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Examining partnerships in the technical assistance provided by the Climate Technology Centre and Network for enhancing technology development and transfer in alignment with the Paris Agreement

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ABSTRACT

The Climate Technology Centre and Network (CTCN) serves as a global platform for climate technology transfer, uniting diverse institutions with specialized technical assistance (TA) services to aid developing countries. Central to CTCN's mission is the pursuit of the long-term vision for technology development and transfer worldwide, as prescribed in Article 10 of the Paris Agreement. Integral to this endeavor is the active involvement of technology service providers, essential for addressing the technological needs of developing nations. However, there is a dearth of exploration into the collaborations involved in CTCN TA projects and how the international technology sharing behaviors have evolved since network establishment in 2014. This study scrutinizes the roles of and relationships among the participants of 236 CTCN TA projects conducted under the initial two Programme of Works (PoW) (2014 ~ 2018, 2019 ~ 2022) guiding CTCN's climate technology transfer efforts. Social network analysis reveals a reduction in participant diversity, with increased engagement from private-sector entities and decreased involvement of universities and research institutes during the second PoW period. Additionally, the substantial contribution of technology service providers during this timeframe is affirmed. Drawing from these insights, a dual strategy is proposed to sustain the participation of universities and research institutes as technology service providers for the CTCN TA program.

Key words: Climate Technology Centre & Network (CTCN), Paris Agreement, Technical Assistance (TA), Transformational Change, Technology Innovation, Social Network Analysis (SNA)

1. Introduction

The importance of climate technology transfer and innovation in addressing climate crises has grown significantly since the establishment of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992. Recognizing this, the Conference of Parties in 2010 established the Technology Mechanism (TM), comprising the Technology Executive Committee (TEC) and the Climate Technology Centre and Network (CTCN). The primary objective of TM, as outlined in Article 10, paragraph 4(d) of the Paris Agreement, is to strengthen cooperative action on technology development and transfer at different stages of the technology cycle. As the implementing body of TM, CTCN facilitates the transfer of environmentally sound technologies to developing countries, aiding them in meeting their Nationally Determined

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Contributions (NDCs) through its technical assistance (TA) provision.

Technology assistance is a collaborative effort that engages the National Designed Entities (NDEs), the requesting proponent in the developing countries, and the CTCN's network members, who serve as the technology service providers. NDEs act as focal points, reviewing and approving TA requests and corresponding response plans, while network partners contribute policy and technical expertise to deliver technological solutions, capacity-building initiatives, and implementation guidance. Each network member institution must indicate its capabilities regarding the types of climate technology services they can provide to developing countries. As of August 2023, the CTCN had 807 registered network member organizations that constitute climate technology stakeholders from different fields such as academia, research, finance, and includes non-government, private sector, and public sector. Together, these institutions have implemented approximately 158 technology support interventions in collaboration with NDEs to address the climate technology needs of developing countries.

CTCN's strategic approach is guided by its Programme of Work (PoW), which outlines multi-year strategies and activities. The first PoW (2014 ~ 2018) focused on responding to the developing countries' requests for TAs, including building local capacity and networks as well as increasing information flow and knowledge sharing. The second PoW (2019 ~ 2022) shifted its focus towards providing strategic and tailored assistance to developing nations, with a strong emphasis on supporting the needs of small island developing states (SIDS) and least developed countries (LDCs). This period centered on five key themes: innovation, implementation, enabling environment & capacity-building, collaboration & stakeholder engagement, and support. While both periods emphasized promoting low-carbon and climate-resilient development, the second PoW placed greater emphasis on fostering innovation and entrepreneurship, as well as scaling up climate technology projects.

The announcement of the third PoW (2023 ~ 2027) in March 2023 introduced two key enablers—a national system of innovation (NSI) and digitalization—and identified five system transformation factors: the water-energy-food nexus, buildings and infrastructure, sustainable mobility, energy systems, and business and industry. Future TA requests will be structured around these enablers and factors, underscoring the significance of technology innovation, including research, development, and demonstration (RD&D) activities, in propelling CTCN into a transformative phase. As the third PoW commenced, it is crucial to conduct a comprehensive review of the outcomes from the past PoWs to determine the necessary steps for alignment with future directions. A clear assessment of CTCN's current state and the challenges it has encountered will be vital for informing strategic decision-making going forward.

Technology service providers (TS provider) assume a critical role in supporting the technological development and transfer endeavors for developing countries. The collaborative efforts of three essential actors are pivotal for facilitating effective technology transfer: academic and research institutions (as technology providers), the private sector (serving as both technology providers and market activators), and government bodies (acting as regulators) (Lee and Mwebaza, 2022). Academic and research institutions, along with technology-oriented private enterprises, act as TS providers for CTCN TAs by contributing expertise, knowledge, and access to relevant technologies and customizing solutions to meet the specific requirements and challenges faced by individual developing countries or regions. However, the focus of these institutions differ: academic and research organizations typically lead RD&D activities, pioneering climate technologies and offering training and educational programs to support implementation and maintenance of these technologies in developing countries. Meanwhile, private sector entities focus on driving these innovations to market after the RD&D stage. Together, academia and industry contribute vital scientific and technical expertise to identify, evaluate, and deploy cutting-edge technologies that advance climate action in developing nations.

Understanding the roles and partnerships of participants in CTCN TA projects, including the participation of the TS providers, offers valuable insights into the evolving landscape of global technology transfer and innovation within the context of climate change. With the third PoW strong emphasis on technology innovation, collaboration among TS providers and other stakeholders will be essential to effectively address global climate challenge. Assessing the involvement of TS provider institutions allows us to gauge significant global technological innovation and evaluate CTCN's effectiveness in achieving the global technology development and transfer outlined in Article 10, paragraph 4 of the Paris Agreement. Despite existing studies primarily consisting of qualitative analyses focusing on innovative outcomes (Kim et al., 2023; Lee and Mwebaza, 2020; Lee et al., 2020), there remains a limited understanding of the dynamics between CTCN partners, particularly member institutions' roles regarding technology provision.

This study aims to provide a comprehensive understanding of technology transfer dynamics among CTCN partners in implementing TA projects. We examine interrelationships among network members involved in CTCN-facilitated TA projects, aiming to identify limitations and areas for improvement, with a specific focus on enhancing the involvement of academic and research sectors pivotal in driving the technology development stage, especially RD&D stage, of the technology innovation. A comparative analysis of partnership dynamics during the two PoWs was conducted. We investigate the overall configuration of the partnership network for TA implementation, identify influential member types, assess partnership strengths across PoWs, and examine observed changes. These findings lay foundations for informing future strategies to enhance technology development and transfer to meet the long-term vision of the Paris Agreement by accelerating the engagement of TS provider institutions.

2. Literature review

2.1. Climate Technology Transfer from the Innovation Perspectives

Technology transfer is a multifaceted and interactive process involving the physical transfer of hardware, equipment, knowledge, and experiential insights (Bozeman, 2000; Wahab et al., 2012; Pandey et al., 2022) aimed to strengthen the innovative capacity of its recipients. In this context, the National System of Innovation (NSI), highlighted by the CTCN, serves as a pivotal framework for understanding the mechanisms of global technology and information exchange. Initially introduced as the "system of innovation" by Lundvall (2016), the innovation system refers to the framework for examining and analyzing innovation processes taking its systemic nature into account (Blanco et al., 2022). An innovation system comprises components, relationships, and attributes. Components represent the operational elements, relationships depict the interconnectedness between these components, encompassing both market and non-market aspects, and attributes encompass the characteristics and capabilities of the components that define the system (TEC, 2015). NSI delineates the interconnected actors, institutional contexts, and interrelationships underlying technological advancement at the national level. Actors encompass diverse organizations, including private firms, academic and research institutions, and public agencies, all of which are actively engaged in technology development and transfer (TEC, 2015). Institutional settings encompass the norms, legal frameworks, and cultural practices that influence the activities of these actors. Interlinkages encapsulate the connections and collaborations among these actors within their institutional settings, such as partnerships between industry entities and universities (Lee and Mwebaza, 2020; TEC, 2015). The strength of an NSI and its connections to external innovation systems directly impact the capacity of a country to drive and implement technological changes (Hekkert et al., 2007). Consequently, the NSI framework serves as a practical tool that empowers researchers and policymakers to formulate concrete policy measures aimed at bolstering the innovation capacity of a country (TEC, 2023).

RD&D initiatives, such as pilot projects, hold significant promise for enhancing NSI in developing countries, as revealed by observations of TEC (2015). RD&D encompasses a spectrum of activities from the initial research phase to product development and its eventual real-world testing, in which the outcomes of rigorous research efforts are applied to practical feasibility tests. These activities play an essential role in technology transfers because their results function as the foundation for transitioning from the 'technology push' to 'market pull' dynamics. (Ayuso et al., 2015; TEC, 2015). RD&D facilitates the creation of superior, more advanced, and cost-effective technologies (TEC, 2015). The significance of RD&D has been emphasized by several international institutions engaged in technology transfer endeavors. For instance, IPCC identifies RD&D expenditure as a key metric for gauging innovation (Blanco et al., 2022). Technology Framework of the UNFCCC recognizes the transformative impact of collaborative engagement between the public and private sectors in the context of climate technology RD&D, as evidenced by Decision 15 / CMA.1, Annex. Additionally, the International Renewable Energy Agency (IRENA) acknowledges that RD&D activities are crucial for augmenting the innovation capacity of Latin American nations in the realm of renewable energy technologies (Ayuso et al., 2015).

2.2. Network Analysis in Climate Change Research

As the NSI framework stipulates, the various actors involved in climate technology transfer interact through networks regulated by laws and sociocultural codes of conduct (TEC, 2023). The complex nature of the innovation process in international technology transfer suggests necessitates the active participation actors irrespective of the activity type (Burnett and Williams, 2014; Lavis et al., 2003). A prominent theoretical framework that examines the role of actors in an innovation process includes the triple-helix interaction. Etzkowitz and Leydesdorff (1995) introduced this interaction and suggested that innovation can be best achieved through synergistic collaborations among universities, industries, and government institutions. While the roles of these collaborators lack clearly-defined boundaries, academic and research institutions spearhead R&D efforts while collaborating with private enterprises, industry actors engage in symbiotic relationships with their academic counterparts for technology product design, and government entities provide incentives to foster partnerships between academic / research institutions and industrial stakeholders (Dooley and Kirk, 2007). Building on this foundation, Van Horne and Dutot (2017) scrutinized the challenges faced by universities, industry players, and intermediary organizations within the Canadian forest product industry. In a similar vein, Liu and Liang (2013) delineated the multifaceted roles of researchers, entrepreneurs, and governments in international technology transfer, emphasizing the pivotal role of researchers in technology workforce development and research, development, and demonstration efforts.

Empirically oriented literature, distinct from qualitative case studies, has increasingly turned to social network analysis (SNA) to explore actor roles (Protogerou et al., 2010; Sousa and Salavisa, 2015) and the impact of actor diversity on innovation system performance (Arranz et al., 2020; Calvo-Gallardo et al., 2021; de Arroyabe et al., 2021; Van Rijnsoever et al., 2015). Protogerou et al. (2010) underscored the evolving role of universities and research institutes in information society technologies within the EU Framework Program (FP). Sousa and Salavisa (2015) emphasize the significance of universities in disseminating knowledge and the growing importance of private companies in international knowledge sharing related to sustainable energy technologies. Through SNA applied to collaborative innovation projects on biogas energy technology in the Netherlands, Van Rijnsoever et al. (2015) demonstrated that greater actor diversity positively influences technological diversity, whereas an increased number of project partners has the opposite effect. Similarly, de Arroyabe et al. (2021) analyzed the agri-food network funded by the FP from 2008 to 2014 and concluded that the EU's research consortia have cultivated a network of organizations and institutions that facilitate information dissemination and cooperation among firms. Kang and Park (2013) employed SNA to investigate partnership dynamics in 3816 Clean Development Mechanism (CDM) projects, revealing the fundamental framework of partnerships between industrialized and developing countries. Arranz et al. (2020) examined the UK nanotechnology collaboration network from 1977 to the present, revealing universities as the primary knowledge generators, whereas industry and government actors play more peripheral roles. Furthermore, Calvo-Gallardo et al. (2021) demonstrated that the geographical distribution of consortia and the diversity of partner institutions significantly influence the performance of energy programmes under FP.

Given the status of the CTCN as the official platform for climate technology development and transfer under the UNFCCC, an investigation into its TA implementation network offers a valuable avenue to assess the efficacy of CTCN's innovation mechanisms and the progress of its programs in fulfilling the long-term vision of the Paris Agreement. However, the CTCN TA implementation network remains largely unexplored, representing a gap in understanding. By delving into this network, insights can be gained into the types of influential institutions and the strength of partnerships among member entities. This examination of TA implementor networks provides valuable insights for crafting targeted policy recommendations aimed at enhancing collaborative technology innovation initiatives, including RD&D activities.

3. Methodology and Data

3.1. Methodology

Social network analysis (SNA) techniques were used to investigate the intricate web of CTCN-TA projects. A social network is essentially composed of nodes and ties, with nodes representing individuals or entities, and ties symbolizing the connections between them. SNA is widely employed for gaining deep insights into the structural characteristics and dynamic intricacies of partnerships (Batallas and Yassine, 2006). Unlike purely descriptive statistics, SNA offers an understanding of the qualitative facets of collaboration among organizations, encompassing aspects such as resource flows, the structural roles and positions of network participants, and the relational dependencies inherent in collaborative projects (Batallas and Yassine, 2006; Greve and Salaff, 2001).

Various SNA measures have been employed to reveal the fundamental traits of network connections. These include metrics such as network size (the total number of nodes within the network), distance (the average number of connections between nodes), density (the ratio of actual connections to potential ties within the network), and diameter (signifying the reach or influence scope of the nodes).

In our endeavor to comprehensively analyze the network, the notion of centrality emerged as a pivotal concept. Understanding the centrality of each actor is paramount because the positions and relationships of nodes considerably influence the overall structure and functionality of a network (Batallas and Yassine, 2006). Notably, organizational connectivity within a network can vary, with some nodes having more intensive connections than others. Degree of centrality, a well-established measure, quantifies the number of direct relationships that a node maintains with other nodes (Freeman et al., 1979). Nodes occupying central positions in the network enjoy greater access to critical resources, ultimately leading to enhanced performance and a competitive edge through direct connections with a larger number of network participants (Liu, 2011).

The degree of a node $d(n_i)$ was calculated based on the measures presented by Proctor and Loomis (1951). This represents the number of ties incident on individual nodes. The degree of centrality index of a node is denoted by $CD(n_i)$. Importantly, this centrality index is influenced by the overall network size and attains a maximum value of $g-1$ (equivalent to the total number of actors in the network, excluding the node itself). For a more meaningful and comparative assessment of centrality within the network, we used a standardized measure, which measures the proportion of nodes adjacent to n_i

$$C_D(n_i) = d(n_i) = x_{i+} = \sum_j x_{ij} \quad (1)$$

$$C'_D(n_i) = \frac{d(n_i)}{g-1} \tag{2}$$

Where, n_i is the node, g is the overall network size,

Betweenness centrality quantifies the number of geodesic (shortest) paths passing through a given node. Consequently, nodes with high betweenness centrality, which serve as connectors between indirectly connected nodes, act as repositories of information and exert control over information flow within the network (Freeman et al., 1979). Betweenness centrality indicates the significance of an actor in the network, whereas degree centrality examines the impacts of an actor on the network. The standardized betweenness centrality index of a was computed by summing the proportion of times a node was positioned between others (Barabási et al., 2000), using the given formula:

$$C'_B(n_i) = \frac{\sum_{j<k,i\neq j,i\neq k} \frac{g_{jk}(n_i)}{g_{jk}}}{\frac{((n-2)(n-1))}{2}} \tag{3}$$

Here, g_{jk} (n_i) signifies the number of geodesics linking j and k that contain j in between, and g_{jk} is total number of geodesics linking j and k.

In addition to examining the overall network density, which evaluates all types of ties as a characteristic of the entire network, the density can also be calculated for specific partitions or between groups. For example, it can be computed as the sum of all values divided by the number of potential ties within or between partitions. The density between partitions gauges the average value within each matrix $block_m$, revealing the intensity of the relationships between specific pairs of groups.

3.2. Data Description

This study focused on analyzing 236 TA projects that were supported by CTCN and implemented between 2014 and 2022. The data used in this study were sourced from a publicly available project database available on the CTCN website. We examined and compared the response plans and closure reports for each project, cross-referencing this information with the data recorded in the database. To assess changes in project partnerships for different time periods, we divided the projects into two phases: the initial PoW period, spanning 2014 to 2018, and the second PoW period, covering 2019 to 2022. Consequently, 129 projects were completed during the first PoW period, whereas 107 were completed during the second, indicating a comparable number of completed projects relative to their respective durations.

The various network members of CTCN employ a diverse array of TAs, which include activities such as piloting in local conditions, conducting technical assessments, providing technical support for policy and planning documents, conducting relevant training, and developing implementation plans. The CTCN categorizes its member organizations into three groups: consortium, knowledge, and network partners. The consortium partners include 14 specialized institutions such as the United Nations Environment Programme (UNEP), who played a key role in establishing the CTCN and remain actively involved in its operations. Knowledge partners play a crucial role in supporting the mission of CTCN by facilitating the collaboration, generation, management, and sharing of valuable knowledge, experience, and best practices at the national, regional, and global levels. Currently, there are 124 knowledge partners, which include consortium partners, network members, UN agencies, and non-governmental organizations. All 14 consortium member organizations were simultaneously registered as knowledge partners. Network members comprise 807 registered institutions that constitute climate technology stakeholders from different fields such as academia, research, finance, and includes non-government, private sector, and public sector, along with 158 NDEs.

Initially, this study scrutinized data on the organizations participating in each project. Notably, in some cases, specific network member organizations were not disclosed, with projects indicating collaboration with external consultants. This trend saw a significant increase, constituting 9.3% of the total during the first period, which increased to 61.7% during the second period. This shift can be attributed to the introduction of the Fast TA project track in 2018. While normal response TA projects undergo selection via an open international bidding process and are subsequently carried out by network member organizations, Quick Response Projects address immediate resolution needs and receive approval from the CTCN staff. They provide essential TA to developing countries through contracts with consortium organizations without a separate bidding process. In situations requiring even greater urgency than Quick Response projects, the Fast TA project track involves international external consultants and operates within a timeframe of up to two months. Projects without a designated network member organization are presumed to fall under the Fast TA category. However, projects that lack information about partner organizations were excluded from the partnership analysis because of the impossibility of conducting such an analysis. Notably, during the second period, these types of projects constituted the majority of projects, posing a significant limitation on our partnership analysis. Projects featuring only one participating partner organization accounted for 90 (69.8%) during the first period and 33 (30.8%) during the second period. Conversely, projects involving two or more participating organizations represented 27 (20.9%) projects during the first period and eight (7.5%) during the second period.

Examining projects with institutional information revealed that the total number of network partners participating in both the first and second periods was reduced by half. During the first period, there were 70 participating institutions, whereas during the second period, the number decreased to 35, indicating a 50% reduction. This decline can be attributed to the fact, as mentioned earlier, that many projects were executed not by network knowledge consortium partners but by external consultants. When examining the types of member institutions, the number of consortium and knowledge partners representing specialized organizations decreased from 16 (22.9%) in the first period to 8 (22.9%) in the second period, with the proportion remaining the same. The number of general network member institutions decreased from 54 (77.1%) in the first period to 27 (77.1%) in the second period, whereas the participation proportion remained unchanged.

Statistical analysis was conducted for identifying the

Table 1. Description of TA data applied for the network analysis

	Total period (2014 ~ 2022)	First period (2014 ~ 2018)	Second period (2019 ~ 2022)
Number (Proportion) of projects	236 (100%)	129 (100%)	107 (100%)
- NDE and external consultants only	73 (30.9%)	12 (9.3%)	66 (61.7%)
- Unilateral (NDEs and 1 partner org.)	120(50.8%)	90 (69.8%)	33 (30.8%)
- Bilateral and multilateral (NDEs and multiple partners)	43 (18.2%)	27 (20.9%)	8 (7.5%)
Number (Proportion) of partners	92 (100%)	70 (100%)	35 (100%)
- Consortium / Knowledge partners	16 (17.4%)	16 (22.9%)	8 (22.9%)
- Network partners	76 (82.6%)	54 (77.1%)	27 (77.1%)
Number (Proportion) of partners	92 (100%)	70 (100%)	35 (100%)
- Consortium / Knowledge partners	16 (17.4%)	16 (22.9%)	8 (22.9%)
- Private partners	46 (60.5%)	33 (47.1%)	18 (51.4%)
- Research and Academic partners	13 (17.1%)	18 (25.7%)	6 (17.1%)
- Public organizations	2 (2.6%)	3 (4.3%)	1 (2.9%)
- Other organizations	15 (19.7%)	16 (22.9%)	10 (28.6%)
Number (Proportion) of partners	92 (100%)	70 (100%)	35 (100%)
- Consortium / Knowledge partners (%)	16 (17.4%)	16 (22.9%)	8 (22.9%)
- Network partners providing TS	32 (34.8%)	22 (31.4%)	27 (37.1%)
- Network partners not providing TS	44 (47.8%)	32 (45.7%)	16 (40.0%)

trends in the type of participating institutions. Private companies exhibited an increasing engagement trend over time, with the number of participating companies increasing from 33 (47.1%) in the first period to 18 (51.4%) in the second. In contrast, research and academic institution partners decreased from 18 (25.7%) in the first period to 6 (17.1%) in the second period. The number of public institutions decreased from 3 in the first period to 1 in the second, while the number of other organizations decreased from 16 in the first period to 10 in the second.

We adopted a classification approach based on the capacity of institutions to provide technical services (TS), rather than focusing solely on their types. In this context, institutions were categorized as TS providers if they indicated their ability to offer services related to "Technology Development and Transfer" or "Innovation & RD&D" related to climate technology upon joining CTCN. In the first period, 22 institutions (31.4%) were identified as capable of providing TS. This number increased to 27 during the second period, accounting for 37.1% of the total number. Conversely, the number of institutions that did not provide TS decreased from 32 (45.7%) in the first period to 16 (40%) in the second period.

Organizational data for each project consortium were collected and presented in a two-mode binary matrix that captured the relationships between nodes and events. As shown in Table 2, this matrix interprets the projects as affiliated relationships. Additionally, NDEs and government agencies associated with each country were included as participating organizations, forming a partnership matrix. NDEs were classified as a distinct organization type labeled "NDE." The presence or absence of an organization's involvement in a project was indicated by 1 or 0, respectively. To facilitate analysis, a two-mode matrix was transformed into a one-mode-valued matrix based on the actors, which

Table 2. Example of two-mode binary network data

	TA 1	TA 2	TA 3	TA 4	…
Organization 1	0	1	1	0	…
Organization 2	1	0	0	0	…
Organization 3	1	1	0	1	…
…	…	…	…		…

illustrated the distribution and strength of partnerships between organizations through projects, enabling the utilization of various SNA techniques using UCINET.

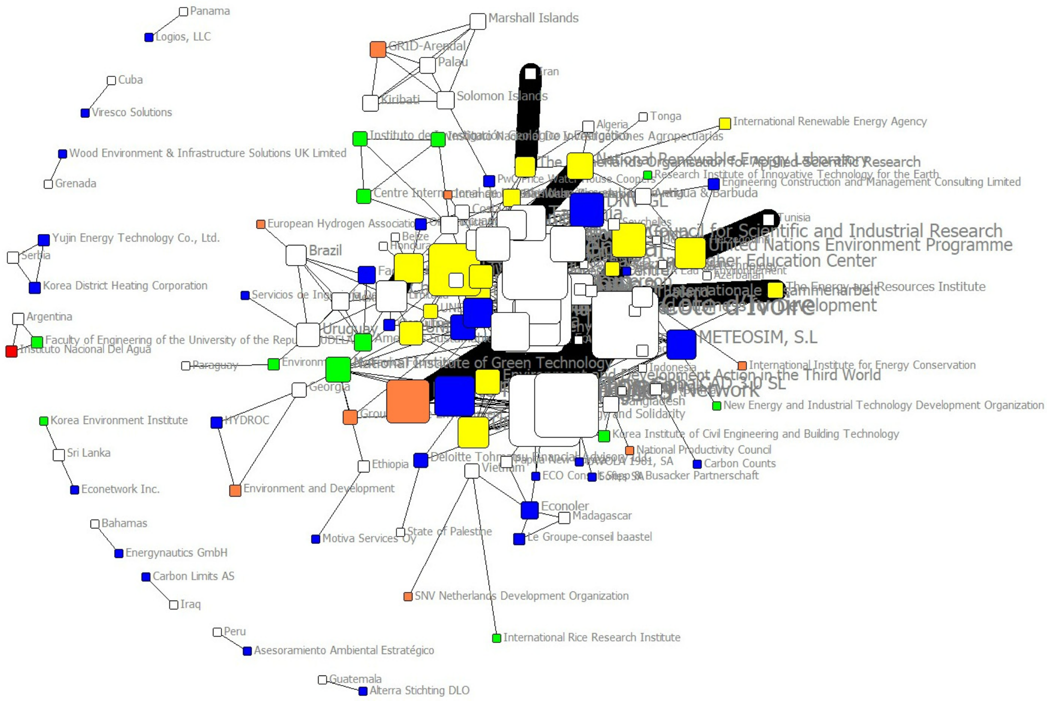
4. Analysis

The analysis was divided into three sections. The first part provided an overview of the partnership network structure, while the second part measured the network centrality of each organization to identify the most significant institutions in terms of partnership formation for technology transfer. The third part assessed the density and strength of partnerships between groups of institutions and identified the types of institutions that demonstrate either strengthening or weakening collaboration.

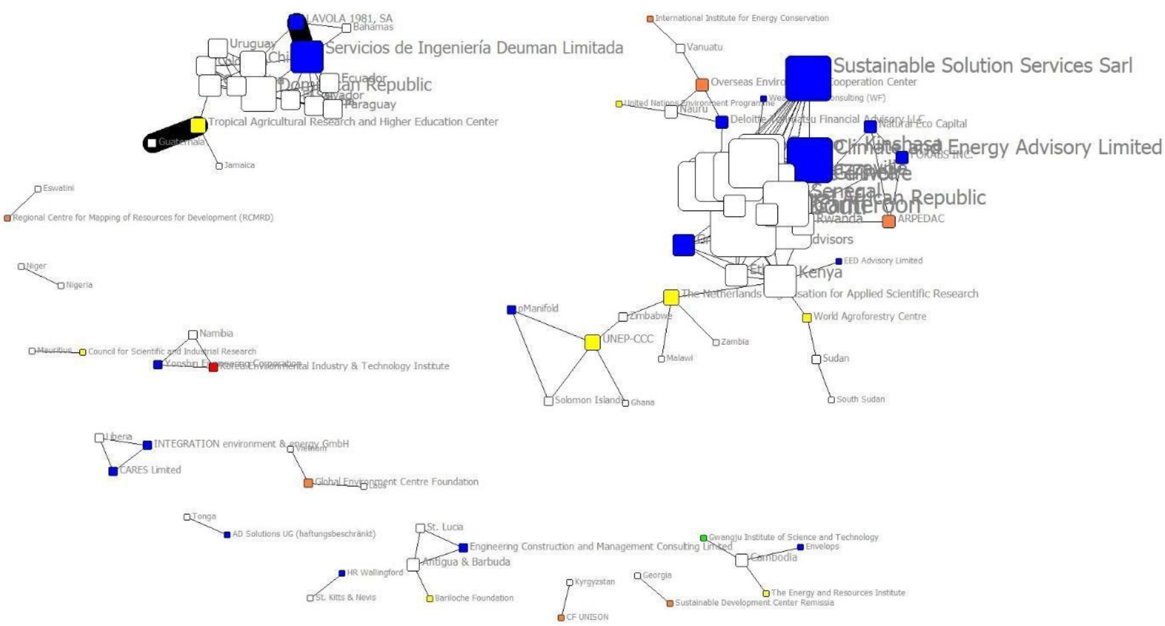
4.1. Overall partnership structure

We examined the overall partnership structure in the CTCN TA network to understand the collaboration patterns, information flow, and influence dynamics. Table 3 presents a detailed analysis of the network structure. Over time, the number of participating institutions decreased, resulting in fewer relationships between institutions. The average degree, which represents the average number of relationships held by each institution, decreased from 5.26 to 3.59. This decline can be attributed to the fact that many CTCN TA projects were executed by external consultants during the second PoW period.

Consequently, the density of partnerships in the network decreased from 0.04 to 0.03 between first and second PoW, indicating that the network became sparser and more disconnected. By contrast, the component ratio increased from 0.07 in the first period to 0.32 in the second period, indicating that the network became notably fragmented into smaller components. Consequently, the network diameter, which provides insights into the reach or scope of influence of the nodes within the network, also increased from 9 to 10, indicating that each institution had to form more relationships to collaborate with others. Additionally, network connectedness, which measures the proportion of the theoretical number of



(a) The First PoW period (2014 ~ 2018)



(b) The Second PoW period (2019 ~ 2022)

Fig. 1. Comparison of the inter-organizational relationships during (a) first PoW period (2014 ~ 2018) and (b) second PoW period (2019 ~ 2022) (Color legend: Yellow, Consortium / Knowledge Partners; Blue, Private; Red, Public; Green, Research sector; Orange, Other; White, NDE)

Table 3. Overall structure of CTCN TA partnership networks

Network Properties	First period (2014 ~ 2018)	Second period (2019 ~ 2022)
Number of projects	129	107
Number of actors	151	111
Number of relations	794	398
Average Degree	5.26	3.59
Diameter	9	10
Density	0.04	0.03
Component ratio	0.07	0.32
Connectedness	0.71	0.17
Fragmentation	0.29	0.83

connections achieved, decreased from 0.71 to 0.17 between the first and second periods. This indicates a considerable weakening of the interconnections between institutions during the second period compared to the first period. Furthermore, fragmentation increased significantly from 0.29 to 0.83.

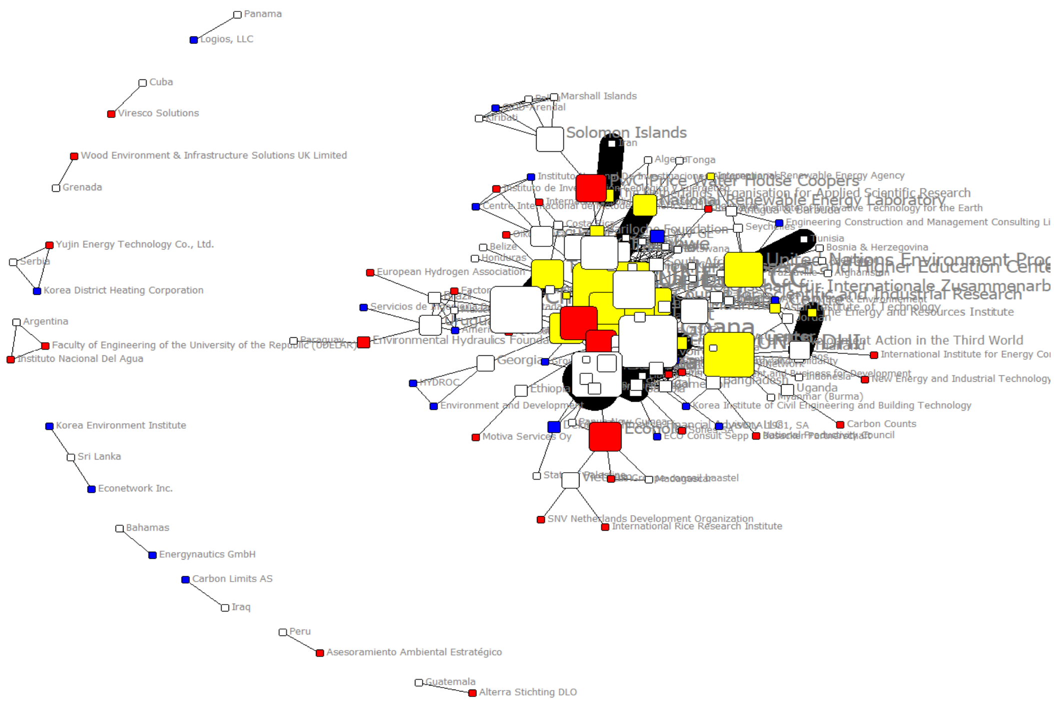
Fig. 1 provides visual support for the findings presented in table above. During the first PoW period, the network revolved around central core institutions, creating a highly interconnected structure resembling a single large clique. In addition, smaller segmented subgroups were observed on the network outskirts. As the second PoW period commenced, the network was divided into two primary groups and a more significant number of segmented subgroups emerged. Notably, no connections were found between these groups, suggesting the presence of a decentralized structure. Fig. 1 also reveals that that the consortium, knowledge partners, and private companies played pivotal roles in the central cliques during the first period. In the second period, collaboration was predominantly driven by specific companies, whereas a few consortia and knowledge partners occupied structural positions, occasionally bridging the gaps between groups. In summary, the relationships among the participating institutions transformed from a hierarchical structure to a more segmented and clustered arrangement. As the project progressed into the second period, the diversity of the participating institution types diminished, with network partnerships primarily led by a few selected companies.

4.2. Centrality analysis of the network partners

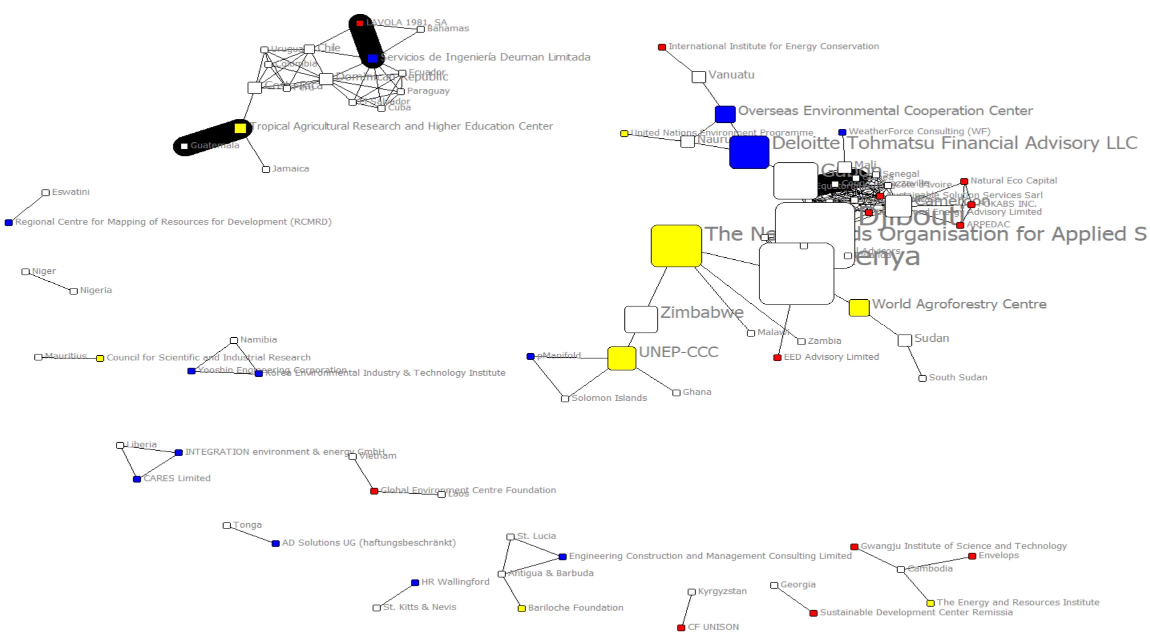
We calculated the degree and betweenness centralities by identifying the network partners that played central roles, and listed the top five institutions according to their centrality values in Table 4. In case of ties in the centrality values, tied partners were given the same rank. The results of the centrality analysis showed the active participation of companies in both PoW periods. Examining the degree centrality, the centrality of companies from developed countries was notably high in the first period, whereas in the second period, companies from developing countries also appeared on the list of highly central institutions. However, this trend was not as evident for betweenness centrality. In the first period, the top five central institutions included one research institution each for both degree and betweenness centralities; however, in the second period, they were absent from the list. We further examined whether highly central network partners also provided TS services. The results concerning betweenness centrality indicated that there was a stronger tendency for highly between-central network partners to provide TS in the second period. For instance, only one of the top five inter-central network partners provided TS in the first period, whereas this number increased to three in the second. When considering degree centrality, there was an overall increase in the proportion of institutions providing TS from 25% to 30% between the first and second periods. Fig. 2 depicts the collaboration between institutions, with nodes colored differently based on their provision of TS. The size of the nodes in the fig. is proportional to their betweenness centrality values due to a stronger tendency for highly between-central network partners to offer TS. Consequently, during the first period, the central institutions marked in red were primarily those that did not provide TS. However, in the second period, some institutions providing TS, represented by blue nodes, emerged as highly central actors playing core roles within the network.

Table 4. The most degree-and between-central network partners

Rank	The first PoW period (2014 ~ 2018)					The second PoW period (2019 ~ 2022)				
	Value	Name	Country	Type	Provision of TS	Value	Name	Country	Type	Provision of TS
Degree Centrality										
1	0.036	Private Financing Advisory Network	Austria	OTH	No	0.059	Climate and Energy Advisory Limited	Kenya	PR	No
							Sustainable Solution Services Sarl	Cameroon	PR	No
2	0.033	Partners for Innovation	Netherlands	PR	No	0.041	Servicios de Ingeniería Deuman Limitada	Chile	PR	Yes
3	0.027	DNV GL	Norway	PR	**Yes**	0.027	GreenMax Capital Advisors	USA	PR	No
4	0.022	Centro GlobalCAD 3.0 SL	Spain	PR	**Yes**	0.018	LAVOLA 1981, SA	Spain	PR	No
		METEOSIM, S.L	Spain	PR	No					
		Water Environment and BusinIor Development	Spain	PR	No					
5	0.018	National Institute of Green Technology	South Korea	RE	No	0.014	ARPEDAC	Cameroon	OTH	No
							Deloitte Tohmatsu Financial Advisory LLC	Japan	PR	Yes
		Carbon Trust	UK	PR	No		FOKABS INC.	Canada	PR	No
							Natural Eco Capital	Nigeria	PR	No
							Overseas Environmental Cooperation Center	Japan	OTH	Yes
Between Centrality										
1	6.714	Carbon Trust	UK	PR	No	3.003	Deloitte Tohmatsu Financial Advisory LLC	Japan	PR	Yes
2	5.468	Econoler	Canada	PR	No	1.301	Overseas Environmental Cooperation Center	Japan	OTH	Yes
3	5.414	PwC Price Water House Coopers	India	PR	No	0.278	Servicios de Ingenieria Deuman Limitada	Chile	PR	Yes
4	5.248	National Institute of Green Technology	South Korea	RE	No	0.047	LAVOLA 1981, SA	Spain	PR	No
5	1.329	DNV GL	Norway	PR	Yes	0.017	Global Environment Centre Foundation	Japan	OTH	No



(a) The 1st PoW period (2014 ~ 2018)



(b) The 2nd PoW period (2019 ~ 2022)

Fig. 2. Comparison of the relationships among organizations with or without technology services during (a) first PoW period (2014 ~ 2018) and (b) second PoW period (2019 ~ 2022)
(Color legend: Yellow, Consortium / Knowledge Partners, Blue, organizations providing technology services; Red, organizations not providing technology services; Gray, NDE)
* Node size is proportional to the between-centrality

4.3. Group Density

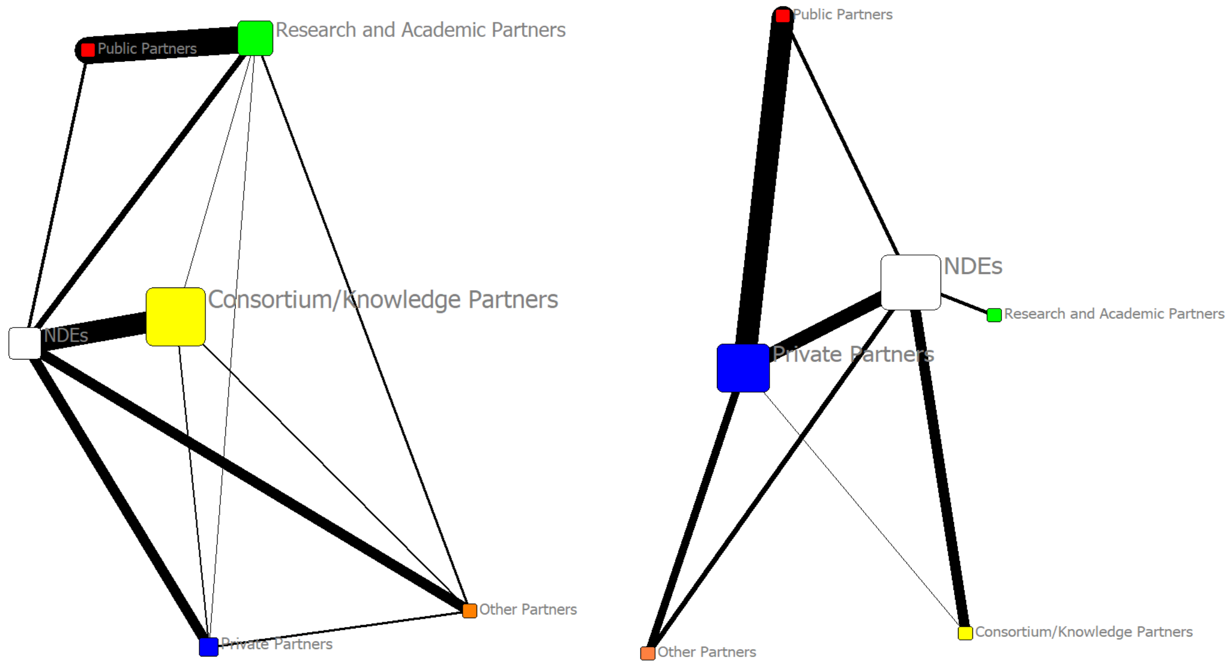
We calculated the collaboration density between different types of institutions participating in CTCN TA projects based on their cumulative collaboration strength. Table 5 and Fig. 3 represent the results. As the project progressed into the second PoW period, the collaboration density between the consortium and the knowledge partner group and other groups, such as private companies, research and academic institutions, and other types of network partners, weakened. Collaboration between consortia and knowledge partner institutions also decreased. In the first PoW period, the relationship density between the consortium and knowledge partner groups was 0.133. However, there was no observable relationship in the second period. This indicates that during the early formation of the CTCN TA network, consortia, and knowledge partners made significant contributions towards network development. However, as the CTCN TA network matured, the network member institutions gradually transitioned to a role in which they drove collaboration.

In contrast, the collaboration density between the private company group and other network partner groups exhibited a noticeable upward trend. For instance, during the first period, no collaboration existed between private companies and public institutions. However, in the second period, this collaboration emerged with a density of 0.056. Moreover, the relationship density between private companies and other groups such as NGOs increased from 0.01 to 0.024. Additionally, collaboration within the private company group strengthened, with the relationship density rising from 0.012 in the first period to 0.033 in the second.

On the other hand, collaboration among non-company groups decreased as the project advanced into the second period. The collaborative ties observed between public institutions, research institutes, universities, and other groups that was observed during the first period completely disappeared during the second phase. As a result, the only connections among these groups were connected through private companies, indicating that the network had become increasingly dependent on companies.

Table 5. Densities between the stakeholder categories

Period I						
	C/K Partners	**Private**	**Public**	**Research & Academic**	**Other**	**NDEs**
C/K Partners	0.133	0.008	0.000	**0.005**	0.007	0.068
Private	0.008	0.012	0.000	**0.005**	0.010	0.034
Public	0.000	0.000	0.000	**0.083**	0.000	0.012
Research & Academic	0.005	0.005	0.083	**0.061**	0.009	0.020
Other	0.007	0.010	0.000	**0.009**	0.000	0.034
NDEs	0.068	0.034	0.012	**0.020**	0.034	0.053
Period II						
	C/K Partners	**Private**	**Public**	**Research & Academic**	**Other**	**NDEs**
C/K Partners	0.000	0.007	0.000	**0.000**	0.000	0.028
Private	0.007	**0.033**	**0.056**	**0.000**	**0.024**	**0.039**
Public	0.000	0.056	0.000	**0.000**	0.000	0.013
Research & Academic	0.000	0.000	0.000	**0.000**	0.000	0.013
Other	0.000	0.024	0.000	**0.000**	0.000	0.017
NDEs	0.028	0.039	0.013	**0.013**	0.017	0.039



(a) The 1st PoW period (2014 ~ 2018) (b) The 2nd PoW period (2019 ~ 2022)

Fig. 3. Relationships among organizations with or without technology services
(Color legend: Yellow – Consortium / Knowledge Partners, Blue – Private, Red – Public, Green – Research sector, Orange – Other, White – NDE)

Table 6. Densities between the stakeholder categories

Period I				
	C/K Partners	Network Partners providing TS	Network Partners not providing TS	NDEs
C/K Partners	0.133	0.003	0.010	0.068
Network Partners providing TS	0.003	0.009	0.013	0.027
Network Partners not providing TS	0.010	0.013	0.012	0.033
NDEs	0.068	0.027	0.033	0.053
Period II				
	C/K Partners	Network Partners providing TS	Network Partners not providing TS	NDEs
C/K Partners	**0.000**	**0.010**	**0.000**	**0.028**
Network Partners providing TS	**0.010**	**0.038**	**0.011**	**0.022**
Network Partners not providing TS	0.000	0.011	**0.044**	**0.040**
NDEs	0.028	0.022	0.040	**0.039**

Finally, as the project progressed into the second period, research institutions became isolated and disconnected from the broader CTCN TA network. They were involved individually in TA projects but no longer had connections with other network partner groups, including private companies.

This study also examined the cumulative group density of collaborative relationships between consortium and knowledge partner groups, and groups with and without TS provision. As the project moved into the second PoW period, the collaboration between the TS provider group and the consortium and knowledge partner groups strengthened, as did the internal collaboration within the TS provider group. In contrast, collaboration between groups without TS provision weakened both the TS provider group and consortium and knowledge partner groups, leading to their disconnection. Additionally, there was a trend toward increasing internal group collaboration density among institutions without TS. Overall, the group density analysis confirmed that TS-based network member institutions played a central role in CTCN TA partnerships as the project progressed to the second period.

In summary, private companies were the most influential implementing partners in the CTCN network during both first and second periods. However, there was a notable shift in the second period, with an increase in the involvement of companies from developing countries compared to the dominance of companies from developed countries in the first period. Other types of network member institutions played relatively minor roles, and there was a reduction in the diversity of participating institutions during the second period, aligning with the trends shown in fig 4.1. Furthermore, as the project progressed into the second period, network partners providing TS occupied between-central positions, underscoring their essential role in mediating information and fostering relationships among different institutions within the CTCN TA network. This emphasizes the growing significance of TS providers in promoting collaboration and knowledge exchange within the networks.

5. Conclusion and Discussion

While existing studies have emphasized the roles and functions of institutions such as NDE in activating CTCN TA, this study takes a different approach by exploring the relationship dynamics within CTCN, aiming to understand how the relationships among TA participants evolve over time and what drives these changes. As a result, this study identified changes in the network of implementing organizations associated with CTCN TA projects and the factors driving these changes as follows.

First, the CTCN TA project network is dominated by a few types of institutions, and that the diversity of participating institutions has reduced over time. Interactions between academia, private sector, and government policymakers (the triple helix) are important for generating new ideas, exchanging knowledge and skills, and increasing the likelihood of process improvement and problem solving (Björklund and Gustafsson, 2015; Brink, 2017; Hjalmarsson, 2015; Lee and Mwebaza, 2022; Luengo-Valderrey et al., 2020; Sedlacek, 2013). Numerous empirical studies on Triple Helix cooperation for environmental sustainability indicate that increased collaboration among universities / science, industry, and government leads to a more efficient and effective innovation process. Notable examples include Sedlacek's (2013) case study on the role of universities in fostering sustainable development at the regional level, Luengo-Valderrey et al.'s (2020) research on 5,000 Spanish companies, Hjalmarsson's (2015) study on renewable energy in Stockholm's transport system, Björklund and Gustafsson's (2015) investigation of the environmental impact of municipal goods distribution in Sweden, and Brink's (2017) study on offshore wind parks.

However, as the number of participating organizations decreased from the first period to the second PoW period, the structure of the collaborative network of CTCN TA participants also changed, as the overall interaction among all organizations decreased by approximately 49.9%. In the first PoW period, a centralized network in the form of a core periphery emerged, with institutions tightly interconnected as a single clique. This is because of the active involvement of consortium and knowledge partners, and private companies centered on NDEs in TA projects, resulting in similar distribution of their participation. Other organizations such as NGOs, universities, and research institutes were directly or indirectly connected to the main network partners and participated in project implementation. In contrast, during the second PoW period, networks centered on NDEs and private companies were more prominent, and the density of partnerships among consortium and knowledge partner groups, as well as private companies, research, and academic institutions, tended to decrease.

The increased participation of private companies in CTCN TA projects observed during the second PoW period can be attributed to multifaceted factors. A notable contributing factor to this evolution is, the support and emphasis provided by the Conference of the Parties (COP), the highest decision-making body of the UNFCCC. For instance, Article 11 of Decision 9/CP.26 underscored the indispensable role of the private sector in translating RD&D efforts into market-deployable climate technologies. Additionally, Article 23 welcomed the interaction between CTCN and the private sector, encouraging the provision of TA and capacity building through Small and Medium-sized Enterprises (SMEs) and other network members. Furthermore, Article 15 of Decision 11/CP.26 called upon the CTCN to enhance its services by fostering greater engagement with private sector network members. These guidelines indicate a clear trajectory towards increased private sector participation in CTCN TA projects in the future. Concurrently, as the CTCN funding mechanism matured, consortium and knowledge partners initially led the projects; however, over time, this leadership increasingly shifted to general partners, such as private companies. Participating organizations appeared to have accumulated experience with the CTCN process and underwent a refinement process in which they clarified roles and responsibilities, identified collaboration needs, and strengthened their financing mechanisms. Furthermore, the capacity of general partner organizations, including private firms, expanded significantly during this period. Leading partner organizations assumed greater responsibilities, often taking on roles initially held by consortium and knowledge partners. Consequently, the initially dense partnerships centered around consortium and knowledge partners evolved, leading to a decrease in partnership density over time and resulting in a more segmented and decentralized main network.

Second, a network centrality analysis of CTCN TA projects revealed a progressive rise in the engagement of companies in developing countries over time. This trend reflects the priority placed by international RD&D initiatives on supporting developing countries with limited financing capacities and less robust innovation systems in facilitating local knowledge sharing and capacity development. At COP27, held in Sharm el-Sheikh in 2022, CTCN decided to prioritize the participation of developing countries in TA, particularly for countries with limited capacity. For example, Article 20 of Decision 18/CP.27 encourages the CTCN to sustain aid to developing countries, even those not previously assisted by the CTCN, by engaging private sector entities and network members. As previously emphasized, the guidelines provided by the COP exert a crucial and decisive influence on the operational direction of the CTCN, and can therefore be identified as the primary driver of the changes observed in our analysis. Moreover, the increasing participation of companies from developing countries indicate that CTCN TA program is progressing in a general direction towards its mission by “working with stakeholders engaged in a wide range of activities related to climate technologies to facilitate south-south, north-south, and triangular collaboration and cooperation” (CTCN, 2024).

Third, the role of technology service (TS) providers, such as research institutions and universities, in facilitating technology development, transfer, innovation, and RD&D was more emphasized in the second period compared to the first period, whereas industry-academia collaboration in the CTCN TA implementation efforts has weakened over time. Universities and research institutes were included in the top five key implementers of the CTCN TAs during the first PoW but were excluded from the list for second PoW. The previous studies suggest that the collaboration with TS providers within the Tripple Helix framework plays an active role in fostering ecosystems for climate technology innovation (Björklund and Gustafsson, 2015; Brink, 2017; Hjalmarsson, 2015; Lee and Mwebaza, 2022; Luengo-Valderrey et al., 2020; Sedlacek, 2013). These studies highlight the role of TS providers in adapting existing technologies to local conditions, encouraging the entry of private enterprises into new markets, and developing local capacity, particularly in developing countries. According to our observations and interview with researchers, however, the reduced involvement of research institutions and universities during the second PoW period can be attributed to several challenges. These institutions often struggle to engage with CTCN TA projects due to relatively low project budgets compared to domestic R&D funding, the complexity of the participation process, and the requirement for international competitive bidding, which further discourages participation. Additionally, the lengthy and unpredictable timeframe required to initiate projects complicate budget and project planning for R&D institutions.

To summarize, The CTCN TA network displayed a fairly balanced distribution of participation among various stakeholder groups in its initial phase, but the second phase saw a distinct shift toward greater involvement from private sectors and developing countries. Although the importance of technical service (TS) providers grew during this period, universities and research institutions continued to exhibit low levels of engagement.

Therefore, provision of appropriate incentive scheme is essential to offer incentives for research institutions to participate in the TA project network. Research institutes and universities play a vital role in creating an innovation system by providing capacity building and knowledge transfer to developing countries, thereby attracting private companies and consumers to participate in R&D programs (TEC, 2021). It is desirable to have a balanced participation of academia and industry; hence, the cooperation between private companies and research institutions must be strengthened. Based on an evaluation of its performance from 2018 to 2021, the 2021 report on the second independent review of the CTCN found that the CTCN had established itself as a pivotal climate technology matchmaker for global technology transfer through its core service areas. The report recommended that the CTCN further strengthen its role by deepening engagement with technology providers (UNFCCC, 2021). In its third Programme of Work (PoW) for 2023 ~ 2027, the CTCN has emphasized enhanced collaboration with technology owners through its network of institutions, including research organizations and key stakeholders (CTCN, 2022). As a result, the overall trend in CTCN technical assistance implementation is progressing favorably, fostering technological innovation and driving transformational change in developing countries within the CTCN’s mandate.

As the role of the TS providers from the research and academic sectors has been weakened over time in comparison to those from the industry sector, a dual strategy that combines both top-down and bottom-up approaches is necessary to boost research and academic involvement in the future. Employing top-down strategies involves incentivizing research institutions and universities by creating favorable conditions, such as offering advantages in the TA selection process or establishing dedicated funding streams for research initiatives like RD&D. Prioritizing or fast-tracking applications from pioneering institutions engaged in cutting-edge research can further enhance participation. Moreover, increasing technological collaboration between research institutes in developed and developing countries can strengthen their national innovation systems and support technology commercialization, while also fostering research exchanges and collaborative R&D between institutions in both countries. Such collaborations also promote research exchanges and joint R&D initiatives between institutions in both developed and developing countries, in alignment with the CTCN’s ultimate role as a global technology matchmaker, as outlined in its third Programme of Work, which emphasizes the importance of national innovation systems and digitalization. In parallel, bottom-up approaches are essential to raise awareness and build capacity within research institutions and universities. Awareness campaigns, training sessions, and informational outreach can inform these institutions of the opportunities available through CTCN, encouraging greater engagement in international projects. Additionally, supporting institutions in acquiring the skills and knowledge required for international collaboration—such as project management, proposal writing, and technology assessment—can enhance their capacity to contribute to and benefit from these projects. To facilitate collaboration, CTCN could also develop platforms or regional hubs that connect academic institutions with industry leaders and technology providers. These networks would serve as incubators for research ideas, enabling cross-sector collaboration and providing access to industry-specific tools and expertise. Furthermore, programs that promote student and faculty exchanges between research institutions in developed and developing countries can stimulate the exchange of knowledge and innovative ideas, fostering long-term partnerships. Striking a balance between top-down and bottom-up strategies will not only increase the participation of research and academic institutions in TA projects but will also amplify the innovation spillover effects of CTCN initiatives, ultimately enhancing global technology transfer and commercialization efforts.

The findings of this study are significant in suggesting ways to expand the role and cooperation of network partners participating in CTCN TA projects in the future. They can also inform the preparation of a policy framework to enhance the capacity of TS provider organizations, especially academic and research institutions, to participate in CTCN projects. However, many TA projects during the second PoW were conducted by external consultants, and the response plans and closure reports of many projects were not fully disclosed on the website and were only utilized for internal communication. This limited the research because the project data were not fully available in the public database. If more complete data can be obtained through cooperation with the CTCN, more accurate and meaningful results can be obtained in subsequent studies.

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