

Article

# **Explaining the Diffusion of Renewable Electricity Technologies in Canadian Remote Indigenous Communities through the Technological Innovation System Approach**

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**Abstract:** This paper applies the Technological Innovation System (TIS) approach for the first time in the context of remote indigenous communities in Northwest Territories (NWT) and Ontario, Canada, to explain the diffusion of Renewable Energy Technologies (RETs). These communities need reliable and sustainable electricity to address social, environmental and economic development issues. The study examines the diffusion of RETs during the 2000–2016 period, identifies the systemic and transformational failures responsible for the functional performance of the TISs, and generates insights about factors that have the potential to sustain the development of RET projects. Findings suggest that the TIS-proposed causal mechanisms were present and performed as expected. Since the accumulation of TIS functions influences the rate of deployment of renewable technologies, policy intervention to improve local learning and networking could lead to accelerated diffusion of RETs to the benefit of remote communities and other stakeholders.

**Keywords:** technological innovation system; sustainable electricity systems; renewable energy; remote indigenous communities

## 1. Introduction

There is increasing interest in the role of renewable energy technologies (RETs) within community sustainability transitions, ranging from energy efficiency measures to energy efficient housing development and local electricity generation [1–3]. Overall, 144 Canadian remote indigenous communities, with an approximate population of 100,000, depend upon diesel generators to meet their electricity needs [4,5]. Remote, or off-grid, communities are permanent or long term (five years or more) settlements with at least 10 dwellings that are not connected to the North American electricity grid or the piped natural gas network [5]. The transformation of these local electrical systems through the introduction of RETs therefore has the potential to reduce environmental impacts in the form of carbon emissions, fuel spills and leakages, increase electricity supply and reliability, as well as improve socioeconomic conditions through new housing and business connections and reductions of community electrification costs [4].

However, despite the multiple potential benefits of RETs in off-grid communities [6], the diffusion of such projects remains low. Research in 133 remote indigenous communities indicates 71 RET projects in Yukon, Northwest Territories (NWT), Ontario, British Columbia, Ontario, Quebec and Newfoundland and Labrador between 1980 and 2016 with a total of 31.5 MW or 13% of the total electricity generation capacity. However, if hydroelectricity is excluded, 63 of these projects were small scale wind and solar applications with a total capacity of 1.6 MW, or less than 1% of the total electricity



generation capacity. Fifty-three of these projects were developed after 2006 and the majority were installed in NWT (29 projects) and Ontario (13 projects) [7–13].

Prior research on the introduction of RETs in remote indigenous communities' electrical systems concentrates on the identification of technical factors that influence a project's financial viability, such as the choice over the extent of the renewable energy resource component (low, medium or high penetration RET integration), economies of scale, developers' expertise, availability of distribution infrastructure, smart grid considerations, lower cost storage technology, reliable, robust equipment, and packaged systems using plug-and-play control technologies (see for example, References [14–21]).

In addition to quantitative studies, a limited number of qualitative contributions provide insights on structural, institutional and sociocultural factors for the successful deployment of RET projects in Canadian remote indigenous communities [22–25]. Furthermore, the dynamics of the transition of remote indigenous communities' electrical systems to more sustainable ones have been explained using the Multi-Level Perspective (MLP) framework [26,27] and the interaction of co-evolving factors, such as destabilizing mechanisms at the landscape level, stabilizing mechanisms and governance structures at the regime level, and the adoption of innovative technologies at the niche level [28]. However, the MLP is unable to elaborate in detail, first, how the implemented governance structures that influenced the transition process came about, and, second, the roles and strategies of participating actors, the interactions between actors and institutions, and the role of resource distribution in the development of networks and actors' capacity [29,30].

This level of detail could be provided through the technological innovation system (TIS) approach and the use of functions and functional interactions [31]. The TIS approach defines innovation systems as "a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion and utilization of technology (Carlsson and Stankiewicz, 1991, p. 111)" (cited in Reference [29]). Actors, institutions and interactions (relationships) between them are introduced as the unit of analysis [31,32]. Actors include private consumers, firms, governmental agencies, universities, non-governmental organizations (NGOs) and a multitude of other organizations participating in any given technological innovation. Institutions are considered the laws and regulations, technical, formal and informal rules and norms, visions, and expectations that shape the interactions among actors [29]. Finally, interactions (or relationships) are means of transferring codified and tacit knowledge at the individual or organizational level; as such, interactions are developed and exchanged between the elements of the system through cooperative relationships or the establishment of networks between different actors, between actors and institutions, and among institutions [29]. Wieczorek and Hekkert add infrastructure, in the form of physical (artifacts, machines, roads, buildings), financial (financial programs, subsidies, grants), and knowledge (expertise, know how, strategic information), as important structural components, the existence and performance of which may directly influence the uptake of a certain TIS [33].

The performance of a TIS depends on the way that actors engage and interact with each other at multiple levels thereby influencing the quality of three main functions, the generation, diffusion, and use of the innovation investigated [34,35]. These functions, in turn, depend on the quality and interactions generated by a set of "sub-functions", defined as F1 (entrepreneurial activities), F2 (knowledge development), F3 (knowledge diffusion), F4 (guidance of the search), F5 (market formation), F6 (mobilization of resources), and F7 (creation of legitimacy/support from advocacy coalitions) [31,32]. It is during the formative period of the TIS that the interactions between sub-functions may create virtuous cycles (or motors of innovation) or processes of cumulative causation leading to the uptake of the TIS; the successful fulfillment of a function possibly leads to the fulfillment of other functions leading to the reinforcement of the process and a virtuous cycle [31,36]. The sub-functions in turn are influenced by the existence and quality of the structural elements, so it is the constant interplay between the system elements, coordination mechanisms, and the development of interrelations that defines the dynamic character of the TIS that may or may not lead to the uptake of certain innovative products within a specific environment [31–33].

Empirically, operationalization of the functional pattern is achieved through a set of indicators or diagnostic questions, which can be both qualitative and quantitative, describing the content of the function [32]; for example, entrepreneurial activities (F1) can be measured through the number of new firms established or new projects undertaken, and the function guidance of the search (F4) can be measured through the targets developed by governments or press releases that set expectations and future policy goals [29]. Mapping of TIS functions through activities (their operationalization) over a time period can additionally create an evolutionary pattern of the innovation under examination [34].

Accordingly, the uptake of a TIS can be examined through an analysis of both the functional and structural components that form the TIS. A combined functional-structural analysis will explain the diffusion of the innovation through the presence, or lack of, or weakness of functions, which, in turn, may be the result of systemic problems of the TIS examined. The systemic problems (or systemic failures or weaknesses) were categorized as actors' problems (presence and capabilities), institutional (presence and capacity), interaction (presence and quality), and infrastructure (presence and quality) problems [33,37,38]. Therefore, policy-related issues result from the proposition that both the structure and functions of a TIS are influenced by the existence and quality of different actors and their capabilities, institutions, and infrastructure, as well as the existence and quality of the interactions [30,32,39]. Both structure and function can be influenced by "inducement" and "blocking" mechanisms, which are responsible for the shaping of the TIS dynamics. Targeted policies may affect the mechanisms that induce the transformation process creating the "virtuous cycles" of successful activities, resulting in the moving of key processes and the diffusion of the specific technological innovation, and the transition from one sociotechnical regime to the (more sustainable) desired next one [29,32,40].

The TIS approach has been criticized for its (internal) focus on innovations' functional performance and a lack of integrating external factors [29,41], concepts of power [42] and political intervention [43]. Accordingly, systemic problems within a TIS were extended to include directionality (lack of shared vision), policy coordination (lack of horizontal and vertical policy coordination), demand articulation (absence of public demand) and reflexivity (involving actors in processes of self-governance) failures [41]. Furthermore, recent TIS studies on the diffusion of RET innovations argue for exploring the link between deployment and local contexts, institutional conditions, and learning [44–47], which could only be partially captured through a comparative structural analysis of regional or national TISs [48].

In terms of empirical studies, the TIS approach has been used to examine the development, generation and deployment of innovations as either a single process in developed countries [49–51], or as an innovation aimed at replacing existing products in developing countries [39]. Furthermore, the approach has been used to examine both the deployment of infrastructural level energy innovations, such as combined heat and power [52] and district heating [53], as well as the deployment of less technologically demanding RET applications in both developed [54] and developing country contexts characterized by remoteness [55] and energy access challenges [56,57]. Accordingly, the purpose of this study is to apply the TIS approach to explain the diffusion of RET projects, primarily in the form of solar applications, in the specific political, cultural and institutional context of Canadian indigenous remote communities (see for example, References [58–60]) in Northwest Territories (NWT) and Ontario between 2000 and 2016, and generate insights about factors that have the potential to sustain their development.

This paper is structured as follows: Section 2 presents the methodological approach, followed by the results and discussion in Sections 3 and 4. Section 5 offers concluding remarks.

#### 2. Materials and Methods

To explain the diffusion of RETs in Canadian remote indigenous communities and identify factors influencing their deployment, the performance of the NWT and Ontario TIS are assessed through a combined functional and structural analysis. The steps proposed by References [32,33] are followed (Table 1).

Step

Step 1

Step 2

Step 3

Descriptio

that influence the functional performance

Analysis and comparison of the NWT and

Ontario TISs functional performance

Identification and analysis of systemic

problems responsible for the

blocking mechanisms.

through event mapping.

Definition and structu under consideration. Identification of blocki

of the TISs.

Table 1. Research process.				
n	Supporting Framework	Methods	Results	
re of the TISs				
ng mechanisms	Table 2 (based on	Systematic review of academic and policy documents and key informant interviews	Section 3.1	

in a remote indigenous community.

non-academic, policy, utilities' and

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First, the TIS under investigation is defined and the structure, functional pattern, and the main blocking mechanisms and underlying systemic problems that hinder the fulfilment of the functions in both TISs are identified using the framework presented in Table 2 (Sections 3.1 and 3.2). In a second step, the systemic problems responsible for the poor functional performance of both the NWT and

Table 2. Framework for the analysis of the TIS in remote indigenous communities.

Ontario TIS are "precisely identified" and analyzed [33] (p. 85) (Section 3.3).

Functions	Evaluation of Functions Based on Diagnostic Questions	Identification of the Reasons Affecting Function Performance	Identification of Systemic (Actors, Institutions, Networks, Infrastructure), and Transformational (Directionality, Demand Articulation, Policy Coordination and Reflexivity) Failures Responsible for the Blocking/Inducement Mechanisms
Fn n = 1, 2, , 7		Blocking/inducement mechanisms) affecting Fn	Actors: Presence? Capabilities? Institutions: Presence? Capacity/quality? Interactions: Presence? Intensity/quality? Infrastructure: Presence? Capacity/quality? Presence and quality (effectiveness) of directionality measures? Presence and quality (effectiveness) of demand articulation measures? Presence and quality (effectiveness) of policy coordination measures? Presence and quality (effectiveness) of reflexivity measures?

Adapted from [32,50]. See also [61].

In a third step, the functional performances of the NWT and Ontario TIS during the 2000–2016 period are analyzed and compared in order to, first, explain the diffusion of the TISs, and, second, to generate insights concerning the main factors that influence the deployment. Functional performance during the period investigated is assessed through mapping actors' activities (events) that changed institutions, influenced interactions and modified infrastructure, and, therefore, addressed systemic problems and contributed to TIS function changes and fulfillment. Events are then allocated to functions based on operationalization indicators [43] described in Table 3. Findings follow in the form of a narrative that explains the historic development of both TISs through changes in the structure and functions' interactions. Events that contribute positively to function fulfillment are marked with a positive (+) sign, and events that influence functions in a negative way are marked with a negative (-) sign (Section 3.4).

Section 3.3.

Section 3.4.

System Function	Operationalization Indicators
F1. Entrepreneurial activities	Development of remote community owned RET projects.
F2. Knowledge development	Conducting renewable resource surveys, monitoring studies, feasibility studies. Community energy plans. Small scale RET experiments. Participation in research projects.
F3. Knowledge diffusion	Training of community members. Promoting energy related education, developing energy campaigns, organizing and participating in conferences, exhibitions, workshops, charrettes, seminars, meetings.
F4. Guidance of the search	Establishing targets for RETs. Design of policies and regulations that favor RET solutions. Design of policies and regulations that favor RET solutions in remote indigenous communities. Establishing expectations from RETs projects on indigenous lands. Providing direction and expressing interest in RETs options. Publication of results from studies involving RETs in remote communities.
F5. Market formation	Regulatory arrangements that allow local governments and their organizations to participate in the electricity generation process as Independent Power Producers (IPP). Power Purchase Agreements (PPAs). Net metering agreements.
F6. Resource mobilization	Providing financial incentives (for project capital, technical training, electricity generation). Providing loans. Providing loan guarantees. Financing research projects. Mobilizing cooperation with the private sector.
F7. Support from advocacy coalitions/legitimization	Advocating for indigenous RETs projects in remote communities. Statements of indigenous leadership on the cultural fit of RETs projects. Community visions and expectations favoring RETs deployment.

Table 3. Functions and operationalization indicators for the NWT and Ontario TIS.

Data on the blocking mechanisms were collected through interviews with members of a remote indigenous community and a systematic review of academic and policy documents. The semi-structured interviews with 10 key informants, members of a remote northern Ontario community actively pursuing RETs projects, were conducted in October 2014. Interviews were undertaken following the Tri-Council policy requirements and received ethics clearance from the Office of Research Ethics at the University of Waterloo. Participants were proposed by the Band Council, were over 18 years old and consented in writing and to be interviewed orally. Secondary data were collected through a search in Scopus and Web of Science databases of the keywords: "renewable" AND "electricity" AND "barriers" AND "indigenous" AND "Canada", which returned 113 and 12 documents respectively. After eliminating studies irrelevant to Canadian context, seven documents were related to Canadian remote indigenous communities, of which only one document discussed barriers to RETs implementation. The search was then extended to non-scholarly journals and the internet and 13 documents were identified, presented in Section 3.2, which described barriers to RET deployment into Canadian remote indigenous communities.

Data for the event analysis were collected through multiple literature reviews of academic and non-academic, policy, utilities and communities' literature. Event analysis included only events that signaled a change of state and communicated public importance [62]. A list of the events and their allocation to functions is presented in Tables A1 and A2 in Appendix A.

#### 3. Results

## 3.1. TIS Structure

The NWT and Ontario TISs (see also References [8,11]) are defined through a niche component (a new technology or sociotechnical practice) and its supporting system [29]. The niche consists of a sociotechnical practice, defined as the deployment of existing RETs in remote communities by indigenous governments with the purpose of undertaking (partially or in full) the electricity generation functions currently performed by Crown corporations (state utilities), with the aim to improve community sustainability, and environmental and socioeconomic conditions. This deployment encompasses both the domestication and societal embedding of new technologies, as well as measures involved in selecting, designing, purchasing, commissioning, and installing [63,64] solar and wind turbine applications in remote indigenous community diesel systems, to create hybrid solutions that provide acceptable power quality and supply. The supporting system includes a network of actors and institutions that jointly interact and contribute to the RET deployment. In addition, the TIS is concerned with the associated administrative procedures (such as planning and permitting), institutional and organizational changes, and regulatory and fiscal arrangements that allow for indigenous ownership of the RET application and participation in the electricity generation process.

The deployment of RETs in NWT and Ontario can be represented as two different TISs, with different and shared participating actors and their networks, and subject to shared and non-shared institutions. Key stakeholders in electricity generation include local indigenous governments and residential consumers, the federal and provincial/territorial governments, utilities operating mostly at "arm's length" from provincial/territorial governments, governmental agencies, academic and research institutes, non-governmental organizations, and the private sector. Indigenous people are subject to specific governance structures (the Indian Act; Land Claims and Self Government processes) [65], lack market economies [66], have historically experienced high unemployment and low educational attendance levels [67–69], and most importantly, have specific cultural values and worldviews on economic development, environmental governance and resource exploitation [58,70,71].

In addition, community electrical systems are the joint responsibility of both federal and provincial governments, with the federal government responsible for capital upgrades of the electricity generation equipment, and the provincial government responsible for maintenance and operations [72]. Furthermore, high electricity generation costs are subsidized by both federal and provincial governments, through cross subsidies, and direct and indirect funding. Communities also exhibit similar challenges, such as housing shortages, environmental concerns, economic development needs [4,71,73], competing and shifting Band Council interests and priorities, and fluctuations in federal and state funding [74]. Entrepreneurial ventures within remote communities are the sole responsibility of indigenous governments and Local Development Corporations (LDCs) that aim at activities that fulfill three main goals, namely, economic development (in the form of revenue generation and employment), cultural preservation (in the form of minimal impact of ventures on lands and waters, ecological wellbeing, traditions and culture), and self-governance (expressed through the use of local resources, participation in management, and ownership of assets supporting self-sufficiency and self-reliance) [75–79].

#### 3.2. TIS Functions Performance

The successful deployment of RETs in Ontario and NWT indigenous communities will depend on a well-functioning TIS, influenced by the specific institutional setting and indigenous cultural, socioeconomic and self-governance considerations. The fulfillment of the TIS functions is influenced by the existence of blocking mechanisms. Table 4 presents the blocking mechanisms, identified through a review of academic and policy literature [22–24,80–89] and informants' interviews, and their influence on the different TIS functions. The performance of the functions is discussed below.

System Functions	Blocking Mechanisms		
F1. Entrepreneurial activity	<ul> <li>-Lack of capital/access to capital [22–24,80,82–84,86,87,89] and key informants' interviews.</li> <li>-Vested interests [84].</li> <li>-Lack of capacity (community expertise) [23,81–85,87–89] and key informants' interviews.</li> <li>-Infrastructural deficiencies [81,86,89].</li> </ul>		
F2. Knowledge development	<ul> <li>-Existing regulatory processes associated with electricity generation [23,81,84,88,89] and key informants' interviews.</li> <li>-Lack of legal/regulatory framework on RETs deployment [80,82,83,87,88].</li> <li>-Lack of capacity (community expertise and energy education) [23,81–84,86–89] and key informants' interviews.</li> <li>-Lack of networks [80,82,86] and key informants' interviews.</li> </ul>		
F3. Knowledge diffusion	-Lack of capacity (community expertise and energy education) [23,81–84,86–89] and key informants' interviews. -Lack of networks [80,81,86] and key informants' interviews.		
F4. Guidance of the search	<ul> <li>-Existing regulatory processes associated with electricity generation [23,81,84,88,89] and key informants' interviews.</li> <li>-Vested interests [84].</li> <li>-Lack of capacity (community expertise and energy education) [23,81–84,86–89] and key informants' interviews.</li> <li>-Lack of networks [80,82,86] and key informants' interviews.</li> </ul>		
F5. Market formation	-Existing regulatory processes associated with electricity generation [23,81,84,88,89] and key informants' interviews. -Vested interests [84]. -Subsidies [80,81].		
F6. Mobilization of resources	-Electricity planning considerations [23,81,84,88,89] and key informants' interviews. -Bureaucratic procedures [key informants' interviews]. -Lack of capacity (community expertise and energy education) [23,81–84,86–89] and key informants' interviews.		
F7. Support from advocacy coalitions/legitimization	-Vested interests [83]. -High capital (investment) costs and reliability concerns [82,83,86,87,89] and key informants' interviews.		

Table 4. Key blocking mechanisms and their influence on the NWT and Ontario TIS functions.

## 3.2.1. Entrepreneurial Activity (F1)

The communal character of indigenous communities, limitations under the Indian Act, and cultural perceptions on entrepreneurship point to LDCs as the appropriate business development entity for RET experimentation within indigenous communities [90]. Community-owned RET projects could provide electricity directly to community members, or power community buildings under net metering agreements, or generate renewable electricity from stand-alone projects, which can be sold to non-indigenous utilities that operate the local systems. Community entrepreneurial activities are hindered by the lack of community financial resources and technical expertise, infrastructural deficiencies and electricity generation regulations, as well as community interests favoring the continuation of diesel electricity generation.

## 3.2.2. Knowledge Development (F2)

Knowledge development of RET applications at the community level takes the form of understanding potential community socioeconomic and environmental impacts and benefits, identifying the availability of local renewable resources and potential generation sites, developing technical solutions and implementation techniques, as well as improving human capacity in terms of technical and managerial skills. The knowledge development function is blocked by existing regulatory processes associated with electricity generation and

a lack of a governmental focus on addressing indigenous governance concerns through RET development. Furthermore, knowledge development and community knowledge development capabilities are blocked by limited linkages with other actors (e.g., academia and industry) and a lack of communal capacity to participate in renewable resources surveys and monitoring studies, feasibility studies, community energy plans, and small scale RET experiments.

## 3.2.3. Knowledge Diffusion (F3)

Knowledge diffusion involves the dissemination of information within and across multiple communities on the cultural appropriateness, adaptation to local needs, potential benefits, and implementation difficulties of RETs. Favorite methods for the diffusion of knowledge, information exchange, and learning facilitation in indigenous communities include the establishment of networks that enable community participation in meetings, conferences, workshops, charrettes, training of community members and promoting energy-related education. The knowledge diffusion function is blocked by limited linkages and inadequate networks between indigenous remote communities and specialists that can facilitate learning from established projects.

## 3.2.4. Guidance of the Search (F4)

The guidance of research function represents the selection process that evaluates innovative solutions and facilitates their adoption, while taking into consideration community priorities and concerns based on local sustainability and governance perspectives. Indigenous perspectives on RETs deployment include pursuing and articulating specific targets, policies, and regulatory and fiscal reforms and incentives to improve communities' electrical systems. Guidance of the search is blocked by the existing electricity generation regulatory framework, consisting of planning principles, regulations, electricity rates and subsidies, and lack of provincial targets and policies for the development of RETs. Furthermore, the function's performance is influenced by community vested interests and risk averse attitudes; lack of technical, managerial and financial capacity; as well as the lack of networks that could modify current community and governmental preferences through multiple interactions.

## 3.2.5. Market Formation (F5)

Since the deployment of RETs in remote communities has to compete with established diesel generation, a market for renewable electricity should be instigated [32]. The market formation function for new renewable electricity generation is blocked, first, by reliability and safety regulations due to technical constraints associated with the penetration level of renewables in isolated diesel systems [14,17]; and second, the isolated nature of local diesel electricity markets supported by multiple subsidies necessitates the availability of financial resources for the establishment of new schemes that would support indigenous ownership of RET projects and compensate for vested interests in diesel, while maintaining residential electricity prices at the present level. Regulatory and fiscal arrangements that allow local governments and LDCs to participate in the electricity generation process take the form of Independent Power Producers (IPP) policies and generation incentives in the form of Power Purchase Agreements (PPAs) and net metering agreements.

## 3.2.6. Mobilization of Resources (F6)

The high cost of RETs and lack of community resources necessitates financial, material and capacity support for their deployment [91]. Furthermore, mobilization of resources for new renewable electricity generation in the area of remote indigenous communities is influenced by uncertainty over future electricity demand growth. This results from community and industrial development, and a preference of both NWT and Ontario governments towards large scale, cost minimizing electricity generation options, such as hydroelectricity, in association with grid extensions to supply future mining projects [92,93].

The implementation of RET projects would have to overcome the resistance of established interests in diesel-generated electricity [94] and community consumers' concerns over reliability and increased costs [88,95]. Furthermore, inclusion of indigenous perspectives on the anticipated contribution of RETs in the governance of community electrical systems, and design of policies that provide sustainable environmental and socioeconomic benefits would allow for higher acceptance of RETs by indigenous people.

The underlying systemic and transformational problems responsible for the blocking mechanisms that influence the performance of functions in both TIS are analyzed in the next section.

#### 3.3. Systemic Problems Influencing the NWT and Ontario TIS Performance

#### 3.3.1. Hard Institutional Problems

Two main sets of formal institutions influence the guidance of the search, knowledge development, resource mobilization and market formation functions. First, the regulatory framework for the introduction of RETs, consisting of utilities' planning principles, technical, operational, and safety regulations, and existing rates and subsidies structures, is different in each province. The planning principles focus on energy security, affordability and reliability, reduction of environmental impacts and cost minimization [96], combined with business strategies aimed at electricity generation flexibility [92,97]. Technical, operational, and safety regulations relate to electricity services quality, since high RET penetration levels within local and isolated provincial grids are subject to balance and reliability considerations [14,98]. Furthermore, high electricity generation costs lead to differentiated electricity rates for residential and commercial/governmental consumers funded by provincial and federal subsidies. The height of direct electricity subsidies for residential customers in remote communities ranged between \$3.5 million in 2015–2016 in Yukon [99], to \$34 million in 2015 in British Columbia [100], and approximately \$34 million in 2013 for Rural or Remote Rate Protection (RRRP) contributions in Ontario [101,102]. Finally, total energy-related direct governmental subsidies in Nunavut were approximately \$30 million for 2012–2013 [103]. These subsidies make cost comparisons between diesel powered electricity and RET options difficult and further reduce the motivation for RET deployment.

Second, formal institutions related to property rights, governance under the Indian Act, and indigenous views on development are responsible for limited entrepreneurial activities. Lack of property rights limits the possibility for non-indigenous and indigenous private entrepreneurial activities within reserve lands [66], and hinders access to banking loans, since traditional land is not accepted as collateral for financing purposes [75,77]. In addition, all economic activities within reserves, including energy development, are subject to indigenous governments' environmental licensing and regulation authority, which promotes projects under careful interpretation of treaty and indigenous rights and community socioeconomic benefits [103,104].

#### 3.3.2. Soft Institutional Problems

The existence of soft (informal) institutions associated with social norms, values and culture [37] within indigenous communities influence multiple TIS functions, including guidance of the search, knowledge development and market formation. First, communities have established vested interests in diesel generation through LDCs that cooperate with utilities, acquire rents, and provide employment through diesel storage and distribution [94]. These community interests benefit from diesel dependency and influence market formation, legitimization and social acceptance of the TIS, thus limiting guidance for the search for alternative entrepreneurial activities [105]. Second, risk averse attitudes of indigenous governments may influence guidance of the search away from risky RET applications (such as wind and solar, due to the inherent intermittency of these resources). Third, a community focus on economic development guides indigenous governments' decisions towards grid electrification,

since grid electricity is considered a low risk, reliable, and affordable alternative able to support productive community activities [92,106].

#### 3.3.3. Interaction Problems

Interaction problems are caused by the lack of information exchange and/or the quality/intensity of information exchange between actors, and primarily impact the following functions: guidance of the search, knowledge development and diffusion and legitimization of the TIS [33]. Although local governments maintain direct or indirect relationships with the federal and provincial governments, utilities, private firms and other communities through tribal, provincial, and national political affiliations and interprovincial networks, such as the Assembly of First Nations (AFN), it is apparent that the quality/intensity of interactions and communication between indigenous people and other actors involved in the TIS are affected by various issues.

First, type and extent of interactions with provincial governments are influenced by cultural/political differences based on indigenous views on resource-driven development, with community members divided between those favoring economic development, and those preferring traditional Indigenist approaches [107,108]. Many projects are opposed due to potential impacts on the community's way of life and traditional activities [109]. Second, issues of trust, past relationships, grievances, and land claim disputes, which in turn are affected by indigenous choice of negotiation tactics, compatibility of goals, group cohesion and government perception of the indigenous group, shape the interaction between indigenous people, governments, and private actors [110,111]. Third, interactions favoring RET deployment may be deterred due to local government established focus on (lock-in to) diesel technologies due to the stability of significant revenues provided by diesel vested interests [94]. Fourth, interactions may also be blocked due to the lack of intermediaries, such as mediating organizations and educational institutions that may act as "bridges" helping to surpass issues of trust between indigenous communities and governments, utilities, and the private sector. Interactions with communities that have already implemented RET projects are important, since the sharing of experiences and practices assists in the development of internal capacity to maximize benefits from the projects and legitimizes RETs [112,113].

#### 3.3.4. Capability and Infrastructural Problems

Knowledge infrastructure within the TIS takes the form of specialized knowledge and expertise generated by universities, research institutes and industry, while financial infrastructure consists of supporting incentives, grants and subsidies [33]. At the community level, capability problems take the form of low administrative, managerial and technical capacity [15,20,86]. Lack of local expertise combined with risk avoidance attitudes influence RET-related guidance of the search, knowledge development and diffusion, and entrepreneurial experimentation. Furthermore, lack of physical infrastructure hinders RET implementation on reserves and erodes legitimization. Limited access during winter through a network of ice roads, year-round access by airplanes and/or barges, high accommodation, communication, and energy costs, and lack of specialized equipment (such as cranes) increase the investment cost of any project in remote communities, and necessitate the mobilization of state financial resources [22,24,94].

## 3.3.5. Transformational Failures

Transformational failures [50] are responsible for the underperformance of the guidance of the search and knowledge development, and, in turn, the other TIS functions. Prior to 2000, indigenous participation in renewable electricity generation was minimal and RET project development and ownership were driven by cost considerations of utilities and provincial governments, pointing, therefore, to a lack of shared vision regarding the direction of the electrical system transformation process and a directionality failure. In addition, early governmental support through national energy efficiency policies revolved around tax write-off incentives and financial assistance for R&D activities and implementation studies [114], instead of targeting the transformation of community

electrical systems through engagement and support of indigenous self-governance aspirations in the form of community participation in the decision making and planning process, indicating, therefore, both a policy coordination and a reflexivity failure. Furthermore, limited joint learning processes between governments, utilities, and communities, as well as communities' human capacity issues [23,115], hindered learning processes on the potential environmental and socioeconomic benefits of the introduction of RETs, thus contributing to both reflexivity and demand articulation failures.

## 3.4. Performance of the NWT and Ontario TIS between 2000 and 2016

## 3.4.1. The NWT TIS Performance

## (1) NWT policy intervention to address systemic problems

In NWT, policy intervention during the 2001–2016 period to support RET deployment was introduced through public workshops and energy charrettes that captured stakeholders' differing perspectives on the future of NWT's energy system and led to multiple reviews of energy and electricity-related targets and policies. This interactive approach allowed for reflexivity, directionality and indigenous demand articulation issues to be addressed. During the same period, energy policy coordination issues were ameliorated through the establishment of the Ministerial Energy Coordinating Committee (MECC) that periodically monitored policy coherence at the horizontal level (between sectoral policies) [116,117].

In addition, hard and soft institutional problems influencing multiple functions of the TIS were addressed through federal and territorial programs that were sequentially introduced. Initial programs emphasized capital cost reduction in RET projects, followed by programs focusing on capabilities improvements and network formation through RET-related studies, and technical and educational assistance. Finally, during the 2013–2016 period, regulatory and financial arrangements were introduced to support community owned electricity generation. Network failures were mitigated through the participation, to varied extents, of utilities, universities, research institutes, the private sector and supporting organizations in the development of RET studies and projects. NTPC, ARI, NGOs like Pembina, and non-governmental agencies like Arctic Energy Alliance (AEA), engaged in renewable resource monitoring and feasibility studies, policy recommendations, advisory services, and equipment deployment, and contributed to the direction of the search, knowledge development and diffusion, mobilization of resources, and legitimization of the TIS [84,118–121].

## (2) NWT TIS functional pattern (2001–2016)

The functional build-up of the NWT TIS was initiated with the release of the first NWT Energy Strategy in 2001 (+F4). In the same year, the provincial RETCAP (2001–2003) and the federal Aboriginal and Northern Climate Change Program (ANCCP) (2001–2003) were launched (+F4) providing capital support for RET projects (+F6). These early actions were followed by the Aboriginal and Northern Community Action Program (ANCAP) (2003–2007), engaging indigenous communities to take action to reduce GHG emissions, through community energy planning, community capacity building and wind studies in the Arctic, and promoting collaboration between local, federal and territorial government, utility, education institutes, and renewable energy companies (+F6) [24,122,123]. As a result, feasibility studies for the installation of wind turbines were conducted between 2003 and 2006 for most of the remote indigenous communities (+F2). However, results indicated that wind turbines were financially viable for a limited number of communities (–F4) [21]. In 2006, a demonstration solar application was installed in the community of Jean Marie (+F1).

The NWT government's commitment to the use of sustainable energy sources was further established during the 2007–2011 period. In 2007, the 2007 Energy Plan and the 2007–2011 Greenhouse Gas Strategy were released, both targeting the development of renewable applications and reductions in territorial emissions (+F4) [124,125]. In the same year, the first conference on wind turbine systems for the electrification of diesel powered communities was organized bringing together communities,

utilities, governments and private actors (+F3) [126]. At the same time, the federal government launched the first phase of the ecoENERGY for Aboriginal and Northern Communities Program (EANCP) (2007–2011) funding RET project costs and renewable resource monitoring and feasibility studies (+F4, F6) [122,127], while the territorial government established CREF, as part of the Alternative Energy Technologies (AET) program for financially supporting RET project costs (+F4, F6) [128]. Furthermore, the territorial government initiated a dialogue with communities through the review of existing regulations, rates and subsidies for electricity (+F4) and focused on the coordination of all activities targeting energy reduction through the establishment of a coordinating committee and the use of AEA as a one stop agency for the delivery of programs to the communities (+F4). AEA conducted a significant number of energy planning projects during 2008–2015 and, following the latest technology developments, the Aurora Research Institute (ARI) initiated a new round of optimization studies on the feasibility of wind and solar applications (+F2, F3) [119] (see also References [20,21]). Continuous dialogue between stakeholders led to reviews of the electricity process in 2008, 2009 and 2010 [95–97,129], revealing community interest in participation in RET projects, and leading to a revised Energy Strategy and Greenhouse Gas Strategy in 2011 (+F4) [117,125]. By the end of the 2007–2011 period, 10 small scale solar projects had been installed in remote communities, bringing the total number of solar installations to 11 (+F1) (Table 5).

Time	Time	NWT		Ontario	
Period	Interval	Installed Projects	Average Project Capacity	Installed Projects	Average Project Capacity
2001–2006	6 years	1	1.3 kW		
2007-2011	5 years	10	4.1 kW		
2012-2013	2 years	10	16.6 kW	3	19.3 kW
2014-2016	2 years	8	31.9 KW	10	30.0 kW
Total	-	29		13	

Table 5. RET projects in NWT and Ontario.

During the subsequent 2012–2016 period, a new round of guidance of the search, knowledge development and mobilization of financial resources activities led to an increase in the number and the average capacity of community RET projects. By 2012, multiple theoretical and empirical contributions on remote microgrids technology had been developed globally [130]. In Canada, several new optimization studies on the feasibility of RETs in indigenous remote communities added to knowledge development (+F2) [18,131,132]. Furthermore, in 2012, the NWT government announced its 2012 Solar Energy Strategy and organized the 2012 Energy Charrette to engage communities in the electricity planning process (+F4) [133,134]. The second phase of EANCP (2011–2016) was launched in 2011 emphasizing RET deployment in remote indigenous communities in addition to the continuous financial support from CREF (+F6) and in 2013 the NWT government announced its 2013 Energy Plan, which included its commitment to a reflexive and collaborative policy development (+F4) [135]. Ten higher scale solar projects (16 kW average capacity) were installed in 2012 and 2013 (+F1).

The subsequent 2014–2016 period is characterized by the second Energy Charrette in 2014, where the impacts of previous targets and programs were discussed and further deployment of small scale renewable projects was emphasized (+F2, +F4) [136,137]. Specialized workshops and conferences were organized in Ontario and NWT (Wind-Diesel Workshop, 1–2 June 2009, Ottawa, ON; 1st Renewables in Remote Microgrids Conference, 25–26 June 2013, Toronto, ON; 2nd Renewables in Remote Microgrids Conference, 15–17 September 2015, Yellowknife, NWT) supporting knowledge diffusion and interactions between multiple actors, including indigenous governments (+F3). In addition, regulatory arrangements were introduced in 2014–2015 in the form of net metering and IPP policies that allowed for indigenous communities to participate in the electricity generation process creating a market for indigenous owned

RET projects (+F5) [138,139]. Eight higher scale (32 kW average capacity) projects were developed in 2014 and 2015, resulting in a total of 18 solar projects between 2012 and 2016.

Over the 2001–2016 period in which the NWT TIS evolved, a total of 29 solar projects with a total capacity of 464 kW were developed in 19 of the 25 diesel powered remote indigenous communities. Fourteen communities developed one solar project, three communities installed two solar systems, one community installed three solar plants and one community installed six projects [8].

#### 3.4.2. The Ontario TIS Performance

#### (1). Ontario policy intervention to address systemic problems

In Ontario, policy intervention during the 2001–2016 period in favor of RET deployment included support for both off-grid RET projects and communities' connection to the provincial grid [93]. Reflexivity, directionality and indigenous demand articulation issues influencing the guidance of the search towards RET deployment were addressed by the Nishnawbe Aski Nation (NAN), Tribal Councils, and community leaderships expressing an interest for sustainable options to address community electricity needs [72,140,141]. Furthermore, in a similar process to NWT, systemic problems were addressed through sequentially introduced federal and provincial financial support for projects' capital costs, community training, and community-owned electricity generation. Network problems were improved through the participation of numerous actors, including governmental agencies (IESO, HORCI), NGOs, universities [142], and the private sector that cooperated with indigenous communities in R&D activities related to microgrid planning, testing, and training [143]. Technical, educational, and training support for a number of projects was provided by Shibogama Technical Services [144], an indigenous company supporting the members of the Shibogama Tribal Council, while project deployment and installation of solar projects were performed by indigenous owned enterprises [145]. These indigenous driven RET ventures improved local knowledge, generated local employment, contributed to the legitimization of the TIS, and pointed to the importance of trusted intermediaries for successful project deployment [146,147].

## (2). Ontario TIS functional pattern (2001–2016)

The functional build-up of the Ontario TIS started with the governmental commitment towards renewable electricity generation expressed in 2003 and was supported by both requests for proposals and the 2006 introduction of early feed-in-tariffs to attract investments in renewable electricity generation (+F4, +F6) [148,149]. Indigenous interest in renewable electricity generation and the connection of communities to the provincial grid to improve socioeconomic conditions was expressed in 2008 by NAN, the political organization representing Ontario's remote indigenous communities (+F4) [72,141]. In 2009, the government introduced the Green Energy and Green Economy Act (GEGEA), which included financial incentives for indigenous communities' participation in RET projects (+F4) [150]. In the same year, and parallel to the federal EANCP program, both the Aboriginal Loan Guarantee program (ALG) and the Aboriginal Energy Partnerships Program (AEPP) were established by the Independent Electricity System Operator (IESO) to support indigenous participation in both on-grid and off-grid RETs through the development of community energy plans, feasibility and technical studies, resource assessments and training (+F6) [151,152].

Furthermore, between 2010 and 2013, optimization studies examining the potential of wind applications in Ontario's remote communities were developed (+F2) [20,21] and the second phase of EANCP focusing on RETs for remote indigenous communities was introduced (+F6). Knowledge exchange between academia, government, utilities, private sector and communities was facilitated through the organization of the NAN energy conference in 2012 [140], the first conference on renewable microgrids in Toronto in 2013 and the 2014 NOFNEC indigenous environmental conference (+F3). To support off-grid RET deployment, Hydro One Remote Communities Inc. (HORCI) (a subsidiary of Hydro One Inc., Toronto, ON, Canada), the utility serving 15 of the remote indigenous communities [153], introduced

a net metering and stand-alone arrangement creating a market for local electricity generation (+F5) [154]. In 2013, two small scale solar projects and one wind turbine project were developed in three communities (19.3 kW average capacity), followed by 10 higher capacity projects (30 kW average capacity) installed between 2014 and 2016 (+F1) (Table 5).

In total, as the Ontario TIS evolved from 2008 to 2016, 358 kW of RET were installed in 11 of the 25 diesel powered remote indigenous communities. Five projects were installed in HORCI serviced communities and six in communities operating as Independent Power Authorities (IPA). All projects were installed under net metering arrangements on electricity intensive buildings with a view to displacing full cost electricity, thereby reducing expenses of local governments.

However, during the same period a competing TIS was established, initiated with the governmental commitment of the connection of remote indigenous communities to the provincial grid and the electrification of future natural resources development in the Ring of Fire area (+F4 towards an alternative niche) [93]. Technical studies verified the feasibility and financial viability of the connection of 21 of the 25 remote communities (+F2, alternative TIS) [155–157], and led to the prioritization of the grid connection project in the 2013 update of Ontario's LTEP (+F4, alternative TIS), and, in turn, the participation of 21 remote indigenous communities in the establishment of the transmission company Wataynikaneyap Power that will connect the communities to the provincial grid and provide electricity to mining projects in the Ring of Fire area (+F1, alternative TIS) [158].

### 4. Discussion

The relationship between the functional performance and the diffusion rates of RET projects is discussed in terms of presence and intensity of functions, and the existence of interactions between functions [31].

The analysis of the NWT and Ontario TISs demonstrates that the functional build-up during the investigated period shows a positive relationship to the number of RET projects developed and the transition toward more sustainable energy systems (Figure 1). In both TISs, the functional build-up is initiated with guidance of the search towards the introduction of RETs into community diesel systems followed by mobilization of financial resources, which are used to attract multiple actors, and the development of local knowledge through feasibility and resource monitoring studies. The results of these studies improved actors' learning on RET deployment, led to interactions between indigenous governments and other participants, and initiated a new round of guidance of the search, mobilization of resources, knowledge development and diffusion. Eventually, regulatory and fiscal arrangements were negotiated for the formation of local markets and the installation of higher capacity solar applications on community buildings. In NWT, the larger scale Colville Lake project [159], and the community-owned Lutselk'e solar plant that operates as an IPP producer, contribute further to the legitimization of the TIS [121,160], and signal an interest among communities towards higher renewable penetration projects under IPP ownership. The integration of higher penetration RET projects into isolated diesel power plants (measured through the ratio of the renewable component output (kW) over the primary community electrical load (kW) (instantaneous penetration) and the ratio of the renewable component energy output (kWh) over the community electricity generation output (kWh) (average penetration) [14]) is associated with increased technical complexity of control devices for maintaining acceptable power quality, higher reductions in diesel consumption, and higher, but riskier, financial returns. Subsequent new governmental targets for RET deployment in remote communities [161–163], and the search for new financial mechanisms [164] indicates positive feedbacks between functions and a virtuous cycle characterizing the TIS development.

However, in Ontario, although the interaction of functions led to the functional build-up and entrepreneurial activities within a shorter time frame than in NWT, the functional performance was interrupted by a shift of community interest to a competing alternative [165], namely the potential connection to the provincial grid (new guidance of the search). The new alternative was embraced by communities who anticipate increased socioeconomic benefits through their participation in

Wataynikaneyap Power. As a result, high capacity off-grid electrification projects are expected only for the remaining four communities that are unable to connect [166].



**Figure 1.** Accumulation of functions and RET projects developed in the NWT and Ontario TIS. Source: Data from Tables A1 and A2 in Appendix A.

These results are consistent with the results of References [48,55] that report a positive relationship between the diffusion of RET products and projects and functional intensity in developing countries.

Results also point to three policy-related implications. First, the system-building functions in both TISs, as demonstrated by their strength, are guidance of the search and knowledge development. The functional build-up is initiated with actors' shared interest towards renewable solutions and, given the availability of financial resources, the development of knowledge for the introduction of RET into community electricity systems. Knowledge development in turn engages a significant number of actors in studies and experiments that improve and diffuse knowledge on the deployment of RET. The functional pattern in both TISs consists of successive "morphogenetic rounds" of guidance of the search, mobilization of resources, knowledge development and diffusion, which, eventually, lead to new guidance of the search for ownership of higher capacity and complexity RET projects [36] (p. 96).

Second, results point to the importance of financial resources mobilization for both the initiation of the functional build-up and the improvement of the functional performance, given the high investment costs and the limited financial, technical and managerial capacity of indigenous communities. NWT has spent approximately \$21 million on studying renewable energy applications for remote communities [167] and the federal government provided, between 2003 and 2016, \$65 million through ANCAP and EANCP for knowledge development on the feasibility assessment and integration of RETs into indigenous communities [168].

Third, a comparison between the NWT and Ontario TIS and the rest of the provinces and territories suggests that the system building functions (guidance of the search and knowledge development) are influenced by local institutional factors. Guidance of the search is influenced by the alignment of federal and provincial governments and utilities perspectives with indigenous aspirations to participate in the electricity decision making process, as demonstrated through NWT's multiple electricity reviews, and in Ontario, through the adoption of the NAN agenda on both off-grid and on-grid participation in

RETs. In addition, the performance of the knowledge development function in both TISs is influenced by the existence of local educational and research facilities (universities, research institutes and local agencies) that conducted specialized research, engaged communities in development and installation of RET projects, and contributed to "learning by searching" and "learning by doing" [54].

Finally, functions and the functional build-up in both TISs benefitted from the evolution of a localized network that was formed to promote the deployment of RETs in remote indigenous communities by addressing interaction and transformational failures. These formal networks, consisting of local actors (provincial government, utilities, communities, educational and research facilities, NGOs), but also the federal government and national scale NGOs (Pembina) as well as private firms (Bullfrog Power), were able to build trust and shared expectations, and improve local skills and knowledge through learning processes [146] in order to access, develop and deploy resources in a more effective way than other provinces and territories [169,170].

The importance of the functional build up for the diffusion of RET projects is demonstrated by the lack of such projects in Nunavut, Quebec and Newfoundland and Labrador indigenous communities during the 2000–2016 period. In Nunavut, despite early guidance of the search towards RETs [171] and knowledge development in the form of studies conducted between 2001 and 2009 [172,173], reduced availability of renewable resources (wind, solar and hydro), poor legitimization due to the failure of previous wind projects [174], as well as lack of financial resources from the government of Nunavut and QEC, blocked RETs deployment from 2001 to 2016 [175]. In Quebec, although early guidance of the search for community RETs led to a number of studies financed by Hydro-Quebec [176], diverging and competing community priorities (grid connection and hydroelectricity generation) limited development to only one wind project over the 2001–2016 period [177–179]. Finally, no RET projects were developed in Newfoundland and Labrador between 2001 and 2016, due to a lack of interest towards community RETs from provincial and indigenous governments, and limited commitment of financial resources towards feasibility studies on community wind, solar and hydroelectricity options [131].

## 5. Concluding Remarks

The aim of this paper was, first, to explain the diffusion of RET applications in remote indigenous communities in NWT and Ontario by analyzing the performance of the technological innovation systems, and, second, to identify factors that have the potential to sustain the development of these RET projects. The analysis shows that between 2000 and 2016, policies and programs in both jurisdictions addressed systemic and transformational failures, which allowed for the accumulation of TIS functions, which, in turn, led to the deployment of solar projects in the communities. In addition, the analysis points to the guidance of the search and knowledge development functions as the driving forces for the build-up of the functional system. The NWT innovation system case suggests that a highly inclusive and reflexive policy design initiated by the territorial government for addressing the energy needs of the isolated territory, as well as the establishment and support of a local network, contributed to the uptake of the innovation system. In the case of Ontario, guidance of the search was driven by indigenous communities' focus on RET projects, while the functional build-up evolved over a shorter period of time than NWT, as it benefitted from both knowledge developed in NWT and the establishment of a network of actors. Furthermore, the study also shows that, given the financial constraints present in most indigenous communities, governmental support is decisive for improving actors' presence, capabilities and interactions, and the creation of market formation mechanisms necessary for the undertaking of entrepreneurial activities.

The results confirm that the TIS approach can be used to study the diffusion of technological innovations in the specific institutional setting characterizing remote indigenous communities. Recent legal decisions prioritizing indigenous perspectives, lack of a market economy, and an indigenous focus on economic development, environmental protection, and self-governance signals that the determinants of RET diffusion are more complex than simple technoeconomic factors. Within the communities, locally owned RET projects are blocked by multiple institutional, capacity and infrastructural barriers that hinder their development. These systemic failures can be addressed through the functional approach proposed by the TIS.

In addition, the analysis of the functional evolution reveals that local governments and band councils engage in RET entrepreneurial ventures by (1) taking advantage of a sequence of events initiated by the provincial and territorial governments' interest in the use of renewable energy to reduce carbon emissions and electricity generation costs, and the availability of financial support for resource monitoring and feasibility studies contributing to the guidance of the search and knowledge development and diffusion; (2) learning through searching, training, and experimenting from projects installed in communities; and through engaging with numerous actors to improve knowledge on the specific applications and their potential to contribute to indigenous goals; and (3) modifying and articulating their perspectives, based on accumulated learning, towards RETs policies and programs that are supportive of indigenous aspirations and sustainability goals.

Furthermore, results suggest that, given the "system building" nature of the functions guidance of the search and knowledge development for community entrepreneurial activities, the aim of federal, provincial/territorial and indigenous governments should be policies targeting systemic and transformational problems (capabilities and interaction failures) that block these functions. Policy intervention for network building, capabilities improvements and knowledge development through experimenting with RETs will support further learning and empower indigenous communities and participating actors, enable them to adjust their perspectives and articulate policy direction according to their values and beliefs, and strengthen their governance structures. Accordingly, further research should, first, investigate local learning processes [64,180] in the environment of remote indigenous communities in terms of who, how, and what is learned related to RET deployment. Second, given that knowledge development and diffusion are facilitated by local networks, further research could focus on both the role that community leadership and trusted local intermediaries play in the definition of the guidance of the search and knowledge development and diffusion, as well as their strategies for guiding the build-up of local TIS functions.

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#### Abbreviations

AANDC	Aboriginal Affairs and Northern Development
AEA	Arctic Energy Alliance (AEA)
AEPP	Aboriginal Energy Partnerships Program
ALGP	Aboriginal Loan Guarantee Program
ANCAP	Aboriginal and Northern Community Action Program
ANCCP	Aboriginal and Northern Climate Change Program
ARI	Aurora Research Institute
GEGEA	Green Energy and Green Economy Act
CREF	Community Renewable Energy Fund
EANCP	Aboriginal and Northern Communities Program
HORCI	Hydro One Remote Communities Inc
IESO	Independent Electricity System Operator
INAC	Indigenous and Northern Affairs Canada

IPA	Independent Power Authorities
IPP	Independent Power Producer
kW	Kilowatt
kWh	Kilowatt-hour
LDCs	Local Development Corporations
MLP	Multi-Level Perspective
MW	Megawatt
NAN	Nishnawbe Aski Nation
NFL	Newfoundland and Labrador
NGO	Non-Governmental Organization
NOFNEC	Northern Ontario First Nation Environmental Conference
NTPC	Northwest Territories Power Corporation
NWT	Northwest Territories
PPAs	Power Purchase Agreements
RETs	Renewable Electricity Technologies
R&D	Research and Development
TIS	Technological Innovation System

## Appendix A

Table A1. Main events and events' allocation to functions for the NWT T	'IS
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Year	Event	Function
1998	GNWT Official Statement on Climate [116].	Guidance of the search
1998	Establishment of Arctic Energy Alliance (AEA).	Guidance of the search
0001	Aboriginal and Northern Climate Change Program (ANCCP)	Knowledge development
2001	(2001–2003) [122,181].	Resources mobilization
2001	RETCAP (2001–2003): provincial program providing 50% rebates for equipment and system balance costs.	Resources mobilization
2001	A Greenhouse Gas Strategy for the Northwest Territories [125].	Guidance of the search
2003	Aboriginal and Northern Community Action Program (ANCAP) (2003–2007) [122,181].	Resources mobilization
2003	Feasibility studies for wind projects for Sachs Harbour, Tuktoyaktuk, Holman and Paulatuk [182]	Knowledge development
2003	Feasibility studies for wing projects for Sachs Harbour, Ulukhaktok, Paulatuk, Tuktoyaktuk, Yellowknife, Inuvik [183].	Knowledge development Guidance of the search Knowledge diffusion
2006	Feasibility studies for wind projects for 31 communities in NWT [172,173].	Knowledge development Guidance of the search Knowledge diffusion
2006	Jean Marie FN solar photovoltaic demonstration project.	Entrepreneurial activities
2007–2011	ecoENERGY for Aboriginal and Northern Communities Program (EANCP) (Phase 1: 2007–2011) [127,168].	Resources mobilization
2007–2016	CREF (2007-todate) as part of the Alternative Energy Technologies (AET) program providing funding for RETs projects costs [128].	Resources mobilization
2007	-Energy for the future-An Energy Plan for the Northwest Territories -A Greenhouse Gas Strategy for the Northwest Territories 2007–2011 [124 125]	Guidance of the search
2007	Remote Community Wind Energy Conference Tuktoyaktuk [126].	Knowledge diffusion
2007–2016	CREF (2007-todate) as part of the Alternative Energy Technologies (AET) program providing funding for RETs projects costs.	Mobilization of resources
2008	<ul> <li>-2008: Energy priorities framework-Ministerial Energy Coordinating Committee (MECC).</li> <li>-2008: Review of Electricity Regulation, Rates and Subsidy Programs in the Northwest Territories [96,116].</li> </ul>	Guidance of the search

Year	Event	Function
2008–2015	Feasibility studies for wind and solar projects for Colville Lake, Deline, Jean Marie River, Trout Lake, and Fort Providence in NWT [119,184].	Knowledge development Guidance of the search Knowledge diffusion
2008	Optimization studies for wind projects for 12 communities in NWT [20].	Knowledge development Guidance of the search Knowledge diffusion
2008–2015	Community energy profiles: community energy planning activities by AEA [118].	Knowledge development Guidance of the search Knowledge diffusion
2009	-Electricity review. A discussion with northerners about electricity. -Creating a brighter future: a review of electricity regulation, rates and subsidy programs in the northwest territories [95,129].	Guidance of the search
2009	Inuvik: development of two small scale solar photovoltaic projects. Efficient, Affordable and Equitable: Creating a Brighter Future for	Entrepreneurial activities
2010	the Northwest Territories' Electricity System. Response to the 2008 and 2009 NTPC review [97].	Guidance of the search
2010 2010	Optimization studies for wind projects for 12 communities in NWT [21]. Development of solar projects in Sachs Harbour and Wekweèti. -NWT energy report. Report of Ministerial Energy Coordinating	Knowledge development Entrepreneurial activities
2011	Committee (MECC). -2011: A Greenhouse Gas Strategy for the Northwest Territories 2011–2015 [117,125].	Guidance of the search
2011	AEA: Publishing the "Best energy practices for remote facilities" guide [185].	Knowledge development Guidance of the search Knowledge diffusion
2011	Development of solar projects in Nahanni Butte, Norman Wells, Paulatuk (two projects) and Inuvik (two projects).	Entrepreneurial activities
2011	AANDC and NRCAN publication: Status of remote communities [5].	Guidance of the search Knowledge diffusion
2012–2016	ecoENERGY for Aboriginal and Northern Communities Program (EANCP) (Phase 2: 2012–2016) 2011) [127].	Mobilization of resources
2012–2015	Community energy profiles: community energy planning activities by AEA [118].	Knowledge development Guidance of the search Knowledge diffusion
2012 2012	Development of solar projects in in Gameti and Whati. Northwest Territories Solar Energy Strategy 2012–2017 [133].	Entrepreneurial activities Guidance of the search
2012	NWT Energy Charette [134].	Knowledge diffusion Guidance of the search
2013	Development of solar projects in Fort Good Hope, Fort Providence, Fort Simpson (three projects), Inuvik (two projects), and Tulita.	Entrepreneurial activities
2013 2014	The NWT Energy Action Plan [135]. Development of a solar project in Fort Liard.	Guidance of the search Entrepreneurial activities
2014	NWT Energy Charette [186].	Knowledge diffusion Guidance of the search
2014	NTPC net metering [138].	Market formation
2015	IPP policy and net metering policy for aboriginal community projects [138].	Market formation
2015 2015	2nd Renewables in Remote Microgrids conference [164]. GNWT response to the 2014 NWT energy charrette report [137].	Knowledge diffusion Knowledge diffusion
2015	Development of solar projects in Aklavik, Colville Lake, Gameti, Lutselk'e, Tsiigehtchic, Whati, and Wringley-Pehdzeh Ki FN.	Entrepreneurial activities
2016 2016	NWT-Energy strategy discussion [162]. CBC announcements for RET indigenous projects [121,159–161].	Guidance of the search Legitimization

## Table A1. Cont.

Year	Event	Function
2001	Aboriginal and Northern Climate Change Program (ANCCP) (2001–2003) [122,181].	Mobilization of resources
2003	Aboriginal and Northern Community Action Program (ANCAP) (2003–2007) [122.181].	Mobilization of resources
2003	Governmental commitments for renewable electricity generation.	Guidance of the search,
2004 2005	Call for proposal and request for proposals for renewable	Mobilization of resources
2004-2003	electricity generation [148].	Wobilization of resources
2006	RESOP, Feed-in-tariffs and net metering policies for renewable	Mobilization of resources
2000	electricity introduced [148].	
2007–2011	ecoENERGY for Aboriginal and Northern Communities Program (EANCP) (Phase 1: 2007–2011) [127,168].	Mobilization of resources
2008	OEB (talks about the communities' goals and the NAN) [72].	Guidance of the search
2009	GEGEA Act [149].	Guidance of the search
2009	Aboriginal Loan Guarantee Program (ALG) [151].	Mobilization of resources
2009	Aboriginal Energy Partnerships Program (AEPP) [152].	Mobilization of resources
2010	2010 Ontario's LTEP [93].	Guidance of the search
2010	OPA: Draft technical report for the connection of remote communities [155].	Guidance of the search
2010	Optimization studies for wind projects for 16 communities in Ontario [20,21]	Knowledge development
2011	AANDC and NRCAN publication: Status of remote communities [5].	Guidance of the search Knowledge diffusion
2012–2016	ecoENERGY for Aboriginal and Northern Communities Program (EANCP) (Phase 2: 2012–2016) [122 181]	Mobilization of resources
2012	NAN Energy conference [187].	Knowledge diffusion
2013	Optimization study for Kasabonika Lake First Nation [18].	Knowledge development
2012	REINDEER program (a HORCI communities' diesel	Marilant farma tian
2013	displacement incentive) [154].	Market formation
2013	2013 Ontario's LTEP [93].	Guidance of the search
2013	1st Remote Microgrids Conference in Toronto.	Knowledge diffusion
2013	Development of two solar projects in Kingfisher FN and Wawakapewin	Entrepreneurial activities
	2014 Northern Ontario First Nations Environmental	
2014	Conference (NOFNEC)	Knowledge diffusion
	IESO programs launched: Aboriginal Transmission Fund (ATF).	
2014	Remote Electrification Readiness Program, Education and Capacity	Mobilization of resources
	Building (ECB) Program [188].	
2014	Development of two solar projects in Deer Lake FN, and one solar	<b>T (1)</b>
2014	project in Kasabonika Lake FN.	Entrepreneurial activities
2014	Indigenous press on the development of a solar project in Deer Lake [189].	Legitimization
2014	NCC press announcements on indigenous projects [144].	Legitimization
2014	IESO: Draft technical report for the connection of remote communities [154].	Guidance of the search
2015	Development of solar projects in Fort Severn FN, Keewaywin FN, North Spirit Lake FN, Poplar Hill FN, Muskrat Dam FN, and Weenusk FN.	Entrepreneurial activities
2016	Development of a solar project in North Karibou Lake FN.	Entrepreneurial activities
2016	Optimization study for Kasabonika Lake First Nation [19].	Knowledge development

Table A2. Main events and events' allocation to functions for the Ontario TIS.

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