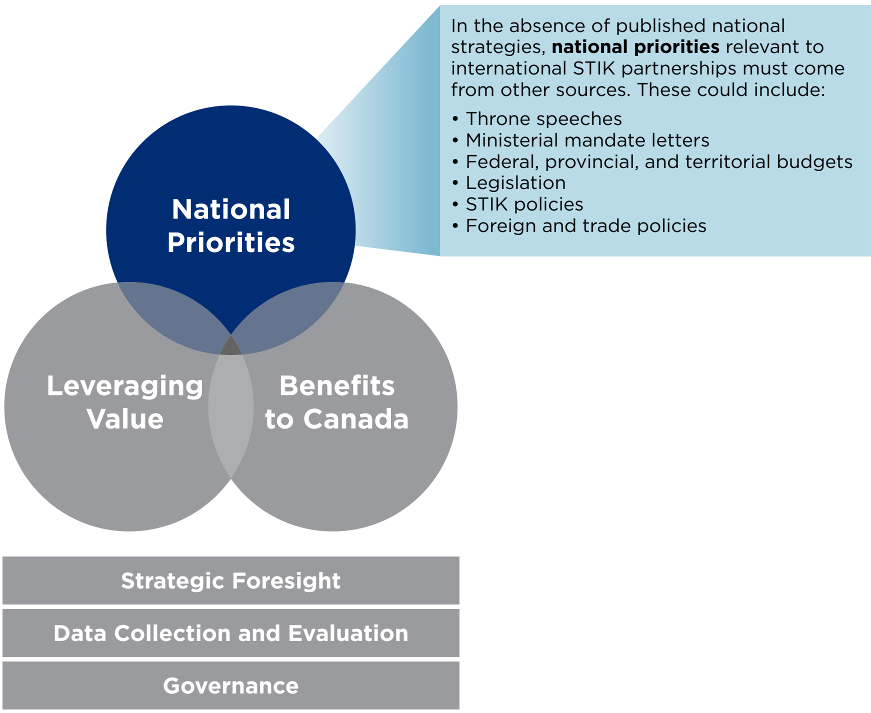


Figure 2 Identifying National Priorities to Articulate the Goals of a Partnership

Identifying national priorities helps users of a framework articulate international STIK partnership goals. Goals that reflect multiple interests, such as those that include specific provincial and territorial, global, or departmental or programmatic priorities, offer wider potential benefits than those that reflect only national-level considerations.

National priorities may be sourced from throne speeches, ministerial mandate letters, budgets, legislation, STIK policies, and foreign and trade policies. Areas where priorities overlap among ministries may be particularly relevant for international partnerships, as they can reflect a broader level of potential engagement across departments and agencies.

What We Heard

Interviewees, guest speakers, and workshop participants commented on the need for a long-term STIK vision for Canada, in order to help establish clear priorities at national, subnational, and organizational levels.

Subnational priorities may further articulate key criteria or provide a more detailed rationale for engaging in (or not) or continuing (or not) an international partnership. Provincial and territorial STIK policies, strategies, and funding announcements can speak to whether partnership opportunities align with subnational government priorities. Similarly, depending on the context, the particulars of departmental or programmatic priorities in other orders of government can provide further criteria for the evaluation or prioritization of international STIK partnership opportunities.

Leveraging Value

Maximizing outcomes from international STIK partnerships demands organization, strategy, and coordination among players in the STIK ecosystem — both domestic and international. Articulating goals makes clear which objectives a potential partnership will address; another important step in evaluating any proposed or ongoing relationship is to assess activities in relation to the ecosystem of domestic and international activities and agreements (Figure 3).

A robust understanding of the current system, and of Canada's strengths and weaknesses, is foundational to making informed international STIK partnership decisions that address short- to long-term needs. Knowledge of existing agreements and the benefits they provide can help guide partnership decisions toward available resources or away from avoidable hurdles. Strategically leveraging value can take many forms — partnerships can be chosen to build on strengths, address weaknesses, or help secure future technology needs and areas of growth. Understanding the global STIK landscape is a necessary component of setting priorities and identifying opportunities to advance Canadian interests.

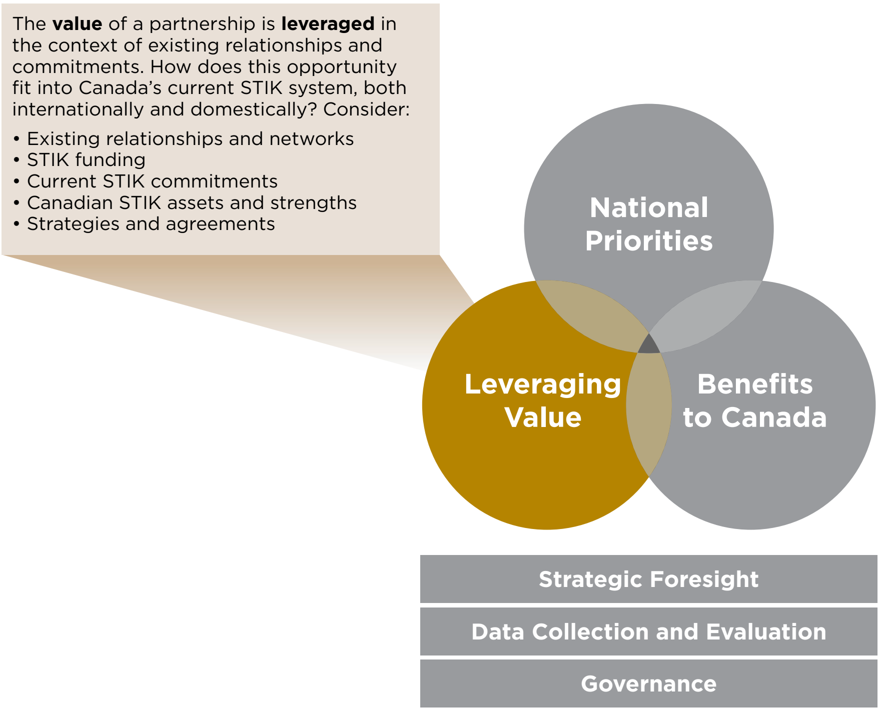


Figure 3 Assessing and Leveraging the Value of Proposed Partnerships

Successful international STIK partnerships will not only create new relationships, but also help support existing relationships and activities in relevant areas both domestically and internationally. An assessment of the strategic value provides an opportunity to examine complementarity as well as uniqueness, both of which may inform further negotiations of partnership agreements.

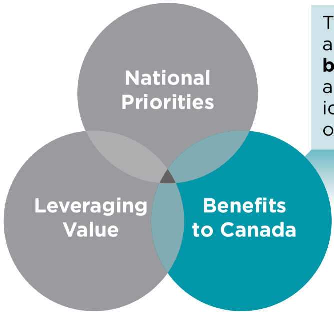
What We Heard

Creating value for Canada is an essential outcome of international STIK partnerships. Interviewees and workshop participants commented on the lack of an existing framework to help coordinate international and domestic STIK activity around a strategy, in order to increase value for Canadian organizations.

Benefits to Canada

To be successful, any international STIK partnership Canada enters into must create some benefit for the country. Broadly, a STIK partnership provides benefits by advancing Canadian interests and building capacity in Canada. This capacity may include introducing new ideas, insights, innovations, or unique knowledge. *Benefits to Canada* can also improve national resilience — for example, by addressing urgent issues of national security in the short term, or by contributing to sustainability over the long term. Users of any framework need to identify the benefits to Canada relevant to the goal(s) of the partnership under consideration, then choose the indicators or metrics that best predict, or directly measure, those benefits. If the partnership opportunities include those already established — that is, if the decision is on whether to continue a partnership rather than choosing among new opportunities — users may opt to directly measure past benefits. If the partnership seeks to build a new relationship, the indicators chosen will be those best suited to predict outcomes (Figure 4).

Indicators are tools that collect and synthesize quantitative and qualitative measures (metrics) of interest to facilitate meaningful evaluations and comparisons at different scales (e.g., among countries, disciplines, institutions). Selecting and evaluating indicators and metrics are complex tasks that require a substantial investment of time and human resources early in the decision-making process. However, this work transforms the framework elements into a useful tool for decision-making. Details about different types of indicators, their uses and limits, as well as potential applications to different scenarios, are examined in depth in Chapters 4, 5, and 6. These chapters examine benefits to Canada in three main categories: those related to innovation, to science capacity building and knowledge production, and to national resilience.



There is a wide array of indicators and metrics to measure potential **benefits to Canada**. From the articulated goals, criteria are identified for evaluation. Areas of consideration include:

National Resilience	Criteria (example indicator)
Diplomacy	• Diplomatic outcomes (new policies, innovation centres)
Sustainability	• Sustainability (development, emissions) • Reciprocity (fair mutual benefit) • Commitment and vision (use of foresight)
Security	• National security (security networks) • Foreign influence (vulnerability) • Cybersecurity (alignment, threats) • Research security (sanctioned activities)

Innovation	Criteria (example indicator)
Collaboration and Commercialization	• Collaboration readiness (complementarity) • Commercialization and scale-up (firm size and performance) • Inputs (R&D investment, resources) • Assets (tangible and intangible) • Outputs (growth)
Trade	• Trade system (imports and exports) • Regulations and barriers (tariffs, quotas) • Standards setting and regulatory alignment (standards creation, adoption)

Scientific Capacity and Knowledge Production	Criteria (example indicator)
Excellence	• Rigour (peer review) • Production (publications, other outputs) • Impact (citations)
Open Science	• FAIR* principles (policies) • Collaboration (co-authorships)
Talent	• Potential (network position) • Expertise (citations) • Mobility (policies, programs)
Infrastructure	• Location (uniqueness) • Institutions (rankings) • Facilities (accessibility)

Figure 4 Increasing Innovation, Scientific Capacity and Knowledge Production, and National Resilience as Benefits to Canada

International STIK partnerships must bring some benefits to Canada to justify their pursuit. The identification of these benefits helps establish evaluation criteria. Useful indicators reflect the qualities a partner brings to the table that will result in those benefits to Canada, as evidenced by the potential partner's existing activities, outputs, and relationships.

*FAIR (findable, accessible, interoperable, reusable) principles of open data

Success Factors

While the elements outlined above — *National Priorities*, *Leveraging Value*, and *Benefits to Canada* — are necessary for the decision-making process, they are incomplete. Additional considerations — strategic foresight, data collection and evaluation practices, and governance factors — are foundational to the responsiveness, longevity, and success of a framework (Figure 5).

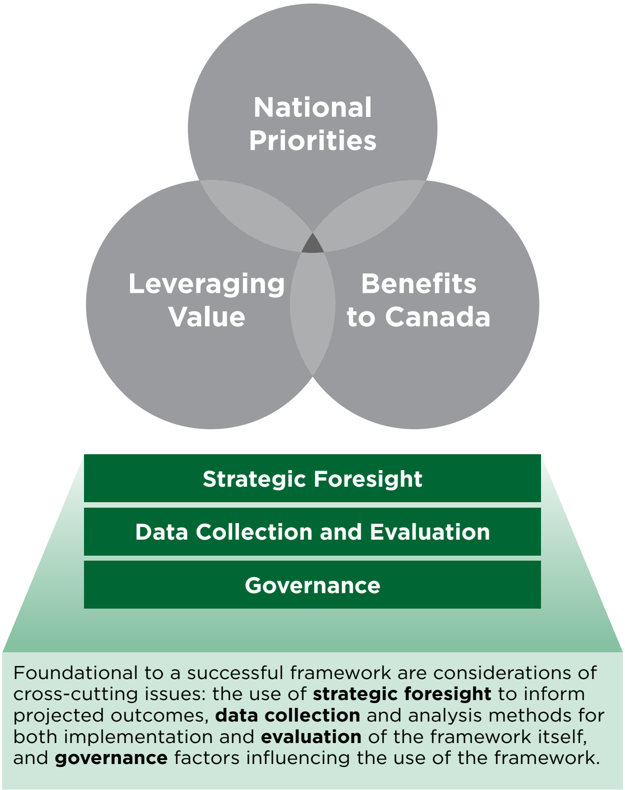


Figure 5 Foundational Elements for Success: Strategic Foresight, Governance, and Data Collection and Evaluation Practices

The main elements of a decision-making process — setting goals to address *National Priorities*, *Leveraging Value*, and measuring anticipated *Benefits to Canada* — are incomplete without an infrastructure to implement the process. A governance structure with coordination, resourcing, and accountability helps ensure effectiveness, longevity, and transparency; accessible, up-to-date data repositories and data sources help ensure responsiveness; ongoing evaluation of framework implementation provides a basis for adaptation; and the use of strategic foresight helps ensure decisions speak to the short and long terms.

What We Heard

Interviewees, workshop participants, and guest speakers repeatedly mentioned the need for coordination and clear communication channels among organizations engaging in international partnerships. They also cautioned that any new framework should not increase bureaucratic burdens and place constraints on Canada's ability to be responsive and flexible in pursuing international partnerships.

While there is little evidence to suggest that any one approach to implementing a decision-making framework will best suit the Canadian context, the panel notes there are key success factors that can support the implementation of any such framework. These are explored further in Chapter 7.

Putting It All Together

Once the framework elements have been chosen, the next step is assembling and ordering those elements in a logical format to inform the evaluation of potential STIK partnerships. For example, a user may apply the framework elements to choose among a set of potential opportunities. Figure 6 provides an example of how to organize the framework elements into a functional framework for such a decision-making process. As a first step, users would identify the *National Priorities* relevant to that group of partners and their own interests in order to articulate goals and desired outcomes of the potential partnership. Next, they would specify the expected *Benefits to Canada* that would flow from meeting those goals and outcomes and select or create appropriate indicators and metrics. In parallel, they would examine existing domestic and international landscapes to ensure that any potential partnership is *Leveraging Value* from what currently exists. They would then weight and evaluate the collected information and rank the partnership opportunity against other opportunities to make a decision. Implementation considerations are foundational to a decision-making framework.

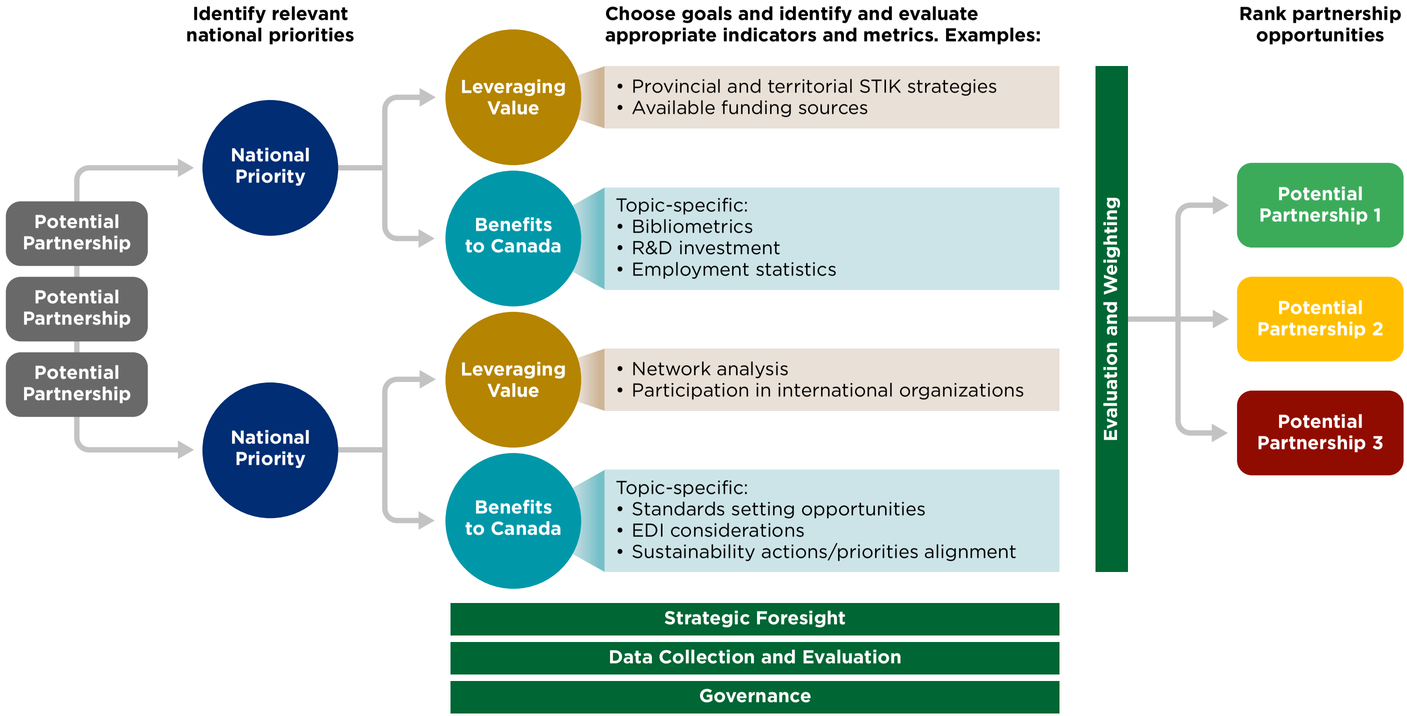


Figure 6 Example of a Framework for Evaluating International STIK Partnership Opportunities

Assembled elements in a sample framework for choosing among three potential international STIK partnership opportunities. With the evidence summarized in this report, the user would identify the *National Priorities* expected to be advanced by the partnership, articulate those as goals of the partnership, and choose appropriate indicators and metrics to address those goals delivering *Benefits to Canada* and *Leveraging Value*. Effective implementation is supported by strategic foresight, data collection and evaluation, and governance. The gathered information is then used to weight and rank the partnership opportunities.

Final Reflections

In a changing geopolitical context, with dramatic technological and scientific advancements, Canada needs a more proactive and strategic approach to its international STIK partnerships. However, there is no one-size-fits-all framework to international STIK partnership decision-making. Success will depend on experimentation, evaluation, and flexibility in the use of framework elements to design and implement approaches best suited to the context today, and for future generations.

Canada has long balanced the local and the global — and the top-down and the bottom-up — in its decision-making processes. For decades, STIK partnerships have been driven by research needs and the network connections of researchers in Canada and abroad. These mechanisms are vital to a thriving, responsive STIK ecosystem. However, the Government of Canada has also struggled for decades to coordinate STIK efforts, to provide clear direction and support for decision-makers, and to present a clear point of entry for potential international partners. In this report, the panel presents the building blocks to construct a collective strategy.

Contents

1

Introduction

Opportunities for partnerships are growing rapidly alongside the increasing complexity of new scientific discoveries and emerging industry sectors — such as quantum technology and artificial intelligence (AI) — as well as shifting geopolitical relations. More nations than ever are participating in science, technology, innovation, and knowledge production (STIK). Major imperatives such as the COVID-19 pandemic, supply chain issues, and global climate change further highlight the urgency of international STIK cooperation and collaboration. At the same time, discussions of sovereignty and national interests abut the movement toward open science and transdisciplinary approaches.

No nation alone has the necessary resources — be it knowledge, skills, or facilities — to be self-sufficient in attaining economic competitiveness, high living standards, and quality of life for its people. International partnerships are imperative. Yet, federal government resources to support such partnerships are limited, and engagement with foreign actors can increase risks to national security and sovereignty. Decisions must therefore be made about which partnership opportunities to support, while also recognizing the evolving geopolitical, economic, and security realities facing Canada. Thus, engagement in international STIK partnerships demands strategic and coordinated approaches.

The scientific enterprise is inherently future-focused and supports long-term prosperity and resilience. The strategic pursuit of international STIK partnerships advances Canada's national interests by supporting the contribution of STIK to its foreign and trade policies and, in turn, enhancing the contributions of international engagement to Canada's STIK agenda. The contributions Canada can make — and has made — on the global stage go well beyond what might be expected given its size. Contributions to the security, prosperity, and well-being of Canada and the world will be even greater with strategic, sustained, and reciprocated international STIK partnerships.

1.1 The Charge

Recognizing the opportunities and challenges created by the expanding international STIK system, Global Affairs Canada (GAC) (hereafter, the sponsor) and 10 supporting departments and agencies, asked the Council of Canadian Academies (CCA) to convene an expert panel to provide an evidence-based and authoritative assessment on the following question and sub-questions:

In a post-COVID world, how can Canadian public, private, and academic organizations evaluate and prioritize science, technology, and innovation (STI) partnership opportunities with foreign countries to achieve key national objectives, using indicators supported by objective data where possible?

- How do federal and selected provincial and territorial science-based departments and agencies, the STI organizations they fund (e.g., the Canada Foundation for Innovation), and academic institutions (collectively, the Canadian STI ecosystem) currently evaluate international STI partnership opportunities and select priority foreign partners to achieve their objectives?
- Considering international best practices, what would be the key elements of a new framework to evaluate international STI partnership opportunities for Canada, including criteria, indicators, and objective metrics where possible?
- What are the necessary governance and other success factors to make effective use of a new federal framework for international STI collaboration on an ongoing basis?

To address the charge, the CCA convened a multidisciplinary and multi-sectoral panel of nine experts from Canada and the United States (the Expert Panel on International Science, Technology, Innovation, and Knowledge Partnerships, henceforth the panel). Members contributed their expertise in relevant areas — such as science and technology (S&T) program evaluation, science diplomacy, economics, trade, innovation, and global security — as well as practical experience in building and managing international partnerships. This report reflects the panel's consensus based on its assessment of the evidence.

To maintain CCA panel independence, the sponsor did not appoint panel members, nor did they engage with the panel during the assessment process, with the following exceptions: (i) at the panel's first meeting, at which time the sponsor was invited to present the charge, and (ii) at two sponsor briefings prior to public release, where the Chair presented the panel's main findings; these briefings were scheduled after the panel formally signed off on the content of the report.

External peer review provided feedback to inform panel deliberations and the nine reviewers remained anonymous to the panel until after the report was finalized. This process was overseen by an independent peer review monitor appointed from the CCA's Scientific Advisory Committee, further supporting the integrity of the process.

1.2 Definitions

To maintain a common language throughout the report, the panel adopted the following definitions, while also recognizing the interconnected and overlapping nature of these terms:

S&T activities are "all systematic activities which are closely concerned with the generation, advancement, dissemination and application of scientific and technical knowledge in all fields of science and technology, that is, the natural sciences, engineering and technology, the medical and agricultural sciences, as well as the social sciences and humanities" (OECD, 2015). Science is a systematic way of building knowledge — knowledge acquired through the scientific method is universal (i.e., applicable anywhere) and refined and refuted through the communal practices of sharing results and organized skepticism (i.e., publication and peer review) (Merton, 1973). Typically, technology is defined as science applied to practical tasks in industry (Barber *et al.*, 2006), though, as Brooks (1980) notes, technology as a concept includes the "knowledge of how to fulfill certain human purposes in a specifiable and reproducible way." Technology can also drive the creation of new fields of inquiry in science — for example, by revealing previously immeasurable phenomena or creating new problem spaces (Brooks, 1994).

Innovation (I) is "a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that have been made available to potential users or brought into use by the unit" (OECD/Eurostat, 2018). Key elements of innovation, in contrast to technology, include the creation or preservation of value (whereas new technology may have no specific value yet attached to it) and the fact that it must be implemented — that is, introduced on the market, in the public sector, or in other systems (OECD/Eurostat, 2018; Chen *et al.*, 2019; Yun & Liu, 2019).

The panel recognizes that, in practice, international partnerships are not limited to the definitions above, but rather encompass a broad spectrum of knowledge production. Thus, the panel has added **knowledge production (K)** to the STI acronym, so as to include knowledge systems other than science, including both the practices of knowledge production and the body of knowledge itself (*sensu* Cornell *et al.*, 2013). For example, Indigenous knowledge comes from the understandings of a multitude of different knowledge systems, reflecting "cognitive, embodied, instinctual, and spiritual" ways of knowing (Kovach, 2021). Notably, Indigenous knowledge systems are relational, built upon "self in relationship with the natural world, the human world, kin, community, place, and land" over a long history with a place or territory, and inextricably linked to language and philosophy (Kovach, 2021). The framework elements discussed in this report are intended to speak to international partnership opportunities across knowledge systems; they are potentially of use to all "agents, practices and institutions that organize the production, transfer and use of knowledge," including, notably, Indigenous knowledge systems (Cornell *et al.*, 2013).

Overall, this report examines the elements of a framework for evaluating and prioritizing international **science, technology, innovation, and knowledge production (STIK)** partnerships.

1.2.1 Types of International STIK Partnerships

For the purposes of this report, the panel considered STIK partnerships as relationships that establish or support cooperative STIK activities at a national or organizational level (Figure 1.1). Such partnership agreements may take the form of bilateral or multilateral S&T agreements, formed among nations. These agreements offer diplomatic tools to formally establish or maintain relationships among nations with specific STIK foci. In cases where trust between nations is high and relationships are long-established (such as that between Canada and the United States), these agreements are rarely used. Instead, most agreements are negotiated at a secondary level, among national or subnational agencies and ministries, and can include both public and private sector actors.

Secondary agreements may be memoranda of understanding (MOUs) that establish project boundaries and expectations, such as funding levels and access to infrastructure. These agreements may also come in the form of joint statements or protocols, which tend to establish positions or aspirations for relationships, rather than project-level details. Nation-to-nation agreements can also establish and financially sustain joint (or multi-national) workshops, working groups, commissions, or other such entities, whose mandates can include the development of MOUs or joint statements and protocols. The panel also recognizes that a number of other agreements among nations can influence STIK relationships, including those related to trade, finance, international standards, regulations, and export controls. These adjacent agreements are not STIK partnerships *per se* but are discussed in this report as relevant to STIK partnership decision-making.

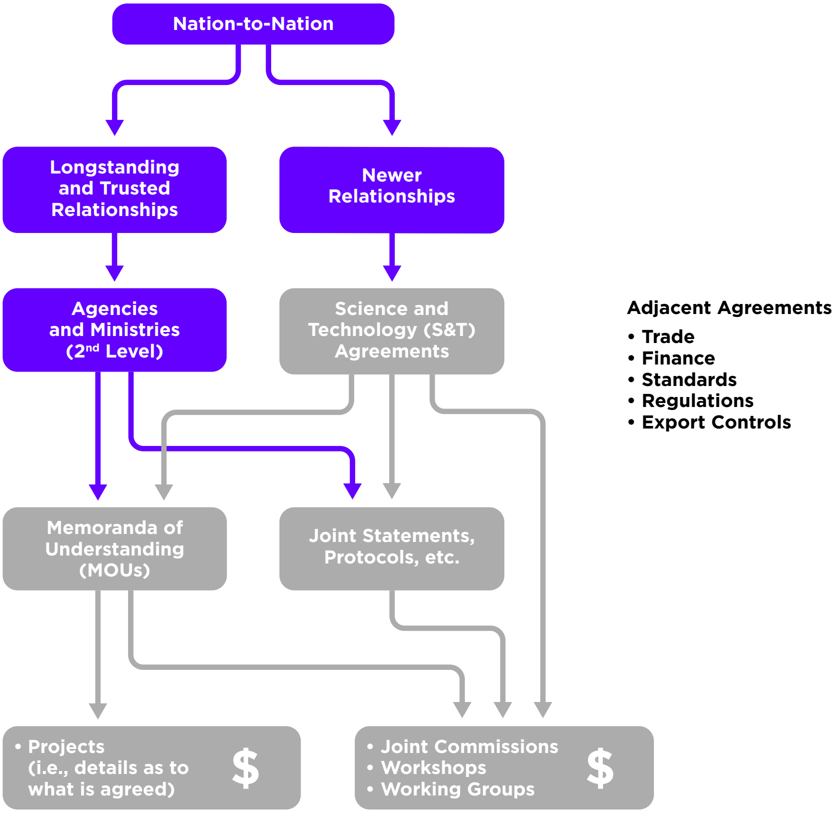


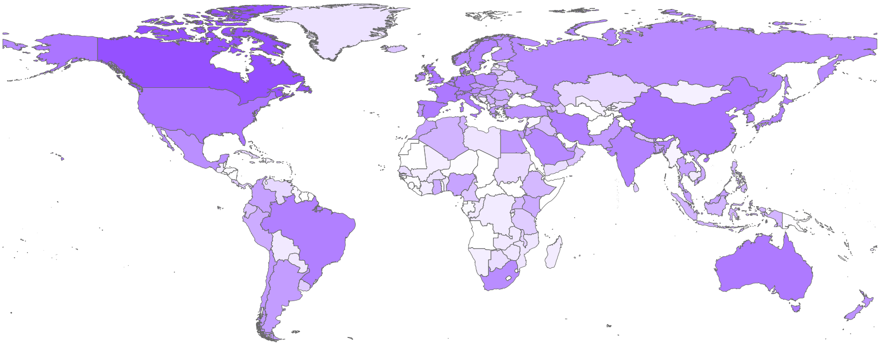
Figure 1.1 Types of International STIK Partnership Agreements and Relationships

Nation-to-nation relationships operate at different levels (purple boxes). They may be established formally, through nation-to-nation S&T agreements, or by individual agencies and ministries though MOUs, or joint statements and protocols. These agreements can establish relationships through research projects, working groups, commissions, or other types of STIK activities. STIK relationships and activities (grey boxes) are also influenced by other types of international agreements, such as those related to trade, finance, and international standards.

1.3 International Context

Science and technology have been used since the Age of Exploration to further the goals of states, when scientific and exploratory missions were funded to both advance knowledge and claim territory as a way of securing sources of wealth (Skolnikoff, 1993). Science is an integral part of the industrial system of a nation (Salomon, 1973), and modern science and higher education co-evolved with the formation of nation-states (Flink, 2020). New scientific knowledge and technological advances have long impacted international relations both directly — with their potential to alter power dynamics (e.g., altering the nature of weapons, or the substance of dependency relationships) — and indirectly through unanticipated externalities (e.g., climate change, demand for natural resources) (Skolnikoff, 1993). Indeed, as Salomon (1973) observes, given principles of universality, communalism, and objectivity, the concept of a national scientific community is contradictory to the fundamentally international nature of the scientific enterprise.

The landscape of global knowledge production is changing. According to the Organisation for Economic Co-operation and Development (OECD, 2022a), total spending on research and development (R&D) for all OECD member countries combined rose 248% — from US$650 billion to US$1.6 trillion (constant prices using 2015 base year and purchasing power parities) — from 1991 to 2021. From 2007 to 2020, the number of countries contributing to 90% of the world's scientific publications rose from 30 to 42 (OECD, 2022e). More countries participate in international conferences and partnerships to advance knowledge and address critical problems than ever before; indeed, more than one quarter of all science is being done through international collaboration (Wagner *et al.*, 2015). In 2021 alone, researchers in Canada co-authored at least 10 publications with their counterparts in each of 157 different countries and regions (Figure 1.2). In 2020, 28% of scientific publications from all OECD countries — and 32.8% of publications from Canada — involved international collaboration (OECD, 2022e).



Data source: OECD (2023c)

Figure 1.2 International Collaborations with Canada in Scientific Publications, 2021

Bilateral international collaboration (whole counts) with Canada for 2021. Colour intensity indicates co-authorship with researchers in a particular country or region, with darker colours signifying larger numbers of co-authored publications. Note that data presented here are limited to countries with which Canada had a minimum of 10 co-authored publications, calculated using Elsevier's Scopus Custom Data, Version 1.2023.

Advancing STIK is an increasingly global endeavour

International partnerships can accelerate the pace at which STIK occurs in a nation, leading to more discoveries and contributing to improved commercialization (TCS, 2023). International cooperation can be a competitive advantage for industry; for example, multinational firms, through collaborations and a worldwide diffusion of R&D, exploit international networks to access new technologies (Ostry & Nelson, 1995). The complementarities and uniqueness of resources and knowledge can contribute to enhanced innovation and entrepreneurship through collaboration at the firm level (Ferraris *et al.*, 2020; Lam *et al.*, 2021). Nations that do not pursue international partnerships have less access to the discourse among leading research groups and can miss out on knowledge transfer opportunities to the detriment of their national competitiveness, wealth creation, and public benefit (Johnson *et al.*, 2022). Canadian companies benefit from international partnerships by gaining insight into new and emerging markets — a particular priority given Canada's declining performance in advanced-industry output relative to the global average over the past 20 years (Atkinson, 2022).

Addressing global challenges requires international collaboration

Global issues (e.g., climate change, pollution, pandemics, biodiversity loss, cybersecurity, oceans management) extend beyond the ability of an individual state to resolve (Davis & Patman, 2015; Deodoro *et al.*, 2021). These challenges are inextricably connected to S&T — as causal factors, but also as means for recognizing and understanding the issues, not to mention finding solutions (Skolnikoff, 1993; Paár-Jákli, 2014; Davis & Patman, 2015). Foreign policy decisions related to such global issues require evidence and expertise from across a diversity of knowledge disciplines and ways of knowing (Paár-Jákli, 2014). Participation in diplomatic activities provides scientists and knowledge holders with a mechanism to influence negotiations that impact major societal issues; in turn, such participation can also raise the profile of science as an international public good (Ruffini, 2017). International STIK partnerships also provide Canada with opportunities to advance the state of knowledge in areas of national importance, while supporting international endeavours. However, with limited resources available to secure and maintain international STIK partnerships, Canada must make strategic choices if it wishes to take advantage of the opportunities for national benefits and contribute meaningfully to the global public good.

International partnerships operate within a fundamentally changed geopolitical context

International cooperation depends on the free circulation of people and ideas, and rapidly evolving geopolitical contexts influence this exchange. For example, changes to U.S. trade and industrial policy since 2016 reflect an increasingly protectionist strategy (Metiu, 2021). Likewise, the international rules-based order, which supports such cross-border cooperation, is under increasing stress (GSPIA Task Force on National Security, 2022). For example, China represents a challenge for international STIK activities, given the legal obligations of Chinese individuals and institutions to support, assist, and cooperate with the Chinese military and intelligence apparatus and, moreover, to keep such activities confidential (GSPIA Task Force on National Security, 2022). Russia has prioritized developing its defence apparatus and has become increasingly aggressive in its efforts to change the international rules-based order and counter outside influence and interests (Shull & Wark, 2021). With its full-scale invasion of Ukraine in February 2022, Russia obviated existing security arrangements and added volatility to the geopolitical context (Richter, 2022).

In response to these realities, the Government of Canada is strengthening its approach to research security, announcing, in February 2023:

> *Grant applications that involve conducting research in a sensitive research area will not be funded if any of the researchers working on the project are affiliated with a university, research institute or laboratory connected to military, national defence or state security entities of foreign state actors that pose a risk to our national security.*
>
> GC (2023a)

In January 2024, the Government of Canada released the *Policy on Sensitive Technology Research and Affiliations of Concern* supported by a list of Sensitive Technology Research Areas and a list of Named Research Organizations (GC, 2024).

Changing geopolitical contexts can also be a driver of international STIK partnerships, however. Science diplomacy, for example, is the part of international relations in which the interests of scientists, including those working in higher education, intersect with those of foreign policy (Flink, 2021). This intersection of S&T and foreign affairs has been increasingly evident since World War II, as S&T developments greatly altered relations among countries (Skolnikoff, 1967). S&T is included in the foreign policy toolkit alongside a range of other non-coercive instruments, including culture, communications, intelligence, and development assistance (Gates, 2020). Long-standing relationships of influence between science policy and diplomacy include bilateral and multilateral higher-education funding programs; the observation of scientific activities abroad; the promotion of investment opportunities, products, talent, and funding programs abroad; and intelligence-gathering and surveillance activities that target scientific and technological advances (Flink, 2020).

Because funding for science comes primarily from national (and subnational) sources, Copeland (2015) argues that a nation's values will be reflected in, and shaped by, its domestic science framework and international partnership choices. Science diplomacy can be a form of *Track II diplomacy* — unofficial, non-structured interactions by non-state actors, including scientific and cultural exchanges (Davidson & Montville, 1981). Science diplomacy also contributes to international relations through common-interest building, providing a starting point for negotiations that differs from, for example, conflict resolution (Berkman, 2019). It is in the balance of both long-term timescales (i.e., where goals reflect sustainability and common-interest building) and short-term timescales (i.e., where goals reflect security considerations and conflict resolution) where informed decisions regarding international engagement are made (Figure 1.3).

Berkman (2020) describes the security to sustainability timescale as a *continuum of urgencies*. Urgency reflects the short-term risks related to political, economic, cultural, and environmental instabilities that demand immediate attention, but also requires acting in the present moment to address long-term challenges of "balancing economic prosperity, environment protection, and societal well-being across generations" (Berkman, 2020).

Adapted with permission from Berkman (2020)

Figure 1.3 Informed Decision-Making Across a Continuum of Urgencies

To be successful, international STIK partnerships must navigate the continuum of urgencies. This involves addressing security concerns and sustainability timescales, negotiating strategies for conflict resolution, and building toward common interests from the local to global scale.

1.4 Canadian Context

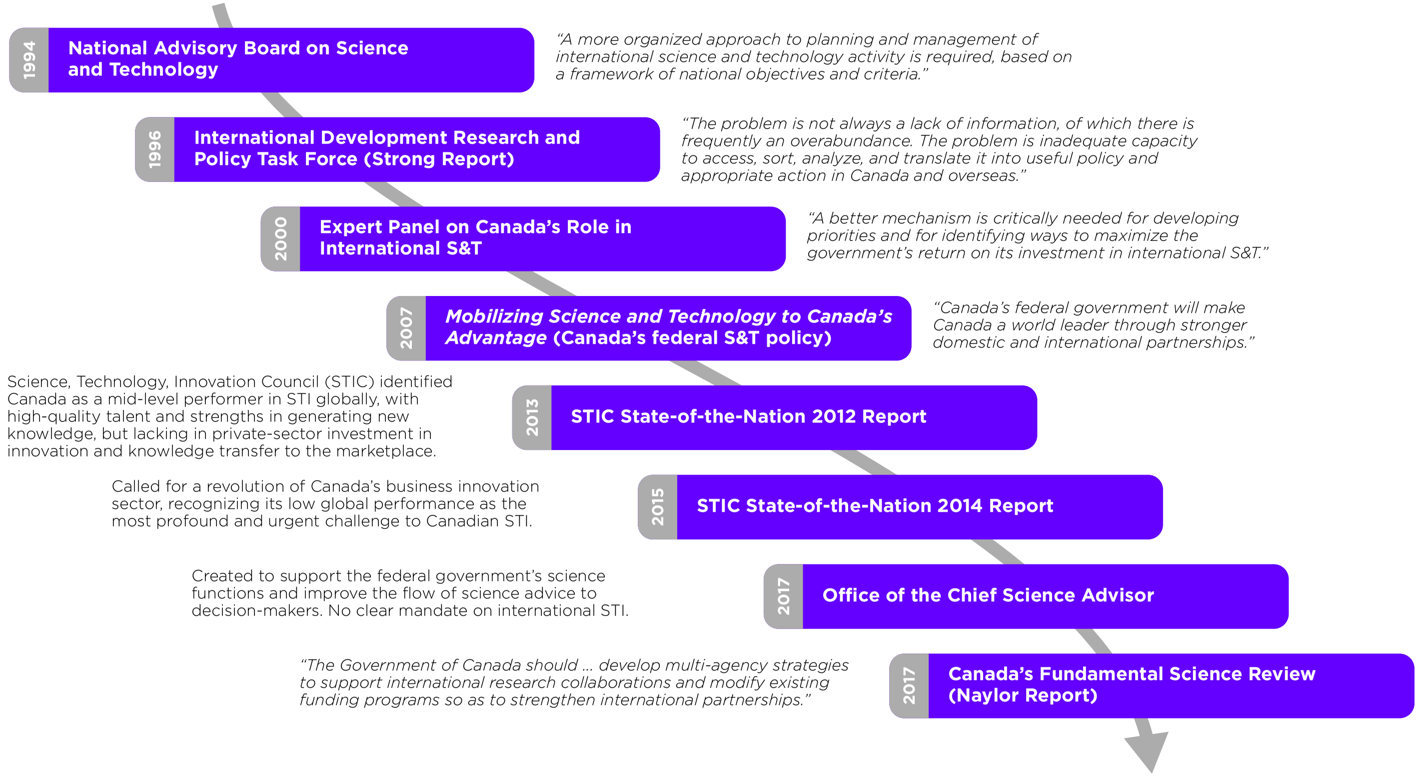
Canada's STIK system "came of age" around the end of World War II (Kinder & Dufour, 2018). In the post-war period, Canada's STIK policies focused on international relationship building to facilitate new scientific and technological developments (Ghent, 1979). This period was also marked by an increase in bilateral agreements, aging science infrastructure, low research funding, and an increasing recognition of domestic S&T as a core element of Canada's foreign policy (Fast, 2007). Addressing these issues ultimately culminated in the creation of independent, not-for-profit, science funding foundations, such as the Canada Foundation for Innovation (CFI) and Genome Canada, among others (Fast, 2007). Since 2000, a variety of initiatives and strategies have encouraged private sector participation and investment in S&T, supported internationally recognized research contributions, and advanced industrial sector development (e.g., the Global Innovation Clusters program) (ISED, 2021b).

Canada has struggled to coordinate domestic and international STIK policy and activity

While Canada is a significant participant in the internationalization of science, its domestic STIK activity coupled with its strategic positioning in global STIK activity have long been areas of concern for policy-makers. Repeated calls for a national strategy or framework to help coordinate these efforts have remained largely unanswered (Figure 1.4). For example, though a variety of federal departments, agencies, and granting councils provide support for international collaboration, each pursues its own objectives with minimal coordination (Canada's Fundamental Science Review, 2017). Canada's Fundamental Science Review (2017) recognized an urgent need to "develop multi-agency strategies to support international research collaborations and modify existing funding programs so as to strengthen international partnerships." In response, the Canada Research Coordinating Committee (CRCC) established an international framework that is applicable in cases where CRCC member agencies (i.e., CFI, CIHR, NSERC, and SSHRC)[1] have "converging or intersecting international priorities" (CRCC, 2020). However, the CRCC framework is a complement to the international strategies of the individual member agencies, which represent a small fraction of the actors pursuing international partnerships across Canada's STIK ecosystem.

The potential detriments of not having an effective framework for choosing and building international STIK partnerships are substantial. The absence of an effective decision-making framework and related governance may lead to duplication of effort, conflicting policies, dilution of impact, and a lack of clarity for potential partners seeking to work with Canada. As well, Canada may lag on collaboration readiness, missing opportunities to secure talent, share expertise, gain access to unique facilities or research sites, and leverage funding from international sources, ultimately hampering Canada's STIK endeavours.

1 CFI and the Tri-Council granting agencies: Canadian Institutes of Health Research (CIHR), Natural Sciences and Engineering Research Council of Canada (NSERC), and Social Sciences and Humanities Research Council (SSHRC).



Sources: NABST (1994); International Development Research and Policy Task Force (1996); ACST (2000); GC (2007); STIC (2013, 2015); Canada's Fundamental Science Review (2017); OCSA (2021a)

Figure 1.4 A Brief Timeline of Reviews, Recommendations, and Actions Taken to Strengthen Canada's International STI Activities

There is no current or historical strategy in Canada to coordinate or prioritize international science, technology, and innovation (STI) partnerships, though there have been multiple calls for such a strategy over the years.

Canada cannot afford to miss out on international STIK partnership opportunities

Without effective STIK partnership decision-making, Canada may fall further behind in an increasingly competitive global knowledge economy. In the face of a climate crisis, increasing authoritarianism, pandemics, wars, rapid and disruptive technological advancements, and economic nationalism, building strategic partnerships is challenging. However, the panel emphasizes that the prize for getting it right — for taking risks, seizing opportunities, and exploring possibilities under uncertainty — will outweigh the profound costs of inaction. By being much more intentional about STIK partnership building, Canada can realize economic, trade, geopolitical, and social gains. At the same time, it will enjoy the benefits of building capacity, enhancing research excellence, and improving evidence-based responses to crises at the regional, national, and international levels (EC, 2010; Dufour, 2021).

1.5 The Panel's Approach

The panel's work began at a time when COVID-19 pandemic measures were being lifted; its work was therefore carried out in hybrid format (i.e., a mix of virtual and in-person meetings). The panel met nine times over the course of 16 months to review evidence, discuss implications, and deliberate on its charge.

1.5.1 Sources of Evidence

The panel's assessment was based on a review of published literature, including peer-reviewed and grey literature (e.g., policy documents, government publications and websites, webinars, reports by national and international organizations and committees). To better understand the breadth of perspectives on Canada's international engagement in STIK, the panel collected evidence through additional activities, including:

- a one-day workshop with nine experts from academia, research organizations, industry, and government;
- discussions with eight invited guest speakers representing specific expertise and experience in international STIK partnerships, including Indigenous perspectives;
- a questionnaire and follow-up interviews led by CCA staff with 18 member organizations of the federal government's Interdepartmental Network on International S&T (INIST);

- two staff-led meetings with government officials from the United Kingdom, who spoke to STI partnership decision-making processes; and
- semi-structured interviews led by CCA staff with three of Canada's S&T counsellors.

In discussions with federal departments and agencies, other organizations in the STIK ecosystem, workshop participants, and guest speakers, panel members identified myriad challenges besides coordination that hinder Canada's ability to effectively compete in the global STIK arena. These include pragmatic issues, such as mobility constraints imposed by long wait times for visas, the inability to obtain visas altogether, and a lack of formal recognition of foreign credentials. Other challenges reflect the uneasy confluence of government and STIK systems, such as those created by a lack of synchronization among the timelines of research partnerships, funding programs, and bureaucratic processes. Similarly, policies guiding STIK practices and investments can create tensions and an apparent incoherence for those attempting to navigate new or ongoing partnership agreements (e.g., guidance on open science versus research security). To highlight the insights gained through these evidence-gathering exercises, key messages heard by the panel are summarized in "What We Heard" boxes throughout the report.

What We Heard

INIST member interviews revealed to the panel key messages repeatedly heard from across departments and agencies. It was notable that all organizations interviewed were already engaging in international STIK partnerships at some level, and that bibliometrics were the data most frequently used to evaluate these partnerships, both internally (e.g., through project reporting) and externally (e.g., using the SciVal database). Interviewees spoke consistently of the need for better guidance and coordination, and they were widely supportive of a framework. They cautioned the panel, however, that any useful framework must be flexible and facilitate ecosystem-wide information sharing.

1.5.2 Scope

The framework elements summarized in this report are intended to be inclusive of all international STIK partnership opportunities, encompassing those with traditional partners as well as emerging economies. The charge envisions a data-driven framework; thus the report privileges quantitative data sources in its discussion of indicators and metrics. However, the panel emphasizes the importance of qualitative research, expert judgment, and political considerations in decision-making on STIK partnerships, and discusses these aspects where appropriate in the report. It also notes that, while this report reflects the current moment of exponential change, researchers in Canada have a long, successful history of international STIK collaboration. The urgency of the moment reflects the opportunity for strategy and adaptation to the changing global context — an inflection point — and the panel's concern about the costs of inaction if Canada does not seize this opportunity.

While the main thrust of this report is on nation-to-nation or organization-to-organization STIK partnership opportunities, other users of the framework elements were also considered by the panel, such as individual researchers; subnational governments, departments, and agencies; non-governmental organizations (NGOs); business enterprises; and academic institutions. For instance, an individual researcher might find the framework elements useful for strategic decision-making on the choice of co-author or collaborator. The panel did not explicitly consider individual-level partnerships in its evidence review.

The panel considered the evaluation of partnership opportunities to be inclusive of both new and renewed collaborative relationships. Evaluations of existing international programs, priorities, and partnerships, however, were considered out of scope, as were evaluations of domestic partnerships and programs.

Evidence on the applicability and limitations of framework elements, such as indicators and metrics, is reviewed in this report; however, the panel does not make specific recommendations. Rather, the report is meant to be a tool for creating a decision-making framework. It provides an overview of the state of knowledge about key elements, which can then be adapted to a variety of contexts.

1.6 Report Structure

Chapter 2 introduces the framework elements and presents an overview of their goals and related criteria, as well as considerations for implementation. Chapter 3 looks at the domestic and international STIK landscapes, setting the context in which a framework may be implemented. Chapters 4 through 6 offer an in-depth review of key indicators and metrics relevant to evaluating potential benefits to Canada in terms of innovation (Chapter 4), scientific capacity and knowledge production (Chapter 5), and national resilience (Chapter 6). Chapter 7 examines aspects of governance and other factors that can contribute to successful use of a framework.

2

Framework Elements

This chapter presents a high-level overview of the key elements of an evidence-based, data-enabled framework to evaluate and prioritize international science, technology, innovation, and knowledge production (STIK) partnership opportunities with foreign countries and organizations.

The first step in developing any such evaluation is the articulation of goals or desired outcomes — in this case, national priorities for Canada's engagement in international STIK partnerships. However, the panel notes that without a national STIK strategy or foreign policy to align these framework elements to, it is necessary for the users themselves to identify the priorities of interest. Moreover, while users are expected to be primarily in the federal government and associated entities, the panel anticipates that any public, private, or academic organization participating in international STIK partnerships may find uses for some framework elements in their own decision-making processes. Thus, the panel presents the framework elements independent of any one decision-making structure to offer an approach that is flexible enough to be of value to partnerships at all levels of STIK development — from a bottom-up, researcher-driven perspective to a top-down, mission-driven perspective — and inclusive of both government-supported and independent organizations.

2.1 The Framework Elements

The three key steps of a strategic evaluation process are: i) articulating goals, ii) identifying, evaluating, and weighting appropriate indicators, and iii) making a decision. In this report, the first two steps are supported by the framework elements: *National Priorities, Leveraging Value*, and *Benefits to Canada*. The third step, decision-making, occurs in the area of overlap among all three elements (Figure 2.1).

Identifying the *National Priorities* that potential partnerships are meant to advance will help users articulate the goals and desired outcomes, which then inform the areas of focus for the next two elements. *Leveraging Value* is assessed through the identification of existing relationships, resources, strategies, and commitments that may complement or detract from a new or ongoing partnership opportunity (see Chapter 3 for an overview of the international and domestic STIK landscapes). Articulating the anticipated *Benefits to Canada* will allow users to identify the indicators and metrics needed to evaluate a partnership's potential or historical outcomes (explored in detail in Chapters 4, 5, and 6).

While there are unique aspects to all three of these elements, weighting and evaluation are applied in the area of overlap; that is, a decision can be made through the combined evaluation (weighting and prioritizing) of indicators and metrics that speak to all three elements. The success of a decision-making framework will be determined by the level of support available for its implementation, including strategic foresight capacity, data sources and analyses, governance, and the ability of users to evaluate and adapt a framework to changing contexts (Chapter 7).

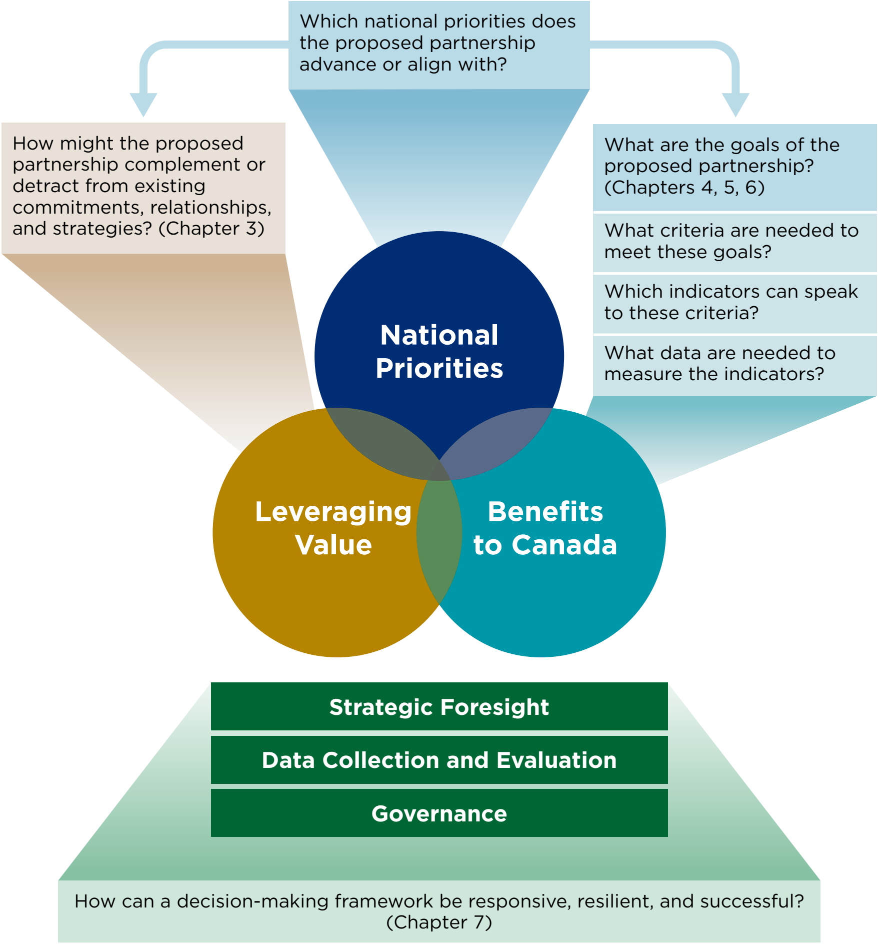


Figure 2.1 Elements of a Framework for Prioritizing International STIK Partnership Opportunities

The evaluation and prioritization of international STIK partnership opportunities are centred on meeting *National Priorities*. An initial articulation of partnership goals is necessary to further identify desired outcomes (*Benefits to Canada* and *Leveraging Value*) and their associated indicators and metrics. Foundational to a framework's success are considerations of strategic foresight, data collection and evaluation, and governance.

2.1.1 National (and Other) Priorities

Operating under the premise that users of a framework will largely be federal departments or agencies assessing whether to continue or enter into new partnership agreements, the panel presumes that goals will broadly reflect the priorities of the Government of Canada. For example, the Crown — through the House of Commons and Senate — enacts laws to ensure "peace, order, and good government" in Canada (GC, 1867). Though these are broad descriptors, all government activities must align with these core values. However, as a mechanism to choose among STIK opportunities, these goals are too broad to be actionable. A further specification of goals and desired outcomes is therefore necessary to compare partnership opportunities (Figure 2.2).

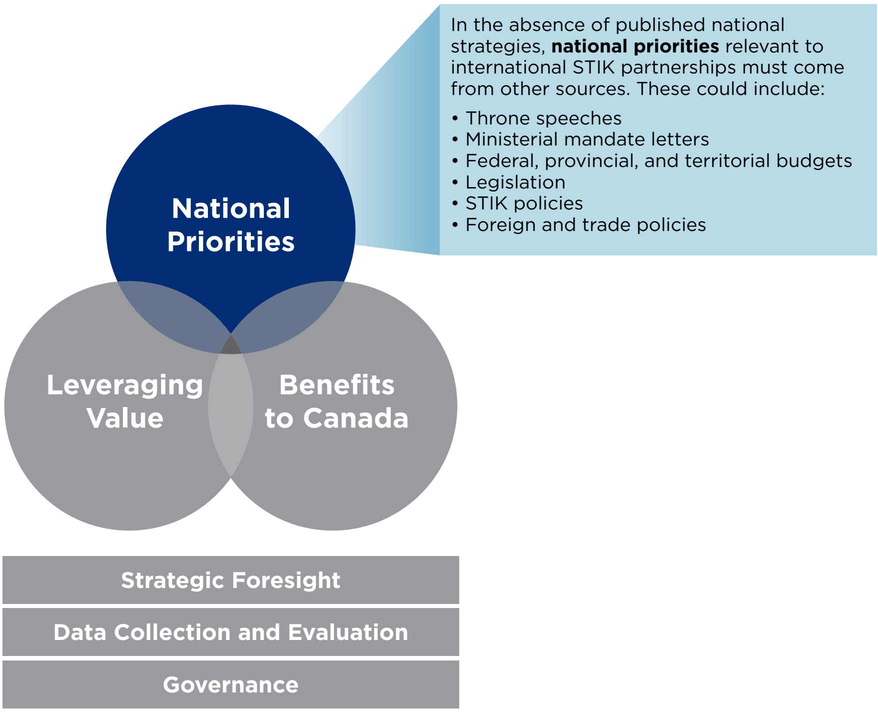


Figure 2.2 Identifying National Priorities to Articulate the Goals of a Partnership

Goals that reflect multiple interests (such as those that include specific provincial and territorial priorities, global priorities, or departmental or programmatic priorities) offer wider potential benefits than those that reflect only national-level considerations.

National priorities help actors identify high-level goals for international STIK partnerships

National priorities may be sourced from throne speeches, ministerial mandate letters, budgets, legislation, STIK policies, and foreign and trade policies. At the federal level, Canada's STIK policy is the responsibility of Innovation, Science and Economic Development Canada (ISED), while GAC (among others) contributes to guiding and supporting Canada's international STIK activities (TCS, 2015). Goals of international STIK partnerships may therefore reflect priorities identified in ministerial mandate letters issued by the Office of the Prime Minister.

For example, at the time of this report's publication, priority areas of overlap among ministerial mandate letters included climate change, clean technology, and a net-zero economy; Indigenous reconciliation; advancing equity, diversity, and inclusion (EDI); cybersecurity; digital leadership; health and well-being; and advancing democracy and human rights (PMO, 2021a, 2021b, 2021c). The automotive, aerospace, natural resource, agri-food, mining, and manufacturing sectors were also explicitly mentioned in the mandate letter to the Minister of Innovation, Science and Industry, as were the fields of photonics, quantum, and AI (PMO, 2021b). These priorities were also evident at the G7[2] leaders summit held in June 2022, where the Prime Minister re-stated the commitment of Canada and other G7 members to a sustainable planet, a safe environment, healthy lives and global health architecture, sustainable infrastructure and development, and global digitalization (PMO, 2022).

National priorities are dynamic and may shift in response to changing governments, global contexts, and emergent pressures. The initial step of articulating goals may be considered an iterative and collaborative one; a diversity of perspectives and a habit of revisiting framework priorities will help ensure the appropriateness of goals within a given context. For example, while an individual federal agency or department could make use of the framework elements to meet their specific mandates, it may be valuable to bring together other agencies and departments, to maximize efficiency and ensure priorities relevant across government are not missed. Moreover, creating opportunities for broader inputs from the public and private sectors — such as subnational governments, academia, industry, and Indigenous communities — can provide additional value at this stage.

2 Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States.

Subnational priorities can provide specificity in partnership goals

While national-level STIK partnership opportunities are examined in the context of federal priorities, further considerations may also be given to subnational priorities, including those of provincial and territorial governments, departments, or funding programs. Subnational priorities may further articulate key criteria or provide a more detailed rationale for engaging (or not) in an international partnership. The details of provincial and territorial STIK policies, strategies, and funding announcements can help indicate whether different partnership opportunities align with subnational government priorities. Similarly, depending on the context, the particulars of departmental or programmatic priorities in other orders of government can provide further criteria for the evaluation and prioritization of international STIK partnership opportunities.

Some provinces and territories have STIK policies and international engagement strategies that are broadly consistent with those of the federal government, but with a strategic focus relevant to their regional strengths (e.g., Gingras, 2022). For example, the Government of Quebec's 2022–2025 life sciences strategy, *Using Our Ingenuity to Promote Health*, identifies industrial sectors of interest to the province, such as AI for health diagnostics, and cell and gene therapies (Gov. of QC, 2022). In Ontario, announcements of financial support for the Perimeter Institute and SNOLAB highlight the province's focus on leadership in foundational theoretical and fundamental physics (Gov. of ON, 2021). In 2022, the Government of Alberta announced funding for the Hydrogen Centre of Excellence to support hydrogen innovation and technology — evidence of the province's priorities of economic diversification and resilience (Gov. of AB, 2022). As well, the Government of British Columbia released its *Life Sciences and Biomanufacturing Strategy* in 2023, highlighting its focus on the development and retention of a vibrant biomanufacturing industry in the province (Gov. of BC, 2023b).

International STIK partnerships may also reflect goals related to global outcomes

Global priorities are also worthy of consideration when actors are evaluating STIK partnership opportunities. One articulation of global priorities can be found in the United Nations (UN) *2030 Agenda for Sustainable Development*, which includes 17 interrelated Sustainable Development Goals (SDGs) and a 15-year plan to achieve them (UN, 2022a). The Government of Canada is a signatory to the SDGs and has stated that "advancing progress on the SDGs domestically and internationally is a Government of Canada priority" (GC, 2022b). The panel discusses SDGs in more detail, in the context of national resilience and sustainability, in Section 6.2.1.

What We Heard

Interviewees, guest speakers, and workshop participants commented on the need for a long-term STIK vision for Canada, to help establish clear priorities at national, subnational, and organizational levels.

2.1.2 Leveraging Value

A gap often raised among interviewees, workshop participants, and guest experts with whom the panel engaged — and which has also been included in recommendations and reviews of Canada's international S&T activities (recall Figure 1.4) — is the need for organization, strategy, and coordination among all players in Canada's STIK ecosystem. While the prior step of articulating goals makes overt what objectives are being addressed by the potential partnership, another important step in evaluating any proposed or ongoing relationship is to assess its activities in relation to the ecosystem of domestic activities and international agreements (Figure 2.3).

Not all international STIK collaborations are captured under formalized partnership agreements. Being able to assess the potential to leverage the value of an international STIK partnership requires access to a repository of information on existing domestic and international STIK activities. Chapter 3 provides a high-level overview of the current landscapes, though further efforts would be required to situate a specific partnership opportunity within this space. However, there are a variety of models available to facilitate such work. For example, knowledge of the domestic and international landscapes may reside in — and be shared by — specific personnel and their networks (including S&T and trade officers), an accessible database, or a secretariat; it could also be captured as part of regularly scheduled conferences, joint coordinating meetings, or forum discussions. There are pros and cons to each potential model. Moreover, these models are not necessarily mutually exclusive; multiple models may be useful to ensure broad accessibility and timely intelligence. Such models for framework implementation are examined in more depth in Chapter 7.

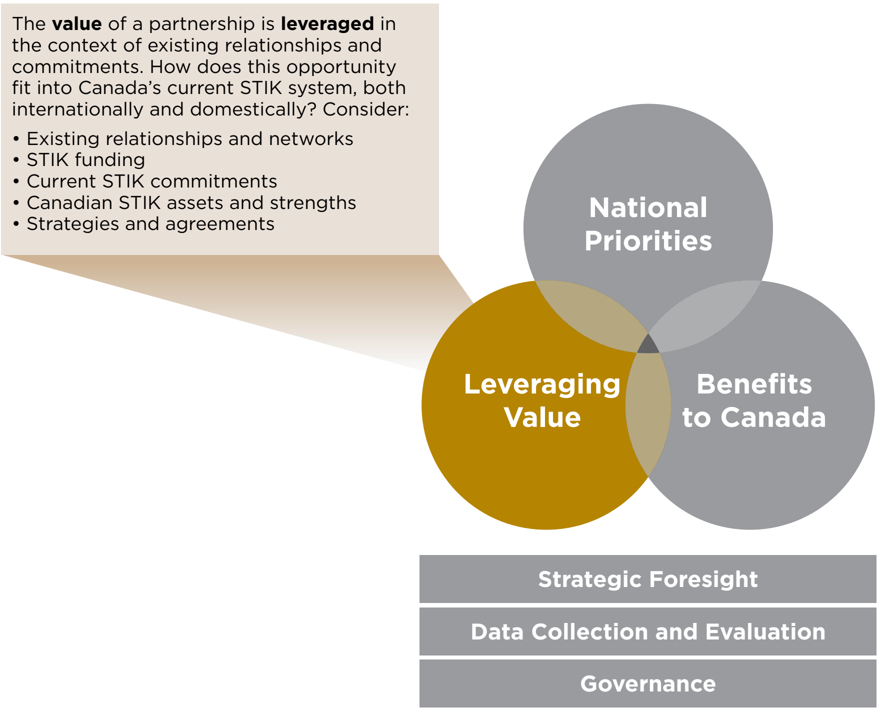


Figure 2.3 Assessing the Value of Proposed Partnerships

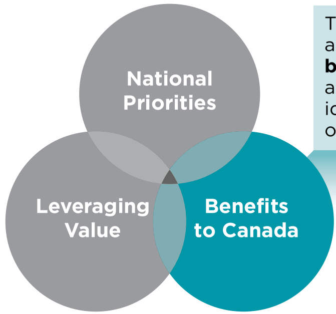
Successful international STIK partnerships will not only create new relationships, but also support existing relationships and activities in relevant areas both domestically and internationally. An assessment of the strategic value provides an opportunity to examine complementarity as well as uniqueness, both of which may inform further negotiations of partnership agreements.

Meeting national priorities and providing benefits to Canada are essential to successful international partnerships. A comparison of indicators and metrics that speak to such goals and outcomes can provide a quantitative evaluation of comparable opportunities. Assessing strategic value can also include the use of qualitative data that evaluates, for example, potential conflicts and confluences, such as alignment in policy and regulatory support for EDI or open science practices. However, judgment is also called for in this step. The exercise of assessing strategic value can help with negotiations and delineating the boundaries of a potential partnership.

2.1.3 Benefits to Canada

To be successful, any international STIK partnership Canada enters into must create some benefit for the country. Broadly, a STIK partnership provides benefits by advancing Canadian interests and building capacity in Canada. This capacity building may include introducing new ideas, insights, innovations, or unique knowledge. *Benefits to Canada*, as envisioned in this report, can also increase national resilience, by, for example, addressing urgent issues of national security in the short term, or contributing to sustainability over the long term. Users of a framework need to identify the benefits to Canada relevant to the goals of the partnership under consideration, then choose the indicators or metrics that best predict, or directly measure, those benefits. If the partnership opportunities include those already established — that is, if the decision is on whether to continue a partnership rather than choosing among new opportunities — users may choose to directly measure past benefits. If the partnership seeks to build a new relationship, the indicators chosen will be those best suited to predict outcomes.

Selecting and evaluating indicators and metrics are complex tasks that require a substantial investment of time and human resources early in the decision-making process. However, this is the work that transforms the framework elements into useful tools for decision-making. Details about different types of indicators, their uses and limits, as well as potential applications to different scenarios, are examined in depth in Chapters 4, 5, and 6. These chapters examine benefits to Canada in three main categories: those related to innovation; to science capacity building and knowledge production; and to national resilience (Figure 2.4).



There is a wide array of indicators and metrics to measure potential **benefits to Canada**. From the articulated goals, criteria are identified for evaluation. Areas of consideration include:

Innovation	Criteria (example indicator)
Collaboration and Commercialization	• Collaboration readiness (complementarity) • Commercialization and scale-up (firm size and performance) • Inputs (R&D investment, resources) • Assets (tangible and intangible) • Outputs (growth)
Trade	• Trade system (imports and exports) • Regulations and barriers (tariffs, quotas) • Standards setting and regulatory alignment (standards creation, adoption)

National Resilience	Criteria (example indicator)
Diplomacy	• Diplomatic outcomes (new policies, innovation centres)
Sustainability	• Sustainability (development, emissions) • Reciprocity (fair mutual benefit) • Commitment and vision (use of foresight)
Security	• National security (security networks) • Foreign influence (vulnerability) • Cybersecurity (alignment, threats) • Research security (sanctioned activities)

Scientific Capacity and Knowledge Production	Criteria (example indicator)
Excellence	• Rigour (peer review) • Production (publications, other outputs) • Impact (citations)
Open Science	• FAIR* principles (policies) • Collaboration (co-authorships)
Talent	• Potential (network position) • Expertise (citations) • Mobility (policies, programs)
Infrastructure	• Location (uniqueness) • Institutions (rankings) • Facilities (accessibility)

Figure 2.4 Increasing Innovation, Scientific Capacity and Knowledge Production, and National Resilience as Benefits to Canada

International STIK partnerships must bring some benefits to Canada, in order to justify their pursuit. The identification of these benefits helps establish evaluation criteria. Useful indicators reflect the qualities a partner brings to the table that will result in those benefits to Canada, as evidenced by the potential partner's existing activities, outputs, and relationships.

*FAIR (findable, accessible, interoperable, reusable) principles of open data

2.1.4 Evaluation Considerations

There are costs and risks associated with international STIK partnerships. In the framework elements described in this report, such costs and risks are captured by the criteria considered when users examine *Leveraging Value* and *Benefits to Canada* and their associated indicators and metrics. For example, research security and other security considerations are associated with international partnerships; the use of security indicators in a data-enabled framework would help establish higher and lower risk partnerships (Chapter 6). International projects may also face logistical challenges, such as working across time zones, long-distance travel, differences in the timing of funding cycles, and differences in management systems and cultures (Wagner, 2018). Some relevant indicators could include open science (to evaluate or establish management expectations) and mobility criteria (Chapter 5). Alignment of funding cycles may be considered when comparing international and domestic STIK ecosystems (Chapter 3). There can also be a political challenge in the justification of spending national funds and resources on international partnerships (Wagner, 2018); the panel notes that governments may tend toward risk aversion. However, the panel also cautions that there are substantial opportunity costs associated with inaction, particularly in the increasingly global STIK network; it emphasizes the value of informed and responsive decision-making.

Aligning indicators with program goals strengthens evaluations

In line with other types of evaluations (e.g., of funding programs), meaningful evaluations of potential STIK partnerships align indicators with specific sets of policy goals (OECD, 2019b). STIK programs are often a means of achieving objectives such as economic competitiveness or sustainability (van den Hove *et al*., 2012; OECD, 2019b). Identifying and collecting data for indicators relevant to STIK policies are integral to the evaluation process (UNCTAD, 2020). Public policy objectives often fall into two categories — economic and societal goals (Diercks *et al*., 2019; UNCTAD, 2020). Economic goals are reflected in key indicators of economic development, such as gross domestic product (GDP), productivity, or employment, while societal goals can include reducing poverty, enhancing food security, or improving health (UNCTAD, 2020).

What We Heard

Interoperability and the compatibility of indicators and metrics were brought up during interviews with members of the INIST, with multiple interviewees noting the value of designing a framework to allow for comparisons across different sectors and strategies, and to benchmark against other countries and organizations.

The UN Conference on Trade and Development's *A Framework for Science, Technology and Innovation Policy Reviews* characterizes innovation systems based on an enabling STIK environment, combining stable macroeconomic institutions, and prioritizing regulatory frameworks directed towards innovation that addresses societal challenges (UNCTAD, 2020). For example, when assessing innovation programs to improve sustainable development, frameworks may need to combine metrics of technological and economic impact with environmental assessment and social impact data. Priority setting — and the choice of appropriate indicators — is a beneficial political process when it is evidence-based and engages a variety of actors with different interests (UNCTAD, 2020).

The panel notes that such an approach to choosing indicators (as well as the indicators reviewed in Chapters 3 through 6) reflects the available literature and should not preclude the creation or development of new ones. This framework approach is best considered as an iterative and dynamic process; where relevant, it could be used to test, modify, and refine indicators for future decision-making.

2.2 Developing and Using a Decision-Making Framework

With the framework elements described, the next step is assembling and ordering those elements in a logical progression to inform the evaluation of potential or existing STIK partnerships. For example, a user may be faced with a need to choose among partnership opportunities. Now is the time to identify the *National Priorities* relevant to that group of partnerships, in order to articulate goals and outcomes; to identify the expected *Benefits to Canada* and assess *Leveraging Value* using appropriate indicators and metrics; to weight and evaluate the collected information; and, ultimately, to make a decision by ranking the priority for engagement among the opportunities. Implementation considerations foundational to any decision-making framework include governance, the potential for strategic foresight activities to inform goals and indicators, and the data collection and analyses required for weighting and evaluation (Figure 2.5).

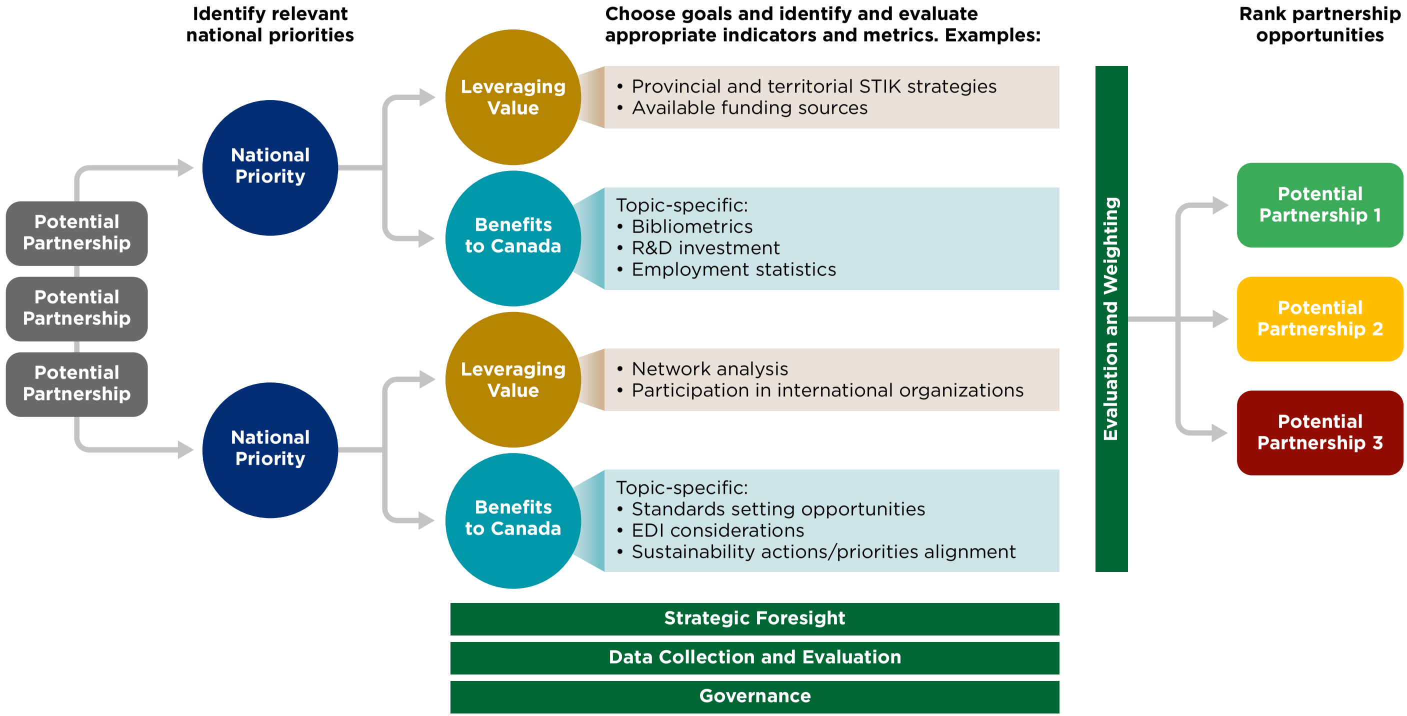


Figure 2.5 Example of a Framework for Evaluating International STIK Partnership Opportunities

Assembled elements in a sample framework for choosing among three potential international STIK partnership opportunities. With the evidence summarized in this report, the user would identify the *National Priorities* expected to be advanced by the partnership, articulate those as goals of the partnership, and choose appropriate indicators and metrics to address those goals delivering *Benefits to Canada* and *Leveraging Value*. Effective implementation is supported by strategic foresight, data collection and evaluation, and governance. The gathered information is then used to weight and rank the partnership opportunities.

2.2.1 Implementation Considerations

Specific criteria, indicators, and metrics are reviewed later in the report, with respect to the element of *Leveraging Value* in Chapter 3 and with respect to *Benefits to Canada* in Chapters 4 through 6. The sections below provide a high-level overview of common considerations for implementation of a data-enabled framework, regardless of which criteria, indicators, and metrics are chosen. These include the use of strategic foresight; data access, availability, and comparability; and options for weighting criteria in the evaluative process. These and additional success factors related to implementation are explored further in Chapter 7.

Strategic foresight can help actors identify indicators relevant to future outcomes

The framework elements provide a foundation for decision-making based on past and present data and experience, in order to anticipate future outcomes. One concern is that chosen indicators, metrics, and data might be made obsolete due to changes in geopolitical context, government priorities, and funding availability, among other factors. While there is no solution to address uncertainty about the future, an approach that includes strategic foresight activities can support explicit consideration of a variety of potential outcomes.

Strategic foresight employs structured methods of examining possible future outcomes to inform current decision-making (OECD, 2019a). Other forward-looking practices, such as visioning and forecasting, require either fixation on a particular image of the future or the generation of a narrow future view, respectively (Fuerth, 2009; Bland & Westlake, 2013; UNDP GCPSE, 2014). Strategic foresight is less about predicting the future (singular) and more about exploring plausible futures (multiple), using many tools and concepts, such as horizon scanning, megatrends analysis, scenario planning, and backcasting for improving anticipation, policy innovation, and the future-proofing of decisions (OECD, 2019a).

Accessible and easily located information sources and networks are vital to success

Systematic collecting and sharing of data on existing and potential partnerships are necessary to the successful implementation of any data-enabled framework. The data collected can help evaluate the success of ongoing partnerships, while also providing a basis for evaluating framework implementation — for example, in the critical examination of the relevance of different indicators and metrics to specific goals or measurements of strategic value. Multiple, diverse quantitative and qualitative indicators are needed to understand the STIK ecosystem (UNCTAD, 2020). Indicators are most effective when they are considered in the specific socio-technical context of their innovation systems and thus require professional analysis. The collection and analysis of these indicators need to be complemented by appropriate expertise, training, and resources (UNCTAD, 2020).

Notably, not all data necessary to the success of a framework are amenable to being housed in a database or repository. For instance, qualitative data sources and methods that support STIK partnership decision-making (e.g., security intelligence, lived experiences, and expertise) will not be easily captured in a database. The ability to find the right people to talk to, and to access their knowledge and experience, is an important component of framework implementation. Using a central portal, maintaining institutional knowledge, and having robust network connections are ways to support these qualitative elements, as are regularly scheduled networking opportunities, such as those afforded by INIST and the CRCC, and by the Joint Science and Technology Coordinating Committee (JSTCC) meetings associated with particular bilateral S&T agreements (e.g., Industry Canada, 2003; GC, 2022d, 2023b).

Weighting criteria ensures comparability and relevance

A data-enabled framework for prioritizing international STIK partnerships will inevitably include a broad complement of different indicators that collectively speak to the potential benefits and leveraging opportunities under consideration. Therefore, an important step in the evaluation of the data is adjusting the data collected to ensure comparability and relevance. This process of weighting criteria involves normalizing data so that they are evaluated on the same scale, and so that evaluation groups (i.e., potential partnerships) can be fairly compared (Ozkaya *et al.*, 2021). There are objective and subjective ways to weight indicators, with pros and cons to both (Iwaro *et al.*, 2014); these are explored below.

Objective weighting uses information gathered about each criterion and applies a mathematical function to compute weights without subjective judgment. These methods address the challenge created by the growing number and complexity of the criteria needed to measure the socioeconomic environment (Yejun & Zhijian, 2008). Examples of objective weighting methodologies include the entropy method, the standard deviation method, and the statistical variance procedure (Yejun & Zhijian, 2008; Iwaro *et al.*, 2014). The collective name for approaches that use multiple criteria in an explicit and transparent way to support decision-making is multiple criteria decision analysis (MCDA).

MCDA methods have been applied across a wide range of decision-making contexts, by policy-makers and others, through ongoing development of new tools and applications (Kurth *et al.*, 2017; Haag *et al.*, 2022). For example, MCDA methods are used in funding decisions regarding health technologies (e.g., in health technology assessments, or HTAs) (Hansen & Devlin, 2019). The MCDA process includes multiple steps: structuring the decision problem, specifying criteria, measuring alternatives' performance, scoring alternatives on criteria, weighting criteria, and applying scores and weights to rank alternatives. This ranking is then used as an input to support decision-making (Hansen & Devlin, 2019). Practical challenges to MCDA methods include informational requirements and technical capacity (Marsh *et al.*, 2018). As well, the complexity of government decision-making may demand processes that are more inclusive of diverse perspectives and values than can be addressed through MCDA methods alone (Beaudrie *et al.*, 2021).

Subjective weighting methods use expert judgment to weight criteria — they are inherently limited by the knowledge and experience of the experts involved. There are a variety of methods used to weight criteria subjectively, such as direct rating, where experts assign a numerical value to different criteria (Ribeiro *et al.*, 2013), or exercises wherein experts rank criteria from most to least important (or vice versa) (Patel *et al.*, 2017; Odu, 2019). Subjective weighting methods often score criteria using pairwise comparisons, where experts are presented with a series of pairs of criteria and rank the criteria as more or less important in each pair (Iwaro *et al.*, 2014). Weights are then determined by measuring the consistency among experts. In a review of different subjective weighting methods, Németh *et al.* (2019) found that there is an important trade-off to consider — the less complex and resource-intensive a method is, the more prone it is to bias.

Integrated approaches use a combination of subjective and objective information to rate criteria (Odu, 2019). The objective analysis helps overcome reviewer bias, while subjective expert opinion helps reflect real-world barriers in the decision-making process that are not captured in the objective data. Thus, integrated approaches can help overcome the weaknesses of either weighting method (Iwaro *et al.*, 2014; Odu, 2019).

2.2.2 Approaches to Using a STIK Decision-Making Framework

Taken together, these framework elements create a structure for supporting decision-making related to entering, exiting, or continuing international STIK partnerships. Chapters 3 through 6 provide users with an evidence base from which to choose indicators and metrics relevant to leveraging existing relationships and activities, and that offer benefits to Canada through innovation, science and knowledge production, and improved national resilience. The options available for the user will depend on key factors, such as whether the partnership opportunities being assessed build on existing partnerships (i.e., are there existing evaluations from which to draw?), the timeline of the proposed partnership, and the scope of the proposed STIK activities.

Timelines may be imposed by administrative considerations. For example, a STIK agreement with a time-limited funding envelope will constrain the timeline for consideration. Similarly, the current status of a technology, commercial readiness, or research needs can inform the scope of the activities under consideration in the partnership (e.g., whether laboratory experiments, field trials, or commercial development are appropriate). These factors — timeline and scope — then inform the choice of indicators or metrics, such as number of publications or patents, regulatory approval, or market share. The ongoing or future evaluation of the chosen partnership is another important consideration, particularly for choosing metrics that can be meaningfully used as baselines or comparators, thus improving future evaluations and use of a framework.

The implementation of a framework will also be different depending on the user — that is, whether the decision-makers include the researchers themselves, department leads or representatives, or elected officials, and whether there are other organizations involved. Such considerations and other governance factors that can contribute to a framework's success are explored in Chapter 7.

3

Leveraging Value: Canadian and International STIK Landscapes

Canada's science, technology, innovation, and knowledge production (STIK) landscape benefits from both domestic and international actors, bringing national prosperity, competitiveness, innovation, and overall well-being to the public. A robust understanding of the current system, available resources, and Canada's strengths and weaknesses is foundational to making informed international STIK partnership decisions that address short- to long-term needs. Knowledge of existing agreements and their benefits can help guide partnership decisions toward available resources or away from avoidable hurdles.

Strategically leveraging value can take many forms — partnerships can be chosen to build on strengths, address weaknesses, or help secure future technology needs and areas of growth. The value that can be leveraged in Canada is found in the public and private sectors, and civil society (e.g., funding programs, research facilities, business investment, and a well-trained workforce); for all STIK actors, knowing what value they can access improves the evaluation of partnership opportunities. Relatedly, understanding the global STIK landscape is crucial to setting priorities and identifying opportunities to advance Canadian interests.

What We Heard

Creating value for Canada is an essential outcome of international STIK partnerships. Interviewees and workshop participants commented on the lack of an existing framework that helps coordinate international and domestic STIK activity around a strategy to increase value.

3.1 Canada's International STIK

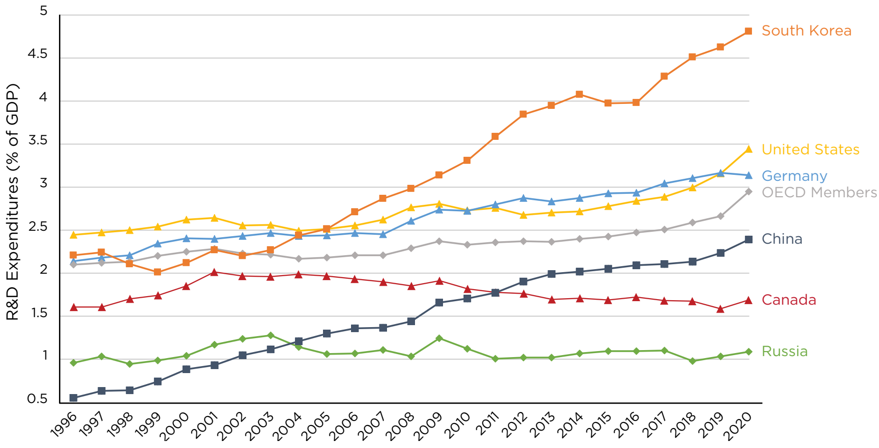
Canada has a deeply integrated STIK ecosystem characterized by numerous international partnerships. It is not unique in this aspect as mentioned throughout this report; science and innovation are increasingly the product of global interconnectedness. Thus, past partnership agreements and decision-making processes both abroad and at home can help inform Canada's future partnerships and decision-making. However, as noted in Chapter 2, Canada lacks published national STIK, foreign policy, and security strategies, which makes it difficult for organizations to define goals and align programs and value with *National Priorities*. In other countries, national STIK strategies are being developed to drive economic growth, improve sustainability and security, and establish nations as world STIK leaders. These include international partnership and policy direction to guide STIK investments (e.g., Gov. of the Republic of Korea, 2022; UKRI, 2022b). While Canada has some resource-, technology-, and region-specific strategies that include aspects of STIK (e.g., GC, 2022e, 2022f; ISED, 2023c), it lacks a comprehensive national strategy. To understand its potential to leverage value from international STIK partnerships, Canada must first evaluate its position within the international ecosystem.

3.1.1 Canada's International Innovation Competitiveness

Given the relatively low level of investment, Canada has not achieved the degree of innovation seen in its peer countries (Gera, 2017; Conference Board of Canada, 2021; Asselin, 2022; WIPO, 2022). The Conference Board of Canada (2021) ranked Canada 10th among 16 peer countries, while the Global Innovation Index (GII) ranked it 15th among 132 countries and 14th among 48 high-income economies (WIPO, 2022). In 2021, Canada had the seventh-highest gross domestic expenditure on R&D (GERD) in the OECD; however, it ranked 19th in the OECD for GERD as a percentage of GDP (OECD, 2022g). Canada's investment in R&D is well behind that of East Asia and Pacific countries, Europe, Central Asia, and the OECD average,[3] and its relative performance has been worsening since 2001 (The World Bank, 2023a).

The rising investment in R&D by upper middle-income and middle-income countries has increased the number of desirable international STIK partners; however, Canada's investment relative to GDP has fallen below the average for these two groups of countries (The World Bank, 2023a). Its GERD as a percentage of GDP (1.7%) is well below that of the most aggressively investing nations: South Korea (4.8%), United States (3.5%), Germany (3.1%), and China (2.4%) (Figure 3.1). Though China's spending relative to GDP is lower than some other countries, it has the second-largest gross R&D spending after the United States. Of the three major R&D-performing sectors — business, higher education, and government — business is Canada's weakest based on investment spending, ranking 21st in business enterprise expenditure on R&D (BERD) as a percentage of GDP in 2021 (OECD, 2022g). Canada's best ranking was 6th in higher-education expenditure on R&D (HERD) as a percentage of GDP (OECD, 2022g).

3 Classifications are according to the World Bank and UNESCO Institute for Statistics (Lileeva & Trefler, 2010).



Data source: The World Bank (2023a)

Figure 3.1 Canada's R&D Expenditures Compared to Select Nations, 1996–2020

Canada's R&D investment (GERD) relative to GDP is falling, while many other advanced economies are increasing their relative spending.

Though investment in R&D in Canada lags behind similarly positioned countries, innovation depends on several factors, including discovery (where R&D funding is applied), but also incubation and acceleration (O'Connor, 2019). Canada's innovation performance may also reflect factors such as a lack of domestic business competition, weak innovation output performance by businesses, and economic protectionism (Conference Board of Canada, 2021; Stasinopoulos Rowell, 2021; Hudson, 2022; WIPO, 2022). According to the GII, Canada has relative weaknesses (compared to similar income groups) in infrastructure, particularly in access to and use of information and communications technology (ICT), energy use, and environmental certifications (WIPO, 2022). Additionally, Canada performs relatively poorly in some aspects of knowledge creation and impact, such as patenting activity and new business development. However, its strengths reflect the importance of international relationships; for example, Canada is a top recipient of venture capital investments and a leader in joint ventures and strategic alliance deals (WIPO, 2022).

3.1.2 Canada's International STIK Partnerships

The Government of Canada has agreements with many countries that facilitate and support international STIK collaboration, each with its own specific goals and opportunities. Canada has built formal STIK relationships and partnerships with both established and emerging economies worldwide, including Brazil, China, France, Germany, India, Israel, Japan, South Korea, the United Kingdom, and the United States, among others, as well as the European Union (EU) (TCS, 2023).

Partnerships — domestic, international, private, and public — contribute to the broader innovation ecosystem. Beyond the economic rationale for STIK partnerships, international STIK collaborations help build Canada's STIK capacity and infrastructure; they drive basic science and lead to further innovation development (Chapter 5), and they help develop national resilience through sustainability and security (Chapter 6). This capacity also creates the added benefit of incentivizing potential partners to work with Canadian organizations.

The activities related to Canada's international STIK agreements are largely supported by federal departments and agencies and cover a wide range of fields, such as health, clean energy, life sciences, climate change, and strategic national innovation priorities, including quantum computing and AI (Wilshaw, 2020). Partnerships are promoted by Canada's Trade Commissioner Service (TCS) through a network of 25 S&T counsellors and officers at 19 embassies and consulates in 11 leading innovation countries, and supported by TCS members in Ottawa and across Canada (Wilshaw, 2020). Federal organizations also prioritize specific partnerships, leveraging the value of their networks "for deeper strategic opportunities of benefit to Canada" (NRC, 2020). For example, the National Research Council of Canada (NRC) seeks to expand the engagement of small- and medium-sized enterprises (SMEs) through participation in Eureka[4] and has identified three important countries for strategic engagement: Germany, the United Kingdom, and Japan (NRC, 2020).

Canada and the United States have long-standing formal and informal STIK partnerships

The United States is Canada's most important economic partner (U.S. Embassy in Canada, 2018; GAC, 2022a). Multiple ongoing agreements between Canada and the United States are designed to promote STIK partnerships and support innovation; however, they frequently seek to address other diplomatic goals. One example is

4 Eureka is a "public network for international cooperation in R&D and innovation, present in over 45 countries" (Eureka, n.d.).

the 2021 *NSF-NSERC MOU*,[5] which enhances collaboration in areas of mutual interest, specifically biomedical research, clean technologies, next-generation automotive technologies, space, Arctic research, cybersecurity, advanced semiconductors, and emerging technologies such as AI, quantum, and genomics (Lander & Champagne, 2021). Additionally, Canada and the United States are advancing a shared STIK agenda, which seeks, among other goals, to further EDI, as well as accessibility in and through joint activities (Lander & Champagne, 2021).

The relevance of such partnerships is also tied to changing geopolitical conditions. For example, recent U.S. legislation, the *United States Innovation and Competition Act of 2021*, calls for strategic cooperation with Canada when managing relations with China, and includes substantial investments in S&T research (Touch, 2022). The ongoing economic and technical competition between China and the United States creates tensions for smaller, middle-power nations that have partnerships with both, such as Canada (Touch, 2022). Not all cooperation is mediated through national agreements, though some formal federal cooperation exists (e.g., the Greening Government Initiative), in part to facilitate informal international collaboration (Gov. of U.S., 2021).

Other international STIK partnerships are supported by formal agreements

Canada has been signing S&T agreements with China since the 1980s, often in the form of MOUs (McCuaig-Johnston, 2019). Early work between these countries includes Canadian development projects in China that were intended to help China rather than benefit Canada (McCuaig-Johnston, 2019). Moreover, academic collaboration has increased to the extent that China is one of Canada's top research partners. Canadian industry has also increasingly partnered with China, which has become Canada's second-largest trading partner (WITS, 2022). The *Agreement for Scientific and Technological Cooperation Between the Government of Canada and the Government of the People's Republic of China* is a federal agreement rather than a department-level MOU. Its goal is to "encourage technological commercialization to accelerate economic growth, increase international competitiveness, and solve global challenges" (ECCC, 2022). Under this agreement, governance and decision-making rest with the China-Canada Joint Committee (CCJC). The agreement funds projects and engages industry, academia, and government participants, leading to China-Canada collaborations (ECCC, 2022).

5 The *Memorandum of Understanding between the National Science Foundation of the United States of America and the Natural Sciences and Engineering Research Council of Canada concerning Research Cooperation*, signed June 15, 2021 (U.S. NSF & NSERC, 2021).

The *Agreement for Scientific and Technological Cooperation Between Canada and the European Community* was entered into in 1996, and its duration is indefinite; it was built upon a 1976 framework agreement for commercial and economic cooperation and has since informed the *Comprehensive Economic and Trade Agreement* (CETA) between Canada and the European Union (EU, 2019). The latter agreement has contributed to improved overall relations between Canada and the European Union (EC, 2021a). Among the actors identified in this agreement are multiple orders of government as well as universities, research institutions, companies, and individuals (EU, 2019). The activities covered under the agreement are based on shared and balanced benefits and include timely information exchange, sharing research facilities, and personnel exchanges.

Federal programs that fund international STIK collaborations can support Canada's research and innovation landscape

Many Government of Canada programs enhance the value of Canada's STIK ecosystem by directly and indirectly supporting international STIK collaborations (Table 3.1). A prime example is the Canadian International Innovation Program (CIIP), designed to facilitate collaborations between Canadian companies and foreign partners to support international R&D with commercialization potential (TCS, 2022a). The program includes funding for partnerships in Brazil, China, India, Israel, and South Korea (TCS, 2022a). Collaborative R&D projects are designed to help SMEs close to commercialization by funding 50% of salaries, contractor fees, and reasonable travel costs (TCS, 2022a; GAC, 2023a). The CIIP also funds partnership development activities, which are educational, networking, and matchmaking activities to facilitate collaborative R&D (GAC, 2023b). The Scientific Research and Experimental Development (SR&ED) program uses tax credits to incentivize R&D investment by Canadian companies (GC, 2022h); international STIK partnerships may benefit from this program when, for example, foreign companies create Canadian subsidiaries that perform eligible R&D work in Canada (Invest in Canada, 2022).

Canada's granting agencies explicitly promote STIK collaboration nationally and internationally. For example, the NSERC Alliance International program funds research between domestic and international researchers; this includes an MOU between Canada and the United States that supports collaboration on quantum science and AI (NSERC, 2022). In 2022, grants included 358 partner organizations from the private sector, 99 from the not-for-profit sector, and 87 from the public sector, covering broad research interests (NSERC, 2022). Similarly, the CRCC New Frontiers in Research Fund supports high-risk/high-reward interdisciplinary and internationally collaborative projects; the fund is a shared venture among CIHR, NSERC, and SSHRC (GC, 2021c; CRCC, 2022).

Table 3.1 Select Funding Programs Whose Value Can Be Leveraged as Part of International Collaborations in the Canadian STIK Ecosystem

Program	International Partnership Role
Agricultural Clean Technology Program	Creates an enabling environment for the development and adoption of clean technology that will help drive the changes required to achieve a low-carbon economy and promote sustainable growth in Canada's agriculture and agri-food sector (AAFC, 2022).
Canada Innovation Corporation (in development)	Designed to help Canadian businesses increase innovation and productivity by developing and protecting intellectual property; it drives product and business development to support Canada's economic growth and job creation (FIN, 2023).
Canada Research Chairs Program	Supports research excellence in Canada by attracting accomplished and promising researchers in natural sciences, engineering, health sciences, humanities, and social sciences (GC, 2022g).
Canadian International Innovation Program	Supports Canadian companies pursuing R&D collaboration with a foreign partner on projects that have the potential for commercialization (TCS, 2022a).
Canadian Technology Accelerators	Provides business opportunities (e.g., support, mentorship, contacts) in 12 global tech hubs to help Canadian companies grow and succeed in international markets (TCS, n.d.).
Global Health 3.0	Funds and enables international health collaborations and promotes action on global health (CIHR, 2021).
Global Innovation Clusters	Boosts economic growth and job creation in Canada by giving rise to strong business partnerships, long-term objectives, competitive advantages, and innovation. There are five clusters focused on ocean sciences, AI, advanced manufacturing, protein industries, and digital technology (ISED, 2023a).
Mission Innovation	Funds R&D, demonstration projects, and related scientific activities that advance clean-energy technologies with the potential to help Canada meet its climate change targets and transition to a low-carbon economy (NRCan, 2022).
New Frontiers in Research Fund	Funds world-class, Canadian-led, interdisciplinary, international, and high-risk/high-reward transformative research (CRCC, 2022).
NSERC Alliance	The Alliance grants help fund collaborations between university researcher and private, public, or not-for-profit actors (NSERC, 2023).
Strategic Innovation Fund	Finances R&D projects for ISED and supports Canada as a top destination for business investment (Lowey, 2021; ISED, 2023b).

NGOs can facilitate international STIK cooperation

STIK collaborations among organizations are often facilitated by NGOs, which operate across a continuum from international to subnational scales. For example, Eureka is an international network of over 45 participating countries (including Canada) that was created to support the growth of SMEs through access to global value chains and international collaboration (NRC, 2023). When COVID-19 triggered a greater need for coordinated innovation at a global scale, Eureka issued two calls for proposals in early 2020 to help enable the collaborative development of new technologies related to COVID-19 and highly infectious diseases generally (Paunov & Planes-Satorra, 2021).

At a national level, the Global Innovation and Technology Alliance (GITA) is a not-for-profit public-private partnership initiative based in India that administers a program to fund cooperative R&D activities between Canadian and Indian companies (GITA, 2018a, 2018b). GITA's Canada-India program is a continuation of the 2005 bilateral *Agreement for Scientific and Technological Cooperation Between the Government of Canada and the Government of the Republic of India* (GITA, 2018a, 2018b). The agreement was created to foster cooperative STIK activities in "fields of common interest and on the basis of equality and mutual benefit," such as smart infrastructure, clean technology, food and agricultural technology, and healthcare (GITA, 2018a).

At a subnational level, C40 Cities is a non-profit organization that provides coordination and guidance to its international network of nearly 100 city mayors, with the goal of coordinating municipal governments' climate actions across international borders (C40 Cities, 2023c). C40 Cities organizes STIK conferences, provides support and acceleration for innovation, and engages with the private sector to drive innovation (C40 Cities, 2017, 2020, 2023b). Its recent activities include creating a climate change measurement framework, which involves identifying actionable indicators and making data and metrics available to cities (C40 Cities & Ramboll, 2019; C40 Cities, 2022). These data are intended to help members evaluate policy outcomes, improve decision-making, and facilitate action across cities. While data collection and sharing requires science partnership, the data in this framework can be used by members to guide the budget process, including innovation activities (C40 Cities, 2023a).

Another example is C100, an organization that connects members of the Canadian technology diaspora (C100, 2022). Through its network, it provides support in the form of mentorships, investment, partnerships, and access to talent. To assess its progress and impact, the C100 tracks the size and diversity of its membership, the international reach of its network, as well as the member's roles in the technology community (e.g., investors, founders) (C100, 2022).

Some partnership agreements facilitate international STIK collaboration through the alignment of laws and regulations

Not all partnerships provide monetary support or invest directly in STIK. Policy partnerships between countries often aim to develop a regulatory environment more amenable to innovation. For example, Canada has strengthened intellectual property (IP) law as a mechanism to support innovation and high-value R&D (Gold *et al.*, 2015). Countries can support STIK collaborations by harmonizing regulations, by recognizing shared standards and norms to reduce burden and duplication, and by increasing interoperability and coherence (OECD, 2020c; U.S. FDA, 2020; TC, 2021). The *Anti-Counterfeiting Trade Agreement* (ACTA) was negotiated among Australia, Canada, Japan, Mexico, Morocco, New Zealand, Singapore, South Korea, Switzerland, and the United States, as well as the European Union and its member countries, to enforce IP rights and improve international cooperation (GAC, 2013).

Similarly, the Government of Canada's *Foreign Investment Promotion and Protection Agreement* (FIPA) model — which was built upon innovations in free trade negotiations such as CETA — seeks to create a stable environment for Canadian investment abroad (GC, 2021b). This model includes IP protection and fair practices for resolving disputes between investors and the state (GAC, 2021a). IP protection can provide the basis for R&D collaboration when the correct institutional and regulatory frameworks are used (e.g., patent pools, knowledge sharing); however, in some instances, it can also enable anticompetitive behaviour (Lerner, 2012). IP can help form collaborations among universities, research institutions, government stakeholders, and industry (Ruimy, 2017). The Government of Canada engages in a number of international treaties that seek to harmonize laws and regulations relating to trademarks, IP, and industrial design, in order to improve partnerships in other markets (CIPO, 2017).

Government programs can help Canada acquire STIK talent through immigration and post-secondary education

Severe labour shortages associated with aging populations, along with a growing demand for highly skilled workers, compromise many countries' growth and nation building, including Canada's (Gopal, 2014; Gu & Stoyanov, 2019). To this end, the Government of Canada has developed several programs to recruit new talent to meet labour market needs. For instance, the Global Talent Stream helps companies hire highly skilled foreign talent and secure post-graduation work permits as a means of recruiting international workers and students (Gopal, 2014; ESDC, 2023). Immigration policies that help international students become permanent residents have made Canada a highly desirable destination for foreign study (Gera, n.d.). Canadian universities compete with those in Australia, the

United Kingdom, and the United States — popular destinations for international students — seeking to gain their market share of the best and brightest emerging STIK talent (Gopal, 2014). International students also generate an appreciable amount of revenue for Canada. For example, in 2018, they contributed an estimated $19.7 billion in direct and indirect economic impacts to Canada's GDP (GAC, 2020).

3.2 Canada's Domestic STIK Ecosystem

The Canadian STIK ecosystem comprises many actors that fund and perform R&D (TCS, 2015; StatCan, 2022d). STIK actors come from the public and private sectors and civil society; public sector actors include the various orders of government (federal, provincial/territorial, municipal, and Indigenous). To meet national and institutional STIK goals, governments, businesses, universities, and non-profits undertake and incentivize science and innovation activities. Though funding is a critical enabler of the STIK ecosystem in Canada, workforce, infrastructure (e.g., equipment, facilities), natural resources, and coordination are also key factors that support international STIK collaborations. Identifiable strengths in research and innovation provide the rationale for collaboration and a foundation for a strong negotiating position.

3.2.1 Canadian R&D Funding and Performance

Statistics Canada tracks R&D funding and performance in seven sectors: the federal government, provincial/territorial governments, business enterprises, higher education, private non-profit organizations, provincial/territorial research organizations, and the foreign sector (StatCan, 2021a). Investment is one crucial aspect of innovation; however, knowing who performs the innovation is necessary to understand the partnership landscape. Innovation activity can be done internally or by providing funding to Canadian or international organizations, which is common among organizations that fund innovation but do not perform their own R&D (Becheikh *et al.*, 2006).

R&D in Canada is primarily funded and performed by business enterprises

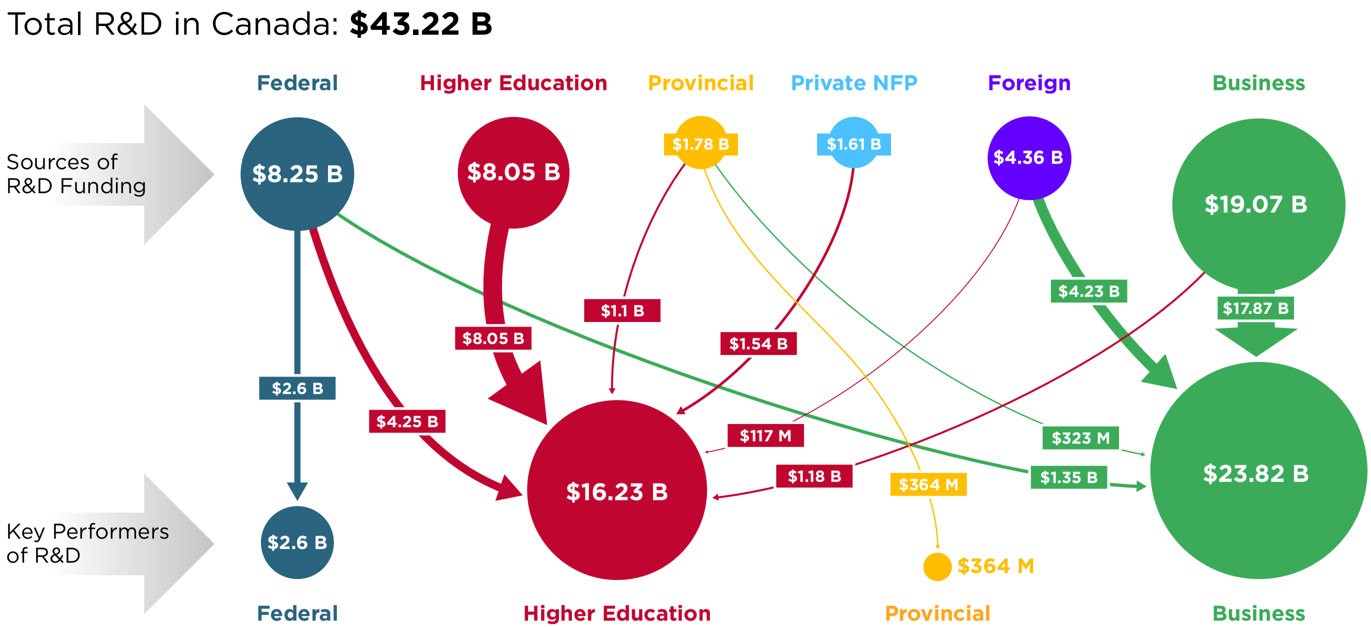
R&D is a major form of S&T activity and is strongly associated with innovation and growth (Clancy, 2022; StatCan, 2022a). In 2022, GERD from all sectors in Canada was approximately $43 billion (StatCan, 2023a). Canadian businesses are the largest R&D funders and performers, spending approximately $19 billion and performing approximately $24 billion on R&D in Canada in 2022. While the federal government was the second-largest source of R&D funding, $8.25 billion in 2022, it performed $2.6 billion on internal R&D that year. Of the funds provided to other actors, \$4.25 billion went to R&D performed in the higher education sector, \$1.35 billion to business enterprise, and \$44 million to private non-profit (StatCan, 2023a). Other key funders of STIK R&D in Canada include provincial/territorial governments and research organizations, and the higher education, private non-profit, and foreign sectors (Figure 3.2).

Expenditures on R&D in the natural sciences and engineering have increased steadily from 2015 to 2020, largely driven by federal government and business enterprise investment, yet still lag other nations (StatCan, 2023a; The World Bank, 2023a). Social sciences, humanities, and the arts also experienced growth in R&D expenditures over this time period, mainly driven by investments from the federal government and higher education (StatCan, 2023a). Canada also benefits from foreign investment; for example, in 2019, it performed approximately US\$6.8 billion in business R&D related to information technologies (IT) in U.S. industries (NCSES, 2019). Though often informative, R&D input is only one early and high-level measure of innovation and thus has important limitations (reviewed in Committee on Assessing the Value of Research in Advancing National Goals, 2014).

Extramural spending is a means by which research is performed and S&T partnership occurs

In 2020, businesses in Canada outsourced \$4.6 billion in R&D to other businesses, hospitals, universities, and so on, with a greater proportion of this money going to Canadian organizations in 2020 than in previous years (StatCan, 2022b). About 70% of this outsourcing was domestic spending, while the rest was spent outside of Canada. When it came to in-house research performed by private firms, nearly two-thirds of all spending was on wages and salaries (StatCan, 2022b).

Canadian-owned companies direct some proportion of their R&D spending to other organizations. In 2020, approximately \$2.2 billion in extramural R&D expenditures went from businesses to other organizations in Canada — mostly to other businesses (\$1.8 billion), but also to higher education and to various other organizations and individuals (~\$0.3 billion); an additional \$1.0 billion went to organizations outside of Canada (StatCan, 2023c).



Adapted with permission: Global Advantage Consulting Group (2023)

Figure 3.2 Major R&D Funding Flows, 2022

The amounts that R&D funders provided to major R&D performers in Canada in 2022, in billions (B) and millions (M). Data are sourced from StatCan (2023a). Totals may not sum due to additional minor funds that are not shown.

3.2.2 Key Areas of Strength in the Canadian STIK System

Key strengths in Canadian industrial R&D lie in scientific R&D services, computer systems design, communications equipment manufacturing, and aerospace products and parts manufacturing (CCA, 2018). R&D intensity is only one aspect of measuring innovation. The 2022 OECD *Business Innovation Indicators* report synthesizes many indicators to score business innovation in member countries (OECD, 2022k). According to OECD innovation indicators, Canada was far below the average for enterprises engaging in international markets (OECD, 2022k). However, these trends appear different when analyzing just the Canadian firms engaging in innovation. Canada had one of the highest percentages of firms undertaking innovation, and those firms had the highest percentage of engagement with foreign markets (OECD, 2022k). Overall, these data suggest that Canada lagged behind in overall international engagement, but its enterprises regularly engage in innovation activities, including in international innovation collaboration.

Similarly, Canada had the highest proportion of enterprises engaged in product innovation (among those that develop products independently), potentially indicating a lack of partnerships (OECD, 2022k). Though it ranked high in innovation overall, Canada ranked in the bottom quarter among countries with firms engaging in product or business R&D; it ranked lower still in funding R&D relative to other innovation activities (OECD, 2022k). Canada has the highest proportion of innovative[6] firms (as a percentage of total firms) across the OECD, though only a small proportion of these firms operate in foreign markets (StatCan, 2021d; OECD, 2022k). Among all surveyed industries in Canada in 2019, 52.5% of firms stated that they conducted any innovation activity (whether in-house or outsourced) (StatCan, 2021d). R&D activity was highest in manufacturing (47.2%), information and cultural industries (42.1%), and professional, scientific, and technical services industries (38.3%) (StatCan, 2021d).

The Canada Innovation Corporation has a potential role in international STIK partnerships

In its 2023 budget, the Government of Canada proposed creating a new innovation agency, the Canada Innovation Corporation (CIC) (GC, 2023c). The CIC's purpose is to leverage private sector expertise to increase business innovation R&D investment in order to ensure that the realized gains from Canadian innovation benefit the Canadian public (FIN, 2023). The CIC will monitor national and international economic trends, use data and evaluations to determine successful

6 *Innovative firms* are those reporting one or more innovations in the reference period (2016–2018) (OECD, 2022k).

initiatives, leverage Canadian assets, and attempt to attract technical and business talent to strengthen Canada's economic competitiveness. It is intended to support international collaboration to expose Canadian businesses to international R&D and foreign markets and complement the international work of other government programs through long-term support for R&D projects that involve international firms (FIN, 2023).

Canada's science and knowledge production system is a source of extensive collaboration and impact

Canada is part of an increasing trend toward international collaboration (Gui *et al.*, 2019). In 2020, Canadian academics collaborated with colleagues in over 200 countries, compared to 168 countries in 2010 (Clarivate, 2023). That same year, more than 54% of all scholarship in Canada was conducted collaboratively with colleagues in foreign countries, up from 38% in 2010. The United States is Canada's most frequent partner, with 33,841 articles published in 2020 — comprising 26% of Canada's international co-publications (Table 3.2). The United Kingdom is Canada's second-most frequent partner after the United States. China has risen to the third position; this represents a shift for Canada, as China was a less frequent collaborator (as measured by co-publications) in the 2000s — Canada-China collaborations increased by more than 75% between 2010 and 2020. Among the top 25 collaborators, only Iran had a greater percentage increase over the past decade (76%) (Clarivate, 2023).

Since 2010, Canada's collaborations with all nations except Venezuela have increased and now include as many as 32 new partners — primarily smaller and more recent entrants into global science (Clarivate, 2023). These new entrants together with China's rise have increased Canada's international footprint, while decreasing the proportional share of Canada's long-term partners, such as France, Germany, and the United States. The proportion of collaborations between Canada and the United States decreased from 34% in 2010 to 26% in 2020, while the proportion of Canada's collaborations with France decreased from 6% in 2010 to 4.9% in 2020 (Clarivate, 2023).

Table 3.2 Canada's Top 25 Collaborating Countries by Co-authorship, 2010–2020

Country	2020 Web of Science Documents	% of 2020 Documents in Top 10%	2015 Web of Science Documents	% of 2015 Documents in Top 10%	2010 Web of Science Documents	% of 2010 Documents in Top 10%
U.S.	33,841	23	24,399	24	17,969	23
U.K.	12,327	29	7,961	29	5,081	27
China (Mainland)	12,277	23	6,563	21	3,015	19
Germany	8,103	31	5,360	30	3,568	27
France	7,681	27	5,239	26	3,560	25
Australia	7,383	31	4,432	29	2,344	26
Italy	5,341	34	3,167	32	2,036	28
Netherlands	4,502	35	2,876	34	1,816	30
Spain	4,447	35	2,460	32	1,518	28
Switzerland	4,002	33	2,313	32	1,423	30
Brazil	3,348	24	1,843	25	852	19
Japan	3,284	31	2,070	29	1,443	21
Sweden	2,691	35	1,781	32	1,031	33
Belgium	2,584	36	1,622	31	896	30
Iran	2,463	21	1,023	15	588	14
India	2,373	27	1,307	23	734	21
Denmark	2,237	35	1,434	35	694	34
South Korea	1,853	34	1,118	28	792	18
Austria	1,761	32	1,022	37	614	32
Norway	1,661	35	1,023	35	569	32
Israel	1,549	32	966	32	638	25
Poland	1,493	33	958	31	522	25
Russia	1,478	33	833	31	494	19
South Africa	1,473	33	899	33	389	28
Saudi Arabia	1,391	23	1,069	19	209	13
Total Top 25	**131,543**		**83,738**		**52,295**	

Data source: Clarivate (2023)

It is also valuable to consider the impact of published works. Canada's collaborations with Belgium, the Netherlands, and Norway achieved the highest impact among partnering countries by generating a greater number of citations for work published in 2020, with more than 35% of published works among the top 10% of the Web of Science database's most highly cited works (Clarivate, 2023). Of the top 25 collaborators, 17 had more than 30% of their collaborative works with Canada in the top 10% most cited (Table 3.2). For works published in 2015 — which have had more time to accumulate citations — collaborations with Bulgaria, Sierra Leone, and Sudan appear to have a disproportionately large impact. Even though the number of articles produced by these collaborations is relatively small, the proportion of these works among the top 10% most cited is higher than for other nations (Clarivate, 2023). In addition to creating value by producing new scientific knowledge, these networks can be leveraged to find productive and impactful international STIK partnerships. Many tools exist to better visualize and navigate these networks, in order to find countries, organizations, and researchers whose capabilities can further Canada's STIK goals (VT University Libraries, 2023).

3.2.3 Assets of the Canadian STIK Ecosystem: Talent, Facilities, Locations, and Resources

Competitive and productive innovation partnerships require scientific talent, cutting-edge equipment, world-class facilities, an enabling regulatory environment, and networks, investments, and businesses to help innovations meet commercial and societal goals. In international partnerships, these assets are shared among collaborators to, ideally, achieve more than could have been accomplished alone. Canada's workforce, facilities, resources, and innovation networks contribute to nationally and internationally collaborative innovation.

Canada is home to a relatively large and well-educated workforce

In 2020, the total number of R&D personnel in Canada exceeded 275,000 (StatCan, 2023b). The business sector employs the largest proportion of R&D personnel, accounting for 65%; higher education has the second largest at 29% (StatCan, 2023b). The federal government alone employs over 40,000 S&T personnel (StatCan, 2022a). Moreover, recently hired researchers — compared to other types of personnel (e.g., technicians, administrative staff) — have been a major source of new growth in R&D employment; researchers occupied 7 out of 10 R&D positions in 2019 (StatCan, 2022c). Canada ranked 16th among the OECD countries in total researchers per thousand employees in 2019 (OECD, 2022j), and it has the most highly educated workforce in the G7 (StatCan, 2022e).

Canada hosts and participates in a variety of networks, services, and research facilities that benefit international collaboration

There are many facilities and resources in Canada that can catalyze innovation and international partnerships. Shared collaborative science facilities, often called big science, act as platforms around which tools, services, and technologies are created to help produce value (Robinson, 2021). Knowledge is viewed as radiating out from big science organizations to related areas; however, the extent of innovation networks generated from this type of shared infrastructure is not well characterized (Li-Ying *et al.*, 2022). The federal S&T network has over 3,500 STIK assets and approximately 200 research facilities (PSPC, 2020). CFI maintains a directory — the Research Facilities Navigator — of publicly funded research facilities, including equipment from over 800 research facilities in more than 28 sectors of application, in order to facilitate collaboration among industry, academia, and government (CFI, n.d.).

Some of Canada's major research facilities, networks, and services include:

- Canada's National Design Network (CNDN) for research on micro-nanotechnologies (CFI, n.d.);
- the Canadian Coast Guard Ship (CCGS) *Amundsen*, an arctic icebreaker research vessel (GC, 2022f);
- the Canadian Light Source (CLS) synchrotron research facility (CLS, n.d.);
- the Digital Research Alliance of Canada's services in advanced research computing, research data management, and research software (Digital Research Alliance of Canada, 2023);
- the International Vaccine Centre (InterVac), a containment level 3 (CL3) research facility (VIDO, 2023);
- the National Research and Education Network (NREN) (CANARIE, 2023);
- Ocean Networks Canada (ONC), a world-leading ocean observing facility (Coastal First Nations, 2022);
- the Ocean Tracking Network (OTN), a global aquatic research, data management, and partnership platform (OTN, 2023);
- SNOLAB, Canada's deep underground research laboratory (SNOLAB, 2023); and
- TRIUMF, Canada's particle accelerator centre (TRIUMF, n.d.).

Canada also plays a role in international facilities, such as the Thirty Meter Telescope International Observatory (TMT, 2022). Many of these research facilities, services, and networks facilitate international collaborations. Big science facilities are also a catalyst for forming international STIK agreements (e.g., Hitachi, 2011; Ribeiro, 2022).

International cooperation forums are valuable as they can be leveraged to initiate and support international STIK partnerships (GC, 2023d). For example, the Asia-Pacific Economic Cooperation (APEC) forum, of which Canada is a member, works to improve economic integration (e.g., strengthening supply chain connections, removing barriers to business, securing trade relations) that can enhance the prospects of new innovations. APEC also supports STIK directly through various innovation awards (GC, 2023d). Similarly, the Organization of American States works to advance science, technology and innovation through a partnership framework (OAS, 2023). The Global Research Council is a worldwide network of science and engineering funding agency leaders who partner to improve international science and describes itself as a resource of "build[ing] a world-class research landscape" (GRC, 2023).

Canada's natural resources, geography, and expertise create opportunities for international STIK partnerships

Natural resource, mining, and energy R&D occurs across Canada and forms the basis for many STIK programs and international partnerships (TCS, 2017; NORCAT, 2022; OFI, 2022; Ribeiro, 2022). For example, consistent cold weather in the Arctic, which makes up 40% of Canada's geography, enables research and innovation in cold climate manufacturing in the automotive and aerospace sectors, among others (TCS, 2017). The Ocean Frontier Institute (OFI) research partnership focuses on the geographically unique physical, chemical, and biological features of the North Atlantic and Canadian Arctic to inform globally relevant ocean predictions (OFI, 2022). Canada's Global Innovation Clusters participate in partnerships to advance agricultural technologies and food security, and to improve supply chains (ISED, 2022). The Natural Resources Canada Office of Energy Research and Development (OERD), through programs such as Mission Innovation, supports energy innovation through public and private partnerships domestically and internationally (OERD, 2023). Individual provinces and territories also offer unique opportunities for locally relevant subnational partnerships. For example, the Saskatchewan Research Council and the Korea Mine Rehabilitation and Mineral Resources Corporation (KOMIR) signed an MOU in 2022 to facilitate cooperation on information exchange, trade and investment, R&D related to critical mineral exploration and processing, and mine rehabilitation (Gov. of SK, 2022). Canada's geography and natural resources, along with the expertise developed around them, combine tangible and intangible assets into a valuable segment of the STIK ecosystem.

Private and public innovation clusters constitute a major part of the Canadian STIK ecosystem

The Toronto-Waterloo corridor is one of the world's largest technology clusters, and includes small, medium, and large enterprises, startups, capital, a highly skilled workforce, and multiple universities (Waterloo EDC, 2022). Within these technology clusters, accelerators and incubators provide capital and entrepreneurial expertise to small businesses and startups (Waterloo EDC, 2023). Other clusters, such as the Cascadia Innovation Corridor, cross international borders (Cascadia Innovation Corridor, 2018). It connects Vancouver, Seattle, and Portland to collectively enhance the Greater Pacific Northwest's position as a "global hub of innovation and commerce" (Cascadia Innovation Corridor, 2018).

The Global Innovation Clusters program encourages collaboration among industry leaders, SMEs, and post-secondary institutions to accelerate growth in key industries, including digital technologies, plant proteins, advanced manufacturing, AI use in supply chains, and oceans (ISED, 2021a). It facilitates innovation by attracting talent, research, capital, and companies; by connecting partners and collaborators; by innovating with new products and processes; by growing industries; and by empowering SMEs to accelerate growth and access new markets and IP (ISED, 2021a). The program brings together researchers, academics, Indigenous organizations, non-profits, businesses, accelerators, and financing to enhance commercialization (ISED, 2021b, 2023a).

Startup ecosystems combine funding, infrastructure, business and technical expertise, and market access, contributing to the broader innovation ecosystem. Canada's startup ecosystems differ in their domestic and global strengths (Box 3.1).

Box 3.1 Top 100 Startup Ecosystems: Canada Among a Global Ranking

In the 2022 *Global Startup Ecosystem Report*, the Toronto-Waterloo corridor ranked 17th globally; Vancouver and Montréal ranked 30th and 36th, respectively, and Calgary and Ottawa ranked in the 61st to 70th and the 81st to 90th tiers, respectively. Atlantic Canada, if considered collectively as an ecosystem, would have been ranked 66th globally, recognizing its growth and innovation in several sectors, including ocean technology. Calgary was a substantial recipient of venture capital investment in Alberta, while Edmonton was noted as an area having young, educated talent for startups. Notably, Montréal's universities collectively attract the highest amount of research funding in Canada — over $1.34 billion annually. Its ecosystem strengths are in life sciences, AI, analytics, and financial technology. Approximately half of all venture capital in Canada went to companies in the Toronto-Waterloo ecosystem in 2022, totalling $7.7 billion. This region is also the third largest and fastest-growing North American innovation ecosystem.

(Startup Genome, 2022)

3.3 International STIK Partnership Evaluation Programs and Frameworks

The availability of international STIK decision-making frameworks, methodologies, and techniques is limited. Among Canadian STIK organizations, there are likely to be tools and evaluations that are not publicly available; a similar situation likely holds for other countries. A lack of publicly available information does not imply a lack of internal capacity for data-enabled STIK decision-making. There are, however, some international examples that offer insights into the practices that could be used to better inform Canada's international STIK partnerships.

Data-enabled decision-making techniques can be adapted and used across fields and countries

In 2014, the Swedish Ministry of Education and Research, together with the Ministry of Industry, sponsored an analysis of research and innovation indicators in Canada, Germany, Great Britain, Japan, Norway, Singapore, South Korea, and the United States (Tillväxtanalys, 2014). Indicators were broadly categorized as inward (e.g., attracting talent and investment) and outward (e.g., increasing political influence and accessing new markets). The indicators reflected countries' attitudes toward international science and innovation cooperation. For example, in Singapore, partly because of the country's size, internationalization is considered integral to the national R&D system. In contrast, the United States considers international cooperation important but can depend on its attractiveness to fuel that cooperation. The Swedish analysis examined various roles for indicators that could inform international STIK partnerships and identify driving forces, internationalization mechanisms, and important actors in global innovation (Tillväxtanalys, 2014). International evaluation practices continue to evolve, with many countries undertaking evaluations of STIK partnership programs. A few examples are reviewed below to highlight current practices.

South Korea's KISTEP provides extensive capacity to support STIK decision-making

South Korea has a dedicated S&T evaluation and planning department: the Korea Institute of S&T Evaluation and Planning (KISTEP, 2021a). Among its core functions are planning and coordinating S&T policy and facilitating global S&T cooperation (KISTEP, 2020). KISTEP reviews the international S&T cooperation plan, studies the development of an evaluation methodology for international S&T cooperation, monitors the S&T diplomacy agendas of other countries, develops strategies for collaboration with, for example, Horizon Europe, and assesses strategic S&T official development assistance programs (KISTEP, 2021b). These activities use environmental, health, bibliometric, and economic indicators, among others (KISTEP, 2021a). KISTEP's reporting can be as granular as relating progress toward deriving new indicators or updating current ones (KISTEP, 2021b). It studies Korean and foreign S&T performance, statistical systems, and indicators to measure "domestic and foreign S&T diplomacy and international cooperation" (KISTEP, 2021b).

Through its work, KISTEP produces strategies, tools, and indices to inform S&T decision-making, including foresight plans with horizons of 20 years or more (KISTEP, 2021c), multiple-country comparisons of 100 indicators (KISTEP, 2022), and the multi-nation *Composite Science and Technology Innovation Index* (KISTEP, 2021b). In some cases, it performs more specific supporting tasks, such as analyzing R&D investment, international cooperation, and industrial trends on a particular topic (e.g., infectious disease). KISTEP activities are not limited to evaluations; it also engages in international cooperation on training programs, strengthens strategic partnerships, and participates in international forums (KISTEP, 2021b).

The United Kingdom uses multiple approaches to evaluate international STIK partnership programs

The following two paragraphs draw on CCA staff interviews with officials from the United Kingdom. In recent years, the United Kingdom developed an International S&T Partnerships Framework (ISTPF) focused on seven families of strategic technologies: advanced materials and manufacturing; AI, digital and advanced computing; electronics, photonics, and quantum; robotics and smart machines; energy and environment technologies; bioinformatics and genomics; and engineering biology. The ISTPF identifies and evaluates 43 international partners (at the country level) in three categories: world leaders (13), research and innovation intensive countries (12), and S&T emerging nations (18). The intention is to focus on the 25 countries in the first two categories but allow departments to use their overseas development assistance funds to support the other 18. The current government has indicated a narrower range of seven focus countries.

The ISTPF is stewarded by the Department of Science, Innovation and Technology (DSIT) and is meant to guide rather than direct, recognizing that various departments will adapt the framework to their particular needs. It is not expected that the framework will guide university or other players' partnerships beyond government. Implementation consists of cross-government mapping of S&T partnerships, strategic planning (including vision for partnership, local strategic context, outcomes to be achieved and specific deliverables, and resources required) and coordination of visits, exchanges, networks, and multilateral science efforts. Half of a dedicated ISTP Fund is distributed to UK Research and Innovation (UKRI; see below) and half to public sector research establishments (PSREs; e.g., government laboratories, the Meteorological Office) and national academies. Governance for ISTPF consists of:

- the National Science and Technology Council (ministerial level);
- the Office for Science and Technology Strategy (a Privy Council-level secretariat that supports the NSTC with strategic analyses and insights);
- the Government Office for Science (GO-Science; an organization within DSIT that focuses on science policy as a cross-departmental analysis and coordination group); and
- a governance board for the ISTP Fund that consists of DSIT, the Foreign, Commonwealth and Development Office, UKRI, PSREs, the national academies and the Chief Science Adviser.

UKRI is an umbrella research organization composed of nine member councils. It supports research and innovation in the United Kingdom, often through the promotion of international collaborations (UKRI, 2022a). Its Fund for International Collaboration (FIC), launched in 2018, has undergone a baseline and interim evaluation process (Rosemberg & Brown, 2021). This early evaluation provides insights into the measures and methodologies used to assess international partnership programs through a combination of interviews, workshops, surveys, portfolio analyses, and appraisals of research outputs and impact. UKRI based its evaluation methods on those done for international partnership programs in Austria, Switzerland, and the United States (Box 3.2).

Box 3.2 FIC's Review of Foreign Programs that Support International Partnerships

As part of the Fund for International Collaboration's *Baseline and Interim Process Evaluation*, Rosemberg and Brown (2021) reviewed similar programs from other countries, along with their evaluations. Their findings for select foreign programs are summarized below.

The Swiss bilateral cooperation programs in S&T focus on promising research relationships with emerging hotspots with non-European countries. Partnership decisions are based on mutual interest, scientific excellence, and co-financing, and projects are evaluated by each country separately through peer review (IRIS Group, 2020; Rosemberg & Brown, 2021). These programs use top-down priority setting with bottom-up peer review for partnership decisions. The evaluation of these programs is conceptualized along a logic model timeline — inputs, activities, outputs, short- and long-term effects (IRIS Group, 2020). Inputs include funding and governance; activities encompass promotion and administration of grants; outputs are the number and nature of projects; short-term effects are the publications, collaborations, and skills that result from the program; and long-term impacts are improvements to the research landscape and improved economic measures (IRIS Group, 2020).

In the United States, the National Science Foundation (NSF) Partnerships for International Research and Education (PIRE) initiative is a multinational program supported by the NSF's co-funding agreements with 18 countries (Rosemberg & Brown, 2021). Research and effective collaboration were the focus of this evaluation (Martinez *et al.*, 2015). To measure research outcomes, publication quantity and quality were used along with the career stage of the researchers involved. The frequency of international collaborations during and after the program was also evaluated. Alignment between PIRE and participating institutions was identified as benefiting international projects (Martinez *et al.*, 2015). Research outcomes were compared to other NSF programs as quasi-experiments to provide a more robust measure of success and to identify specific strengths and weaknesses of the program (Rosemberg & Brown, 2021).

(Continues)

(Continued)

The Austrian Science Fund (FWF) includes many international collaborations in its scientific research portfolio — these are the product of both top-down and bottom-up partnerships (Rosemberg & Brown, 2021). The FWF's 2017 evaluation was able to assess more than a decade's worth of data. The evaluation primarily employed bibliometric analyses to compare the FWF's portfolio to other international projects as controls. Volume, quality (i.e., citation impact), and a partner's economy (e.g., emerging, developed) were considered when assessing research. Collaboration measures included the sustainability and formation of partnerships and the program's effect on the general culture of cooperation (Rosemberg & Brown, 2021).

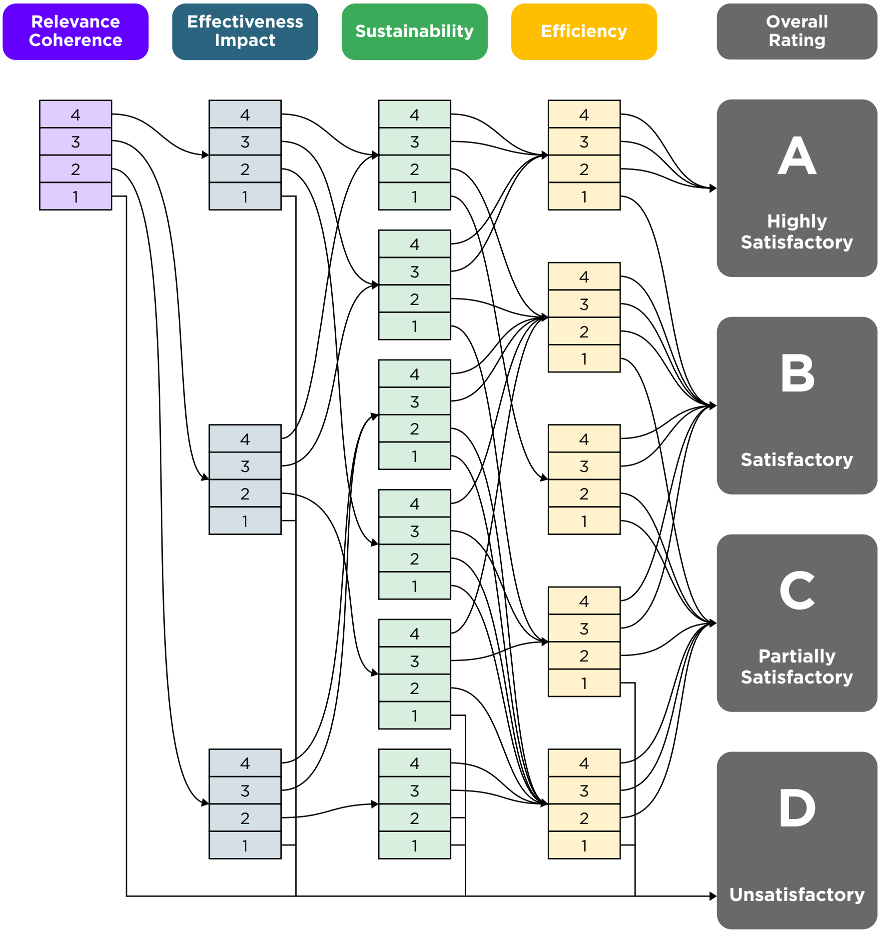
Certain themes arise from these three examples: the importance of internal partnership data, research outputs, and tools (including bibliometrics); the use of those tools to analyze these data; and the need for comparison and benchmark programs (Rosemberg & Brown, 2021). Other important conclusions include the fact that evaluations provide valuable learning opportunities — especially for complex and novel programs — and that robust evaluations use a variety of approaches, often pairing bibliometrics with more in-depth measures of impact.

The FIC's evaluation enumerated the programs, their association with a priority country, the classification of projects (e.g., R&D, training, facilities) as the proportion of projects and grant value, and the staffing of projects (Rosemberg & Brown, 2021). Mentions of other countries in research council delivery plans were used to measure collaboration. This was in addition to counting MOUs with countries, ranking countries by the number of participating organizations, and grant collaboration. The type of partner (e.g., universities, private, public, hospitals) was also a factor. Even in the early stages, programs had begun to leverage funding to attract other investments — both the value and source of the new investments were noted. IP data, tools, methods, and software and technical products were all measured as important outputs of the partnership program, while economic indicators such as profit, workforce, and investment deals were measured for companies. These indicators were compiled in an impact evaluation framework that identifies where data can be found, what they measure, whether they apply to academia or businesses, and whether there is an internal counterfactual or government benchmark against which to compare them (Rosemberg & Brown, 2021).

Partnership evaluations often happen at the program level, especially given that many international partnerships are sector specific. One example of this is the United Kingdom Space Agency's (UKSA) economic evaluation of the International Partnership Programme; it uses indicators, surveys, counterfactuals, and benchmark comparisons to measure the program's secondary economic benefits (Sadlier *et al.*, 2019). This program was evaluated based on benefits to the United Kingdom — including industrial effects (e.g., contract income, gross value added, employment), grantee benefits (e.g., ripple effects), and broader effects (e.g., spillover effects, strategic effects, environmental impacts) — as well as benefits to the world (e.g., achievement of UN SDGs) (Sadlier *et al.*, 2019). The report was part of broader evaluations, including a cost-effectiveness analysis from other UKSA projects (Sadlier *et al.*, 2019). The United Kingdom also has an independent public organization called the Independent Commission for Aid Impact that evaluates foreign aid programs, including the Newton Fund, which supports research and innovation partnerships (ICAI, n.d.-a, n.d.-b). These evaluations assess whether a program fulfills its goals, was designed adequately to do so, and upholds U.K. social values, such as gender equality (ICAI, 2019).

Japan's evaluations are important tools for advancing policy and diplomatic goals

Japan's National Institute of Science and Technology Policy (NISTEP) is a government research institution under the jurisdiction of the Ministry of Education, Culture, Sports, Science and Technology (NISTEP, n.d.-b). One of NISTEP's responsibilities is to generate the data necessary for evidence-based policy-making using evaluation methodology and quantitative indicators to facilitate the implementation of new policy (Ueyama, 2021; Oyama, 2023). Doing this can require conducting research and developing data infrastructure (NISTEP, n.d.-b). S&T partnerships are seen as important to Japan's foreign relations (NISTEP, n.d.-a). The Japan International Cooperation Agency (JICA) uses *ex-ante* evaluations to set goals and indicators for a project by identifying the necessary considerations for the project, reviewing previous projects, choosing target outcomes, and creating an evaluation plan (JICA, 2021). Upon project completion, *ex-post* evaluations help determine project success (JICA, 2021). Criteria in this evaluation are rated sequentially — relevance and coherence, effectiveness and impact, sustainability, and efficiency — on a scale of one to four, in order to arrive at a final rating (Figure 3.3).



Adapted with permission from JICA (2021)

Figure 3.3 JICA Evaluation Structure for International Collaboration

The Japan International Cooperation Agency (JICA) combines OECD Development Assistance Committee criteria into its own rating framework. Programs move from left to right though the framework receiving a score for each criteria, resulting in an overall program rating. This evaluation is not designed to be comprehensive but to provide a useful measure of the effectiveness of the project.

In 2019, Japan's Science and Technology Research Partnership for Sustainable Development (SATREPS) program was evaluated using Japan's Official Development Assistance guidelines (Sato, 2020). This evaluation method assessed the OECD Development Assistance Committee's criteria categories such as *relevance of policies*, *effectiveness of results*, and *appropriateness of processes* within a custom framework (Sato, 2020; JICA, 2021). This process uses expert evaluations, surveys, interviews, and indicators to measure progress in each category (Sato, 2020). Within the category *relevance of policies*, the assessment measured how the program reflects the policies of Japan, the partner country, and other countries or entities partnering in the same fields in the partnering country (e.g., the United Kingdom, European Union), as well as the program's relationship to international priorities (e.g., UN SDGs). The second category, *effectiveness of results*, considers training and travel of researchers, access and provisioning of equipment, and patents and publications, among other metrics. This category also emphasized practical benefits and utilization of research outcomes as important outputs. The assessments in this category were built, in part, on the evaluations of each research project within the program. The third category, *appropriateness of processes*, involved an examination of the program itself, including administration and governance by both partners. The 2019 evaluation added a fourth category, *diplomatic viewpoints*, which explicitly acknowledged the role of science in building diplomatic relations. It used research interconnectedness measures to assess whether the program satisfies higher-level policies such as addressing global issues (e.g., sustainability), socioeconomic development, and national security needs (Sato, 2020).

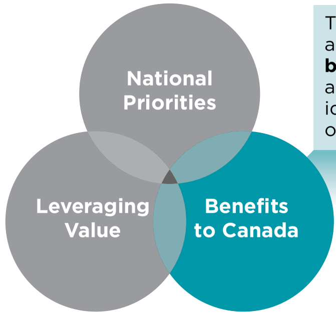
4

Benefits to Canada: Indicators of Innovation

Science, technology, innovation, and knowledge production (STIK) are crucial drivers of economic development (UNESCO, 2021c), and international STIK partnerships, especially, are increasingly seen as a source of benefits to Canada. They advance Canada's economic agenda by building domestic capacity, establishing an international reputation, commercializing research findings, strengthening economic competitiveness, and furthering talent development (Pfotenhauer *et al.*, 2016; UNESCO, 2021c). The Government of Canada identifies the development of talent and accelerating the commercialization of technologies for economic and social benefits as critical elements of international STIK partnerships (see ECCC, 2022). These partnerships also provide access to new markets and reduce the risks associated with entering them, helping to guide product development and validation (TCS, 2022a).

Collecting and utilizing high-quality data in a decision-making framework can improve tactical (i.e., short-term) and strategic (i.e., long-term) STIK partnerships. Increasingly, a vast amount of available data are being used to improve strategic STIK decision-making, including decisions about whom to partner with (Geum *et al.*, 2013; Radziszewski, 2020). Valuable information already exists in the databases and indices of government agencies, organizations, and firms, and plays a role in data-driven STIK decision-making. Sharing information in a coordinated fashion is limited, which, according to the organizations interviewed as part of this report, reduces the data's value. Individual indices and international frameworks include a range of strategies for using indicators to measure impacts. For example, quality-of-life indices range from a composite of 10 to 130 indicators (FIN, 2021).

Though available data are extensive, they represent a small fraction of the information used for decision-making in a specific topic area or regarding a particular goal. Through an innovation lens, the most valuable indicators measure a partner's ability to enhance innovation capacity, improve or create trade opportunities, and forward Canadian economic interests toward *National Priorities* and *Leveraging Value* (Figure 4.1). However, there are other considerations when choosing indicators; some are more relevant, comparable, or attributable to outcomes than others. Indicators also differ in their comprehensiveness, accuracy, consistency, granularity, or comparability (i.e., among countries or across time). Collecting data on these indicators throughout a partnership can become the basis for accountability, in the sense that it provides a foundation for ongoing partnership evaluation.



There is a wide array of indicators and metrics to measure potential **benefits to Canada**. From the articulated goals, criteria are identified for evaluation. Areas of consideration include:

National Resilience	Criteria (example indicator)
Diplomacy	• Diplomatic outcomes (new policies, innovation centres)
Sustainability	• Sustainability (development, emissions) • Reciprocity (fair mutual benefit) • Commitment and vision (use of foresight)
Security	• National security (security networks) • Foreign influence (vulnerability) • Cybersecurity (alignment, threats) • Research security (sanctioned activities)

Innovation	Criteria (example indicator)
Collaboration and Commercialization	• Collaboration readiness (complementarity) • Commercialization and scale-up (firm size and performance) • Inputs (R&D investment, resources) • Assets (tangible and intangible) • Outputs (growth)
Trade	• Trade system (imports and exports) • Regulations and barriers (tariffs, quotas) • Standards setting and regulatory alignment (standards creation, adoption)

Scientific Capacity and Knowledge Production	Criteria (example indicator)
Excellence	• Rigour (peer review) • Production (publications, other outputs) • Impact (citations)
Open Science	• FAIR principles (policies) • Collaboration (co-authorships)
Talent	• Potential (network position) • Expertise (citations) • Mobility (policies, programs)
Infrastructure	• Location (uniqueness) • Institutions (rankings) • Facilities (accessibility)

Figure 4.1 Benefits to Canada — Innovation

Enhancing innovation capacity requires partners to be ready to collaborate and have the capacity for commercialization and scale-up. For a partnership to be successful, it needs adequate resources (i.e., inputs and assets), while past outputs can indicate reliable processes and overall capacity. Trade is essential for accessing the materials and markets required for generating benefits from innovation activities.

What We Heard

Interviewees from STIK organizations consistently described the need for more accessible and high-quality data. Mechanisms commonly reported by government agencies to achieve this were better access to internal and external data — including interdepartmental data sharing — and increased data collection to enable analysis and comparison of international partnerships and programs. Valuable data have been collected as part of internal program evaluations. Risk assessments and program frameworks exist, but they are underutilized in the absence of active coordination and information sharing.

Indicators used within a broader decision-making framework can help actors navigate the complexity of international STIK partnerships by helping them identify partners and measure their successes (Wu *et al.*, 2009; Geum *et al.*, 2013; Qi *et al.*, 2022). Collaboration, commercialization, and trade indicators can provide valuable insights into the potential partner's compatibility; existing innovation capacity; market and network competence and knowledge; and resources and assets (Table 4.1). Partnerships chosen to advance innovation toward commercialization need to identify intermediate success indicators supporting end goals to ensure ongoing productivity and commitment. Ultimately, this type of evaluation could help identify partnerships that provide access to the resources necessary for R&D, scale-up, and commercialization such that the partnership de-risks the project.

Table 4.1 Criteria, Indicators, and Examples of Metrics of Innovation

<table>
<tr><th>Innovation</th><th>Criteria</th><th>Indicators</th><th>Examples of Metrics</th></tr>
<tr><td rowspan="5">Collaboration and Commercialization (Section 4.1)</td><td>Collaboration readiness</td><td>Previous collaboration practices, shared direction, complementarity</td><td rowspan="5">• Willingness to share assets vs. exploitative negotiating practices
• Trust and transparency indices
• Technological capacity complementarity
• ROI for innovation investments
• Development-stage-appropriate capacity
• Manufacturing efficiency and lead time
• R&D spending/intensity (e.g., GERD, BERD, and as a % of GDP)
• R&D personnel ratio
• Innovation-relevant assets
• Level of training and education
• Production of prototypes
• New innovation products</td></tr>
<tr><td>Commercialization and scale-up capacity</td><td>Firm size, performance, innovation strategy, development stage</td></tr>
<tr><td>Inputs</td><td>R&D investment, resources committed</td></tr>
<tr><td>Assets</td><td>Tangible and intangible assets</td></tr>
<tr><td>Outputs</td><td>Financial, industry, and market growth, enabling factors, market realities</td></tr>
<tr><td rowspan="3">Trade (Section 4.2)</td><td>Trade system</td><td>Imports/exports; trade agreements</td><td rowspan="3">• Imports/exports as % of GDP
• Services trade measured as labour mobility
• Time to import goods
• Trade facilitation performance
• Import/export control lists
• Membership in regulatory organizations
• More favourable agreements and regulations</td></tr>
<tr><td>Regulations and barriers</td><td>Tariffs, quotas, and permitting</td></tr>
<tr><td>Standards settings and regulatory alignment</td><td>Standards creation and adoption</td></tr>
</table>

4.1 Collaboration and Commercialization

Innovation ecosystems are complex partnership networks not confined by international borders nor are they composed of exclusively government actors. Organizations (i.e., public and private) create partnerships throughout the innovation ecosystem to improve commercial success; therefore, it is necessary to have a strategic understanding of international partnerships to drive economic growth. Innovation clusters are built to facilitate and benefit from these types of cooperation (CIC, 2018; ISED, 2021a). Private companies looking for constructive collaborations and government organizations looking for industry partners can use commercialization indicators to aid decision-making. Economic actors such as countries and corporations require indicators that grasp the complexity of innovation ecosystems, in order to ensure that STIK policy decisions, including partnerships, produce effective results — for instance, successful commercialization (Carayannis *et al.*, 2018).

There are many indicators related to the economics of STIK partnerships (Hall & Jaffe, 2018; UNCTAD, 2020; OECD, 2021a); those that measure collaboration readiness, capacity, financial inputs, assets, outputs, and performance can be used to inform international STIK partnership decision-making. Such metrics can guide investment and policy decisions for actors and programs of various sizes; however, the choice of metrics will differ in scope and granularity to account for size differences among the organizations involved. Indicators can be used most effectively when their interpretation explicitly considers scale. National-level economic and investment metrics are important for the success of innovation firms. However, choosing which firms to include in a national-level analysis can influence measurement, as significant heterogeneity among firms can exist within a country, given that firms are also subject to sectoral trends and many firm-level factors (Janz *et al.*, 2004; DIISR, 2009). For example, GDP and GERD may be valuable indicators of national-level economic status and trends, whereas firm-level R&D investment and product and process innovations may be better indicators for smaller firms (DIISR, 2009; Kijkasiwat & Phuensane, 2020). Information in the private sector may be harder to access, and the national-level effects of a given partnership may be difficult to assess; however, many subnational indicators exist to aid decision-making and evaluating success.

4.1.1 Collaboration Readiness and Compatibility

A decision-making framework can help actors determine how desirable a potential partner is, based on how ready it is to collaborate. Collaboration readiness is a combination of soft social factors (e.g., trust, alignment of norms, values, and goals) and hard technical factors (e.g., complementary competencies, technological fit) (Rosas & Camarinha-Matos, 2009; Schellekens, 2021). Measuring collaboration readiness helps actors anticipate the strength of a prospective partner's innovation contributions and its capacity for action toward a common goal (Noseleit & de Faria, 2013). Identifying cultural compatibility among partners — such that there is shared trust, reliability, and innovativeness — can help minimize partnership friction and enhance benefits (Clampit *et al.*, 2015). To the extent possible, observing a candidate organization's internal behaviours, and its behaviours in previous partnerships, can provide evidence of its likely behaviour in a future partnership (Romero *et al.*, 2009; Rosas & Camarinha-Matos, 2009). Assessing past performance can also help actors determine how successful an organization has been in its prior collaborations (Romero *et al.*, 2009). A shared direction in the form of a commitment to governance, alignment of strategies, and willingness to share assets and knowledge can help signal more robust readiness. Contribution of resources, capability, and cultural complementarity can boost reciprocity and trust in relationships, which supports better performance (Sarkar *et al.*, 2001).

Some indicators help measure characteristics that may benefit a partnership, such as an organization's agility, trustworthiness, openness, creativity, reliability, and honesty (Rosas & Camarinha-Matos, 2009). In some cases, data exist to help assessors quantify these traits (e.g., OECD, 2011; Brodherson *et al.*, 2017; Transparency Global, 2022). For example, the Accenture Strategy Competitive Agility Index scores companies' competitiveness based on growth, profitability, sustainability, and trust (Roark, 2018). An index by Transparency Global (2022) uses six key indicators to determine a transparency score: exceeding transparency requirements; clear and simple terms of service; accountability, including high-quality governance; transparent costs; open, accurate communication; and employee and customer trust.

Potential partners' negative behaviours can also help identify their future effectiveness, including practices observed during negotiations (Rosas & Camarinha-Matos, 2009). These practices could be those attached to conflicts of interest or problematic affiliations. They might also take the form of past or current partnerships based on non-business relationships at the expense of other organizations of greater merit, failure to meet commitments, unrealistic expectations, and the exploitation of power in negotiation (Rosas & Camarinha-Matos, 2009). These non-beneficial partnership considerations can be identified using tools such as past collaboration assessments or by modelling relevant behaviours (e.g., trust) to identify low performers; these can provide insights into the strengths and weaknesses of future partners and their collaboration readiness (Mun *et al.*, 2009; Romero *et al.*, 2009).

Collaboration readiness helps actors determine partnership compatibility

Partners need to effectively complement each other's competencies by expanding the skills, expertise, and technical and financial resources available to the project. At a fundamental level, collaboration readiness can reflect the budget, staff, training, information, and technology that can be expected through the partnership based on past collaborations (Romero *et al.*, 2009). Methods have been created to help identify whether partners have the technological capacity to complement each other. For instance, patent citation analysis can identify technological overlap in each partner's capabilities or complementary strengths (Mowery *et al.*, 1998; Noseleit & de Faria, 2013). Data suggest that partnerships work best when actors are neither too similar nor too different (Noseleit & de Faria, 2013). Finding the right balance between partners — in terms of overlapping capacities that complement one another, yet with sufficient unique competencies to diversify their respective portfolios — can help predict productivity (Mowery *et al.*, 1998; Noseleit & de Faria, 2013). Various bibliometric indicators can help measure the breadth of knowledge a partner brings to a venture; in some cases, this knowledge diversification improves outcomes (Mindruta, 2013).

Knowledge exchange is shaped by a potential partner's culture and national strategies

A partner's national ecosystem provides additional collaboration indicators, which can inform the likelihood of partnership success and knowledge exchange (Vasudeva *et al.*, 2013). A partner's network, which can include other institutions, companies, and suppliers, can be an indicator of its capacity and thus make it a more attractive partner (Pervan *et al.*, 2015). A developed and interconnected local network of SMEs supported by government programs can encourage innovation in developing markets (Pervan *et al.*, 2015).

What We Heard

Tapping into a partner's network can provide potential benefits, but it can also engender risk. Interviewed agencies cited third-party associates of STIK partners as potential hazards when there is insufficient transparency regarding those associates and their activities.

One overarching reason for assessing a potential partner's collaboration readiness — be it based on their values, past performance, stage of development, or technical complementarity — is minimizing the risk of the partnership dissolving and the project failing, and maximizing returns (Rosas & Camarinha-Matos, 2009; Lafrance, 2013). Risk is an essential component of innovation for all organizations, but SMEs are particularly affected when attendant risks do not produce the desired outcome (Brown & Wynn, 1997; HBR, 2013). Choosing partners correctly is part of strategically reducing risk, in order to improve performance (Wang *et al.*, 2010). Risk-taking is, however, a valuable feature of STIK organizations, since it correlates with increased innovation, while risk aversion can indicate other incompatibilities (e.g., risk aversion may limit the adoption of open innovation) (Wan *et al.*, 2005).

Evaluating and managing risk is complex, but many frameworks exist to help improve outcomes (Vanderbyl & Kobelak, 2008; Wang *et al*., 2010; Tarasova *et al*., 2017). Sharing risk is an important aspect of compatibility between partners — it helps ensure fair apportionment of risk and benefit (Tallaki & Bracci, 2021). Effective risk sharing allows partners to take on the risks they are most capable of managing (Bovis, 2012). An organization's size, financial stability, and corporate culture all contribute to its acceptance of risk. For example, a financially fragile company may be willing to take on a lot of risk, whereas a stable company may be more reliable but more risk averse (Rosas & Camarinha-Matos, 2009). Having both partners contribute data to the risk assessment can improve outcomes and fairly distribute risk between partners (e.g., Li *et al*., 2015). Risk assessments are tools regularly used by the STIK organizations interviewed for this report. Conceptually, collaboration readiness can help actors pick partners to mitigate and share financial risks and the risk of project delays.

4.1.2 Commercialization and Scale-Up Capacity

For partnerships with or among private S&T organizations, measuring commercialization and scale-up requires indicators that reflect the realities of innovation in a particular sector for a given firm; these will provide the most robust and valuable partnership insights (DIISR, 2009). Firm size is a simple indicator of innovation capacity. Aligning needs with the strength of firms of different sizes may create better-aligned partnerships (Rosas & Camarinha-Matos, 2009). Small firms seem to have the advantage of managerial efficiency in their innovation programs, but large firms have access to greater resources (Bughin & Jacques, 1994; Becheikh *et al*., 2006), which, among other things, can allow them to better navigate government programs. Moreover, smaller companies may be less capable than larger ones at marketing new innovations (González-Benito *et al*., 2015). Small, nimble firms may be preferable for early-stage development, whereas larger firms may have access to more commercialization resources (González-Benito *et al*., 2015). Firm size also allows comparisons of innovation activities weighted by the number of employees, which can provide a more accurate measure of commitment to innovation activity and more granular insights into commercialization capacity (DIISR, 2009).

Firm size is a critical factor in scaling innovations (Spithoven *et al*., 2013; Radziwon & Bogers, 2019). A firm's network, likewise, increases its commercialization and scale-up capacity. Interactions with other firms, access to public goods (e.g., transport infrastructure, universities), availability of scale-up expertise, and the entrepreneurship ecosystem all affect scale-up through a firm's network (OECD, 2021c). A firm's location and network can be indicators of access to labour, ease of doing business, and access to core inputs (OECD, 2021c). New businesses often depend on more established ones for scaling; therefore, the age of a business may indicate the type of role they are more suited to. Open innovation, where organizations manage knowledge flows across organizational boundaries to accelerate innovation, is an integral part of how innovation scale-up and growth occur, especially for SMEs. Ensuring the alignment of an organization's goals with that of the innovation ecosystem, and with regional and national economic strategies, is important to understanding the value of the innovation network (Radziwon & Bogers, 2019; OECD, 2021c). Misalignment in the goals and approaches of different types of partners and stakeholders (e.g., academics, CEOs, policy-makers) can result in conflict; for example, university and industry partners may have different thresholds when it comes to the need to generate profit (Radziwon & Bogers, 2019). Such conflicts can, however, be more indicative of a partner performing the wrong role in a network rather than being an ineffective partner.

Identifying complementarity in innovation capacity (e.g., technology adoption, incremental changes to existing technology, in-house R&D) can also help align innovation and commercialization to support the success of partnerships (Arundel & Hollanders, 2005; DIISR, 2009). Depending on each partner's capacity and the chosen commercialization strategy, evaluating the commercialization partner's outputs — such as new products to international and domestic markets, or adoption of international innovations — could align innovation strategies and commercialization needs (DIISR, 2009). Choosing partners with compatible innovation and commercialization strategies is key.

Financial performance is an important indicator of commercialization

R&D and financial indicators are often readily accessible (Dziallas & Blind, 2019) and can help actors assess the likelihood of a STIK partnership's commercial success. Indicators such as return on investment (ROI) from innovations, new-to-market or new-to-business sales, and percentage of innovations that achieve their financial targets can measure the potential for the commercial success of new innovations (reviewed in Dziallas & Blind, 2019). The performance of new products can be measured by assessing the average time it takes for the product to become profitable or the number of profitable products a firm has produced in a given timeframe (Hittmar *et al.*, 2015; Dziallas & Blind, 2019). A potential collaborator's portfolio of innovations can be used as a prospective and ongoing indicator of success to help others measure partnership value (Kim, 2014). Though patents and other IP rights can be used as indicators of commercialization progress, viewing them as financial assets by considering their economic value (and how patents or IP position a company relative to its competitors) may prove more informative (Pakes & Griliches, 1980; Blind *et al.*, 2006; Kim, 2014; Dziallas & Blind, 2019).

Project maturity and stage guide the choice of partner and which indicators to employ

As a product matures and its Technology Readiness Level (TRL)[7] increases, the knowledge and resources necessary to continue its development will change (Rybicka *et al.*, 2016; Schellekens, 2021). An academic researcher may be a valuable collaborator in knowledge creation and patenting early in development but may not be the most suitable partner for commercialization (Rosas & Camarinha-Matos, 2009). At this stage, indicators such as patents, trademarks, and design innovations can mark intermediate progress. Throughout development, the need for new knowledge will arise, and the ability to find partners (and the capacity to apply their knowledge) contributes to the technological and organizational capabilities of a company. When choosing a partner for manufacturing and scale-up, various production, stability, and delivery metrics can help actors evaluate suitability (e.g., Chu *et al.*, 2000). These can include manufacturing and transportation costs, delivery lead time (i.e., the time between when an order is placed and delivered), previous quality performance, various customer performance metrics, and financial stability (Chu *et al.*, 2000).

Dziallas and Blind (2019) categorized and reviewed indicators according to their relevance to different phases of the innovation process, including stages of commercialization. Each phase has a set of indicators assigned to it. Indicators in the strategy, product definition, product concept, and validation phases focus on financing, as well as on planning future scale-up and commercialization activities. During the production phase, the focus shifts to early measures of output and productivity. In this phase, the cost of production, manufacturing efficiency, internal lead time, and process time all help measure the efficiency of production (Dziallas & Blind, 2019). Another group of indicators measures a partner's ongoing monitoring of commercialization activities, such as regularly re-evaluating manufacturing systems and production processes (Lester, 1998; Yang *et al.*, 2015). Once these steps are complete and there is a market-ready product and sufficient production capacity, there is a shift to end-stage, market-oriented indicators, such as lead time, labour productivity, cost savings, the extent of adoption, and overall project milestone completion (Dziallas & Blind, 2019).

Measuring the value that is added by each phase of innovation and commercialization provides actors with a more robust understanding about where key contributions are being made. This concept is known as the *smile curve*. According to this concept, most value is added at the beginning of the process (through R&D) and at the end (through sales and service). Design, manufacturing,

7 "Technology Readiness Levels (TRLs) are a systematic metric/measurement system that supports assessments of the maturity of a particular technology and the consistent comparison of maturity between different types of technology" (Mankins, 1995).

and distribution, which comprise the centre of the curve, provide relatively less value (Dedrick *et al.*, 1999; Mudambi, 2008). Analysis of a nation's industries can help actors identify the stage at which a country can contribute most, according to its capacity to add value (Aggarwal, 2017). This analysis can help actors assign tasks between organizations and identify locations that maximize the advantages of a partnership (Mudambi, 2008). Using indicators specific to the commercialization stage, combined with understanding the value that stage adds, can help actors select partners with the necessary capacity in a location, in order to maximize the value of that partnership. Canada has not been historically successful in securing value along the smile curve value chain (Ciuriak & Goff, 2021).

4.1.3 Inputs

Indicators that measure investment in, and early progress of, a STIK partnership can be described as upstream metrics (Blumenthal *et al.*, 2019). Upstream metrics, such as research inputs, processes, and methods, are generally easier to quantify as they are often project-based, transparent, and easy to understand (e.g., funding, publications). Moreover, attribution is relatively straightforward for these metrics. Inputs are the human, material, informational, and financial resources invested (Blumenthal *et al.*, 2019). However, not all upstream investments will be equally fruitful; therefore, these metrics may need to be followed by more tangible output metrics throughout project development. Selecting metrics along the innovation chain to complement inputs can provide valuable data when it comes to choosing partners, measuring ongoing successes and failures, and informing planning, in order to produce more meaningful results (UNCTAD, 2020).

Financial inputs in the form of R&D spending and investment contribute to new products, and increased productivity and profitability (Jefferson *et al.*, 2006). In some cases, a partner's total resources (e.g., staff, R&D budget) can inform partnership decisions; in most scenarios, it is more informative to determine what specific assets will be allocated to the partnership's projects (Romero *et al.*, 2009; Schellekens, 2021). The extent of innovation activity and increased access to capital to support it correlate with high success for SMEs (Kijkasiwat & Phuensane, 2020). This type of spending and investment can be quantified many ways: (i) GERD is the total domestic spending by all actors on R&D (OECD, 2022a); (ii) government expenditure on R&D (GOVERD) is the portion of GERD performed by the public sector (OECD, 2015); and (iii) BERD is a measure of intramural R&D expenditures in the business sector and can be used for high-level measures of business investment (OECD, 2015). R&D investment positively correlates with productivity increases (Blanco *et al.*, 2016; Das & Mukherjee, 2020).

Foreign direct investment promotes capital, technology, and trade flow among countries

National levels of foreign direct investment (FDI) stock can indicate favourable countries or markets with which to seek financial partnerships. Its flow can indicate Canadian STIK investment abroad, and foreign investment domestically. These data can be evaluated among partner countries, or (where more granularity is needed to inform decision-making) among industries or firms. Firm-level FDI has been positively associated with institutional quality and innovation performance (Saikia, 2022; Yue, 2022). However, FDI does not guarantee success. Other factors, such as complementarity and the recognized value of a company, contribute to the value of FDI (Wang & Wong, 2016). FDI does not drive innovation alone — human capital, R&D strategies, and enabling local policies are also needed (Crescenzi *et al.*, 2022; Guo *et al.*, 2022b). *FDI qualities indicators* measure the effect of FDI on other economic and innovation factors, such as productivity, R&D expenditures, technology adoption, and training, as well as broader goals such as job security, the gender employment gap, and sustainability (e.g., CO_2 emissions) (OECD, 2022d).

Other indicators exist to measure inputs at different parts of the innovation process

Financial inputs can be measured at various levels, such as new venture capital investments and SME spending on innovation (Chen, 2008). At the firm level, R&D spending has been shown to be a more consistent comparator of innovation than other types of survey data, likely due to the familiarity of firms with measurements of R&D compared to measurements of product, process, marketing, or organizational innovations (Cirera & Muzi, 2016). The financial situation of a business (e.g., equity-to-debts ratio) is positively related to its investment in R&D (Beneito, 2003). More directly, R&D personnel ratio, knowledge and technology transfer, sales of new products, and R&D budgets and business investments affect innovation activity and help actors identify innovating corporations (reviewed in Dziallas & Blind, 2019). Moreover, the source of R&D funding (internal versus external) affects R&D activity at the firm level, with external funding imposing greater constraints, particularly on smaller firms (Czarnitzki & Hottenrott, 2011; Elshaarawy & Ezzat, 2023). Thus, both the amount of funding and how it is accessed are relevant considerations when examining input indicators (Czarnitzki & Hottenrott, 2011). Lastly, though input indicators can show broad trends in STIK funding, they often fail to capture all investments (Hall & Jaffe, 2018).

4.1.4 Assets

Tangible assets may be used as indicators of innovation activity, as higher levels correlate with R&D investment and firm growth (Radhakrishnan *et al*., 2017). Moreover, tangible assets appear to complement R&D investment by reducing risk — firms with higher levels of both tangible assets and R&D investment are more likely to show moderate growth, whereas those with high R&D investment but low levels of tangible assets are more likely to be in either the top or bottom quartile for growth (Radhakrishnan *et al*., 2017). However, the value of assets as indicators may be best understood in relation to the business strategy and industry context; for example, firms using asset-light models may perform better in some sectors than others (Varadarajan *et al*., 2021). Asset value will be dictated by the partners' needs and the physical infrastructure necessary to achieve the set objective. Intangible and tangible assets are, together, essential to undertake certain innovation activities; they can also act as collateral to help secure funding for innovation activities (Czarnitzki & Hottenrott, 2011; OECD/Eurostat, 2018; Brown *et al*., 2022).

Data are increasingly considered both products and assets in STIK partnerships

Intellectual capital and other such assets are essential strategic innovation investments that can contribute to firm-level and broader economic growth (OECD/Eurostat, 2018). Data can be used to improve firm efficiency and productivity and are increasingly viewed as valuable capital assets (Ciuriak, 2019; Chen, 2022). For new technologies, such as AI, database ownership and curation are key assets at the international level and may contribute to evaluations of a potential STIK partner (Ciuriak, 2019).

Skilled labour is an asset required for translating inputs into knowledge and outputs

One indicator of an organization's innovation capabilities is the knowledge and skill of its employees (OECD/Eurostat, 2018). For individual industries, more granular data may be necessary to detect whether there is a sufficient number of trained workers for that sector or discipline (e.g., Shen & Luo, 2021). Including metrics that consider training in addition to formal education (e.g., enrolment, degrees, occupation) — particularly training programs and funding related to innovation adoption and diffusion — may be useful in quantifying the capacity of human capital (Hall & Jaffe, 2018). A complementary analysis could include measuring demand for specific STIK skills (e.g., starting salaries) to help locate imbalances in the innovation labour market (Hall & Jaffe, 2018). Assets, inputs, investments, and personnel form the basis for better normalizing and understanding innovation data. For example, normalizing the number of workers allows for the R&D personnel ratio to be measured, which can help with firm- or program-level evaluations (Song & Oh, 2015; Hall & Jaffe, 2018).

4.1.5 Outputs

In part, economic outputs from innovation activity reflect a strengthening knowledge-based economy (WD, 2012). These outputs can be used as indicators to help identify partners in strong innovation economies with proven performance. Outputs can be measures of value creation — the implicit goal of innovation. For example, GDP growth is a commonly used metric; other indicators of innovation output include the marginal rates of return or gross value added above STIK investment, though these are more challenging to measure (Hall & Jaffe, 2018; McLaren, 2022). Innovation outputs reflect new or improved goods, services, or processes, which can be measured, for example, by the volume of new product exports or sales (Carayannis *et al.*, 2018; OECD/Eurostat, 2018). Cost reduction and improved quality of products are firm-level measurements of process innovation and are positively associated with firm performance (OECD/Eurostat, 2018). However, economic outcomes can be challenging to attribute directly to process innovations (Rammer, 2016).

Economic outputs can inform a high-level evaluation of a potential partnership

The Hamilton Index of Advanced-Industry Performance uses OECD output data to assess sectoral competitiveness over time, comparing national performance (Atkinson, 2022). Combining longitudinal sectoral data across nations allows for benchmarking against other nations and among industries, while providing insights that cannot be drawn from national trends alone. The index provides a global benchmark for advanced-industry outputs by examining economic GDP output relative to a region's share of global GDP (Atkinson, 2022). National advanced-industry performance can indicate where a partner operates in a robust economic environment.

The GII identifies many economic output indicators, including labour productivity growth; the density of new firms entering the ecosystem; the proportion of high-technology manufacturing relative to all manufacturing; exports of ICT services; and high-tech exports as a percentage of total trade, among others (WIPO, 2020). Various granular or organization-specific metrics can measure innovative outputs that result from organizations in the STIK space, in the form of new or improved products, product adoption, services, logistics, methods of production, or support activities (WD, 2012; Hall & Jaffe, 2018). The OECD's *Oslo Manual 2018* mentions cost reduction and improved quality of innovative products as valuable innovation outputs. Innovation outputs of these types are positively associated with firm performance (OECD/Eurostat, 2018).

Because of the time it takes for an innovation to generate economic benefits, outputs aligned to various stages of innovation can help evaluate the progress of STIK partnerships. For early-stage innovation projects, research outputs — published papers, new methods, and patents — may be the most appropriate indicators (reviewed in Dziallas & Blind, 2019). Intermediate outcome indicators (i.e., measures taken prior to completion), such as the development of a prototype, production cost, and labour productivity, can indicate progress toward an economically viable commercial product (Dziallas & Blind, 2019).

Considerations of market characteristics help inform interpretations of output indicators

The output of STIK investments is affected by many factors beyond spending, inputs, capacity, and labour. The types and quantity of innovations change in response to macroeconomic circumstances (e.g., expansion, recession); therefore, evaluating performance relative to such changing market forces can improve one's understanding of a potential partner's outputs (Ortiz & Salas Fumas, 2020; Bernstein *et al.*, 2021). Some indicators quantify features of the innovation environment to help facilitate product innovation. Market indicators such as demand, growth, and competition are established indicators that provide information during commercialization and market launch (U.S. Congress OTA, 1995; Syrneonidis, 1996; Vives, 2008). The innovation environment can also be characterized by indicators such as the number of innovative businesses and new venture start-ups (Dziallas & Blind, 2019). Understanding the broader environment will help actors interpret outputs by measuring against reasonable goals that reflect real market conditions.

4.2 Trade

Trade is an integral part of the Canadian economy (Bank of Canada, 2018; GAC, 2022c). The combination of multi-country production chains, the infrastructure and logistical capacity necessary to support them, and increasingly complex governance (e.g., tariffs, non-tariff trade barriers, proliferating regional or bilateral free trade agreements) need to be considered to effectively account for trade in STIK partnership decisions (IOM *et al.*, 2013). Trade factors into STIK partnership decisions in various, and potentially competing ways, such as through the acquisition of materials, sales and market access, and knowledge and skills exchange.

International trade involves transactions in goods and services between a domestic and international entity (OECD, 2022b). Trade can be measured in many ways that can inform partnership decisions. For both goods and services, the simplest indicators measure the amount and value of imports and exports (WITS, 2022). Other indicators identify the efficiency or permissibility of a trade environment (OECD, 2018a; WITS, 2022). These data can be used in aggregate, or broken down by sector or business size, to increase their relevance to decision-making (OECD, 2022c; WITS, 2022). However, approximately 17% of Canadian trade is service trade — a rapidly growing sector of the world economy (Office of the Chief Economist, 2022). Essential aspects of this trade include international partnerships between STIK organizations, the import and export of S&T services and personnel, and educational services. These same indicators can be used to evaluate Canadian trade competitiveness and growth; provide insight into how attractive Canada is as a trading partner; and measure how successful Canadian programs are at STIK in international markets (Cheong, 2010; Plummer *et al*., 2010; GAC, 2022a).

4.2.1 Trade Performance

A simple metric for trade performance is the time it takes to import and export goods and services (The World Bank, 2023b). The volume of trade itself may indicate a potential preferred partner; high levels of trade may reflect good trade relations, a low regulatory burden, or high demand in that sector (UNCTAD, 2018). The ease of doing trade is crucial for SMEs, for which the costs of trading can be disproportionately high (OECD, 2018b).

Composite indicators can identify partners with favourable trade environments

The OECD's measure of trade facilitation performance, and the indicators that support it, can inform trade considerations within a broader framework (OECD, 2018b). These indicators include information availability, ease of formalities (e.g., harmonization with international standards, electronic payments, single submission points for documentation), governance and impartiality, and intranational and international cooperation (OECD, 2018a).

Other composite indicators include trade measures, demonstrating how trade can be used alongside other indicators as part of evaluations. For example, the GII includes trade indicators such as average tariffs (WIPO, 2022). It also uses trade measures as indicators of business sophistication and knowledge absorption — enablers of innovation. These indicators include IP payments as a percentage of trade and high-tech or ICT service imports and exports. Potential partners with higher scores in IP, high-tech, and ICT exports, for example, demonstrate greater innovation productivity and may make better trading partners (WIPO, 2022).

Understanding the trade landscape may be complemented or superseded by sector- or firm-level performance data

Trade indicators can also form the basis for more advanced analysis, such as estimating value added by countries or sectors through goods and services (Guilhoto *et al.*, 2022; Halton, 2022). These indicators, such as trade value or Trade in Value Added (TiVA), can be analyzed at the industry, sector, or product level, which can help actors identify trade markets more precisely than analyses of national-level data (OECD, 2017, 2022f). Firm-level export value data can be found in national and regional government surveys and end-of-fiscal-year reports, which often have to be acquired from private data providers (Breinlich *et al.*, 2020). Firm-level export values have a strong, positive relationship with productivity (Breinlich *et al.*, 2020) and, in some cases, are linked to greater innovation through increased R&D activity (Girma *et al.*, 2008). A firm's export behaviour and performance can be indicative of its prospect of survival under adverse financial conditions (Görg & Spaliara, 2014). Firm-level export data can also be used as indicators to evaluate policies designed to promote exports (Arkolakis *et al.*, 2021). These sector- and firm-level data can indicate which organization an actor might partner with, and in which markets.

Training, innovation capacity, and trade converge in international education

International education is an aspect of trade supported by the TCS to increase prosperity by "attracting talent; boosting Canada's innovation capacity; promoting global ties; and fostering a vibrant Canadian economy" (TCS, 2020). In this way, international education partnerships, such as those in Canada's International Education Strategy, are STIK partnerships that contribute to trade (GC, 2020); international students have an annual economic impact of nearly $20 billion on Canada's GDP (GAC, 2020). Awareness of (and experience with) training and knowledge exchange opportunities, annual spending, number of students studying domestically and abroad, and sales and licensing of educational services and products can all be used to determine the efficacy of international educational STIK partnerships (GC, 2020). Many indicators can provide insights into several relevant partnership domains. For example, international education is captured in Canada's service exports (GAC, 2020); training can be measured as part of science and innovation capacity (Sections 4.1.2 and 5.3), and the mobility of students can be a measure of knowledge diffusion and collaboration (Section 5.3.3).

Beyond the goods and services exchanged, trade partnerships provide other benefits. The integration of markets through trade facilitates knowledge exchange or spillover through research publication, knowledge acquisition, and reverse-engineering (Melitz & Redding, 2021). International trade can support knowledge exchange that benefits both parties, because proper planning can eliminate spending on duplicated research — a better value proposition for all parties (Melitz & Redding, 2021).

4.2.2 Tariffs and Barriers

Other indicators inform the costs associated with trade — primarily the taxes on import and export goods and services (OECD, 2018a; WITS, 2022). The aggregate country-level tariff and tax rate can reveal the overall favourability of a market, but indicators of tariffs and permit requirements for specific goods and services are more valuable for firms dealing in them (Table 4.2). Trade tariffs and barriers limit market access and can increase costs. The Government of Canada maintains a tariff information database and information on economic sanctions, export and import controls, trade barriers, and trade and multilateral recognition agreements, which improve partnership decisions (GAC, 2017b, 2022d; TCS, 2022b; GC, 2023f). The World Bank's Temporary Trade Barriers Database along with International Monetary Fund data can help identify where trade opportunities or risks exist (The World Bank, 2021; Estefania-Flores *et al.*, 2022).

More amenable trade policies (i.e., lower tariffs, better subsidies, favourable regulations) can indicate where Canada may have a greater comparative advantage (Kowalski, 2011), which helps actors identify beneficial markets for partnerships. International STIK partnerships can address the causes of trade barriers (e.g., phytosanitary concerns) or meet regulatory requirements, reducing the negative impacts of trade barriers. For example, China restricted the import of Canadian canola in 2009 because of concerns over the spread of the fungal disease blackleg; the restriction was later repealed following science-based approaches and agreements on best practices (Sun, 2020). A similar ban was reinstated in 2019 and subsequently lifted in 2022 (The Canadian Press, 2022). While geopolitical factors can play a bigger role than science in such trade disputes (Hui, 2016), STIK partnerships can inform evidence-based regulations, such as by determining appropriate safety standards (e.g., Udomkun *et al.*, 2017) or through development of diagnostic testing methods (e.g., Gleim *et al.*, 2021).

Table 4.2 Examples of Trade Regulations on Goods in the Canadian Market

Regulation	Requirement	Goods	Reference(s)
Export and Import Permits Act	Permitting for export of military and strategic goods and technology	Dual use, munitions, nuclear non-proliferation, nuclear-related dual use, miscellaneous goods and technology, missile technology control regime, chemical and biological weapons non-proliferation, arms trade treaty	GAC (2022b)
	Export quota to the U.S.	Peanut butter and paste	GAC (2023d)
	Tariff rate quota or tariff on agricultural imports	Including beef and veal, hatching eggs and live fowl, prepared and preserved meats, dairy and cheese, wheat and barley products	GAC (2023c); GC (2022a, 2023g)
Food and Drugs Act	Monitoring compliance with and enforcement of regulatory requirements for imported and exported drugs	Active pharmaceutical ingredients, human drugs, veterinary drugs, medical devices, natural health products, blood and blood components for transfusion, human cells, and tissues and organs for transplantation	HC (2020)
Comprehensive Economic and Trade Agreement	Quotas for specific products imported to the EU to "receive preferential tariff treatment"	Including high-sugar-containing products, textiles and apparel, vehicles, fish and seafood, processed foods, dog and cat food	GAC (2022e)
Softwood Lumber Agreement	Countervailing duty and antidumping laws affecting Canadian softwood lumber imports to the U.S.	Softwood lumber	GAC (2023e); Gov. of BC (2023a)
Plant Protection Act	Import permit for approved agents	Insects, mites, nematodes, and other organisms used as biological control agents against plant pests	CFIA (2022)
Safe Food for Canadians Regulations	Regulatory performance oversight and monitoring of imports and exports	Food is defined as "any article manufactured, sold, or represented for use as food or drink for human beings, chewing gum, and any ingredient that may be mixed with food for any purpose whatever" (GC, 1985).	GC (1985, 2018)

Trade regulations can create barriers to accessing foreign markets

Trade regulations designed around reasonable health, safety, environmental, or agricultural policies — rather than to create a competitive advantage — may still constitute a barrier, limiting Canadian entities' access to foreign markets. For example, while an import restriction enacted after the detection of bovine spongiform encephalopathy (BSE) may have been a prudent policy, it took 20 years to produce a track record of safety that could satisfy hesitant trading partners (Stephenson, 2019; AAFC, 2023; Gov. of AB, 2023b). Effective, evidence-based trade regulations can help stabilize supplies of resources, maintain supply chains, ensure sustainable environmental development, and mitigate volatility. These types of bilateral and multilateral agreements are designed to create the market conditions for the trade of innovative products and new drugs (Canada-EU, 2016; GAC, 2017a; OECD, n.d.).

In areas such as healthcare, food, and agriculture, innovative products — or those that benefit from recent innovations — may be subject to multiple trade barriers. These barriers may provide opportunities for partnership and innovation. For example, agricultural innovations (e.g., breeding, genetic modification) for crops such as soybeans, pulses, and peanuts may be affected by multiple trade barriers, such as quotas (e.g., GAC, 2023d), phytosanitary certification (CFIA, 2015), agricultural certification (USDA, 2017), and food safety testing (Ahn & Rhodes, 2021). The regulatory burdens imposed by these trade barriers may affect the cost benefit analysis guiding investment, R&D, and partnerships to the most favourable markets and away from less favourable ones. Decisions in response to trade barriers may ultimately impact profit. New testing and certification can facilitate importation, increase sustainability, improve health, encourage product acceptance, and even boost prices for certified products (e.g., aflatoxin-safe peanuts) (Udomkun *et al.*, 2017). In this way, international STIK partnerships, through new technologies and regulatory cooperation, can help address trade barriers that may affect the viability of, for example, agricultural innovations in the market.

4.2.3 Standards Setting, IP, and Regulatory Alignment

One measure of successful STIK partnerships — identified by Canadian STIK organizations interviewed for this report — is the adoption of Canadian standards by other countries and multilateral organizations, as well as Canada's own commitment to accept international standard-setting processes. Existing arrangements can be indicators of the current ease or difficulty of doing business in partnering markets, guiding decisions about where to partner for new innovations. The adoption of international standards is an indicator of innovation (WIPO, 2022). For Canadian firms and their potential partners, adherence to international standards can increase confidence in an organization's capacity. The GII includes ISO 9001 (an international standard for quality management) and ISO 14001 (an international environmental management standard) as two innovation indicators (WIPO, 2022).

International STIK partnerships can help in establishing standards, which furthers trade

Using STIK partnerships to set standards can assist with other goals, such as environmental protection and disease prevention (GAC, 2018). For example, genetically modified organisms (GMOs) and their products are strictly regulated in the European market, requiring approval for market entry (Arcuri, 2017). This restrictive EU approval system allows very few imported GMO products for human consumption (Arcuri, 2017). In 2009, the contamination of flax grown in Canada with a GMO strain resulted in import restrictions and new testing requirements (Viju *et al.*, 2014). CETA formalized bilateral dialogue on relevant new legislation for biotechnology of mutual interest (Sinclair *et al.*, 2014) and created shared objectives that facilitated cooperation while opening dialogue for future negotiations (Arcuri, 2017). Dialogue between Canada and the European Union continues, with the goal of encouraging the trade of biotechnology-derived agriculture products (GAC, 2021a).

What We Heard

Influencing how standards are set is both a goal and an outcome of Canadian regulatory organizations that use the number of negotiations, membership in relevant organizations, signed agreements, and adopted Canadian standards as indicators of productive STIK partnerships.

New standards can arise as part of goal or target setting for international bodies, or they can come to be through the adoption of shared international standards — which has the added effect of making Canada more competitive and attractive. Standards setting ultimately helps countries develop domestic best practices and can supplement other success metrics. Moreover, the global testing, inspection, and certification market is a multi-billion-dollar industry (valued over US$300 billion in 2022) in which Canada competes (Grand View Research, 2022).

4.3 Implementation Considerations

Indicators will be most informative for partnership decisions when they are chosen to align with the stage of development, timeframe, and specific needs required to further each new innovation. Features such as data quality, comparability, availability, ease of collection and interpretation, appropriateness of scale, and granularity are always necessary considerations. Some indicators are more appropriate or valuable for evaluating the potential and risk of specific international partnerships and partners. Innovation indicators such as those included in this chapter are best used alongside indicators that measure other goals (e.g., alignment with social values, sustainability, and inclusion), in order to find innovation partnership strategies that support the broader set of priorities for a STIK partnership, as is the case for inclusive innovation (Box 4.1).

Box 4.1 Inclusive and Social Innovation

Inclusive innovation structures innovation across multiple dimensions. This includes extending the benefits of innovation to underserved people, addressing global challenges (e.g., poverty, climate change, health crises, food security), and engaging multiple stakeholders (Sanjiv, 2020; ESDC, 2022). Inclusiveness and equity can drive innovation, while social innovation (see below) and social finance can be tools to produce social impacts that contribute to individual and collective well-being (ESDC, 2022). Inclusive innovation envisions partnerships as necessary components when it comes to addressing challenges that are too large to be tackled by one organization (Sanjiv, 2020).

Closely related to inclusive innovation is *social innovation*, which is based on the idea that the traditional, primarily technological ways markets, states, and civil society have engaged in innovation are no longer sufficient to meet the demands of global challenges (Howaldt *et al*., 2016). The Social Innovation and Social Finance Strategy Co-Creation Steering Group, launched by Employment and Social Development Canada (ESDC, 2022), identified several elements needed to support more inclusive types of innovation driven by public, private, and non-profit actors: capacity and skills; funding and capital; market access; an enabling policy and regulatory environment; evidence and knowledge sharing; and awareness and mobilization. Social innovation needs broader empowerment and participation among the public, which may require new forms of governance (Howaldt *et al*., 2016). For example, co-creation and co-production are foundational to social innovation that can address human needs not being met by the current system (Martins *et al*., 2022).

(Continues)

(Continued)

As with innovation more broadly, inclusive and social innovation benefit from accurate data and evaluation; these data cover, for example, national and firm-level economics, funding, and administration, and they can quantify social outcomes (ESDC, 2022). The data and techniques used to measure impacts are being developed and are part of ensuring and enabling an innovation ecosystem has the capacity and talent available to analyze them — which is also important for the success of inclusive innovation (Howaldt *et al.*, 2016; Martins *et al.*, 2022; ESDC, 2022). In sum, inclusive innovation is an example of building data into an innovation framework that simultaneously supports a social and economic agenda.

Because of the complex nature of international STIK decision-making, multiple indicators used systematically and reproducibly can enhance strategic decision-making. Some indicators may provide insight into several aspects of a potential partnership. For example, measurements of a partner's assets can help actors evaluate that partner's potential capacity for a given task, but it can also help them evaluate a partner's financial stability and risk profile (Radhakrishnan *et al.*, 2017). At a broader scale, government policy choices, as well as legal and regulatory frameworks, explicitly and implicitly affect the STIK environment (Hall & Jaffe, 2018; Dziallas & Blind, 2019). IP, tax and trade policies, enterprise transparency, and openness to foreign STIK partnerships can all provide insight into the value added by a partner's innovation ecosystem. General infrastructure (e.g., water, energy, ICT, transport) supports productivity, physical mobility, health, and information sharing, whereas specialized infrastructure (e.g., laboratories, testing and monitoring facilities) and advanced manufacturing capacity facilitate the innovation process, as well as knowledge generation and exchange (UNCTAD, 2020).

5

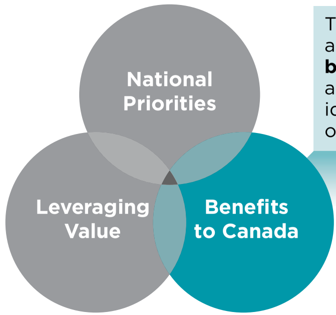
Benefits to Canada: Indicators of Scientific Capacity and Knowledge Production

Any international science, technology, innovation, and knowledge production (STIK) partnership Canada enters into must create some benefit to Canada if it is to be successful. Broadly, a STIK partnership provides benefits by building capacity in Canada. The identification of these benefits, and the timescales at which they operate, helps establish evaluation criteria. Useful indicators reflect the qualities a partner brings to the table that will help produce those benefits for Canada, as evidenced by that potential partner's existing activities, outputs, and relationships (Figure 5.1).

In many ways, science is a public good; in addition to espousing values of communalism and universalism, scientific knowledge is not depleted through use (Ruffini, 2017). Indeed, scientific knowledge increases in value when it is shared, and scientific networks — exchanges of knowledge, skills, and expertise — emerge as a natural consequence of the practice of science (Wagner, 2018). Scientists rarely work in isolation; they seek out collaborators to access (or support the building of) equipment, skills, expertise, study objects, locations, or other resources (Wagner, 2018).

Although science is a public good, the benefits accrued from knowledge production will be limited without adequate education and access to relevant technical expertise and scientific networks (Salter & Martin, 2001). In a review of the literature, Salter and Martin (2001) enumerate six types of benefits gained by funding basic research: increasing the stock of knowledge, producing skilled graduates, developing new instrumentation and methodologies, generating networks and social interactions, technological problem-solving, and creating new firms.

Such benefits might also reasonably be considered the desired outcomes of international STIK partnerships. Notably, it is not just the stock of knowledge that matters; it is the capacity to use that knowledge — as manifested in skilled graduates, new instruments, and problem-solving capabilities — that results in social and economic benefits (Salter & Martin, 2001). Scientific research can be basic, exploratory research that expands humanity's understanding of the universe; applied research conducted with a particular problem or application in mind; or use-inspired, which balances scientific exploration with identifiable societal goals (Stokes, 1997). For example, Canada's Fundamental Science Review (2017) noted a variety of potential objectives related to supporting fundamental science, which are indirectly achieved through curiosity-based research, such as a cleaner and safer environment, longer and healthier lives, and economic prosperity.



There is a wide array of indicators and metrics to measure potential **benefits to Canada**. From the articulated goals, criteria are identified for evaluation. Areas of consideration include:

National Resilience	Criteria (example indicator)
Diplomacy	• Diplomatic outcomes (new policies, innovation centres)
Sustainability	• Sustainability (development, emissions) • Reciprocity (fair mutual benefit) • Commitment and vision (use of foresight)
Security	• National security (security networks) • Foreign influence (vulnerability) • Cybersecurity (alignment, threats) • Research security (sanctioned activities)

Innovation	Criteria (example indicator)
Collaboration and Commercialization	• Collaboration readiness (complementarity) • Commercialization and scale-up (firm size and performance) • Inputs (R&D investment, resources) • Assets (tangible and intangible) • Outputs (growth)
Trade	• Trade system (imports and exports) • Regulations and barriers (tariffs, quotas) • Standards setting and regulatory alignment (standards creation, adoption)

Scientific Capacity and Knowledge Production	Criteria (example indicator)
Excellence	• Rigour (peer review) • Production (publications, other outputs) • Impact (citations)
Open Science	• FAIR principles (policies) • Collaboration (co-authorships)
Talent	• Potential (network position) • Expertise (citations) • Mobility (policies, programs)
Infrastructure	• Location (uniqueness) • Institutions (rankings) • Facilities (accessibility)

Figure 5.1 Benefits to Canada — Scientific Capacity and Knowledge Production

Increasing scientific capacity and knowledge production will depend on the excellence of the research demonstrated by the potential partner, as well as its commitment and practices related to open science. Potential gains for Canada can also result from access to talent and infrastructure.

This chapter examines the indicators and metrics relevant to potential partnerships with a scientific or knowledge production focus. The panel subdivided considerations relevant to international STIK partnerships into four main areas of benefits: excellence, open science, talent, and infrastructure (Table 5.1). The chapter examines each of these areas of benefits, identifies their associated criteria, indicators, and metrics, and provides a brief overview of the evidence on their use and limitations. It concludes with some additional considerations about science diplomacy, EDI, and Indigenous knowledge.

Table 5.1 Criteria, Indicators, and Examples of Metrics of Scientific Capacity and Knowledge Production

Scientific Capacity and Knowledge Production	Criteria	Indicators	Examples of Metrics
Excellence (Section 5.1)	Rigour	• Scholarly output • Citations	• Number of indexed publications • Number of citations (weighted by field) • Citation metrics • Peer review rankings and evaluations • Qualitative assessments by a community of practice • Number of books, chapters, technical reports, white papers • Altmetrics • Visual innovations, oral histories, ethnodramas, dialogues • Geographically and culturally specific assessments of local and Indigenous knowledge
	Productivity	• Grey literature • Peer review	
	Impact	• Social impacts • Non-scholarly output	
Open Science (Section 5.2)	FAIR principles	• Open access publication • Data-sharing practices • Code-sharing practices	• Number of findable, accessible papers • Number of preprints • Indexed data sets • Findable, accessible code • Open access policies, regulations, licensing information • Number of co-authored indexed publications, citation metrics • Number of co-authored books, chapters, non-scholarly outputs and grey literature • Attendance, hosting of international conferences • Signatories on international treaties, conventions • Peer review, community of practice assessments of collaboration
	Collaboration	• Co-publications • Participation in international treaties and conventions • Participation in international research organizations, conferences	

(Continues)

(Continued)

Talent (Section 5.3)	Network potential	• Labour force • Education and training opportunities • Publication patterns	• Number of STEM, humanities, and social sciences graduates • Higher education participation, completion, and graduation rates • Number of new doctorates • Total R&D personnel • Social network analysis of publications • Semantic analysis of publications • Leadership at international organizations • Participation in intergovernmental organizations • Immigration and emigration data • Co-publications • Diplomatic apparatuses (funding, personnel, embassies)
	Expertise	• Network position • Influence	
	Mobility	• International migration • Bibliometrics • Mobility supports	
Infrastructure (Section 5.4)	Location Institutions Facilities	• Uniqueness • Complementarity • Institutional rankings • Bibliometrics	• Numbers and types of STIK facilities • Research needs and accessibility of specific locations, facilities • Peer review, community of practice assessments of institutions, facilities • Publication rates, citation metrics applied at institutional levels

5.1 Excellence

We engage in science to increase our collective knowledge about the universe; knowledge production is therefore a key goal of any scientific endeavour, including international partnerships. While the concept of scientific excellence is widely used in policy and funding discourses, it is often vaguely defined, if defined at all (Sunkel, 2015). It is also most often measured quantitatively by bibliometrics or qualitatively by peer review (Sunkel, 2015). For the purposes of the framework elements, the panel considers excellence to be evidenced by an improvement in the quality of knowledge production.

There are multiple dimensions related to measurements of scientific quality. For example, Polanyi (1962) recognized three dimensions: plausibility, originality, and scientific value. That is, research of the highest quality is plausible (i.e., scientifically sound), original (i.e., creates new knowledge), and valuable (i.e., important for other researchers) (Polanyi, 1962; Aksnes *et al.*, 2019). More recently, a fourth dimension of research quality — societal value and relevance — reflects the importance of research for society as a whole (Gulbrandsen, 2000; Lamont, 2009). These dimensions are explored via the three criteria — rigour, productivity, and impact — discussed below.

5.1.1 Rigour and Productivity

Evaluating a potential partnership's contribution to knowledge production is a complex task. It requires consideration of expected timelines for discovery, the potential for network effects, and other non-linear ways in which knowledge production can influence technology development and innovation (and vice versa) (Brooks, 1994; Wagner, 2018). While there exist widely used metrics related to rigour and productivity, such as bibliometrics (summarized in Table 5.2), the interpretation of those metrics is complicated by other factors, such as the research mission and local relevance (Hicks *et al.*, 2015). As well, the indicators themselves have been subject to substantial critique, particularly in relation to their applicability to different fields of study, their potential to be highly skewed, and the exclusion of other research products, such as reagents, software, or data — see, for example, the *San Francisco Declaration on Research Assessment (DORA)* (Cagan, 2013). Evaluative metrics is a contested field — best practices are not resolved, and new methodologies are areas of ongoing development (Leckert, 2021). Creating a robust evaluation framework involves transparency in defining parameters (e.g., goals, timelines, benchmarks, comparisons) as well as their limits and constraints; indicators and metrics; data sources and measurement methodologies; and the methods used to weight and interpret results.

Table 5.2 Common Bibliometric Indicators of Scientific Excellence

Indicator	Measured Characteristic	Definition
Scholarly output	• Rigour • Productivity	The number of publications by an entity (e.g., author, institution) indexed (e.g., in Scopus, Web of Science).
Field-weighted citation impact	• Impact	The number of citations received by an entity's publications compared with the average number of citations received by all other similar publications in the data universe.
Total citations	• Impact	The number of citations received by an entity's publications.
Citations per publication	• Impact	The average citation impact of the publication (total citations divided by total publications).
Top cited publications	• Impact	For example, the number or proportion of the 10% most cited publications (overall or in a field).
Publications in top journal percentiles	• Impact	The number of publications in the top 1%, 5%, 10%, or 25% of the most-cited indexed journals (e.g., in Scopus).

Sources: OECD (2022h); Cucari *et al.* (2023)

Much has been written about the appropriate application of metrics of research quality in the evaluation of prospective, ongoing, and past research projects and programs (e.g., CCA, 2021). However, at a minimum, the number of research articles published in peer-reviewed journals provides a metric of scientific rigour or plausibility. That is, journals publish articles that have passed through a review by an editor and peers, who decide whether the research presented within is rigorous and defensible, among other considerations (Ferreira *et al.*, 2016). Thus, metrics of research production, such as publication rates and citations, can offer some insight into the quality of the contribution an individual, institution, or country is making to knowledge production. However, there are several caveats and shortcomings in the use of quantitative metrics to examine rigour that point to the importance of including aspects of qualitative assessments, which, in turn, may be criticized for their potential to lack objectivity (Schmoch & Schubert, 2008).

Bibliometrics provide useful, but not comprehensive, indicators of rigour and productivity

Publication rates can be used as a measure of research productivity (e.g., Lowcay *et al.*, 2004), but this measurement is constrained by the limits of the indices that mine such data and by the publication practices of different domains and countries. For example, the two largest citation indices in the world, Scopus (Elsevier) and Web of Science (Clarivate), vary in their coverage of different scientific and scholarly fields (Aksnes *et al.*, 2019). Aksnes *et al.* (2019) found high coverage of journal articles and book publications in medicine and health, as well as the natural sciences and technology, with comparatively lower coverage for the social sciences and humanities. Mongeon and Paul-Hus (2016) note similar deficits in the coverage of social sciences, arts, and humanities journals indexed by Web of Science and Scopus. Global citation indices are likely to exclude local publications, particularly those not published in English (Ovezmyradov, 2023).

Dissemination practices vary among fields, and the incentive to publish in national versus international academic journals is also a function of the scientific culture of a country (Larivière, 2007, 2018). For example, in 2015, nearly 100% of articles published by authors from Quebec in natural sciences and engineering in Clarivate's Web of Science were in English, compared to 67% of such articles published in the arts and humanities (Larivière, 2018). Publication of books, book chapters, and grey literature may capture a larger proportion of the scientific output in some fields or countries than in others, limiting the comparative value of publication rates based on academic journal articles alone. There is a substantial challenge in accounting for non-scholarly publications in evaluations using citation indices, though some have tried (e.g., Frandsen & Nicolaisen, 2023).

Bibliometric analyses of productivity may also be confounded by predatory or low-quality publishing practices (Box 5.1); this is an important consideration, as is being aware of scientific retractions when using publication rates as an indicator of rigour. Retraction Watch (n.d.) maintains a searchable database of retractions, including by affiliation.

Box 5.1 Predatory Publishing and Productivity Bias

The prevalence of publication in predatory journals — those that take advantage of open-access publication fees to generate profits by publishing articles without genuine peer-review — varies substantially among countries (Xia *et al.*, 2015; Marina & Sterligov, 2021). Inexperienced researchers in developing countries tend to publish more often in predatory journals (Xia *et al.*, 2015), though publications in potentially predatory journals are pervasive in all countries (Marina & Sterligov, 2021). Using Scopus, Marina and Sterligov (2021) found evidence of potentially predatory publishing across all fields, with the highest rates in engineering and medicine. That said, even in those subset areas, rates are low; between 2011 and 2018, an average of 4% of engineering papers in Scopus were flagged as having been published in potentially predatory journals, as were 2% of papers in medicine (Marina & Sterligov, 2021). While publication in predatory journals can circumvent peer review, it is important to note that this does not necessarily preclude rigour in such research; rather, it places a constraint on the interpretation of publication rates as an indicator of quality, demanding additional considerations.

Evaluations of qualitative research demand different approaches

The conceptualization of science as knowledge production writ large includes non-traditional forms of inquiry whose assessments of excellence preclude, for example, bibliometric analyses and other data-driven approaches. Gergen (2014) argues that, "for qualitative researchers concerned with the complexity and nuance of human meaning, controlled measurement is both obstructive and misleading in its outcomes." Excellence is recognizable in the context of a community of practice, with few overarching features that are broadly applicable across such communities. These broad criteria of excellence include contributing to further understanding, linking research to relevant dialogues, applying rigour in study design and implementation, and communicating in ways that are coherent and understandable (Gergen, 2014). The evaluation of research practices through an ethical lens is also important, as is the resonance of the research findings among relevant communities (Tracy, 2010).

These criteria are supported in specific qualitative research practices, such as participatory and action research, where research quality is recognizable in the trustworthiness and validity of the research; in the improvements, resolutions, and transformations it effects; in knowledge mobilization and the distribution of research capacity; and in the processes of mutual learning (Lindhult, 2019). While some indicators of these aspects may arguably be measured by bibliometrics, important and valuable outputs will not be captured, such as visual innovations, oral histories, ethnodramas, and dialogues, among others (Gergen, 2014). Thus, evaluation of potential STIK partnerships that include the aims and goals of other forms of inquiry will ideally also include assessment methods outside of a data-driven approach, such as judgment and review by practitioners from within relevant communities of practice.

There is a lack of indicators and metrics appropriate to other, such as Indigenous, knowledge systems

While citation indices form the main data source for many of the indicators listed above, there is a substantial lack of indicators available to, and appropriate for, the inclusion of Indigenous knowledge across all dimensions of scientific capacity — excellence, talent, infrastructure, and open science (Box 5.2). For example, the UN *Convention on Biological Diversity* explicitly demands the inclusion of Indigenous and traditional knowledge and practices in planning, policy formation, and implementation (UNEP & CBD, 2013), but there are few, if any, data sources relevant to the benchmarking or measurement of trends in these areas.

Trends of interest include changes in land use and land tenure on traditional territories and in the practice of traditional occupations; the degree of respect for and integration of traditional knowledge and practices in national implementation plans; and linguistic diversity (UNEP & CBD, 2013). Of these, only linguistic diversity has an index associated with its measurement: Terralingua's Index of Linguistic Diversity (Harmon & Loh, 2010; CBD, n.d.). The UNESCO[8] Local and Indigenous Knowledge Systems (LINKS) program is intended to "promote local and Indigenous knowledge and its inclusion in global climate science and policy processes" (UNESCO, 2021a). However, as El Bah and Scott (2022) note in the first evaluation of the LINKS program, there are as yet no published performance indicators nor set targets against which to measure the success of the program's objectives.

8 United Nations Educational, Scientific and Cultural Organization.

Box 5.2 Community-Led, Culturally Appropriate, and Relevant Evaluations of Indigenous Knowledge

As with scholarly work published in local journals, in books, and in languages other than English, considerations of knowledge production and capacity building in other knowledge systems — such as Indigenous knowledge — must recognize the inappropriateness of existing indices, and work to find or develop indicators that are culturally appropriate and relevant. This is a challenge, as such indicators will, by nature, be geographically specific and representative of a cultural identity. Nor will existing systems and processes be adaptable to the task, as such indicators will only be relevant and appropriate if their development and definition are led by the communities themselves. Still, the usefulness of evaluations depends on the completeness of the indicator sets used to reflect factors relevant to the affected community. Culturally appropriate indicators enable the information they represent to be given at least equal consideration in decision-making alongside other social, economic, and environmental considerations.

(Morgan *et al*. 2021)

5.1.2 Impact

Along with measurements of rigour and productivity, bibliometric data can be used as an indicator of the value of published research for the scientific endeavour, and its impact. When looking at individual researchers, publication in areas that deviate from their previous field of expertise are indicative of innovation and novelty (Fontana *et al*., 2018; Hall & Jaffe, 2018). Similarly, citation counts are arguably an indicator of knowledge production in that they represent the usefulness of a publication for other scientists' research (Wang, 2016). Citation network analyses that examine both a paper's references and its own citations offers a more robust methodology for measuring originality using bibliometric data (Shibayama & Wang, 2020). However, the same caveats surrounding the use of bibliometric data to assess scientific rigour — such as issues of inclusivity and relevance to different fields — also apply to the assessment of impact.

Citation rates are widely used, but imperfect, metrics of impact

Teplitskiy *et al.* (2022) demonstrate a positive relationship between the number of citations a paper receives and its influence on various aspects of research, such as choice of theory, method, or research topic. Notably, citation rate and influence do not enjoy a one-to-one relationship; influence is disproportionately strong for the most highly cited papers, as demonstrated through a survey of over 9,000 scientists in 15 different fields who were asked for the reason why they cited two select papers chosen from their research article (Teplitskiy *et al.*, 2022).

When influence is measured by language analysis, the relationship between citation rates holds as well, though it is noisy (Gerow *et al.*, 2018). The correlation between influence and citation counts for textual analyses is consistent, but relatively low — between 0.2 and 0.4 (reviewed in Clancy, 2022). Highly cited papers also appear more frequently in patents and government reports (Poege *et al.*, 2019; Yin *et al.*, 2021), though, as Clancy (2022) reasons, factors other than relevance — such as discoverability and investigator prominence — likely contribute to this correlation. Still, patents that cite highly cited papers are themselves more valuable, as measured by how often the patent is then cited by other patents and by how stock prices change after a patent is granted (Poege *et al.*, 2019). Krieger *et al.* (2022) find that patents that are closer to the science (i.e., that directly cite the research, that cite a patent that directly cites the research, that cite a patent that cites a patent that directly cites the research, and so on) also tend to be more valuable, as measured by stock price changes; they also tend to be more novel, with novelty, as well, being associated with value among patents. However, as Tahamtan and Bornmann (2019) note, papers are cited in the literature for a multitude of reasons and, without consideration of citation context, use in the citing document, polarity, or semantic or linguistic analysis, citation rates may be less useful as indicators of impact or value.

Time lags are another important consideration when using citations as indicators of impact. It appears to take about 20 years for the impact of scientific research to manifest in productivity gains (Adams, 1990; Baldos *et al.*, 2018); Marx and Fuegi (2020) find an average lag of 17 years between the publication date of a scientific article and the filing date of the patent that cites it. This time lag differs among fields, with the shortest averaging around seven years in materials and computer science, for example, and the longest in mathematics (upwards of 20 years) (Ahmadpoor & Jones, 2017).

Indicators of societal impacts are an evolving area of research

The societal value of research is an increasingly important aspect of scientific excellence in research evaluation (Zheng *et al.*, 2021). Societal impacts include benefits to users — such as improved efficacy, effectiveness, or experiences — across a diversity of research areas (e.g., healthcare services, medical treatments, diagnostics, teaching and education, legal systems) (reviewed in Zheng *et al.*, 2021). Case studies are used as data sources for measuring research impacts through content analysis and text mining (Zheng *et al.*, 2021).

In addition to case studies, alternative metrics (altmetrics) have been developed as indicators to assess the societal impact of research (Gunn, 2013; Piwowar, 2013). Altmetrics include measurements of interactions with research articles online other than direct citations, such as downloads, clicks, likes, and shares (Fenner, 2013). They can provide measurements of impact beyond science and scientific publications, at a timescale quicker than academic citations, with relatively accessible data (Wouters & Costas, 2012). Potential issues linked with the interpretation of altmetrics as impact indicators include the distortion created by incentives on commercial social media platforms, issues of data quality, and risk of manipulation, among others (Bornmann, 2014).

There are a variety of tools available to assess excellence using a composite of indicators

One web application, excellencemapping.net, visualizes the performance of institutions as measured by Scopus and Mendeley data, while controlling for factors such as population size, gross national income per capita, number of institutions, mean economic growth, and perceived levels of corruption within a country (Bornmann *et al.*, 2021). There is also Elsevier's SciVal tool, which provides a means of accessing research performance data aggregated at the research institution and individual researcher levels (SciVal, 2023). The *UNESCO Science Report* series offers an overview of STIK systems worldwide approximately every five years, with key emerging trends and country-level profiles (UNESCO, 2021b, 2023), while the OECD Science, Technology and Innovation (STI) Scoreboard provides a variety of indicators of research quality aggregated at national and higher levels (e.g., G20, European Union, OECD countries) (OECD, 2022h). These include measurements of publication outputs, top-10%-cited publications, international collaboration, and international mobility. These are also available for select fields, providing an indication of research output and impact by field, such as computer science, AI, virology, and infectious disease. For example, in 2021, Canada published 15.7% of the world's top 10% most-cited publications in computer science, 13.4% of those in AI, and 9.3% of those in virology (OECD, 2022h).

5.2 Open Science

Open science is "the practice of making scientific inputs, outputs and processes freely available to all with minimal restrictions" (OCSA, 2020). The idea behind the open science movement is to share science freely and readily, as early in the research process as possible (Mayer, 2020). Open science is a broad and dynamic term that can encompass a variety of activities within all stages of the scientific process, including open access to publications, research data and methods, software, infrastructure, educational resources, evaluation, and citizen science (EC, 2016; Mayer, 2020).

The Government of Canada has committed to "making federally funded science open by helping to generate research ideas, making data and publications readily available, and making research understandable and useful" (GC, 2022j). In 2020, the Office of the Chief Science Advisor published its *Roadmap for Open Science*, which includes a recommendation to develop an open science strategy for research conducted outside of federal government agencies, and which highlights the importance of monitoring the international context (OCSA, 2020). In terms of international STIK partnerships, the Government of Canada's commitment to open science, together with evidence that more open countries also produce more impactful research (Wagner & Jonkers, 2017), speaks to the value of including explicit consideration of open science indicators as elements of a decision-making framework.

5.2.1 FAIR Principles

Implementation of a commitment to open science includes, for example, adherence to the FAIR principles, which hold that data should be *findable*, *accessible*, *interoperable*, and *reusable* (OCSA, 2020). The *Tri-Agency Open Access Policy on Publications* requires that grant recipients ensure any peer-reviewed journal publications of research supported by funds from CIHR, NSERC, or SSHRC are made freely accessible — either through open-access publishing mechanisms or by housing the publication in an online repository — within 12 months of publication (GC, 2016). Recipients of CIHR funding are further required to ensure publication-related research data are uploaded to appropriate public databases (e.g., gene sequences in GenBank) and that original data sets are retained for at least five years after the end of the grant period (GC, 2016).

Science-based federal departments and agencies have also developed open science action plans (GC, 2022j). These are balanced against existing policies, laws, and regulations that speak to information management, such as Canada's *Access to Information Act* and *Privacy Act* (OCSA, 2021b), the disclosure of confidential business information (e.g., GC, 2019), and security considerations related to the nature of the research being conducted (e.g., DND & CAF, 2021).

There are a growing number of open science indicators and data sources

Open access research publications are perhaps the most developed indicator of open science, supported by data on publications available through tools such as the Directory of Open Access Journals (DOAJ, 2023) and unpaywall.org (Unpaywall, n.d.). Open science data sets combine bibliometrics that measure publications in open-access journals, funding information, and indicators of open data, code, and hardware, in order to provide insights into open science practices (Smith *et al.*, 2016; Open Science Monitor, 2019; Public Library of Science, 2022). For example, the Open Science Indicators data set includes information from 61,000 research articles published in the Public Library of Science (PLOS), approximately 6,500 comparator articles published outside PLOS, and information on data sharing (i.e., data available in online repositories), code sharing, and preprint posting (Public Library of Science, 2022). These open science indicators were developed to align with the FAIR principles of open science (Table 5.3).

Table 5.3 PLOS Open Science Indicators Measures and FAIR Principles

Open Science Indicators Measures Aligned with the FAIR principles			
Open Science Indicator Requirements	**Findable**	**Accessible**	**Interoperable and Reusable**
Essential Requirements	• Output detectable • Unique identifier	• Location type • Location name	• Quality and completeness • Licence information
Desirable Requirements	• Output generated • Output reused	• Access conditions	

Source: Hrynaszkiewicz (2022)

In the European Union, the Open Science Monitor (2019) is developing and refining its indicators. Indicators include those related to open access — such as the proportion of journals, papers, and funders supporting open access publishing — as well as researcher attitudes toward its use (Smith *et al.*, 2016). Data sources include the OpenAIRE platform and the European Innovation Scoreboard (Smith *et al.*, 2016). Open-data indicators include the proportion of funders with policies supporting open publication of data sets, case studies of use, researcher attitudes, and the number of data repositories (e.g., re3data.org registry) (Smith *et al.*, 2016; re3data, 2023). Communication practices, such as publishing pre-prints, registering studies, publishing corrections and errata, open peer review, and altmetrics, can also be used as open science indicators (Smith *et al.*, 2016).

Tensions exist between open science and Indigenous data sovereignty

Article 31 of the *United Nations Declaration on the Rights of Indigenous Peoples* (UNDRIP) states that Indigenous peoples have the right to "maintain, control, protect and develop their cultural heritage, traditional knowledge and traditional cultural expressions, as well as the manifestations of their sciences, technologies and cultures" (GC, 2021a). Canada is a signatory to UNDRIP; as such, it pledges to "take effective measures to recognize and protect the exercise of these rights" (GC, 2021a). The Indigenous data sovereignty movement is a manifestation of Article 31 and asserts, through the practice of data governance, the right to control the conception, collection, interpretation, management, dissemination, and reuse of data that have been derived from, or relate to, Indigenous peoples (Walter & Suina, 2019).

Oguamanam (2019), reflecting on statements made by the Global Indigenous Data Alliance, points out the tension between the FAIR principles of the open data movement and Indigenous data sovereignty: there is a lack of engagement between promoting findable, accessible, interoperable, and reuseable data and supporting the authority of Indigenous peoples to control data related to their territories, lands, knowledge, and language (Oguamanam, 2019). These are also termed the CARE principles of Indigenous data governance, whereby the use of Indigenous data must provide for a *collective* benefit, respect the *authority* of Indigenous peoples to control their data, ensure the *responsibility* to engage respectfully with communities is met, and reflect Indigenous People's *ethics* (Carroll *et al.*, 2021). FAIR and CARE principles are not exclusively in conflict with each other (Carroll *et al.*, 2021). Research projects and, by extension, international STIK partnerships must engage with both when involving Indigenous data.

5.2.2 Collaboration

International collaborations are incentivized by the potential to work with select scholars and diverse perspectives, make gains in creativity and efficiency, and access "unseen" science — that is, research produced and published in languages or journals that are not typically captured in abstract and citation databases (Wagner, 2018). Co-publication can be used as a proxy indicator for scientific collaboration (Niu, 2014). Indeed, research articles with co-authors from more than one country have been found to have higher citation rates than those with co-authors from a single country, suggesting there is a greater impact when research is produced through international collaborations (Wagner, 2018).

Co-publication is a widely used indicator of scientific collaboration

Scientific collaboration measured using co-publication as a surrogate indicator combined with other indicators can help actors predict the value of a future or ongoing partnership (Niu, 2014). For example, Chinchilla-Rodríguez *et al.* (2018) grade countries by combined co-authorship, publication volume and ranking, and extent of international collaboration and mobility, in order to better understand scientific relationships. Measurements of co-publication are drawn from the same bibliometric data sets as those used to measure excellence (Section 5.1).

5.3 Talent

If the advancement of Canada's scientific capacity is a desired outcome of international STIK partnerships, then consideration should also be given to the mobility of Canadian researchers and knowledge holders, as well as to attracting talent to Canada and retaining it. The Canadian research diaspora is representative of knowledge diplomacy by way of its mobility in higher education; however, labour mobility, particularly in the high-tech sector, also plays a substantial role (Stackhouse, 2020; Lilly, 2021). Stackhouse (2020) calls for the mobilization of the Canadian diaspora to promote Canadian values worldwide, including democratic and legal principles, peace, order, and good government. Mobility can also increase Canada's scientific capacity through immigration and the attraction of research potential and established expertise. For example, immigrant inventors have a disproportionately high effect on patent activity in new technology subclasses (i.e., areas where no patent activity occurred previously in that location) (Bahar *et al.*, 2020). This is a result of both the direct patenting activity by new arrivals and the indirect influence of those new arrivals on the patenting activity of resident inventors through localized knowledge spillovers (Diodato *et al.*, 2022).

5.3.1 Network Potential

There are many ways to quantify the labour force required for the translation of inputs into knowledge and innovative STIK outputs (Hall & Jaffe, 2018). The number of science, technology, engineering, and mathematics (STEM) graduates is a leading national indicator for skilled labour in key fields that support STIK (Bain & Cummings, 2021). This indicator has been expanded to include humanities and social sciences, in order to capture the workforce contributing to social innovation (Bain & Cummings, 2021). Measurements of the training necessary to evaluate a specific program can include broader metrics, such as the number of people with appropriate Indigenous and traditional knowledge, vocational, or management training (Dziallas & Blind, 2019; UNCTAD, 2020). However, many of the standard metrics used in this category may miss informal education, such as on-the-job training.

Various higher-education metrics can indicate the potential for highly qualified personnel to contribute to the knowledge ecosystem (e.g., higher-education participation, new doctorates, or completion and graduation rates) (Hall & Jaffe, 2018; Shen & Luo, 2021). A similar but more inclusive metric is total R&D personnel (Shen & Luo, 2021). These data are essential for understanding STIK capacity but also for normalizing input indicators to assess R&D investment per person (Song & Oh, 2015).

5.3.2 Expertise

Researchers in Canada can gain access to diverse and divergent areas of expertise through international STIK partnerships, which reflects another potential benefit. The panel notes that partnerships may be evaluated on their potential to provide expertise in research that directly impacts the lives of people in Canada, such as research on Lyme and other tick-borne diseases, or on materials engineering for cold weather. Indicators of excellence, such as the citation and publication indices discussed in Section 5.1, provide one set of metrics for measuring expertise. Other methodologies used to identify expertise within a field include social network and semantic analysis of publications, which aim to quantify the influence of individual researchers (Zhu *et al*., 2022). New methodologies are also being refined and applied, such as the tensor decomposition technique, in order to measure the role of individual researchers in extended scientific networks (Zhu *et al*., 2022). For partnership opportunities targeting particular fields, emerging technologies, or other specializations, these methodologies may allow for a fine scale assessment of individual or organizational influence and expertise.

Participation in scientific or research organizations may be indicative of influence

Participation in intergovernmental or global organizations, or membership on councils or committees, can be indicative of research quality relevant to a particular area or problem set. These can also indicate at least a nominal level of influence at an international scale. It could mean that individual scientists participate on boards or at international meetings, or there could be secretariat support at the level of housing in a home country. For example, Montréal is host to the secretariats for the *Convention on Biological Diversity* (CBD, 2013), the Multilateral Fund for the Implementation of the Montreal Protocol (Multilateral Fund, 2022), and the UNESCO Institute for Statistics (UIS, 2022).

What We Heard

STIK organization interviewees consider forming, participating in, and setting the agenda and goals of intergovernmental organizations to be indicators of Canada's influence on the global stage and a necessary means of advancing Canadian values internationally.

Formal mechanisms at the science-policy interface (e.g., Intergovernmental Panel on Climate Change, or IPCC) are some of the most advanced forms of science informing diplomacy; they supply negotiations and public decision-making processes with inventories and syntheses of available knowledge, and they can provide independent, evidence-informed assessments of policy options (Ruffini, 2017). International councils are how science informs diplomacy, whereas nternational conventions reflect one of the main outcomes of science for diplomacy (Ruffini, 2017).

The influence of scientific evidence on policy outcomes can indicate relevance of expertise

Science and science diplomacy also inform policy decisions. The ultimate indicator of the effectiveness of science diplomacy is the adoption of science-informed policies. The most challenging set of outcomes related to science diplomacy involves measuring how science supports diplomatic relations, where science is the means by which normal or positive relationships are maintained (Ruffini, 2017). Functioning diplomatic channels can indicate pathways to successful partnerships, while meaningful progress in the field of science diplomacy can inform productive relations with allies and adversaries, and act as indicators of intermediate success toward economic and resilience goals.

Indicators derived from assessments of evidence-informed policy-making in public health may be broadly applicable to other domains (Tudisca *et al.*, 2018). For example, evidence-informed policy indicators used in public health fall into four thematic domains: human resources; documentation; communication and participation; and monitoring and evaluation. Within human resources are indicators such as the number of stakeholders working on the policy, number of partnerships with research institutions, and metrics of researcher involvement in crafting policy. Documentation indicators include the completion of a scientific literature review, citations used in the policy and supporting documents, the publication of policy briefs, and reports on policy results. Communication and participation indicators focus on engagement, consultation, and dissemination of information to stakeholders, researchers, and vulnerable groups. Monitoring and evaluation indicators measure whether evaluations are taking place, and, if so, whether a policy achieved its aims. Such evaluations can also be a source of evidence for future policy-making (Tudisca *et al.*, 2018).

The impact of scientific evidence on public health can be directly measured through disease prevalence, vaccination rates, and adoption of public health guidelines (Tudisca *et al.*, 2018; Buffardi *et al.*, 2020). However, in many instances, the influence of scientific evidence on policy can be difficult to determine, especially given the extent of competing influences on government decision-making (e.g., social and economic pressures, resource availability, general policy directions, implementation capacity); moreover, the standard tools for evaluating research exclude policy engagement (Tudisca *et al.*, 2018; Williams, 2022). Expanding bibliometric techniques to include measures of research influence such as policy-related outputs (e.g., research notes and policy papers) along with additional context (e.g., view counts and downloads) may more accurately reflect this impact (Williams, 2022).

5.3.3 Mobility

Scientific research frequently extends across national boundaries. Science itself is arguably an internationally networked system (Wagner, 2008), and collaboration has been steadily increasing over the past two decades (Wagner, 2018). Graduate students, post-doctoral students, and researchers tend to be highly mobile, a trend that is often explicitly incentivized through the relative competitiveness of candidates with international experience (or, at least, experience at different academic institutions) for tenure-track positions (Stephan, 2012). The mobility of highly skilled workers facilitates knowledge diffusion and boosts innovation performance (OECD, 2008); scholars who are more mobile have the highest global impact (Sugimoto *et al.*, 2017). Bibliometric data and international migration data, like those collected by the OECD and the World Bank, can support the measurement of STIK workforce mobility (Sugimoto *et al.*, 2017; IMI, 2023). These analyses can be used to determine the effects of specific policies on international collaboration (Chinchilla-Rodríguez *et al.*, 2018).

Constraints on international mobility may be indicative of lower potential for success

On an individual basis, mobility may be a function of a variety of factors unrelated to scientific capacity (e.g., family commitments); however, at an organizational or country level, mobility constraints can be indicative of obstacles to success for international STIK partnerships. International collaboration and the mobility of scientists are supported through a variety of diplomatic apparatuses, including embassies and consulates that disseminate scholarship information and recruitment notices, science counsellors and attachés who facilitate contact among the scientific diaspora, immigration and visa services, and funding from research and foreign affairs ministries dedicated to supporting international partnerships and mobility (Ruffini, 2017).

However, international mobility is subject to broader trends in the policy and geopolitical environment (OECD, 2008; Chinchilla-Rodríguez *et al.*, 2018), while the loss of diplomatic relations and the elimination of related apparatuses can halt or prevent scientific cooperation. For example, the imposition of sanctions on Russia over the war in Ukraine has impacted studies of carbon flux in the Arctic over a large geographic area — studies that were being conducted by an international consortium of permafrost scientists (Baker, 2022). Such scientific cooperation is facilitated through the Arctic Council, an intergovernmental forum promoting cooperation in the Arctic. As a result of the war, Canada, Denmark, Finland, Iceland, Norway, Sweden, and the United States suspended their participation in the Arctic Council (Baker, 2022). Other policies — for instance, travel bans, such as the one imposed by the United States in 2017, or the degradation of diplomatic ties between the United Kingdom and the European Union — can also impact the mobility of scholars (Sugimoto *et al.*, 2017; Chinchilla-Rodríguez *et al.*, 2018).

5.4 Infrastructure

Another consideration in the evaluation of potential STIK partnerships is the level of uniqueness or access to infrastructure that a partnership might bring. This could include access to a geographic location, big science facilities, specialized equipment, networks of expertise, or research funding otherwise unavailable domestically. However, uniqueness alone is not the only value of access to infrastructure — complementarity can create helpful redundancies, provide opportunities for experimental replication, or tap into an existing network that adds perspective to current research efforts. While quantitative indicators, such as those included for locations and institutions, may be relevant to big science facilities, the weighting placed on access to these facilities is suited to qualitative judgment and rationale.

5.4.1 Location

There is no one indicator to assess the weighting placed on a particular location, such evaluations are usually qualitative and reflect a rationale for choosing one place over another. That said, a location rationale may be supported by data, such as the size of a Canadian scientific diaspora in a region, the number of existing relationships or funding commitments, and the presence of philanthropic or other investment (e.g., infrastructure, personnel). For example, science and innovation centres (SICs) are institutions built in foreign countries to facilitate STIK relations, either by supporting an existing diaspora or by fulfilling a foreign policy strategy (Box 5.3).

Box 5.3 Science and Innovation Centres

Epping (2020) examines the development and deployment of SICs by Germany and Switzerland over the last 20 years. Deutschen Wissenschafts- und Innovationhaüser (DWIH, or German Centres for Research and Innovation) have SICs operating in Brazil, India, Japan, Russia, and the United States, which seek to support international networking exercises and promote Germany's science and innovation system abroad. These are jointly governed by the German Federal Foreign Office (FFO) and the Federal Ministry of Education and Research (BMBF). The DWIH were launched in 2009 and explicitly conceptualized as part of a new line of foreign policy called "research and academic relations."

Switzerland also uses SICs (Swissnex) to support STI foreign policy goals. In 2000, the Swiss government recognized a brain drain of scientists and businesses to the United States, specifically to the area around Boston. They created the Swiss House for Advanced Research and Education (SHARE) in that region (now Swissnex Boston) to provide a place for members of the diaspora community to connect with each other and stay connected to Switzerland. Swissnex centres are governed jointly by the Federal Department of Foreign Affairs (FDFA) and the State Secretariat for Education, Research and Innovation (SERI). Since 2000, Swissnex houses and outposts have been opened elsewhere in the United States, as well as in Brazil, China, India, and Singapore.

(Continues)

(Continued)

Swissnex was developed through a bottom-up logic, with the outcome of recognizing and strengthening an existing network (i.e., Swiss immigrants in Boston). It then grew to facilitate the exchange of higher-education and scientific enterprises — and to promote Switzerland internationally as a key player in education, research, and science — through the incremental opening of SICs around the world. By contrast, Germany's DWIH was developed from a top-down logic, with SICs opening simultaneously in multiple countries as part of an explicit foreign policy strategy, one highly embedded within the national system and involving a large number of strategic actors. Though Swissnex was originally conceived as a "scientific consulate" distinct from classic diplomacy, both DWIH and Swissnex have become explicitly identified as diplomatic instruments, with the stated goals of facilitating dialogue and international cooperation.

(Epping, 2020)

Participation in treaties and conventions governing global commons and international territories (e.g., *Antarctic Treaty*) provide opportunities for scientists to access unique geographic locations (Berkman, 2019). For example, Canada has been collaborating with the European Space Agency since the 1970s (CSA, 2019a). This collaboration was formalized in 1979 with the signing of the first cooperation agreement, which was renewed in 1984, 1989, 2000, 2012, and, most recently, 2019. While this agreement has resulted in advances in space exploration and science, it has also created benefits for Canadian businesses and supported Canadian leadership in Earth observation and satellite communication — including, for example, the successful deployment and operation of the Swarm mission, the PROBA-2 satellite, and the Soil Moisture Ocean Salinity (SMOS) satellite (CSA, 2019a).

5.4.2 Institutions

A corollary of the examination of scientific excellence and talent among international partnership opportunities is the quality of institutions housed within a particular country or location. Rankings of research institutions are often based on the same bibliometric indicators as those at the individual or country level (Section 5.1). However, some composite indicators can be useful when looking specifically through an institutional lens, such as the Leiden Ranking (based on Web of Science data), the QS World University Rankings (which include survey data and analyses of environmental and social impact), the Times Higher Education World University Rankings (based on survey data and institutional statistics) and the Academic Ranking of World Universities (which includes indicators of awards along with bibliometrics) (ShanghaiRanking, 2021; CWTS Leiden Ranking, 2022; Times Higher Education, 2022; QS Top Universities, 2023).

5.4.3 Facilities

Supporting international scientific collaborations appears to be a relatively straightforward application of the tools of political diplomacy (e.g., the negotiation of conventions and agreements among states) and a major achievement in science diplomacy (Davis & Patman, 2015). For example, the building and operation of large-scale research infrastructure — such as the Large Hadron Collider, the International Space Station, and the Square Kilometre Array — are recognizable successes of worldwide diplomacy for science (Davis & Patman, 2015), as are the treaties and conventions governing global commons and international territories (Berkman, 2019). When the goal is scientific cooperation through common-interest building, diplomacy can facilitate negotiations and contribute to these successes (Davis & Patman, 2015; Berkman, 2019).

What We Heard

For many Canadian STIK organizations, access to and participation in large-scale international research is an indicator of a successful partnership because it provides new capacity to researchers. Participation in these organizations is also a measure of intermediate success, as participation often leads to further collaboration.

5.5 Additional Considerations

Considerations of benefits to Canada related to scientific capacity and knowledge production — but not necessarily captured by the indicators and metrics discussed above — include the role of STIK partnerships in advancing international relations (i.e., science diplomacy), EDI, and Indigenous knowledge.

5.5.1 Science Diplomacy

Science diplomacy can be understood most simply as a set of practices through which researchers and diplomats interact (Ruffini, 2017). The concept of science diplomacy captures various kinds of actions, negotiations, and policy instruments (Johnston, 2012); thus, science diplomacy can support the creation and development of international STIK partnerships. However, it can also be a tool for conflict resolution and building common interests under the broader goal of promoting cooperation (Berkman *et al.*, 2022b). Meeting these goals requires countries to balance narrow and short-term national interests against longer-term common interests with both allies and adversaries (Berkman *et al.*, 2022b); of course, how one engages with allies is different from how one does with adversaries (Deputy Prime Minister, 2022). Among allies with shared values (e.g., NATO[9] signatories, G7 nations, Five Eyes[10] nations) cooperation can strengthen existing connections while building new and deeper alliances with other countries that adhere to a rules-based international order (Deputy Prime Minister, 2022) (Chapter 6).

Science diplomacy describes the intersection of STIK and foreign policy

In practice, science diplomacy is used by government actors to compete with other states, in order to increase innovation capacity, attract foreign direct investment, and access talent (Flink, 2022). While science is not bound by national borders, the organization and funding of basic science operate primarily at a national level and reflect the policies and priorities of the state (Ruffini, 2017). Though science diplomacy is often part of statecraft, it is no longer solely dependent on institutional and state actors; rather, it is shaped by various private and public actors that are not necessarily defined by national interests (Carayannis *et al.*, 2018; Zhang *et al.*, 2022). Science diplomacy is a tool to build national resilience through cooperation by establishing international partnerships (Aukes *et al.*, 2021). Resilience is built by addressing global sustainability challenges that are

9 The North Atlantic Treaty Organization.

10 Australia, Canada, New Zealand, the United Kingdom, and the United States.

too large to be resolved by one nation, and by navigating security threats, with a long-term lens toward addressing those goals (Lowenthal, 2011; Davis & Patman, 2015; Colglazier, 2018; Aukes *et al.*, 2021). National resilience indicators are covered in Chapter 6.

The extent and progress of science diplomacy can be measured with indicators appropriate to the particular goals and expected outcomes. Where science diplomacy attempts to facilitate international collaboration, for example, measures of open science, talent, talent mobility, and scientific results are appropriate. *Knowledge diplomacy* is an area of research adjacent to science diplomacy; these have overlapping concerns, but the former has a more specific interest in the interactions between higher education and international relations. For example, Knight (2019) points to traditional areas of research on international higher education (e.g., mobility, joint research projects, institutional agreements) as well as new developments (e.g., international joint universities, regionalization of higher-education policies, creation of knowledge hubs) as meaningful outcomes of knowledge diplomacy. There is also room to explore the role of public-private partnerships between educational institutions and industry at regional and international levels, as well as implications for the future of the global knowledge economy under this broad concept (Knight, 2019).

STIK diplomatic activities can also be characterized as *innovation diplomacy*, which includes economic diplomacy with an explicit focus on national gains in trade, investment, and technology (Leijten, 2017). It brings in dimensions of national economic interests, trade in high-tech products, IP ownership and protection, and standardization. These aspects of innovation diplomacy can be measured with science, innovation, and commercialization metrics. There are also various types of stakeholders and stakeholder configurations involved in innovation (e.g., value chains, multinationals, local-global linkages often absent from science diplomacy) as well as policy instruments different from those in science, all of which would need to be considered (Leijten, 2017).

STIK partnerships can contribute to advancing a global good

As underscored more than once in this report, global issues cannot be addressed by the actions of one state alone (Davis & Patman, 2015). One of the core tasks of international diplomacy, therefore, is to create the conditions for cooperation among societies to collaboratively address such global challenges. For example, research organized and coordinated by the World Meteorological Organization has improved the quality and accuracy of weather forecasting to the benefit of people worldwide (WMO, 2022).

Global challenges are inextricably connected to S&T — as both causes and means for understanding the issues and finding solutions (Davis & Patman, 2015). Scientific experts play an important role in this process by providing scientific advice to policy-makers, in order to help shape responses to global challenges (Royal Society & AAAS, 2010; Ruffini, 2017). More specifically, scientists can help prepare diplomats for negotiations on new or existing legal instruments, such as international treaties and conventions on climate change (Ruffini, 2017) (Box 5.4). The IPCC is one of the best-known examples of this science-policy interface, though the Pugwash movement — a series of meetings among scientists that began to address the threat posed by nuclear weapons — is an earlier iteration that continues to this day (Royal Society & AAAS, 2010; Pugwash, 2023).

While such mechanisms have provided knowledge to policy-makers and raised awareness of global issues, the application of this awareness and knowledge in diplomatic negotiations has arguably been less than successful (Davis & Patman, 2015), which suggests the need for other outcome-based indicators of success. For example, while the IPCC has been providing assessment reports to policy-makers for over 30 years (IPCC, 2022), international agreements to address climate change have consistently fallen short of meaningful intervention as they are modified through negotiation and consensus-making among states (Davis & Patman, 2015). This shortfall appears to derive, at least in part, from the limitations of the negotiators (e.g., diplomats, NGO representatives) when it comes to incorporating new scientific knowledge into their established scientific beliefs about climate change, and using scientific knowledge to conceptualize the potential outcomes of different climate change scenarios (Milkoreit, 2015).

Box 5.4 The Diplomatic Value of Science

Scientific evidence helps inform and shape diplomacy because the norms of science contribute to knowledge that, ideally, represents an objective reality outside of political ideology (Merton, 1973; Ruffini, 2017). Participation in diplomatic activities provides scientists with a mechanism to influence negotiations that impact major societal issues, such as climate change, food security, and energy policy; in turn, such participation can also raise the profile of science as an international public good (Ruffini, 2017).

5.5.2 Equity, Diversity, and Inclusion

Berkman *et al.* (2022a) note that inclusion is the biggest challenge of informed decision-making and suggest asking questions of content (who, what, when, where) and process (why and how). When applying a framing of inclusion to scientific and knowledge capacity building, it is worth examining potential partnerships through the lens of who will be involved (i.e., representation of participants), the timeframe of the proposed partnerships (e.g., past relationships, present conditions, future aspirations), and the types of knowledge production included (e.g., natural sciences, social sciences, Indigenous knowledge). Support for inclusion over the long term also involves considering the "how" — that is, the proposed governance and infrastructure, including platforms, technologies, and investments available to support STIK partnerships — while recognizing the investment of time needed to build relationships prior to delivering outcomes (Berkman *et al.*, 2022a).

Institutional metrics may reflect different aspects of inclusion

Institutional metrics are often broad in their effects but can be used as indicators of innovation and inclusion; these include measures of government stability, gender and other dimensions of equity, environmental monitoring, or income distribution (Dziallas & Blind, 2019). General infrastructure (e.g., water, energy, ICT, transport) support productivity, physical mobility, and health and information sharing, whereas specialized infrastructure (e.g., laboratories, testing and monitoring facilities, advanced manufacturing facilities) supports the innovation process as well as knowledge generation and exchange (UNCTAD, 2020).

At an individual, departmental, or institutional level, metrics of scientific impacts beyond citations analysis may also be indicative of inclusion. For example, while mentorship is typically measured by the productivity of mentees (e.g., publications, patents), other dimensions — such as retention, career commitment, mentee satisfaction, mentorship awards, and group culture — may speak to aspects of inclusivity and supportiveness (Davies *et al.*, 2021). Depending on the types of potential partnership activities under review, consideration might also be given to aspects of inclusive environments, as detailed, for example, by the Inclusive Environments and Metrics in Biology Education and Research (iEMBER) Network (Campbell-Montalvo *et al.*, 2020). At a broader scale, mentions of diversity and inclusion on institutional websites or mission statements can provide a baseline measurement of the consideration given to these factors (Tennial *et al.*, 2019). The panel notes, however, that such indicators can be challenging to compare among cultures and communities and suggest that considering trends over time may be a more nuanced method of incorporating diversity and inclusion metrics into a data-enabled framework (in contrast to, for example, a strict yes/no decision).

5.5.3 Indigenous Knowledge

There are many challenges associated with incorporating indicators relevant to Indigenous knowledge in the context of international STIK partnerships, including those generalizable to other knowledge systems and ways of knowing (e.g., differences in knowledge dissemination practices, language barriers, assessments of impact), as well as those specific to Indigenous knowledge (e.g., the need for culturally appropriate, community-driven, and locally relevant assessments; Box 5.2) and data sovereignty (e.g., aligning FAIR and CARE principles, Section 5.2.1). Indeed, as Watts (2013) explains, there are fundamental differences between Western and Indigenous worldviews, such as the link between knowledge and place in Indigenous culture and an understanding of society that includes non-human beings as active participants with their own agency.

However, the panel recognizes that such challenges must not preclude the inclusion of Indigenous nations in Canada's international STIK partnerships. The inclusion of Indigenous experts, communities, NGOs, and governments in multi-actor research, stewardship, and governance organizations is linked to project success (e.g., Henshaw, 2010; Reo *et al.*, 2017; Buschman, 2022). Key success factors identified across a range of contexts include:

- respect for, and in-depth engagement with, Indigenous knowledge and practices;
- intergenerational involvement, including youth and elders;
- self-determination (i.e., respect for Indigenous political and governmental authority); and
- investments in capacity building and cross-cultural education (Henshaw, 2010; Reo *et al.*, 2017; Buschman, 2022).

In examining conservation partnerships with Indigenous people, Buschman (2022) emphasizes the importance of co-production throughout all processes and activities in an iterative and reflexive model. Henshaw (2010) notes that policy partnerships with Indigenous communities are successful when efforts are allocated to building coalitions to achieve common goals. Preserving a space for Indigenous voices is one approach — see, for example, the creation of Permanent Participants on the Arctic Council where Arctic Indigenous representatives participate in full consultation on all meetings and activities (Henshaw, 2010). Other examples of Indigenous inclusion in STIK research and policy-making include: (i) revisions to the International Maritime Organization guidelines to address underwater noise from ships to explicitly recognize Inuit Nunaat as a unique environment (IMO, 2023), (ii) the *International Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean* (GC, 2021f), and (iii) the

Qanittaq Clean Arctic Shipping Initiative (CFREF, 2023). However, such approaches will not be sufficient without complementary efforts (e.g., investment, intergenerational engagement) to foster the capacity of Indigenous people to participate in and lead decision-making (Ellis, 2005; Henshaw, 2010).

The panel does not have the expertise or experience to evaluate or comment on the appropriateness of different mechanisms for the inclusion of Indigenous knowledge among the framework elements presented in this report. The First Nations Information Governance Centre has enumerated a variety of existing conflicts between the Government of Canada's information management regime and First Nations data sovereignty (FNIGC, 2022b). The First Nations principles of OCAP®[11] — ownership, control, access, and possession of data — may offer a starting point for the application of a data-enabled framework by or with Indigenous communities (FNIGC, 2022a).

It may be inappropriate for the Government of Canada to use a STIK partnership framework when engaging with Indigenous communities, either domestically or abroad. As Reo *et al.* (2017) note, "Indigenous nations in Canada and the USA regard multi-stakeholder processes as inappropriate mechanisms for settler colonial governments to engage Indigenous governments." Alternative or complementary mechanisms for assessing the potential of international STIK partnerships to foster Indigenous knowledge capacity — as well as knowledge co-creation beyond data generation — must therefore be developed in collaboration with, and through the leadership of, relevant Indigenous governments, NGOs, and communities.

The relationship between Indigenous and Western knowledge is itself a contested space. In meeting with the panel, some guest speakers reflected on their understanding of knowledge production as epistemic pluralism — that is, the recognition that there are diverse means of producing knowledge, but that knowledge itself is universal. In some ways, this is reflected in the interweaving of Indigenous and other knowledge systems as research methodologies. However, other speakers highlighted the importance of maintaining separate cultural trajectories in peace and harmony, as illustrated by the two-row wampum; this reflects the value of alignment, rather than the interweaving, of knowledge systems. There can be no one-size-fits-all approach, since mechanisms must be locally relevant, culturally appropriate, and reflective of specific community needs, worldviews, and priorities.

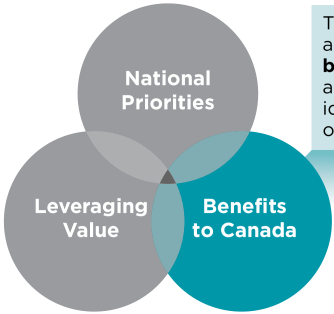
11 OCAP® is a registered trademark of the First Nations Information Governance Centre (FNIGC). To fully understand these principles, see their website at https://fnigc.ca/ocap-training/.

6

Benefits to Canada: Indicators of National Resilience

R*esilience* is the ability to prepare for, and recover from, systemic disruptions arising from environmental, economic, physical, and social shocks (OECD, 2020a). National resilience provides a prospective frame and rationale through which organizations can address systemic risks and set goals for productive partnerships in science, technology, innovation, and knowledge production (STIK) (Linkov *et al.*, 2019). Considering how partnerships and their benefits contribute to national resilience requires anticipating distant time horizons and making a more comprehensive assessment of future benefits. Increased national resilience resulting from improved diplomacy, security, and sustainability in the short and long term is a key factor in determining the value of international STIK partnerships (Figure 6.1). International issues, such as global security, pandemics, and climate change, cannot be addressed without coordinated worldwide effort. Historically, UN agreements such as the *Antarctic Treaty* have advanced multiple national priorities — scientific, diplomatic, and security — to deliver resilience benefits to Canada (Berkman *et al.*, 2011; Das & Mukherjee, 2020).

International STIK partnerships are advanced through diplomacy. Partnerships that meaningfully contribute to Canada's sustainability and security goals can, in turn, lead to improved resilience. As with the process of commercialization (i.e., moving from idea to prototype to product), indicators supporting *National Resilience* in STIK partnership decision-making are most useful when they account for the processes required to advance that resilience (i.e., moving from diplomatic outcomes to policies to sustainability and security) (Table 6.1). A capable diplomatic apparatus for creating partnerships and informing policy will subsequently result in more productive partnerships that are better equipped to provide the cooperation and scale necessary to build resilience, improve sustainability, and bolster security.



There is a wide array of indicators and metrics to measure potential **benefits to Canada**. From the articulated goals, criteria are identified for evaluation. Areas of consideration include:

National Resilience	Criteria (example indicator)
Diplomacy	• Diplomatic outcomes (new policies, innovation centres)
Sustainability	• Sustainability (development, emissions) • Reciprocity (fair mutual benefit) • Commitment and vision (use of foresight)
Security	• National security (security networks) • Foreign influence (vulnerability) • Cybersecurity (alignment, threats) • Research security (sanctioned activities)

Innovation	Criteria (example indicator)
Collaboration and Commercialization	• Collaboration readiness (complementarity) • Commercialization and scale-up (firm size and performance) • Inputs (R&D investment, resources) • Assets (tangible and intangible) • Outputs (growth)
Trade	• Trade system (imports and exports) • Regulations and barriers (tariffs, quotas) • Standards setting and regulatory alignment (standards creation, adoption)

Scientific Capacity and Knowledge Production	Criteria (example indicator)
Excellence	• Rigour (peer review) • Production (publications, other outputs) • Impact (citations)
Open Science	• FAIR principles (policies) • Collaboration (co-authorships)
Talent	• Potential (network position) • Expertise (citations) • Mobility (policies, programs)
Infrastructure	• Location (uniqueness) • Institutions (rankings) • Facilities (accessibility)

Figure 6.1 Benefits to Canada — National Resilience

Building national resilience depends on the success of the diplomatic apparatus in advancing sustainability and security across short timescales. Achieving sustained benefits from STIK partnerships requires planning for multiple potential outcomes, ensuring partners share benefits, and that innovation is sustainable in such a way that current goals do not compromise future goals. Advancing security goals entails countering foreign influence, cooperating with allies, and minimizing security risks while still advancing STIK.

Table 6.1 Criteria, Indicators, and Examples of Metrics of National Resilience

<table>
<tr><th>National Resilience</th><th>Criteria</th><th>Indicators</th><th>Examples of Metrics</th></tr>
<tr><td>Diplomacy (Section 6.1)</td><td>Diplomacy and policy outcomes</td><td>• Influence on international governance
• Use of science in diplomacy</td><td>• Meaningful new policies
• Establishing science and innovations centres
• Membership in international scientific working groups</td></tr>
<tr><td rowspan="3">Sustainability (Section 6.2)</td><td>Sustainability</td><td>• Sustainable development and progress
• Sustainable competitiveness</td><td rowspan="3">• Life expectancy
• Emissions
• Standard of living
• Economic and social indicators
• Matched contributions
• Citation symmetry
• Using foresight or backcasting
• History of effective long-term planning</td></tr>
<tr><td>Reciprocity</td><td>• Non-coercive negotiations
• Fair and mutual benefit</td></tr>
<tr><td>Long-term commitment and vision</td><td>• Planning for the future
• Track record of long-term vision</td></tr>
<tr><td rowspan="4">Security (Section 6.3)</td><td>National security</td><td>• Membership in security networks
• Military capacity
• Social cohesion and government stability</td><td rowspan="4">• Favourable military alliances
• Military expenditures
• Food and energy security
• Economic, political, and security interactions
• Dependence on a foreign power
• Number of cybersecurity attacks
• Technical capacity
• Espionage convictions</td></tr>
<tr><td>Foreign influence</td><td>• Foreign bilateral influence capacity (FBIC)
• Vulnerability to foreign influence</td></tr>
<tr><td>Cybersecurity</td><td>• Cybersecurity hostility
• Cybersecurity alignment</td></tr>
<tr><td>Research security</td><td>• Security agreements and relationships
• Sanctioned and penalized activity</td></tr>
</table>

6.1 Diplomacy

Diplomatic indicators inform STIK partnership decision-making by signalling the progress of diplomatic relations, both formally and informally, across national boundaries. The negotiations and policies set the terms for partnerships and, as such, help determine outcomes including the benefits to Canada. Diplomatic successes fundamentally structure how international actors contribute to addressing grand challenges, build scientific and political capital, and ensure open lines of communication. Many of the most important sustainability and security goals are long term and, therefore, not immediately measurable. Given this long success horizon, diplomatic indicators are necessary signals of short-term progress.

6.1.1 Diplomatic Outcomes

Soft power is the ability to attract, influence, and persuade through culture, political values, and policies (Nye, 2004, 2022). In science diplomacy and international science, soft power derives from scientific culture and values, and the evidence and technologies these produce (Nye, 2004; Copeland, 2015). For example, China tried to use "vaccine diplomacy" to increase its soft power with mixed results; its efforts were adversely affected by its violation of scientific values in terms of secrecy surrounding the COVID-19 outbreak (Chopra, 2022; Nye, 2022). As noted in Chapter 5, the collaborative nature of science has contributed to its use as a foundation for diplomacy — that is, leveraging scientific cooperation to build relationships with countries where other options are not feasible (Ruffini, 2017). These unofficial relationships support diplomacy through the ongoing interaction among scientists when other diplomatic channels break down, and by providing a pathway to influence the governance of global commons and international territories, such as space, the high seas, the seabed, and Antarctica (Ruffini, 2017).

Science diplomacy contributes to international relations through common-interest building, providing a starting point for negotiations that differs from, for example, efforts at conflict resolution (Berkman, 2019). States can also increase their global influence by producing scientific expertise, achieving technical accomplishments (e.g., Sputnik), and hosting international conferences, organizations, and research infrastructure (Ruffini, 2017; Gates, 2020). Diplomatic indicators reflect progress toward addressing global challenges by establishing shared interests and the tools needed to coordinate international solutions to transnational problems.

What We Heard

The STIK organizations interviewed for this study often keep databases of diplomatic activities to help them understand and assess their level of partnership activity.

Science diplomacy requires integration with international networks. It reflects the actions of scientists, politicians, and diplomats working across borders to address common problems through science, engagement, and participation in international organizations and forums. Science diplomacy produces activities that can be measured as progress toward addressing those problems of common interest. Indicators include personnel commitments to scientific collaboration on global challenges, or the number of science diplomats and S&T counsellors at embassies and consulates. Within Canada's science diplomacy apparatus, there is also increasing interest in science advisory positions at the subnational level (Gov. of AB, 2023a; Gov. of QC, 2023; The Canadian Press, 2023). Engagement and leadership in organizations such as the International Network for Government Science Advice (INGSA) and the Global Young Academy reflect diplomatic efforts in the STIK space (GYA, 2023; INGSA, 2023). Joint meetings, such as those that preceded Canada's bid to join Horizons Europe, can indicate a commitment to continued cooperation, shared goals, and integrated strategic partnerships (Hudson, 2020; S4D4C Team, 2020; Open Access Government, 2023).

Science diplomacy indicators include publication, training, networking, and communication metrics

STIK partnerships often seek to advance cooperation and influence international policy to generate more impactful science. The *Using Science for/in Diplomacy for Addressing Global Challenges* (S4D4C) framework identifies performance indicators that can measure science diplomacy activity, which can help produce more impactful STIK partnerships (Brugner & Degelsegger-Márquez, 2018; Meyer, 2021). The selected indicators are based on the SMART criteria, meaning they are chosen to be specific, measurable, achievable, realistic, and time-based (Brugner & Degelsegger-Márquez, 2018). The S4D4C framework has five categories of activities: "the production of text documents, training courses, exchange and networking, the preparation of knowledge resources as well as S4D4C appearances on external platforms and in social media channels," which help evaluate progress toward science diplomacy and science policy goals (Meyer, 2021).

In the S4D4C framework, multiple bibliometric indicators are used to measure diplomatic outputs; these include documents, such as published papers, citations, and downloads (Brugner & Degelsegger-Márquez, 2018). Training metrics rely on details about participants and their roles (e.g., diplomat, scientist), published training materials, surveys of training benefits, and applications of training. Metrics for exchange and networking include the number of participants, benefits, and a study of the value of exchanges. The framework measures the creation of knowledge resources and their appearances on external platforms by the number of resources housed on those platforms and their engagement metrics (e.g., clicks, posts, followers, downloads, requests). The monitoring of these indicators is ongoing, on either a continuous or periodic basis. Close interaction between the evaluator and the project team is considered crucial for the success of this framework (Brugner & Degelsegger-Márquez, 2018).

6.1.2 Policy Outcomes

One of the core tasks of international diplomacy is creating the conditions for cooperation among societies so they can collaboratively address global challenges. Though there are many intermediate steps and enabling factors that can be measured to evaluate science diplomacy and the policy outcomes of STIK partnerships, the creation and adoption of meaningful policy and ensuring its effectiveness are essential. International treaties such as the *Antarctic Treaty* are measurable science diplomacy policy outcomes that promote security and scientific cooperation around common interests (The Antarctic Treaty, 1958; U.S. AVC, 2017). Ongoing cooperation on matters of international importance through similar treaties (e.g., *Convention on the Law of the Sea*, *Framework Convention on Climate Change*, *Convention on Biological Diversity*, *Outer Space Treaty*) can indicate areas of common interest that can be strengthened through scientific cooperation (UN, 1992a, 1992b, 2023).

Participation in international science organizations is a metric of science diplomacy

Participation in international science organizations is a form of STIK partnership as well as a means of enhancing those partnerships. Such participation may provide benefits to Canada through sustainability advancements, policy harmonization, data standards, and research priorities. These memberships are intermediate indicators that can be used as part of a framework along with longer-term sustainability indicators, such as CO_2 emissions. For example, Polar Knowledge Canada (POLAR) provides Canada's representation on the Scientific Committee on Antarctic Research (SCAR), an organization that is part of the International Science Council (ISC) charged with initiating, developing, and coordinating research in the Antarctic region, including setting data standards for Antarctic research (SCAR, 2011, 2020). The collection and sharing of data from this partnership, when combined with future-looking techniques (e.g., horizon scanning), facilitate decision-making and further mutual understanding, international cooperation, and innovation (Kennicutt *et al.*, 2015; Hughes *et al.*, 2022; Bai & Li, 2023).

6.2 Sustainability

Innovation is, by nature, a future-looking process. The decisions made now are opportunities to change the direction of technological development, but the risks of driving over-consumption, destroying the environment, and worsening social inequity must be managed so as not to undermine sustainable development (Adams *et al.*, 2016). The World Commission on Environment and Development (1987) report defines *sustainable development* as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

Burch *et al.* (2022) argue that SMEs, and their innovation activities, are crucial elements of community resilience. Sustainability operates at medium-to-long timescales across a continuum of urgencies (Berkman, 2019). Sustainable innovation thus attempts to address immediate challenges in ways that improve our capacity to deal with subsequent challenges. There are two key features of sustainable innovation (Burch *et al.*, 2022). First, sustainable international STIK partnerships are reciprocal at their foundation because they provide mutual benefit by addressing global-scale problems. Second, committed reciprocal partnerships offer greater benefits and endurance, contributing to multilateral national resilience (Burch *et al.*, 2022). The scale of the challenges that sustainable development attempts to address requires multiple innovation actors — businesses, academics, managers, and policy-makers (Adams *et al.*, 2016).

6.2.1 Measuring Sustainability

Choosing indicators that measure sustainability performance for the purpose of selecting STIK partners requires aligning these indicators to the project's specific objectives and achievement of those objectives. For nation-to-nation partnerships, national indicators and indices can provide insights about appropriate scale. For subnational organizations, a combination of national-, firm-, or organization-level indicators can inform partnership decisions (Edmunds *et al.*, 2019). Many international collaborations exist to collect, standardize, and share sustainability information (UNEP, 2014; IDB, 2020; CDP, 2023).

Composite indices exist to measure specific aspects of sustainability

Sustainable innovation provides benefits through improved social well-being (Cillo *et al.*, 2019) and health is one objective metric contributing to that well-being (Schulte *et al.*, 2015). For example, national-level advancements in health can be measured by specific aspects of health innovation or human development, such as the Human Development Index, which combines indicators related to life expectancy, standard of living, and education (UNDP, 2023). Similar indices exist that measure the environmental sustainability of regions or countries, such as the Environmental Performance Index (Yale Center for Environmental Law & Policy, 2022) and the Environmental Sustainability Index (Honeywell, 2022). The OECD collects national data on sustainability-relevant factors such as environmental innovation, policy, and protection expenditures (OECD, 2023b). Sustainable competitiveness can be an alternative or complementary measurement to economic measures such as GDP (Gebhardt, 2019) (Box 6.1).

Box 6.1 The Global Sustainable Competitiveness Index

The Global Sustainable Competitiveness Index combines indicators for economics, talent, business environment, innovation, health, environmental sustainability, equality, and human rights, in order to rank countries. The index is based on six pillars of equal importance: natural capital, resource efficiency, social capital, intellectual capital, economic sustainability, and governance efficiency. Notably, by clustering related indicators, the sub-indices produce different rankings such that one country could lead in economic stability and another in natural capital. Another valuable feature of this index is that it considers trends in performance as well as the rank of countries, in order to indicate the direction of a country's sustainable competitiveness.

(SolAbility, 2022)

Environmental sustainability progress can be measured at firm and supply chain levels

Measuring how advanced and deeply integrated a company's sustainability practices are can help differentiate potential partners and identify opportunities. For example, Hallstedt *et al.* (2010) note that sustainability in a company can be observed when:

- sustainability is part of its definition of long-term success;
- there is an alignment of its short-term tactical business plans with its long-term sustainability strategy (e.g., backcasting key sustainability challenges);
- it has tools for measuring progress;
- there are specific examples of the implementation of sustainability decisions; and
- there is a system of incentives/disincentives and monitoring to facilitate sustainability implementation.

Assessing a business focus on environmental impacts (and its choice of sustainability-focused suppliers) helps measure its commitment to sustainable strategic development (Hallstedt *et al.*, 2010). In one study, return on equity (ROE) — a measure of financial performance — was used as a signal of environmental disclosure quality because it was observed that more profitable companies issued higher-quality environmental reports (Pizzi *et al.*, 2021). A combination of standards compliance and report-level analysis can identify a prospective partner's substantive rather than symbolic sustainability actions (Hyatt & Berente, 2017; Pizzi *et al.*, 2021).

Trucost is a carbon data provider that publishes firm-level direct and supply chain environmental footprint data, as reported in the S&P Paris-Aligned and Climate Transition Index Series and the S&P Carbon Efficient Index Series (S&P Global, 2020). Actual and forecasted energy consumption and CO_2 emissions can provide valuable data for decision-makers about environmental sustainability (e.g., Ribeiro *et al.*, 2020). The greenhouse gas (GHG) emissions generated by production, transport, and consumption along supply chains can be analyzed as imports and exports of GHGs, in order to clarify the emissions dynamics among partners (WTO, 2021). The GHG trade flow provides more context for emissions and offers insight into economic growth and development (e.g., Kang, 2021). The relation of relevant indicators to other measures of a successful partnership can also provide meaningful insights; for example, there is a positive relationship between a firm's energy efficiency and its productivity (Montalbano *et al.*, 2022).

Supply chains rely on international cooperation as part of supporting food security, healthcare delivery, and the economy more broadly (Hoffman & Kennedy, 2007; Subramanian *et al.*, 2020; Bown *et al.*, 2022; Economist Impact, 2022). The Canadian economy depends heavily on its supply chains for trade and economic growth, and the technology supply chain supports virtually all sectors by resourcing ICT (IEC, 2020). Having resilient supply chains that support the economy and can endure disruptions caused by global events and climate change is a goal for the Government of Canada (SCMA, 2016; TC, 2022). There are two ways supply chains affect sustainability. First, they are themselves a primary source of environmental and social costs associated with consumer goods; because of this, knowledge of a partner's supply chains is part of understanding its absolute effect on sustainability goals (Bové & Swartz, 2016). Second, lack of resilience is a major risk to supply chain sustainability. External factors, such as droughts affecting agricultural products, can decrease supply and deliveries while driving up prices (Bové & Swartz, 2016).

The condition of supply chains can be measured using transportation and manufacturing times, prices, and inventory (i.e., backlogs) (Safane, 2022). Measuring public health supply chain sustainability involves combining economic outputs, such as profit and successful orders, with indicators of supply chain function, such as the speed and extent of healthcare delivery (Subramanian *et al.*, 2020). For food security, both resilience and the environmental sustainability of supply chains are essential indicators. One particularly important measure is food waste resulting from perishable products (Economist Impact, 2021). Social innovations around food distribution are effective ways of reducing food insecurity (Huang & Tsai, 2021). In short, more effective STIK partnerships that build supply chain resilience contribute to national economic success and sustainability.

SDG monitoring provides indicators and exemplifies data collection and sharing

The SDGs are areas of extensive international cooperation as well as drivers of the Canadian STIK policy landscape (Figure 6.2).

Reproduced with permission: UN (2019)

Figure 6.2 The United Nations Sustainable Development Goals

The SDGs emerged from international cooperation and continue to shape Canadian foreign policy and the STIK landscape.

For example, *Canada's 2030 Agenda National Strategy* aims to advance the SDGs in Canada and internationally (GC, 2022c). Sustainability goals are also reflected in other national strategies in Canada, such as *The Canadian Critical Minerals Strategy*, which highlights a focus on human rights and fair and inclusive trade, and *Canada's Indo-Pacific Strategy*, which identifies biodiversity protection and food security, among other goals (GC, 2022e, 2022f). The SDGs are being adopted by other organizations and companies within Canada, in some cases facilitated by the UN Global Compact Network Canada, and are influencing their decision-making (Smale & Hilbrecht, 2016; Universities Canada, 2021; BCCIC, 2022; Global Compact Network Canada, n.d.). They are also shaping research in sectors of emphasis for Canada's innovation, such as AI (Bell Canada, 2021; AI for SDGs Canada, 2022), and are integrated with STIK programs and policies in other jurisdictions, such as China (Guo *et al.*, 2022a) and Japan (JST, 2021).

One key strength of the SDGs is a framework of indicators and methodologies to track progress, measure outcomes, provide data to course correct, and support accountability (Matusiak *et al.*, 2020; UN, 2022b). Both the United Nations and the OECD keep up-to-date indicators and monitoring tools assigned to SDGs (OECD, 2020b; UN, 2022b). For example, the first SDG, "end poverty in all its forms everywhere," has a subordinate target — "by 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters" — to which indicators are assigned (Banks, 2021). These include the loss of human life attributed to disasters, the direct economic loss attributed to disasters (relative to GDP), and the proportion of local governments that adopt and implement disaster-risk reduction strategies (UN, 2022c).

Statistics Canada measures Canada's progress toward the SDGs using the Canadian Indicator Framework (CIF) (GC, 2022b). The CIF provides snapshot measurements of progress and helps inform decisions about future action. Using these data and the framework can generate an evidence-based dialogue among governments and all stakeholders (GC, 2022b). The CIF takes an approach similar to that used in the UN framework, assigning indicators (76 in total) to each goal (StatCan, 2021c); it is also a reporting program used by Statistics Canada to collect, analyze, and disseminate Canadian SDG data (StatCan, 2021b). By identifying specific targets and their associated indicators, the CIF helps policy-makers determine which policies have been successful and identify where further actions are needed. It also complements other data-enabled frameworks, such as Canada's Quality of Life Framework (StatCan, 2021c).

Though the SDGs reflect policy cooperation that can influence STIK partnerships and are examples of coordinated goal setting and data collection nationally and internationally, they do not form a comprehensive accounting of sustainability (Kumar, 2017; Hickel, 2020). It is also important to note the limits of shared goal setting. The SDGs alone are not policies; consequently, they alone will not necessarily produce sustainable innovation (Nature, 2020). Too much focus on specific outcomes related to the SDGs risks distracting actors from the underlying causes of sustainability issues (Montemayor, 2018).

6.2.2 Commitment and Reciprocity Indicators

Reciprocity is characterized by the obligation to fulfill mutual commitments resulting in roughly equivalent exchange (Keohane, 1986). There are material, knowledge, and social components of reciprocity. Measuring it requires measuring the outcomes of the partnership, be they knowledge production, innovation, or any other result of the collaboration. Reciprocity adds a layer of accounting and accountability to the agreed-upon success conditions, to better ensure that partners receive fair returns for their contributions.

What We Heard

Organizations interviewed frequently cited compatible ethical standards, including shared values and respect for Canadian rights, as essential characteristics of productive international STIK partnerships.

In its *Recommendation of the Council on International Cooperation in Science and Technology*, the OECD (2022i) stresses the importance of reciprocity in supporting "mutually beneficial international co-operation in science and technology for economic growth and social development." This recommendation includes a number of tools through which to achieve cooperation, including forming multilateral partnerships to address grand challenges; harmonizing scientific values and norms; addressing all parties' ethical concerns; implementing risk mitigation to maximize mutual benefits; and promoting IP and privacy rights (OECD, 2022i). Values and ethical standards are often national and reflect those of the institutions involved in research (U of T, 2019). However, in many instances, values and ethical considerations may also be field-specific (e.g., AI, health) (WHO, 2011; OECD, 2023a). As part of partnership decisions, ethical behaviour can be measured by collecting value-specific metrics — such as those related to inclusive innovation (Box 4.1) and adherence to international security norms (Section 6.3) — and by evaluating past partnership behaviours (Yarmoshuk *et al.*, 2020). Evaluating the integration of such tools can help actors identify a reciprocal partnership with commitments to common principles.

Past behaviour can be used as an indicator of reciprocity

Organizations interviewed for this assessment indicated that one common measure of reciprocity is an equal financial contribution from both parties. However, they also suggested other ways of contributing to shared benefits, such as in-kind contributions. These can include, for example, the exchange of personnel, services, education, research, and infrastructure, including equipment and supplies (Yarmoshuk *et al.*, 2020). According to interviewees, the conditions for and responsibilities of sharing resources also shape an effective partnership. Partners can commit to reciprocity as part of an agreement in different ways. An agreement can stipulate equivalence, ensuring that each actor receives equal benefits from the partnership (Yarmoshuk *et al.*, 2020). Such benefits can also be contingent upon specific actions, provided only upon completion of those actions. For example, as part of its compensation for contributing to the James Webb Space

Telescope, the Canadian Space Agency receives 5% of the telescope's observation time (CSA, 2019b). In all cases, if one partner fails to provide the agreed-upon benefit, the partnership may be discontinued.

The perception of reciprocity can add to a shared sense of goodwill, in that partners understand they are working in each other's best interest and equally sharing investments and returns. How parties interact and communicate, along with the relationship's age, can alter expectations of reciprocity and trust in the relationship (Liu *et al.*, 2018). Continuous reinforcement of reciprocity in international partnerships occurs through the internalization of norms and contributes to predictability, stability, and trust. This continuous learning implies that trust and reciprocity are part of an ongoing, dynamic evaluation, one focused on creating shared value through future benefits (Liu *et al.*, 2018). Trust is an integral part of establishing and maintaining successful partnerships and leads to partnership empowerment. Ongoing evaluations present partners with the opportunity to build trust through evidence of their commitment to reciprocity.

Reciprocity can drive other outcomes that improve innovation partnerships

Perceptions of reciprocity affect the flow of information and resources in innovation networks. There are methods that can quantify and evaluate the reciprocity of partnering organizations within innovation networks; for example, bibliometrics can measure the asymmetry in citation reciprocity for scientific collaborators (Wang *et al.*, 2020; Yu *et al.*, 2022). Fairer, more reciprocal partnerships are more sustainable to such an extent that reciprocity is a "precondition of a persistent collaboration" (Wang *et al.*, 2020). Sharing information, knowledge, technology, and other resources for the purpose of collaboration reduces barriers and conflicts, which in turn enhances reliance, sharing, and cooperation among reciprocal partners (Yu *et al.*, 2022).

Reciprocity can also be treated as a principle around which a partnership can be structured, and as a tool for advancing organizational goals. Reciprocity and equity, including the sharing of innovations, can be built into the funding for partnerships to improve the effectiveness of investments "through mutual benefit and a focus on equity" (Sors *et al.*, 2022). This strategy is called *reciprocal innovation*, and it is a way of "engaging partners in deep and mutually beneficial ways" (Sors *et al.*, 2022). For this process to work, partners must recognize and measure mutual benefits from this approach (Sors *et al.*, 2022). However, benefit sharing does not need to be equal, but the difference in the benefit gained by one partner must ideally contribute to another shared value-based goal, such as public health (Yarmoshuk *et al.*, 2020). Though one partner receives greater benefits, the arrangement is still structured around being mutually beneficial (Yarmoshuk *et al.*, 2020).

6.2.3 Longer-Term Commitment Indicators

Addressing resilience and long-term sustainability requires actors to envision successes that impact future generations. Implicit in data-enabled frameworks that consider immediate needs in the progress toward sustainability is the fact that indicators must be associated with points along a timescale of generations; it is often the case, however, that indicators are not associated with timeframes (Bond & Morrison-Saunders, 2011). There are calls for implementing indicators along a timescale, such as those found in the EU *Strategic Environmental Assessment Directive*, which requires that data reflect short-, medium-, and long-term environmental effects, as well as cumulative and permanent ones (Gov. of U.K. ODPM, 2005; European Parliament & Council of the European Union, 2021).

Sustainability goals often extend beyond the timeframe of conventional assessments

Timeframes for nuclear power planning (to take one example) require thinking of waste disposal for periods as long as 100,000 years (Bond & Morrison-Saunders, 2011). Longer timescales increase uncertainty, which in turn increases the complexity of decision-making along these timelines. It can be challenging for organizations to sacrifice speedy returns and short-term profits for long-term value; this can be exacerbated by external pressures for immediate performance (Bansal & DesJardine, 2014).

Identifying goals relevant throughout the length of a partnership can help users choose indicators that will best reflect the full timeline under consideration. Climate change is an example of a problem that is best served by this type of thinking. In the near term, innovations that increase deployment, abatement, affordability, and technology development can begin to address immediate needs (Sandén & Azar, 2005). However, longer-term goals are likely better served by advanced technologies that are yet to be fully realized. For example, stricter GHG emissions standards may not be achievable with current technologies; therefore, decision-making to meet these goals involves the consideration of partnerships that can bring about these new technologies in the future. Employing a decision-making framework structured around immediate and future goals can help limit the risk that near-term goals will obscure or hinder long-term planning (Sandén & Azar, 2005).

Long-term planning and vision are enablers of sustainable innovation

At the firm level, sustainability indicators include evidence of enabling regulatory environments (e.g., long-term incentives) and clear mission statements for innovation, as well as dedicated staff and company time (DIISR, 2009). For example, in considering long-term goals of urban sustainability for smart cities, Bibri (2020) notes that such goals reflect changes to environmental, economic, and social systems that in turn depend on the interaction of sociopolitical factors, implementation decisions, new knowledge, and regulatory policies. Advancements, therefore, require scientific research, technological innovation, planning, development, and analysis of different elements that result in formulating and implementing new follow-up strategies (Bibri, 2020). Foresight helps actors identify desired futures and pave the way for practical roadmaps and backcasting (a strategy that begins with a vision of a plausible future and works backwards to identify the steps necessary to reach this vision). Actors can be future-ready by setting milestones and goals, and by assigning indicators to monitor and shape innovation toward a desired future, all the while understanding the indeterminacy and uncertainty of those possible futures (Bibri, 2020).

6.3 Security

Canada's STIK ecosystem conducts research and other activities that have implications for national and international security. Security implications of STIK activities may be direct — as is the case for R&D with military applications — or indirect, such as research related to climate change, food security, pandemics, or dual-use technologies. Canada does not have a publicly available national security strategy to identify and prioritize the areas where national or global security risks intersect with international STIK partnerships.

Threats to sustainability adversely affect national security. For example, climate change is a significant contributing factor to multiple threats (e.g., natural disasters) that can strain domestic resources, which in turn diminishes Canada's capacity to respond to international demands (Shull & Wark, 2021). STIK activities are crucial to Canada's ability to understand, mitigate, and adapt to these threats, and to capitalize on opportunities. These include R&D in technologies that support food security, forecast extreme weather events, and detect and respond to emerging diseases, which can become targets for foreign espionage (Shull & Wark, 2021).

In the past, R&D was largely driven by a demand for military dominance — weapons, surveillance, and medical technologies — that were then "spun-off" for commercial purposes (Alic *et al.*, 1992). With the end of the Cold War, the motivation for industrial R&D shifted to primarily commercial applications, with defence as a secondary application (Alic *et al.*, 1992). The relationship between S&T and geopolitics is bidirectional (Skolnikoff, 1993), and both innovation and innovation partnerships are subject to changing geopolitical security concerns. This interaction means that research priorities and partners change — and guidance on sharing data and technology shifts — in response to the contemporary global context (Wilner *et al.*, 2022). Recognizing that international STIK partnerships include risks and rewards, decisions to pursue partnership opportunities ideally include considerations of research security and potential research outcomes (e.g., unintended applications, other externalities arising from new technologies) as well as the broader geopolitical context.

Forming STIK partnerships requires balancing collaboration benefits — whether technological, economic, humanitarian, or diplomatic — against the potential of worsening national security threats. States that do not fund international partnerships forgo access to leading research and knowledge transfer opportunities, to the detriment of competitiveness, wealth creation, and the public good (Johnson *et al.*, 2022). Still, international STIK partnerships create risks for national security, such as the unauthorized transfer of IP related to military or dual-use applications (e.g., weapons, surveillance) or the theft of research findings that provide economic advantages and support national competitiveness. During times of geopolitical tension, indirect consequences of research security (e.g., on IP) are increasingly seen as a national security issue (Wilner *et al.*, 2022).

What We Heard

Security concerns are top of mind for many organizations, but this increased focus is relatively new. Several Canadian STIK organizations interviewed for this report suggested that training, formalized procedures, and wider data access around security and geopolitical concerns could improve decision-making, including knowing who can provide guidance, what the risks are, and how to minimize them. Though interviewees understand the need to restrict access to information in this space, they noted that the lack of specific guidance limits effective security decision-making.

Many organizations are looking to outside expertise for security information, particularly to federal departments and agencies such as the Canadian Security Intelligence Service (CSIS), ISED, GAC, NSERC, and Public Safety Canada. Interviewees described emerging security concerns as a moving target that is hard to adapt to, with some suggesting that security information needs to be anticipatory, in order to help address future risks. Like other elements of international relations, innovation relies on adjusting to threats accordingly but requires the information and foresight to do so strategically.

6.3.1 National Security Indicators

National security "deals with threats to the people, democratic values and institutions, economy, society, and sovereignty of Canada on a scale that demands a national response" (GSPIA Task Force on National Security, 2022). The risks to Canadian security most relevant to STIK partnerships are those associated with nation-states (e.g., military risk, state-sponsored espionage, cyber attacks) and national and transnational threats[12] (e.g., climate change, natural disasters, disease outbreaks) (Shull & Wark, 2021; GSPIA Task Force on National Security, 2022). Science and scientific partnerships, through science diplomacy, have been part of the strategy for furthering security, peace, and prosperity since at least World War II; although science diplomacy, like all diplomacy, has not been free from setbacks (Colglazier, 2018).

Meeting global challenges will depend on the free circulation of people and ideas (Shull & Wark, 2021). However, today's changing threat landscape highlights how the contemporary multilateral system of rules and institutions, which could support such international cooperation, is under increasing stress (GSPIA Task Force on National Security, 2022). The evaluation and prioritization of potential STIK partnerships must therefore recognize the role such partnerships can play in both protecting and undermining Canada's national security. The Export Control List and the *Wassenaar Arrangement*[13] can provide some guidance on dual-use technologies, as they contain lists of materials, technologies, and components with potential or actual military applications (Horwitz & Wang, 2021).

What We Heard

Interviewed organizations stated that the extent to which security affects partnerships is determined on a case-by-case basis, in order to weigh the risk of project misuse or weaponization of trust against potential domestic and international benefits. Data security and theft, and IP ownership and leakage, were among the most common concerns, though Canadian STIK organizations whose research could be misused or weaponized were deeply concerned about ensuring security and safety.

12 "Transnational security issues can be defined as nonmilitary threats that cross borders and either threaten the political and social integrity of a nation or the health of that nation's inhabitants" (Smith & Berlin, 2000).

13 The *Wassenaar Arrangement* "is a voluntary export control regime whose 42 members exchange information on transfers of conventional weapons and dual-use goods and technologies" (ACA, 2022).

The National Security and Intelligence Committee of Parliamentarians 2020 annual report updated the overview of national security threats[14] to Canada (NSICOP, 2021). It identified five threat categories as priorities: "terrorism, espionage and foreign interference, malicious cyber activities, major organized crime, and weapons of mass destruction." Specific threats were also identified, including espionage targeting Canada's health, science, and technology sectors; cyber threats to critical infrastructure; and the potential for nuclear, chemical, and biological weapons use and the proliferation of dual-use technologies (NSICOP, 2021).

One trade-off to consider is the balance between the drawbacks and advantages of working with partners in authoritarian states, including Russia and China. Many democratic governments recognize that, in areas of mutual interest, continued work with such states is necessary (e.g., GC, 2023h). However, such work requires not "allow[ing] countries to use their market position in key raw materials, technologies, or products to have the power to disrupt our economy or exercise unwanted geopolitical leverage" (Secretary of the United States Department of the Treasury, 2022).

Included in Budget 2023 are steps to "securing our economy" while acknowledging that "depending on dictatorships for key goods and resources is a major strategic and economic vulnerability" (GC, 2023c). Securing the economy involves friend- or ally-shoring, which is being employed by Canada and many of its allies to build supply chains preferentially through trusted partner economies as a way to make them more resilient (GAC, 2021b; GC, 2023c; McDonagh, 2023). Autocratic regimes, as competitors, engage in innovation for weapon development and military purposes, creating the need for military STIK with Canadian allies (DND, 2022). In 2022, there were more autocratic states in the world than democratic ones, continuing a decade-long trend of rising autocracy (BTI, 2022). Indices of political transformation, economic transformation, and governance, such as those in the Bertelsmann Transformation Index *Democracy Report*, can inform security dimensions of decision-making regarding international STIK partnerships (BTI, 2022).

Membership in trusted security networks can be a high-level national security indicator

As noted in Section 5.5, membership in trusted security networks (e.g., Five Eyes, NATO) is a valuable indicator of a safe partner for many national STIK organizations when they are estimating security risks. Because sharing risk and technology data is an essential part of international engagement within secure alliances, the

14 Excluding military threats, which are the purview of the Department of National Defence and the Canadian Armed Forces.

Five Eyes and NATO security alliances are, in themselves, important STIK partnerships. For trusted partners such as the Five Eyes nations, security is often assumed, whereas geopolitics may instead be the primary decision-making factor for a joint venture with a non-trusted partner. Partners whose stated values and past behaviours align with Canada's own can represent straightforward partnership opportunities. Existing trusted research relationships can also indicate an alignment of other values, such as support for liberal democracy and human rights. However, depending on a small set of existing relationships incurs an opportunity cost, such that STIK organizations may be forgoing potentially fruitful opportunities with new partners.

What We Heard

Many Canadian organizations interviewed for this report described international STIK partnerships as a trade-off between security and the greater good, including economic prosperity. One way to set priorities while considering security threats is by assessing the risk of the individual technologies being researched. Some research poses more risk than others and deserves higher scrutiny. Projects that pose a higher security risk may be best restricted to trusted partners (e.g., Five Eyes nations), while those with a low risk of being stolen or weaponized can engage a wider set of partners. Similarly, if the benefit to the international community is great enough, or if the science will sufficiently advance a Government of Canada priority (e.g., enhancing food security), a broader set of partners could be included in the research, since the potential good outweighs the security risk.

Partnerships with countries whose governments violate the values of Canada, or that adversely affect its security, could damage its reputation or undermine its global position, even where the contribution to amoral actions is indirect or unintentional. There are national security risks inherent in partnering with, for example, entities on the *Area Control List* and those sanctioned under the *Special Economic Measures Act or the United Nations Act* (GAC, 2017c; GC, 2021e); as of December 2023, special permission may be required from GAC to engage in research partnerships with individuals or organizations from Belarus, Burma, China, Haiti, Iran, Nicaragua, North Korea, Russia, South Sudan, Sri Lanka, Syria, Ukraine, Venezuela, and Zimbabwe (GC, 1992, 2023j). Furthermore, non-participation in some international regimes linked to scientific development, such as the arms trade and control regime, may be another indicator of security risks that can inform decisions related to international relationships. For example, non-signatories to the *UN Arms Trade Treaty* may be seen to be operating outside international norms for the responsible development and use of some technologies (ATT, n.d.).

National security is complex and requires many indicators to produce guidance

Prikazchikov *et al.* (2021) have developed a model that uses national security, sustainability, social, and economic indicators to evaluate current national stability and security, and to forecast national security risks in the near future. Economic indicators (e.g., external national debt, unemployment rate) and social responsibility indicators (e.g., adherence to environmental regulations; spending on healthcare, education, science, and cultural activities) are combined with security indicators. Security indicators comprise military capacity (e.g., national defence expenditures; presence or size of a nuclear arsenal; involvement in international or civil conflicts; illegal trade in arms), while sustainability indicators might be diseases and epidemics (negative indicators) or new energy companies (potentially positive indicators) (Prikazchikov *et al.*, 2021). These data can support frameworks, scenario development and forecasting models, providing insight into political instability, and informing research planning (The Netherlands Ministry of Security and Justice, 2014; Prikazchikov *et al.*, 2021; PS, 2023). TheGlobalEconomy.com Security Threats Index uses threats to a state (e.g., attacks, bombings) as indicators of fragility and security (TheGlobalEconomy.com, 2023).

Generally, security and stability are valuable for STIK partnerships, but there may be testing or international development reasons for STIK partnerships in unstable regions, which would constitute exceptions. The Global Peace Index focuses on three categories of indicators: societal safety and security, ongoing domestic and international conflict, and level of militarization (IEP, 2023). For some partnerships, it may be appropriate to focus on a specific security sector — using relevant indices and indicators, for example, when considering energy security (Mara *et al.*, 2022).

6.3.2 Foreign Interference and Influence Indicators

Foreign interference refers to activity by a foreign state to advance its interests, deliberately and covertly, over Canada's interests (CSIS, 2022b). These activities are distinct from normal diplomacy, lobbying, and even competition among states. Academic and industrial research is a main target of foreign interference campaigns, wherein malicious actors use recruitment, FDI, and economic tactics to exert control in Canada (CSIS, 2022b). The *Invest in Canada Act* and its accompanying guidelines offer insight into STIK areas that may be targets of investment-based foreign interference, including critical natural resources and infrastructure; technologies requiring valuable or personal data (e.g., biometric or finance data); and sensitive technologies (e.g., AI, aerospace, quantum, biotechnology) (GC, 2017b, 2021g, 2023e). As evidenced in joint ministerial statements and published guidelines, the Government of Canada is placing increased security scrutiny on research partnerships (GC, 2021e, 2023a). This suggests that Canadian organizations in sensitive fields may want to give extra weight to foreign interference indicators — such as another country's public and foreign policies — when making decisions about international partnerships (Box 6.2).

Box 6.2 Implications of China's Policies for STIK Partnerships with Canada

Foreign ownership can be used to advance another state's interests over Canadian ones. Strategic policies for medical research and pharmaceutical R&D in China — such as *Made in China 2025* and the *Precision Medicine Initiative* — support practices such as targeting early stages of development (e.g., grant proposals), buying companies with key technologies, and becoming a chokepoint for pharmaceutical ingredients or generic medicines. In Chinese decision-making on STIK partnerships, economic viability is not the sole criterion when opportunities are evaluated. The state will accept inefficiencies to acquire the technology of interest, which can result in overbidding and overpaying for global assets. This strategy can undercut market prices, outcompeting private enterprises that do not enjoy the same level of state support or sustained funding. STIK partnerships may need to consider the risk associated with foreign ownership, in order to fully realize benefits for Canada.

(Tatlow *et al.*, 2021)

Foreign influence data can be used when assessing potential partnerships

The Government of Canada requires evaluations of foreign ownership, control, or influence (FOCI) for any of its outsourced activities involving access to potentially sensitive information or networks (e.g., NATO, Communications Security

(COMSEC) services) (PSPC, 2022). The types of data found in such assessments could inform international STIK partnership decisions. Generally, FOCI data focus on the country of origin of a company's major shareholders, board of director members, and key contract-holders and clients, as well as its financial liabilities and legal responsibilities such as export control and technology transfer compliance (DCSA, 2010; U.S. GSA, 2018). FOCI indicators measured through a product's whole supply chain may uncover risks linked to ownership in a hostile state that may not be apparent when looking only at the partners' ownership (Exiger, 2022). This type of analysis may uncover hidden security risks associated with a partnership, one that could give foreign governments access to sensitive data and technology (Masters *et al.*, 2023). Information about a prospective partner's operations with foreign actors may identify current influence and interference risks; this does not eliminate risk, however, because ongoing business practices occurring during the partnerships can expose both parties to foreign influence.

One particular area of concern is hostile foreign investment in Canada's STIK industries, whereby state-owned or state-linked enterprises pursue corporate acquisitions or bids to gain access to, or control of, critical infrastructure and strategic sectors, or to further espionage and the illegal transfer of technology and expertise (CSIS, 2022a). Provinces and territories are targeting growth through investment in sectors of the knowledge economy — ICT, bioscience, manufacturing, and clean technologies — that are attractive targets for foreign agents. For example, several provinces and territories host areas that are key to maintaining and supporting Canada's supply chains and import/export economy (CSIS, 2022a). Foreign influence and interference indicators, together with evaluation techniques, could therefore be used to identify potential threats to these sectors, since those threats could adversely affect Canada's security, sustainability, and resilience.

Higher education and research institutions also require means and methods for reducing foreign influence. For example, a lower level of academic freedom in a country where a potential STIK partner is based — as measured by indices such as the Academic Freedom Index — may point to a higher potential for foreign influence in the other country's university or research institutions (EC, 2022). Data of this nature may be sufficient for evaluating lower-risk ventures.

The Formal Bilateral Influence Capacity (FBIC) Index measures the potential for foreign influence based on two main factors: the amount of economic, political, and security interaction (for a given timeframe), and the degree of dependence of one state on the other for economic success and security (e.g., levels of trade as a total or a share of GDP) (Moyer *et al.*, 2021). This index does not account for covert activity, but it does use economic metrics (e.g., trade agreements, aid), security connections (e.g., arms transfers and imports, military alliances), and political factors (e.g., memberships in intergovernmental organizations) (Moyer *et al.*, 2018). The FBIC Index can be used as a data source for STIK partnership decision-making, but it is also an example of how indicators of trade, economics, security, and intergovernmental memberships can be combined to provide insight into more complex priorities (Moyer *et al.*, 2018). For example, it can identify countries where foreign influence is high, indicating they may pose a security risk; alternatively, it can identify areas where adversarial influence is weak or waning, which could constitute an opportunity for a partnership.

Vulnerability to foreign influence can also inform evaluations

Many countries are not themselves adversarial to Canadian interests but may be susceptible to foreign influence. Foreign influence in partnering countries may provide adversaries with a path to unduly influence Canadian institutions or pose a data security risk. The GLOBSEC Vulnerability Index attempts to quantify vulnerability or resilience to foreign influence for eight countries (GLOBSEC, 2021). It considers, among other factors, the public's attitude toward Russia and China, and favourable alliances, such as the European Union or NATO. Attitudes are combined with data and indices relevant to public administration, the information landscape, civic and academic space, and the political landscape, in order to capture aspects of government resilience, media freedom, and civil and academic protection and freedom (GLOBSEC, 2021). While this index only directly applies to the eight included countries, it demonstrates how these types of data can inform partnership decisions when included in other frameworks.

6.3.3 Cybersecurity Indicators

Emerging disruptive technologies — such as advances in cyber, telecommunications, data processing, and analytic technologies — hold promise for improving collective well-being in Canada, but they also contribute to the shifting threat landscape (Shull & Wark, 2021). Facial recognition and machine-learning technologies are dual-use technologies with applications in intelligence and surveillance activities. Cyber attacks and ransomware demands have grown as threats to Canada's national security; they are intertwined with organized crime and critical infrastructure vulnerability (Shull & Wark, 2021), and they are part of foreign interference campaigns (CSIS, 2022b) and industrial espionage, as well (Box 6.3). The Government of Canada's 2018 *National Cyber Security Strategy* explicitly recognizes cybersecurity threats — including ransomware, and data and privacy breaches — and IP or business strategy theft, and notes that attacks on government systems, critical infrastructure, and democratic institutions are growing in sophistication (PS, 2018).

Box 6.3 Cyber Espionage in Canada

The *Geopolitical Cyber Incidents in Canada* report documents 75 attacks related to "international rivalries and strategic competition" between 2010 and 2022. Of these, 45 are categorized as "acts of cyber espionage." The attacks were mainly by foreign actors, often for military, political, or economic reasons. About half of the espionage attacks targeted major tech companies, universities, and other R&D-dedicated entities, while another quarter targeted government agencies. Industrial cyber espionage focused on information technology, finance, energy, and aerospace sectors. The report identifies China, Iran, North Korea, and Russia as the geographic origins of two-thirds of the attacks; however, it also notes that those governments are not necessarily responsible. One-fifth of the attacks were of unknown origin. Such data can inform indicators of cybersecurity risk when actors are making decisions about regional partnerships.

(Gagnon *et al.*, 2022)

Data on cyber attacks can contribute to broader security indicators

The Communications Security Establishment (CSE), Canada's national cryptologic agency, publishes reports and provides guidance on critical cybersecurity threats and vulnerabilities through the Canadian Centre for Cyber Security (Cyber Centre, 2023). Reports and case studies have been published about protecting Canada's healthcare system against cyber attacks — for example, through connected medical devices and health research equipment (Cyber Centre, 2020, 2021). The Cyber Centre also maintains a database of "potential, imminent or actual cyber threats, vulnerabilities or incidents affecting Canada's critical infrastructure" (Cyber Centre, 2022c). Its Cyber Security Audit Program and Harmonized Threat and Risk Assessment Methodology can also help generate the information necessary to inform partnership decisions (Cyber Centre, 2022a, 2022b). According to the CSE, China, Iran, and Russia have all demonstrated an intent to develop cyber-attack capabilities against industrial control systems linked to infrastructure (as reported in NSICOP, 2021). Cyber activities wherein Russia has targeted critical infrastructure have also been confirmed in the United States (U.S. CISA, 2018). The CSE found that Russian actors have attempted to compromise some Canadian targets through cyber attacks, though details have not been made public (reported in NSICOP, 2021).

Beyond Canada, the European Commission Global Cybersecurity Index provides indicators of legal, technical, and organizational measures, capacity building, and cybersecurity cooperation, which may be particularly informative for international STIK partnerships (EC, 2021b). This index can be correlated to other European Commission indices (e.g., Fragile States Index, Eco-Innovation Index) to improve actors' understanding about levels of national resilience, security, and sustainability (EC, 2021b). The Nasdaq has also created various firm- and country-level cybersecurity indices and reports focusing on data breaches, attacks, and industry and national security advancements (Nasdaq, 2023). Furthermore, security ratings compiled by private companies (e.g., UpGuard) can provide external evaluations of cybersecurity (Tunggal, 2022). These are based on commercial and open-source data sets, which are collected and evaluated to produce scores that can be used to measure an organization's security and compare it against others in its industry (Tunggal, 2022).

6.3.4 Research Security Considerations

STIK activities contribute substantially to Canada's economic well-being. Hostile foreign state actors, therefore, may have specific interests in certain sectors of Canada's economy related to research that would offer them similar economic benefits (CSIS, 2022a). In the context of military research, Defence Research and Development Canada (DRDC) delivers "science and technology solutions" to the military and public safety communities through collaborations with industry, academia, and government departments (federal, provincial, territorial, and municipal), as well as international allies (DRDC, 2021). DRDC's international partnerships involve high security and multilateral arrangements, such as the Technical Cooperation Program (TTCP) among the Five Eyes, and NATO's Science and Technology Organization (DRDC, 2021). Compatibility among countries' research values, legal codes, political ideologies, and national interests is an important factor for generating trust and security in international STIK partnerships (NWO, 2022).

Project-level research security considerations can inform broader security assessments

The Government of Canada, in its *National Security Guidelines for Research Partnerships* (GC, 2021e), recognizes the following national security risks linked with international research partnerships:

- Unwanted access to, and potential interference with, research data
- Theft of research data
- Loss of IP, patent opportunities, and potential revenues from commercial applications
- Legal or administrative reprisal
- Loss of potential future partnerships
- Tarnished reputation

Some areas of research are of greater potential interest to foreign actors, particularly those that include the collection and use of sensitive information (e.g., personal data) and those with dual-use potential (e.g., aerospace, biotechnology, quantum science, robotics) (GC, 2021e). When assessing potential research partnerships, security considerations include:

(i) project-specific concerns, such as

- research goals and findings of interest to foreign governments, or their militaries or proxies;
- fields of research with potential military, policing, or intelligence applications;
- potentially sensitive[15] data, such as personal data or large data sets;
- research methodologies or findings with the potential to impact critical infrastructure; and

(ii) research partner considerations, such as

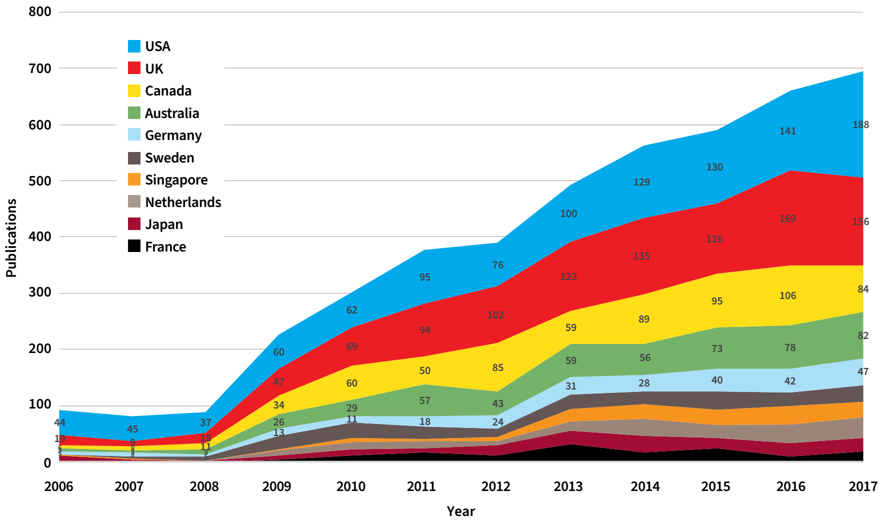
- organizations that are the subsidiaries, parent corporations, or affiliates of third-party governments, or their militaries and proxy organizations;
- potential conflicts of interest; and
- knowledge transfer and IP laws of host countries (GC, 2021e).

15 Sensitive research areas include those on conventional weapons, missile and rocket technology, space technology, chemical and biological weapons and agents, and nuclear programs (GC, 2021d).

These criteria represent the partner organization portion of *National Security Guidelines for Research Partnerships*, which can be used alongside Canada's *Conducting Open Source Due Diligence for Safeguarding Research Partnerships* as the basis for partnership decisions and risk mitigation planning (GC, 2021e, 2023i). Survey tools such as these are likely appropriate for smaller, lower-risk research programs; these tools help ensure programs are not subject to overly complex frameworks and may help researchers identify when their research is higher risk and requires more in-depth consideration. In both situations, these risks must be weighed against the potential rewards of a STIK partnership.

Foreign research and education policies can indicate research security risks

The close links that Chinese STIK institutions have to the military and government, along with the reporting obligations of these institutions' personnel, have implications for research security (GSPIA Task Force on National Security, 2022). Joske (2018) reports on the practices of research collaboration between People's Liberation Army (PLA) scientists and researchers in Australia, Canada, Germany, the United Kingdom, and the United States, among others (Figure 6.3). Roughly 300 Chinese military scientists were sent to Canada between 2007 and 2016 (Joske, 2018). These collaborations have often been supported by taxpayer funds in the host country; PLA scientists and engineers are sent abroad to complete a doctorate, or on one- or two-year excursions as visiting students or scholars. These scientists — who often obscure or fail to disclose their military associations — are directed by China to conduct research in technology sectors of strategic military value, including quantum physics, signal processing, cryptography, navigation technology, and autonomous vehicles. The extent to which universities and governments outside of China are aware of these practices is unclear (Joske, 2018).



Reproduced with permission from Joske (2018)

Figure 6.3 Top 10 Countries for PLA Collaboration

Collaboration measured by co-authorship with People's Liberation Army scientists, from 2006 to 2017, based on publications in Scopus.

China has an overall strategy of acquisition designed to build capacity for the long-term future and to benefit its S&T infrastructure by capitalizing on new information, technology, and skill sets (Tatlow *et al.*, 2021). The strategy is supported using a diverse set of actors, including academia, state-owned or state-supported businesses, and small businesses overseas, which operate strategically within a grey area of plausible deniability (Tatlow *et al.*, 2021). For example, Stoff (2021) documents several published research papers with co-authors from the United States and China and notes that authors' affiliations with certain Chinese universities (whose core missions are to support China's defence-industrial base and advance civil-military fusion) and with schools linked to the PLA's armed police (a paramilitary force that performs domestic security and surveillance) were often absent from English-language publications.

Monitoring existing research projects can inform security evaluations

Monitoring can be informative when, for example, there are unclear or obscured funding sources for the research project; when funding is conditional on research performance, transfer, or replication in a foreign country; or when actors partner with an organization that has charges, guilty pleas, or convictions related to fraud, bribery, espionage, corruption, or other criminal acts (GC, 2021e). A request for access to Canadian facilities, networks, or assets to conduct research unrelated to the project can also be evidence of potential security risks. Constraints imposed on the disclosure and communication of financial or ethical requirements should also raise concerns, particularly when they conflict with the reporting requirements of Canadian funding agencies. More subtle indications of security risks for international STIK partnerships can include offers of equipment or supplies below market value, especially when below cost. Requests to export materials on Canada's Export Control List for research purposes should also elicit additional scrutiny (GC, 2021e). The U15 Group of Canadian Research Universities and Research Canada (2019) have combined several of these indicators with economic and political benefits indicators into a lightweight, proactive risk matrix to help guide international STIK decision-making (Box 6.4).

Research security breaches may occur because of seemingly innocuous activities, such as remotely accessing a private home's WIFI network using a state-sponsored work computer while visiting another country (GC, 2021d). Other scenarios may be more apparent because they violate institutional policies, but their potential impacts on national security may be less noticeable. For example, failing to disclose foreign affiliations and funding, violating export laws or transportation policies, or accessing unauthorized information may be readily explained away based on a supposed error in judgment or unclear understanding of the rules; however, such activities could have substantial negative consequences for data security, undue foreign influence, and institutional reputation (GC, 2021d).

Box 6.4 Anticipating Potential Research Security Threats

U15 and Universities Canada (2019) have co-developed a framework for balancing risk and commercial benefit. Their risk impact matrix weighs impacts (commercial, national security, and domestic or international political interests) according to two dimensions: the impact's size and probability. The suggested risk indicators include funding sources being obscured, suspicious reporting practices, pricing irregularities (e.g., items below market value), and export of controlled goods. Commercial impact considers cost reduction, market size, or revenue growth associated with the field of research as prospective indicators.

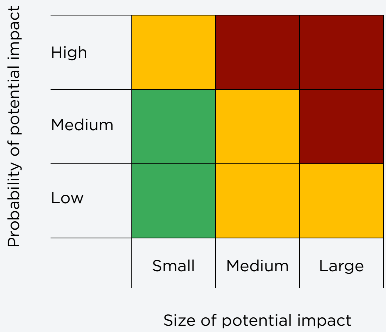
A simple framework like this can guide small, safe projects away from the onerous, more comprehensive evaluations used for high-risk and high-value projects. Potential high value and low-risk partnerships constitute opportunities, as identified by the framework. This framework offers clear direction for any high-risk project (i.e., consult the research office for advice on risk mitigation strategies). The higher the accessibility and quality of the data consulted, the better the guidance this framework can provide (Figure 6.4).

(U15 and Universities Canada, 2019)

Low risk (green): use standard processes to protect your research.

Medium risk (yellow): consider implementing additional risk assessment and mitigation measures to address risk, such as those suggested in this guide, in consultation with your research office.

High risk (red): consult with your research office as a first step and seek appropriate guidance to further assess identified risks and implement significant mitigation measures.



Adapted with permission from U15 and Universities Canada (2019)

Figure 6.4 U15 and Universities Canada Risk Matrix for University Researchers

The risk matrix is a simple, proactive risk and benefit tool to aid the evaluation of potential international partnerships.

7

Framework Success Factors

Recall the framework elements for science, technology, innovation, and knowledge production (STIK) partnerships discussed throughout this report. These include articulating goals for the partnership prioritization exercise by identifying *National Priorities* (Chapter 2), using those goals to examine *Leveraging Value* based on existing international and domestic STIK landscapes (Chapter 3) and establishing relevant *Benefits to Canada* in order to choose appropriate criteria, indicators, and metrics (Chapters 4 through 6). While these elements are necessary for the decision-making process, additional considerations — strategic foresight, data collection and evaluation, and governance — are foundational to a framework's responsiveness, longevity, and success (Figure 7.1).

As noted in Chapter 1, there are more STIK players on the global stage than ever before, as well as more data, information, and evaluation tools available for decision-makers. At the same time, the geopolitical landscape is increasingly dynamic. Canada is well-positioned to find continued and expanded success in this evolving global STIK landscape, but this will require a strategic and responsive approach. The implementation of a decision-making framework will be successful if it helps rather than hinders the processes already used by federal departments and agencies.

What We Heard

Interviewees, workshop participants, and guest speakers repeatedly mentioned the need for coordination and clear communication channels among organizations engaging in international partnerships. They also noted that any new framework should not increase bureaucratic burdens or place constraints on Canada's ability to be responsive and flexible in pursuing international partnerships.

Currently, organizations within the federal government use different and more or less formalized practices to prioritize international STIK partnerships. Rationales for engaging with partners are diverse and include honouring existing agreements; securing relationships to access research sites, infrastructure, or expertise; historical precedence; and economic and geopolitical considerations. In interviews conducted by CCA staff with federal departments and agencies, as well as with other Canadian STIK organizations, participants noted that international partnerships are influenced by a variety of factors, such as opportunity for research collaboration, complementarity of organizational mandates, benefits to researchers and firms, and expanded research capacity. Interviewees also noted that consideration is given to geographic location, emerging markets, existing trusted relationships, and developing or strengthening diplomatic ties. Given such a wide range of motivations and factors involved in international STIK partnerships, the specificity of any decision-making framework is ideally balanced with the flexibility to suit any given context and situation.

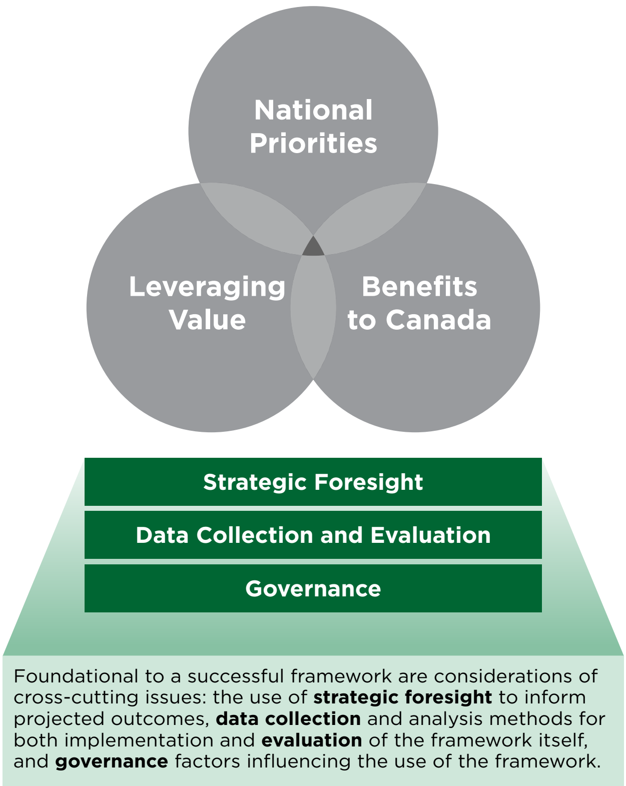


Figure 7.1 Foundational Elements for Success: Strategic Foresight, Governance, and Data Collection and Evaluation Practices

The main elements of a decision-making process — setting goals to address *National Priorities*, *Leveraging Value*, and measuring anticipated *Benefits to Canada* — are incomplete without an infrastructure to implement the process. A governance structure with coordination, resourcing, and accountability helps ensure effectiveness, longevity, and transparency; accessible, up-to-date data repositories and data sources help ensure responsiveness; ongoing evaluation of framework implementation provides a basis for adaptation; and the use of strategic foresight helps ensure decisions speak to the short and long terms.

There is no published national STIK or foreign policy in Canada. This absence, combined with a lack of clarity regarding the governance of, and strategy for, international STIK partnerships across departments and agencies, led some interviewees to express concerns about the imposition of a monolithic, data-driven framework to guide all international STIK partnership decision-making. Such concerns included the introduction of new bureaucratic or administrative burdens, the need for qualitative judgment in the decision-making process, and a loss of autonomy, which could be detrimental to the ability of federal departments and agencies to meet their mandates through partnerships of their choosing. Interviewees expressed concerns that a single framework would not be feasible or sufficiently flexible to accommodate the wide range of organizational mandates and variable needs for STIK partnerships. Many wondered what the governance of such a framework might look like and what structural supports would exist to facilitate its implementation. This chapter will address the final question of the panel's charge, namely:

What are the necessary governance and other success factors to make effective use of a new federal framework for international STI collaborations on an ongoing basis?

While there is little evidence to suggest that any one approach for implementing a decision-making framework will best suit the Canadian context, the panel notes there are key success factors that can support the implementation of such a framework, as envisioned in Figure 7.1: strategic foresight practices; purposeful data collection and formal evaluation of framework implementation; and the attributes of governance that, collectively, create the conditions for iterative learning, coordination, and long-term success.

7.1 Strategic Foresight

Strategic foresight is "a systematic approach to looking beyond current expectations and taking into account a variety of plausible future developments in order to identify implications for policies today" (OECD, 2019a). Foresight is thus a structured and systematic approach to exploring multiple futures through dialogue and debate, reflecting the complexity of systemic interdependencies (Cuhls, 2019). In support of international STIK partnership decision-making, foresight could be valuable in anticipating national priorities, emerging global and STIK imperatives, the rise of new potential partners, and shifts in geopolitics.

Indeed, foresight activities can contribute beneficially to the overall strategic review and direction of innovation ecosystems — and to the prioritization of research and innovation activities and funding — at sectoral, regional, and national scales (Harper, 2013). Other benefits of foresight include more robust decision-making, consensus building, and engagement across a wider variety of participants in a STIK ecosystem (Harper, 2013). Indeed, Meissner (2012) finds a significant correlation between the characteristics of national foresight studies and the innovation performance of 32 countries.

Strategic foresight incorporates a variety of complementary methodologies

Methodologies include horizon scanning, megatrends analysis, scenario planning, visioning, and backcasting (OECD, 2019a). Horizon scanning is often an initial step in strategic foresight activities — expert surveys, literature reviews, and desk research may be employed to identify signals, emerging issues, or possible futures (Cuhls, 2019; OECD, 2019a). For example, large-scale Delphi surveys have been used for S&T foresight by national (e.g., Japan's NISTEP) and multinational (e.g., European Commission) organizations for decades (reviewed in Belton *et al*., 2022). The results from such surveys are used to support and validate national S&T priority setting. They can also support participation and communication both within diverse expert communities and among experts, governments, and the public (Belton *et al*., 2022).

Over time, foresight activities and practices have evolved and expanded with the development of new tools and applications, including embedding big data and AI into "foresight-on-site" (Saritas *et al*., 2022). Beyond improving decision-making, participatory foresight activities are increasingly recognized as opportunities to build relationships and networks among diverse actors, including citizens, at the intersection of STIK policy, technological developments, and society (Meissner & Rudnik, 2017; Rosa *et al*., 2021). Still, there remain significant challenges in integrating foresight and STIK policy, such as the speed of technological change and increasing complexity, uncertainty, and instability (Sokolova, 2022).

Integrating foresight activities into government policy-making can take different forms

In the Government of Canada, strategic foresight expertise is largely centralized in Policy Horizons Canada (OECD, 2021b; Policy Horizons Canada, n.d.-b). Established in 2010, this organization investigates and gains insight into the possible implications of different public polices over a 10- to 15-year timeframe, in order to help agencies develop resilient, future-proof policies and programs (Dawson, n.d.; Policy Horizons Canada, n.d.-b). Three major themes characterize their activities and output: economic, social, and governance futures (Policy Horizons Canada, n.d.-a). Early successes of Canada's foresight activities include their use in the development of oceans policies and the shaping of forward-looking veterinary school curricula (Calof & Smith, 2012). Policy Horizons Canada is one of the "most well-established government foresight ecosystems in the world" and is directly integrated with senior public servants through its steering committee of deputy ministers (OECD, 2021b).

France, Singapore, the United Arab Emirates, the United Kingdom, and the United States have more than one organization dedicated to foresight activities and analysis as an aid to government planning (Dawson, n.d.). For example, three foresight institutions are active in the United Kingdom: the GO-Science Foresight programme, a Cabinet Office team, and the Development, Concepts and Doctrine Centre (Gov. of U.K. Cabinet Office, 2018; U.K. GO-Science, n.d.). While the first two directly serve the Prime Minister, the latter informs defence policies for the Ministry of Defence, serving as its independent think tank (Gov. of U.K., 2022; Dawson, n.d.). Although they each have their own non-overlapping mandates, these organizations also work collaboratively. For instance, in 2014, the Cabinet Office partnered with GO-Science to form the Horizon Scanning Programme Team and undertook foresight analyses on diverse topics, including new technologies, emerging economies, resource availability, and youth behavioural patterns (Ahmed, 2014; Gov. of U.K. Cabinet Office, 2018).

Other economies have integrated foresighting into their STIK policy-making, including Finland, Germany, Japan, South Korea, and Sweden (UNDP GCPSE, 2014; Dawson, n.d.). For example, the Finnish National Foresight Network coordinates Finland's foresight organizations under the Prime Minister's office and the Finnish Innovation Fund Sitra (Gov. of Finland, n.d.-b). The Finnish government's foresight activities support decision-making around societal, technological and economic challenges, representing 30 years of national commitment and leadership among international European collaborative foresight efforts (Gov. of Finland, n.d.-a, n.d.-c). Germany's BMBF Foresight group uses a time horizon of 15 years to provide guidance for agenda setting and prioritization in research and innovation policy (BMBF, n.d.). Japan has used the Delphi method in its foresight activities over multiple decades to inform STI planning and policy, with South Korea developing a similar approach to inform S&T policy and R&D investment, and to identify key technology areas in its S&T framework plan (Harper, 2013). In Sweden, foresight activities have been used to identify strategic national challenges and technology clusters to focus public investment (Harper, 2013).

The panel lists these examples as comparators and learning opportunities only; it does not provide an analysis or rank any one strategy over another. That said, the panel notes that the presence of Policy Horizons Canada as well as foresight capacities in organizations across Canada point to opportunities to leverage these capabilities into STIK partnership decision-making.

7.2 Data Collection and Evaluation

The systematic collection and sharing of strategic data on existing and potential partnerships is valuable for both the use and evaluation of a decision-making framework. Data collected can help actors evaluate the success of ongoing partnerships and provide a basis for evaluating framework implementation; for example, the data can help actors critically examine the relevance of different indicators and metrics for specific goals or measurements of strategic value.

Many countries are making significant investments in their data infrastructure and governance. For example, Germany is investing in data labs in every ministry and in the Chancellery, in order to complement the ministerial statistical officers, data teams, and government research institutes that inform governance (Engler, 2022). This institutionalization of data capacity includes a new office, the Data Service Center, and involves installing chief evaluation officers, facilitating access for data scientists, and creating an overarching strategy to prevent duplication. These efforts resemble the data modernization happening in the United States (i.e., the United States Digital Service) and the European Union (Engler, 2022).

Data strategies that can improve framework implementation include:

- The creation and maintenance of a portal with links to existing databases, indices, or data sources, such as the OECD STI Scoreboard, the SciVal database, and others noted in Chapters 4 through 6, as well as those not captured by this report but identified by framework users.
- The identification of indicators, metrics, and data needs, particularly those common across a variety of users, in order to establish priority data collection protocols and populate an integrated data repository.
- Research and information gathering on new and emerging indicators, metrics, and analytical tools (e.g., Wagner & Whetsell, 2023).
- The collection and collation of existing partnership-specific data relevant to both evaluation and future decision-making.
- The collection of information and feedback by users to identify areas for improvement, missing support structures, and novel applications.

- Centralized and updated information on the Canadian, international, and partner-country STIK landscapes.[16]
- Purposeful long-term data collection (i.e., before and after interventions), which can improve evaluations (Lane & Jeanrenaud, 2018) by helping ensure valid comparisons necessary for *ex-post* and *ex-ante* evaluation (Dziallas & Blind, 2019).

Evaluating a framework's implementation is vital to ensuring adaptability

An important part of all STIK activities involves analyzing and evaluating the processes, tools, and methodologies being used. It follows that implementing a framework to support international STIK partnership decision-making includes reflection and evaluation of the framework itself so it can maintain value and demonstrate improvement. Useful assessments are purpose-driven and evaluated at a timeframe appropriate to the lifespan of STIK partnerships. An iterative and adaptive approach is needed to improve decision-making and risk management in a shifting context. Such approaches may draw from other fields, such as structured decision-making in environmental management, adaptive management applied to wildlife populations, and research, tools, and knowledge related to team science in healthcare and other disciplines (e.g., Gregory *et al.*, 2012; Serrouya *et al.*, 2019; U.S. NIH, 2021). Key components of decision-making for both processes include an iterative approach in which decisions are followed by data collection and analyses to evaluate the effectiveness of the decision made, as well as to inform the next iteration of the decision-making process (Gregory *et al.*, 2012; Serrouya *et al.*, 2019).

Rosemberg and Brown (2021) have noted the main challenges of partnership program evaluations and how to address them. One of them is variation in program complexity, which makes collecting consistent and comprehensive data difficult and requires engaging program management to overcome it. As well, because multiple influences affect the outcomes of these programs, attribution can also be challenging. Employing quasi-experimental and counterfactual approaches can help actors assess the added value of international collaborations. In short, innovation often aims to produce widespread impacts that are not easily measured; thus, a purposefully selected case study may best capture these benefits (Rosemberg & Brown, 2021).

16 For example, the periodic, data-rich the state of S&T in Canada assessments conducted by the CCA include data relevant to international STIK partnership decisions (e.g., CCA, 2006, 2012, 2018).

The readiness of new frameworks to adopt AI may be a key factor in their success

New frameworks that are prepared to incorporate AI into evaluations, data collection and generation, and decision-making will be best positioned to capitalize on the power of these techniques. AI is increasingly becoming integrated into data-enabled decision-making, including in evaluations and partner selection (e.g., Wu & Barnes, 2014; Tufegdžić & Pravdić, 2019). As these tools are developed and applied to international STIK partnership decision-making, new opportunities may arise. Because these models can incorporate large volumes of quantitative and qualitative data, they can help reduce the work associated with such volumes while increasing the speed and simplicity of decision-making (Wu & Barnes, 2014).

AI can also be used to select or improve indicators. For example, tools can be created to find the indicator (or combination of indicators) that provides greater predictive value (Naik & Mohan, 2019). AI can also improve indicators by interpolating missing data or extrapolating future trends (Bienvenido-Huertas *et al.*, 2020). The data used for decision-making may contain trends that are not easily observed. AI can interpret indicators to identify these otherwise obscured patterns, improving predictions and increasing confidence in the data (Weng *et al.*, 2018). It can also support many aspects of STIK planning. For example, in the field of IP analysis, AI can contribute to decision-making by helping actors determine patentability, improve R&D planning, monitor and forecast emerging technologies, estimate the economic value of patents, and understand the effects of patents more broadly (reviewed in Aristodemou & Tietze, 2018).

Key factors for successful governance of AI in decision-making include transparency, interpretability, and explainability (reviewed in Černevičienė & Kabašinskas, 2022). Implementing these principles helps ensure that decisions based on AI can be understood and tested for bias, and that AI reasoning can be confirmed to be accurate, providing stakeholders with greater confidence in the results (Arrieta *et al.*, 2020).

7.3 Governance

Governance considerations are relevant to international STIK partnership decision-making at different scales. At the broadest scale, STIK advances are pursued by an increasingly globalized network of participants; entering an international partnership represents a decision to participate in this global network. Ensuring inclusiveness, fairness, and justice at this level demands effective policy and management tools (Wagner, 2018). Wagner (2018) notes three emergent levels at which science operates: (i) the practitioner (organized in teams), (ii) the discipline or organization, and (iii) the interactions among nations. Because of this structural complexity, knowledge creation and diffusion are non-linear; that is, large changes in one level can be the result of small inputs at a different level. Even within nations, science itself is difficult to govern, given the complexity of the system. Good governance comes from institutions that provide mechanisms to reach consensus, build community, and establish order, legitimacy, and stability (Wagner, 2018). International STIK partnerships themselves provide a mechanism for Canada to participate in the governance of the global STIK network.

With respect to the panel's charge, governance is important in both the narrow sense — stewarding a framework and its implementation — and the broad sense of maintaining a well-functioning ecosystem of decision-making support at the intersection of STIK and international affairs. While implementing a framework built from the elements described in this report is certainly feasible for an individual organization, the panel suggests that a more efficient and effective strategy would include developing an infrastructure to support the network of users. A governance structure could be engaged, for example, to help coordinate and allocate resources (Provan & Kenis, 2007), such as those related to strategic foresight (Section 7.1) and data collection and implementation evaluation (Section 7.2). In the panel's view, the main attributes of successful governance in the context of partnership decision-making are effective coordination, adequate and sustained resourcing, and accountability.

7.3.1 Governance Models

Appropriate governance ensures that partners can voice their priorities and work together, in order to reduce barriers and find solutions. Many of the aspects of successful partnerships also apply to the success of a framework. For example, to be successful, partnerships must be resourced, inclusive of diverse actors (e.g., provinces and territories, academia, business, civil society), and hold broad political support (OECD, 2006). When developing new or sustaining existing partnerships, the OECD (2006) notes that consideration must be given to the location of desired assets, the willingness and capabilities of potential partners, and the objectives of the partnership. Similarly, a framework requires the political will to implement it; articulating how international STIK collaboration can address national priorities will help a framework resonate with policy-makers.

Potential framework users reflect a network of actors in the STIK ecosystem

There are a variety of documented network governance structures. For example, Provan and Kenis (2007) outline three forms of governance relevant to a network:[17] shared governance, lead organizations, and network administrative organizations. In shared governance, each network participant shares governance responsibilities — actions are coordinated either formally, through representatives and scheduled meetings, or informally, through ongoing interactions. Shared governance is decentralized and most effective when there are relatively few, highly engaged participants that share a high level of trust in each other as well as a strong consensus on the collective goal of the network. When there are more participants and less consensus on a collective goal, a lead organization may be effective, as it can make more efficient use of resources and broker relationships among network participants. Lead organizations can emerge naturally from a network, or they can be mandated, for example, by external funding. An external governance structure may be most effective when there are many participants and the need for competencies in governance is high. Such a network administrative organization differs from a lead organization in that it is not a member of the network but is instead external and accountable to network members (Provan & Kenis, 2007).

Shared governance models are relevant to inclusive international STIK collaborations

In the pursuit of international STIK partnerships, it is important that governance not introduce new barriers to participation and collaboration. Given the increasing interest in co-creation and inclusive innovation (e.g., GC, 2017a; ESDC, 2022), co-governance and collaborative governance are emerging concepts relevant to the pursuit of STIK endeavours (Donahue & Zeckhauser, 2011; Gray & Purdy, 2018; Coastal First Nations, 2022; Earl *et al.*, 2023). Florini (2019) argues that "collaborative governance goes beyond the traditional government hierarchies and market-based approaches." In these collaborative models, decision-making authority is shared significantly among all partners, using what Donahue and Zeckhauser (2011) refer to as "shared discretion" (Florini, 2019). Such collaborative governance requires collective decision-making processes that go beyond merely managing a partnership agreement; it involves managing the STIK collaboration risks and opportunities, as well. Florini (2019) highlights how "cross-sector collaborative governance is desirable because it can encompass a greater diversity of skill sets and resources in problem-solving and can generate a wider range of solutions."

17 A network is a group of "three or more legally autonomous organizations that work together to achieve not only their own goal, but also a collective goal" (Provan & Kenis, 2007). Any group of federal bodies and other organizations making use of the framework elements may be considered a network in this sense, reflecting both departmental and organizational goals, as well as national priorities for Canada.

Framework implementation and evaluation would benefit from clear leadership

A characteristic of good framework governance is the presence of a clear lead, whose role is to maintain a framework and provide a window through which potential foreign partners can access Canada.

What We Heard

There is a demand for leadership in international STIK partnership building; however, there is no consensus on who or which department should take that lead. In determining the right steward(s) for a framework, the experience of federal departments — especially those most actively involved in STIK-related activities and partnerships — would be helpful.

Leadership options include a single department, co-leading departments, the creation of a new entity, or an inter-departmental table. A lead organization could be supported by sub-leads with clearly defined duties and responsibilities for various sectors or types of partnerships. These sub-leads would report to the lead, resulting in a multi-tiered governance structure. As one example, the creation of a new position, such as an Assistant Deputy Minister for Scientific Affairs, within GAC could provide leadership and send a clear signal about the importance of STIK in Canada's foreign, trade and development policies (Frosch *et al.*, 1999). Another option is the establishment of an external administrative organization, such as a framework secretariat, which, if appropriately resourced, could also create institutional support for strategic foresight, data collection and management, and framework evaluation.

What We Heard

Interviewees tended to point either to ISED (as the lead for domestic STI policy and for Canada's membership in many multilateral STI forums) or to GAC (as the lead for foreign policy, international trade policy, and bilateral STI agreements at the nation-to-nation level) (TCS, 2015). Given their respective roles, each department could credibly lead the implementation of a framework. However, other organizations (e.g., CRCC, Tri-Council Secretariat) were also identified as having the potential to lead.

7.3.2 Coordination and Resourcing

Effective implementation of a framework will depend on a coordinated approach across the wide range of Canadian actors engaged in international STIK partnerships. As with leadership (and as reviewed in Chapter 3) there are a variety of options available. For example, INIST provides an information-sharing table that includes the relevant federal departments and agencies, as well as some of the federally supported organizations in Canada's STIK ecosystem (e.g., CIFAR, Mitacs). There is also the CRCC, which coordinates the efforts of the Tri-Council granting agencies and the CFI. As well, the Office of the Chief Science Advisor oversees a network of departmental science advisors who could support framework implementation. The proposed CIC may also play a role in international STIK partnerships.

A coordinating structure must be clear and recognizable to ensure success

A coordinating structure that is well aligned with the underlying dynamics of the scientific community is beneficial; in this way, potential framework users can be responsive to bottom-up signals of where science and innovation are going (Dufour, 2021). Beyond information sharing, a coordinating body could have responsibility for:

- reviews of existing and prospective S&T agreements and MOUs (e.g., U.S. NSTC, 2022);
- complementarity studies that periodically explore potential areas of mutual interest between Canada and other countries (e.g., Dufour, 2021); and
- the development of effective indicators and metrics, and maintenance of a STIK data repository.

The panel notes that resourcing of such a coordinating body is essential to ensuring its success. An effectively harmonized, strong, and dedicated funding mechanism for international STIK partnerships may also be helpful in establishing legitimacy and longevity for the coordinating structure.

What We Heard

A lack of funding attached to international S&T agreements was noted among many of the interviewed departments and agencies. Dedicated resources for international STIK partnerships can help ensure activity and shared success.

Intelligence sharing will be key to ensuring relevance of the governance structure

In addition to a data repository, the coordinating structure could benefit users by facilitating intelligence and information sharing on aspects of international partnerships that are not captured by quantitative data sources. For example, Canada has S&T counsellors in select missions abroad who provide a range of services, including services that:

> - *facilitate technology acquisition and technology transfer;*
> - *search out contracts, make introductions, and locate foreign firms interested in arrangements such as joint ventures and R&D collaborative projects;*
> - *gather information on specific S&T areas and direct specialists to more detailed information; and*
> - *familiarize Canadian firms with the business practices and operations of science and technology organizations in host countries.*
>
> EAITC (1990)

What We Heard

One consideration offered by interviewees was making greater use of scientists and engineers from the science-based federal government departments, who can serve in the role of S&T counsellors on secondments. Canada could also make greater use of science diasporas to raise awareness of collaboration opportunities and build cultural intelligence and sensitivity in support of effective collaborations.

Framework elements can complement existing frameworks and strategies

The panel recognizes that there are pre-existing frameworks and strategies in Canada centred on diverse aspects of STIK. These strategies can include relevant aspects of free trade agreements, as well as global, regional, national, provincial/territorial, Indigenous-based, and sector-specific STIK policies and activities, such as *Canada's Indo-Pacific Strategy* (regional strategy), *Canada's National Quantum Strategy* (national technology strategy), the *National Inuit Strategy on Research* (Indigenous strategy), and *The Canadian Critical Minerals Strategy* (sector-specific strategy) (ITK, 2018; GC, 2022e, 2022f, 2022i). The framework elements proposed in this report can be used to complement these strategies; for example, they can help actors identify priorities for the articulation of goals or provide guidance in the choice of indicators. A framework could also be adapted to seek new partnership opportunities; for instance, examining priority countries listed in *Canada's Indo-Pacific Strategy* through the critical lens of a framework could focus Canada's approach and negotiations related to STIK.

Moreover, existing strategies may be leveraged to improve the use of a framework. For example, the Indigenous perspective reflected in the *National Inuit Strategy on Research* could inform partnerships in the Arctic region (ITK, 2018). Similarly, STIK partnerships targeting Canada's natural resources would ideally consider *The Canadian Critical Minerals Strategy* (GC, 2022e). Furthermore, *Canada's Indo-Pacific Strategy*, which positions Canada as a dependable ally willing to cooperate with members of the Indo-Pacific region,[18] is an important consideration when evaluating and prioritizing potential STIK partnerships in that region (GC, 2022f). Awareness of existing domestic and international STIK strategies, guidance, and programs is vital to the strategic implementation of a new framework for prioritizing international STIK partnerships.

7.3.3 Accountability

Accountability is the "means of explaining and enforcing responsibility" (TBS, 2005). It includes clear information flows on how responsibilities are carried out, the identification and correction of problems, and the application of consequences for damaging actions or inaction (TBS, 2005). Success factors such as those applied to environmental governance may be useful tools for a broader governance structure; these include shared decision-making, popular accountability, transparency, and mechanisms for conflict resolution and collaboration (Craig *et al.*, 2017).

In order to be accountable, there must be mechanisms in place to inform the governed population of what is going on (behaviour) and to influence those behaviours (enforcement) (Hale, 2008). While transparency is widely recognized as a success factor in governance, it is neither a guarantee of success, nor the sole factor (Kosack & Fung, 2014). Moreover, to be valuable, information flows must consider factors related to inclusion: Who will use the information? Why should they care about this information? What will they do with it? Without mechanisms in place to act on transparency, thorough accountability measures — such as the ability to exit the system, to collaborate on its improvement, or to confront authorities — will be limited by a lack of knowledge (Kosack & Fung, 2014). For

18 The Indo-Pacific region consists of 40 economies comprising billions of people and almost $50 trillion in revenue; six of Canada's top global trading partners are in this region (GC, 2022f).

example, actions that strengthen accountability include clarifying expectations; adjusting resourcing or building capacity to meet those expectations; improving or creating transparency and reporting mechanisms; and conducting evaluations on the effectiveness of these actions (TBS, 2005).

7.3.4 Balancing Stability and Flexibility

Success factors other than the specific structure or mechanisms of a framework's governance include the need to balance flexibility and stability in the face of changing conditions (Craig *et al.*, 2017). Stable governance structures contribute to legitimacy through shared understandings and expectations, and through predictability and communication in decision-making. However, too much stability can lead to rigidity — that is, an inability to recognize and act on changing conditions and threats (Craig *et al.*, 2017). As in other complex systems, participation, engagement, and coordination among actors will contribute to the success of the governance structure (Ben Yahia *et al.*, 2019).

Stability and flexibility in a governance structure reflects its ability to cope with change

At a high level, flexibility is demonstrated in the mindset and attitudes of leadership; at lower levels, it is manifested in actors' ability to choose among different methods and processes to accommodate current conditions (Müller *et al.*, 2014). The proposed framework elements capture lower-level flexibility in its building-block approach — the steps of identifying priorities and articulating goals allows for flexibility in approaches depending on the user and their specific decision-making context, while the indicators discussion in this report (Chapters 4 through 6) highlights a variety of tools and metrics for assessing potential partnerships that can achieve those goals. Flexibility at a higher level is a consideration of governance structure, including the division of authority, the definition of authority, and the interaction requirements between the governing authorities and the users of a framework (Craig *et al.*, 2017). Building in a formal process that allows for change in the governance structure, along with recurring opportunities to review implementation, are key elements of flexibility. However, too much flexibility can result in arbitrariness; this can be addressed through good governance practices, such as transparency, accountability, inclusiveness, and fairness (Craig *et al.*, 2017).

What We Heard

Many of the interviewed departments and agencies noted that most STIK partnerships are not driven by top-down, federal directives, but rather by the needs and initiative of individuals and teams. Thus, a successful international STIK partnership decision-making framework must allow for sufficient customization to reflect specific user needs.

7.4 Looking Forward

Global STIK participation has reached an inflection point due to new entrants, growing economies, rapidly evolving challenges, and its own overall expansion. Participation in international STIK partnerships is essential to the continued prosperity and well-being of people in Canada and around the world. Strategic and deliberate partnerships, coordinated at a national scale through a decision-making framework built around national priorities, can help Canada seize opportunities, take risks, and find successes. But the need for strategy is acute.

The urgency to respond to long-term, complex, global problems cannot be overstated, and international STIK partnerships are part of that response. The volatility of geopolitics underlines the value of finding space for international cooperation. An effective decision-making framework can balance actions that address immediate concerns with long-term priorities. Strategic foresight activities can pull futures into focus by assembling a plethora of potential indicators and metrics into a decision-making framework, one that can provide a wide menu of options adaptable to changing contexts and considerations. The long-term viability of any decision-making framework depends on the resources committed to its upkeep. Time and again, the panel heard from workshop participants, interviewees, and guest speakers about the need for better coordination and information sharing to support decision-making — it also noted an absence of funding in the creation of many federal partnership agreements.

Canada has long balanced the local with the global, and the top-down with the bottom-up, in its decision-making processes. For decades, STIK partnerships have been driven by the research needs and the network connections of researchers; these mechanisms are vital to a thriving, responsive STIK ecosystem. However, Canada has also struggled for decades to coordinate STIK efforts, to provide clear direction and support for decision-makers, and to present a clear point of entry for potential international partners. In response, the panel presents the building blocks of a framework for making decisions about international STIK partnerships.

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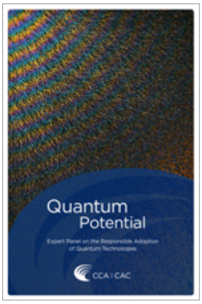
CCA Reports of Interest

The assessment reports listed below are accessible through the CCA's website (www.cca-reports.ca):



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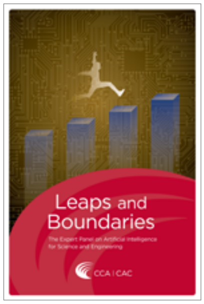

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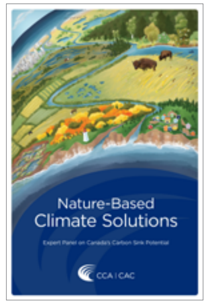

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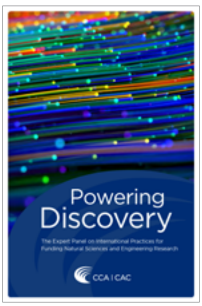

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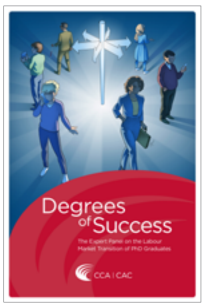

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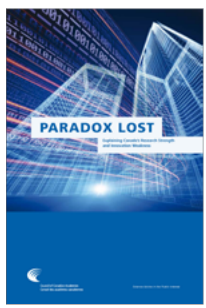

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