

# KIER DISCUSSION PAPER SERIES

## KYOTO INSTITUTE OF ECONOMIC RESEARCH

Discussion Paper No. 1023

“Essence of Multilateral Energy Technology Collaboration:  
A Case Study of International Energy Agency (IEA)  
Technology Collaboration Programmes (TCPs)”

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March 2020



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KYOTO, JAPAN

# Essence of Multilateral Energy Technology Collaboration: A Case Study of International Energy Agency (IEA) Technology Collaboration Programmes (TCPs)<sup>1</sup>

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Abstract

Energy transition has been an important issue in achieving climate action. A “multilateral energy technology cooperation” is often considered a driver that leads to multilateral cooperation being successful. International Energy Agency (IEA) Technology Collaboration Programmes (TCPs) are an interesting case study because they have a long history. For over 40 years, they have worked toward the achievement of energy and climate goals. Statistical analysis was performed to explore the increase in entities’ participation in and the distribution of 38 TCPs. An email survey was administered to learn about the opinions and thoughts of representatives in 18 TCPs. The survey’s purpose was to understand current evidence on the roles and effectiveness of IEA TCPs in energy technology cooperation. The survey responses were analyzed to understand the correlation among input, output, and outcome as well as goal and implementing capacity. The results revealed that most respondents were satisfied with input and output. The current energy policy situation and possible greenhouse gas reduction in one’s country were selected as the main reasons for four outcomes: policy adoption, technology deployment, economic benefit, and social acceptance. Regression analysis demonstrated the correlation among input, output, and outcome of IEA TCPs. These findings have ramifications for future multilateral cooperation and implications for energy collaboration development.

Keywords: Energy; Technology; Multilateral cooperation; Survey

JEL Classification: F53, O33, P48, Q48

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<sup>1</sup> We would like to thank participants of the Research Center for Advanced Policy Studies (CAPS) study group meeting held on December 9, 2019, as well as participants of the International Policy and Institution Study Group meetings in CAPS throughout 2019, for their valuable comments. We would also like to thank Diana Louis and Clair Hilton from International Energy Agency (IEA) for providing information and suggestion on the survey design. We are grateful to Tomonaga Yoshida and Takeda Shutaro from the Graduate School of Advanced Integrated Studies in Human Survivability, Kyoto University, for advice on the survey design. We thank Colin Pattinson for refining and editing language in the survey. We would like to express our gratitude to those who responded to our survey. This work was financially supported by the Joint Research Project between the Research Institute of Economy, Trade and Industry (RIETI) and Kyoto University.

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## 1. Introduction

Climate change is one of the greatest global challenges facing human civilization today. Additionally, soaring world prices for oil, natural gas, and coal, increasing levels of volatility in international energy markets, and heightened anxieties over supply security threaten economic growth and sustainability for states. Global solutions must be found and spread over a short period of time. Under the circumstances, the necessity of energy transition to new energy sources has increased the need for international energy cooperation. Since states seek technology knowledge, policy gain, and the of minimization of risk for single state investment and development, multilateral energy organizations can play an important role in helping realize shared interests in the achievement of energy and climate goals.

According to a literature review on multilateral cooperation on energy technology, multilateral technology cooperation that includes energy has increased since the 1980s, and the sharing has increased rapidly, reflecting the globalization of technology or techno-globalism (Ma & Lee, 2008). States are likely to undergo international cooperation to enforce issues that are difficult to enforce through commitment to linkage to a more enforceable issue (Kemfert, 2004). Through case studies, research suggests that increased research and development (R&D) expenditure on energy technology innovation is likely to induce a non-cooperating state to join climate control coalitions because the technical spillover effects of the increase in R&D investment leads to both economic growth and better energy efficiency. This “reciprocity” encourages clean technology cooperation and produces benefits through institutional innovations, despite unequal benefits among parties (Keohane, 1986). In this sense, the need for international cooperation by ensuring that efficiency gains are produced—as scarce research resources of multiple organizations are brought together—extends the range of potential outputs (Scott, 2003).

If states highly regard clean technology for commercialization, cooperation can be defined as techno-nationalist, whereby states tend to defensively participate in technology cooperation (Ostry & Nelson, 1995). This is because, as governments believe that long-term wealth creation relies heavily on advanced technology, the rapid spread of information and distribution of technology deters from enjoying the benefit of newly developed technology. It implies that the development of clean technology can be performed under the states’ different purposes of technology commercialization and emission reduction (Haas, 1980). Depending on the levels and ranges of issue linkages, a regime is negotiated to build the legitimacy of the multilateral cooperation.

For multilateral energy cooperation, institutions or organizations that have been established are presented in Table 1. However, it is argued that they are considered to demonstrate ineffective performance regarding energy cooperation (Wilson, 2015). Most institutions are in a form of dialogue and non-legal binding. Legally binding institutions include, for example, the Organization of Petroleum Exporting Countries (OPEC) and the World Trade Organization (WTO). However, the OPEC deals with a narrow spectrum of petroleum fuel that produces a large amount of greenhouse gas, while the WTO involves trading issues regarding energy components that are less encouraged in the energy field for cooperation among economic actors. Regardless of scopes in energy sources, the Gas Exporting Countries Forum (GECF), the International Energy Forum (IEF), and the Clean Energy Ministerial (CEM) are dialogue-based groups that are effective at sharing ideas and thoughts on energy issues. The Asia Pacific Economic Cooperation (APEC) and East Asia Summit (EAS) discuss various issues including energy, but they are not legally binding, and economic aspects are primary over energy issues when the two issues overlap. The Energy Charter Treaty (ECT) is a membership-based institution that creates obstacles to promoting energy market integration, despite being legally binding.

Table 1. Multilateral Energy Cooperation

		High Density	
	Organization of Petroleum Exporting Countries (OPEC), T		World Trade Organization (WTO), T Energy Charter Treaty (ECT), T
Narrow Scope			Broad Scope
	Gas Exporting Countries Forum (GECF), D		International Energy Forum (IEF), D Asia Pacific Economic Cooperation (APEC), N East Asia Summit (EAS), N Clean Energy Ministerial (CEM), D
		Low Density	
<p>T: Treaty, D: Dialogue, N: Non-binding  Density: Responsibility, membership, legally binding, etc.  Scope: A number of energy fields  (Source: (Wilson, 2015); restructured by the authors)</p>			

Previous studies and reports on International Energy Agency (IEA) Technology Collaboration Programmes (TCPs) are as follows. Implementing agreements (former TCPs) actively performed key impacts designed to strengthen interaction and advance regional dialogue among countries on road mapping low-carbon technologies (IEA, 2012). TCPs have played a role in sharing information on how to make contributions to achieving policy and business goals through technological innovation (IEA, 2015). Multilateral cooperation had IEAs develop a unique capacity in terms of providing guidance and coordinating multilateral energy technology collaboration. A further scope to broaden TCPs' role can be realized by expanding membership and programmes (IEA, 2017). It is a strong motivation to develop international effort, build on its capacity, and avoid duplication. As a binding framework, TCPs may provide a stable foundation for initiatives undertaking R&D activities over longer timespans, unlike non-legally binding agreements (IEA, 2019). Reports from TCPs provide guidance on technological development and tracking expenditures on energy R&D and venture capital funding. It has been evaluated that TCPs play a significant role in decreasing costs and increasing benefits of R&D endeavors due to cost sharing and information exchanges (Geyer, et al., 2004). TCPs can review technological progress and track current status and innovation needs across energy sectors overall. This helps bring notice of energy R&D gaps and aids governments in establishing innovation roadmaps (IEA, 2019). IEA TCPs were raised in an analytical framework for assessing the emerging policy paradigm called "transformative innovation policy," which includes Mission Innovation and the Global Covenant of Mayors for Climate and Energy (Diercks, et al., 2019). Specific TCPs were mentioned to discuss certain energy technology for low-carbon technologies. GHG (Greenhouse Gas R&D) TCP was employed to discuss the global politics of carbon dioxide capture and storage (CCS) from an international relations perspective, incorporating various organizations of Intergovernmental Panel on Climate Change (IPCC), United Nations Environment Programme (UNEP), and United Nations Development Programme (UNDP) (de Coninck & Backstrand, 2011). Electric vehicle development through bilateral and multilateral cooperation was studied, where TCP Hybrid and Electric Vehicles (HEV) was mentioned (Bhasin, 2014). To get a better overview and identify possible gaps and overlaps between the Committee on Energy Research and Technology (CERT) and working parties/coordination, analysis and visualization were performed to understand the alignment of TCP participation with national policy (Egglar, et al., 2018). The working parties and the coordination group were established by CERT.

To the best of our knowledge, a specific case study of multilateral energy technology cooperation has not been performed. Hence, we chose to investigate IEA TCPs as a case study because they have a long history of over 40 years of achievement of energy and climate goals since 1976 and are still ongoing. This study aims to learn about the role and contribution of IEA TCPs. Through statistical analysis, changes in the

number of participants in TCPs imply an awareness of low carbon-intensive technologies. The survey enables for an understanding of the effort of TCPs in leading successful multilateral energy technology cooperation. By investigating IEA TCPs, it is possible to know the factors for long-living energy technology collaboration and implications for multilateral cooperation in other fields.

## 2. Overview of IEA TCP

### 2.1. Historical change of IEA TCPs

The members of the IEA recognize the need for a new institution to deal with energy technology challenges through multilateral research, development, and demonstration (R&DD) activities. Underlying the circumstance, TCPs were established in 1975 with IEA governing board approval. IEA TCPs, known as implementing agreements prior to 2016, were established as a mechanism for international collaboration that same year. The first 5 years in the 1970s, 34 TCPs were created to perform active joint R&DD mainly focused on fossil fuels and related technologies due to the influence of the oil shock in the 1970s. Afterward, states sought more gain from input of human and financial resources with other states, industrial sectors, and academic bodies. Now, TCPs cover a wide range of clean energy technologies, from fusion power to wind energy and biomass combustion. Sharing technology information and experiences among participants in TCPs produces collective benefits for all participants. Many of the original TCPs still exist today, having altered their programs of work to address emerging technologies specific to their energy topic or sector. Robust and active collaboration has lasted for roughly 40 years to overcome the challenges. TCPs establish a new program whenever challenges arise to be solved.

Period	Number of TCPs established	Establishment background	Main focus of TCPs	Current existing TCPs
1975–1980	35	Oil shock, high oil prices, pursuit of alternative energy	Efficiency in fossil power plants, bioenergy, hydrogen, hydropower, wind power	12
1981–1990	21	Energy efficiency, Chernobyl accident, energy security	Industry, transportation, energy efficiency in building, safety in fusion development	8
1991–2000	15	Kyoto Protocol, climate change action, low-carbon technology	Fuel cells, hybrid electric vehicles, carbon sequestration, wind, geothermal, solar	11
2001–2019	10	Digital technology, electric grid, renewable energy	Smart grid, electricity network, high efficiency in end-use equipment	7
Total	81			38

(Source: (IEA, 2016); restructured by the authors)

The content of energy technology handled by TCPs was freely determined according to the needs of the period, and various contents of activities were recognized (Table 2). In the 1970s, the impact of the oil crisis and rising oil prices called for the development of alternative energy. During the 1980s, energy conservation continued to be pursued, but the impact of the Chernobyl accident in 1986 called for ensuring energy safety. In the 1990s, the development of low-carbon technologies and measures against climate change, such as the adoption of the Kyoto Protocol in 1997, came to be required. In the 2000s, with the spread of digital technology, the need for power and renewable energy networks increased. Although many TCPs have existed since the 1970s, they have been updated to meet the needs of the times.

Since 1975, 81 TCPs have been created, 31 have closed, and 12 have merged, leaving 38 operating today. It can be noted that TCPs support the priorities of their members and are designed to evolve and respond to energy challenges over time. As described in Figure 1, a large number of TCPs were created until 1981—up to 37 programs—although a cease in TCPs was observed. After that, TCPs merged or ceased depending

on the needs of the period, changing the number of TCPs. It is seen that almost 40 TCPs have been operated since the 1980s, despite merging or ceasing.

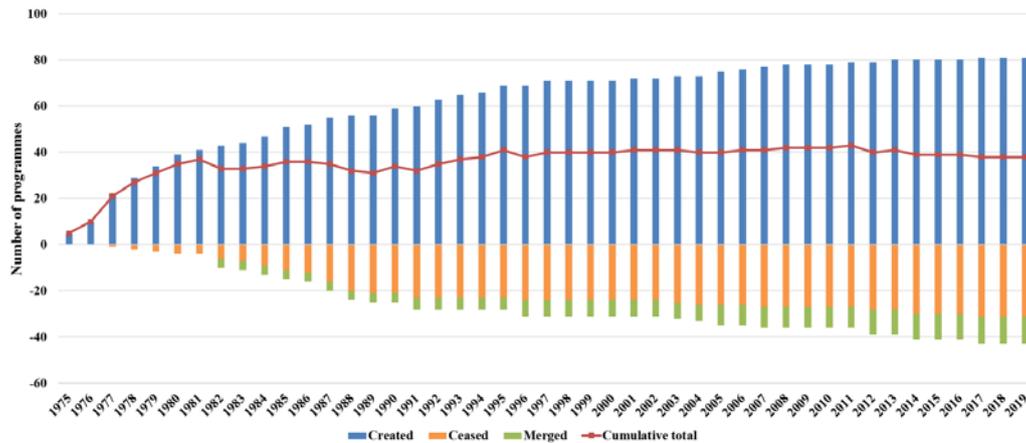


Figure 1. TCPs created, ceased, or merged 1975–2019  
(Source: (IEA, 2016) and data from personal communication with IEA coordinator; restructured by the authors)

Although participants have increased year by year, it was not easy for non-IEA members to participate in TCPs. Since the introduction of the “IEA Framework for International Energy Technology Collaboration” in 2003, non-IEA countries have increased their participation in TCPs (Figure 2). Since then, the participation of companies and industries as well as the government has become more flexible.

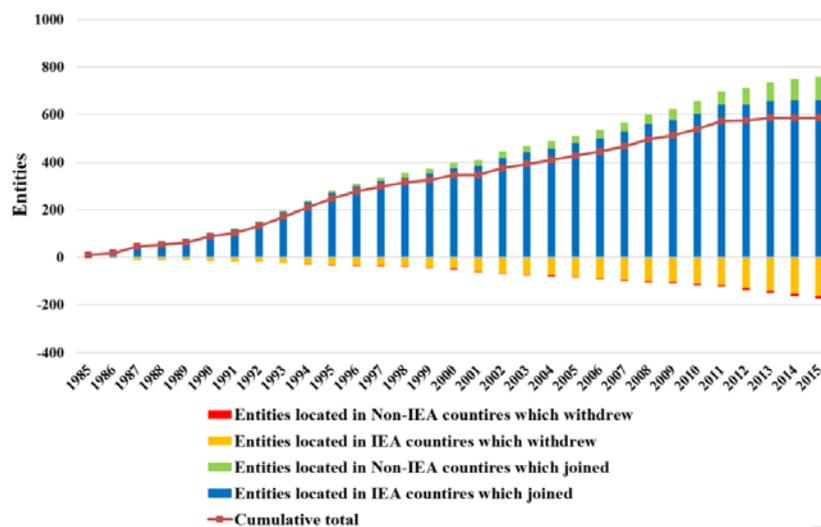


Figure 2. Change in participation in TCPs  
(Source: (IEA, 2016); restructured by the authors)

## 2.2. Structure of IEA TCPs

Currently, 38 programs are in operation. As of January 2020, 38 TCPs have been implemented. The breakdown consists of two cross-cutting, three electricity, five buildings, one industry, five transport, five fossil fuels, eight fusion power, and nine renewable energy TCPs, as described in Figure 3. Among the above-mentioned 38 programs, there are four working parties: Working Parties on Energy End-Use Technologies (EUWP), Working Party on Fossil Fuels (WPFF), Fusion Power Coordinating Committee (FPCC), and Working Party on Renewable Energy Technologies (REWP). On top of the four working parties, the CERT is composed of senior experts from IEA member governments who provide strategic guidance to their working parties.

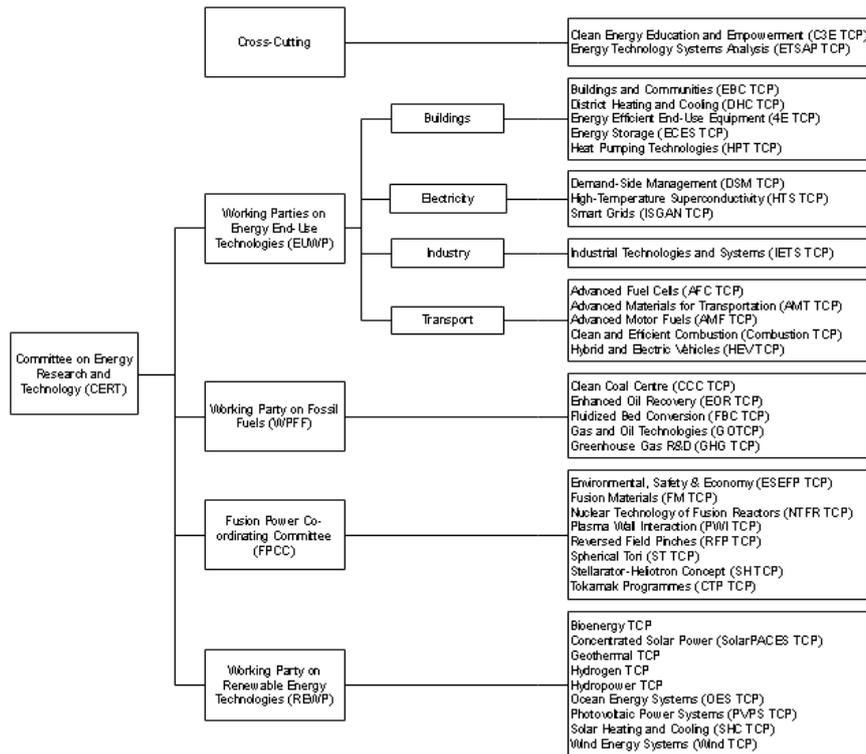


Figure 3. Structure of IEA TCPs  
(Source: (IEA, 2016); restructured by the authors)

Participants in each program can be divided into two groups: contract parties (CPs) and sponsor parties (SPs). CPs indicate governments (both IEA and non-IEA member countries), the EC, and intergovernmental organizations, including national or private corporations designated by a government. CPs from one country can be plural. SPs are public and private sector entities, including non-intergovernmental organizations not designated by a government. Along with the active performance of IEA TCPs, the participation of SPs has increased from 1% in 2002 to 10% in 2019. TCPs have had the capability to create flexible institutions for all entities of CPs and SPs that have continued to allow energy technology innovation to respond to energy challenges over four decades.

Figure 4 demonstrates the overall logical frameworks of IEA TCPs that summarizes the input, output, and outcomes of TCP. Activities conducted by the TCPs are placed into five categories, and all categories are researched by experiments, *in situ* testing, and various analyses to prove the reliability and durability of the technology (IEA, 2016). From 1975–2015, TCP focused 80% of activities on applied research, 12% on information sharing, 4% on proof of concept, 3% on onsite surveys, 3% on pilots, 1% on proof.

Figure 4. Overall logical framework of IEA TCPs

Input	Activity	Output	Outcome
Goals to pursue	Proof of principle (4%)	Various publications of annual reports, technical reports, newsletters, etc.  Forums and conferences held for information and knowledge sharing  Training and webinars from experts for young researchers and students	Policy adoption
Financial resources	Pilot and demonstration projects (1%)		Technology deployment
Human resources	Field studies, measurements, and exchange (3%)		Economic benefit
Central management organizations	Applied research (80%)		Social acceptance toward new energy technologies
Advice/feedback from IEA	Information sharing (12%)		

(Source: Prepared by the authors based on (IEA, 2016) and the authors' hypothesis)

### 2.3. Features of IEA TCPs

Factors for successful TCP performance are as below.

#### 2.3.1. Sharing financial investment and knowledge

Since IEA does not provide financial funding for technology development, CPs and SPs in TCPs must make an investment in R&DD. Implementing agreements in each program establishes the terms of the financing contribution. It is noted that common financial obligations for tasks/annexes are divided equally by participants in some programs, whereas others hold that equal cost can be in the form of cash, services, intellectual property, or the supply of materials. The participants share the knowledge by ensuring the protection of IEA copyrights and intellectual property rights as established by the IEA. By having an equal contribution to a task/annex in a program, participants in each task/annex enjoy the same knowledge from the cooperation. This is different from an International Tokamak Experimental Reactor (ITER) project (potential benefit by contributing a share of the project investment) (ITER, 2019) and Mission Innovation (encourages participating states to make a pledge for investment) (Myslikova, et al., 2017).

#### 2.3.2. Prioritization of technology cooperation over political and economic aspects

Energy is regarded as a significant component of state's economic security, particularly for states with high energy dependency, because their economies are easily influenced by rapid price changes and supply turbulence (Yergin, 2006). Energy security can be interpreted from a broader spectrum of national security and geopolitical strategy. Therefore, political economy aspects prioritize a state's individual approach to energy issues unless the state earns more than it would binding its sovereignty into institutions. However, TCPs clearly target energy technology and segment it into various programs, from fossil fuels to renewables. The tasks/annexes in each program are established depending on the participants' interests and needs in energy technology. Most activities in the tasks/annexes are *in situ* testing and various analyses for the investigation of the reliability and durability of the technology for policy recommendation. This means that energy issues in the TCPs are less likely to be influenced by political and economic issues but rather influence policymakers by proposing technical options.

#### 2.3.3. Freedom of program formulation and participation in/out

Two or more IEA member states, with the approval of the board, can enter into "implementing agreements" to establish programs and projects for energy technology R&D and demonstration. This freedom to form technology programs implies that TCPs are less likely to escalate international competitiveness for commercializing certain technologies in cooperation, as the establishment of a new technology program cannot be tackled by other states. Otherwise, there would be a regulation for other member states to veto the establishment of a new program. Additionally, not all participants in a program are obliged to participate in all tasks/annexes. The decentralized form of programs enables them to freely join/withdraw from the tasks/annexes depending on the circumstance of each participant.

#### 2.3.4. Risk minimization of technology development

Despite the in-depth analysis and simulation of energy technology, pilots and demonstrations are important procedures before deployment. They require a large amount of expenses to produce outcomes, and high risks are expected. Hence, multilateral cooperation in TCPs shares the burden of the risks to reach higher levels of achievement than individual achievement. To minimize the risk and uncertainty as well as maximize the incentives, single best efforts are taken in cooperation for scientific and technological breakthroughs (Paulo, 2014). There have been several pilot and demonstration projects, such as the Grimethorpe pressurized fluidized bed converter in England (1980–1984), the solar collectors and central receiver system in Spain (1981–1985), the CCS facility in Canada (2000–2012), and the ITER for fusion energy in France (2007–present).

#### 2.3.5. Strong willingness against climate change and energy transition

TCPs have been established by perceiving the need for a flexible mechanism to deal with energy technology challenges. Underlying their background is that the IEA was created to collectively respond to the oil disruption after the oil shock in the 1970s. In the beginning, one-third of TCPs were coal-related programs, and the others were alternative energy sources with mostly supply-side solutions. Not only supply-side solutions but also energy consumption reduction as well as increases in the energy efficiency of building and vehicles were also important enough to take up the efforts of almost half of all the programs. After the Kyoto Protocol in 1997, renewable and transport-related technologies were emphasized for international action on climate change, now proving that a socio-technical approach is considered to effectively deploy technology development. Since increasing participants in TCPs, it has been observed that the recognition of global warming and the significance of energy transition are assumed to be the driving forces for energy technology cooperation, as a game theory analysis implies (Urpelainen, 2013).

#### 2.3.6. Robust platform (i.e., IEA) to establish/perform energy technology development/cooperation

Depending on the energy technologies TCPs handles, each TCP reports to the affiliated working party among the three working parties and one committee: EUWP, WFFF, REWP and FPCC. Comprehensive considerations will be given to its senior body, the Energy Research and Technology Committee (CERT). It is considered that the committees and working groups within the IEA will review the activities of the TCP and the existence of a mechanism that provides guidance to help TCP activities remain on track. Furthermore, high-level guidance is also provided. For example, the chairman's summary of the IEA ministerial meeting held in 2015, regarding the TCP, said, "Given the importance of developing and disseminating energy technologies, it is necessary to further reduce costs and promote appropriate policies, strengthen outreach and increase participation of member and non-member countries as well as the research community and industry."

### 3. Methodology

The methodology employed in this study includes: 1) a statistical investigation on changes in participation, with data from a report on IEA TCPs and from personal communication with the IEA coordinator; and 2) the development and testing of a public survey, including using focus groups and respondent screening. A mixed method of concurrent embedded survey design was applied to identify important issues and the reasoning behind these issues to explore potential implications for multilateral cooperation.

#### 3.1. Statistical analysis

This study provides a holistic picture of participants' changes between 2015–2019. Statistics from the IEA compendium book, *Technology Collaboration Programmes: Highlights and Outcomes*, released in 2016, and from personal communication with an IEA coordinator were used for statistical comparison of changes in entities and country participation. This was to obtain trends of joins/withdraws by participants. However, the IEA coordinator, through personal communication, informed that it is not possible to distribute the list of participants joining/withdrawing year by year. Therefore, changes between 2015–2019 were employed for comparative analysis.

Average, mean, and standard deviation were calculated based on the following: a) the number of entities changed per program and b) the number of countries per program. Since entities (i.e., CPs and SPs) are composed of countries, non-governmental organizations (NGOs), interest groups, and companies, the number of CPs and SPs as well as the total number of each between 2015–2019 were determined to understand the number and distribution of changes in CPs and SPs in TCPs. This can indicate whether awareness of low-carbon technology development increased not only for countries, which mostly belong to CPs, but also non-country groups (SPs). Regarding the number of country changes per program, countries are divided into two groups: IEA and non-IEA members. This is because IEA TCPs were mainly established by IEA members. As non-IEA members are mostly developing countries, it would be possible to learn about awareness of low-carbon technologies by analyzing the change in the number of countries. Additionally, the distribution of IEA and non-IEA members across overall TCPs indicates whether IEA and non-IEA members put efforts in comprehensive or specific fields of TCPs.

### 3.2. Survey design and analysis

A cross-sectional, email-based survey for self-evaluation among representatives (i.e., delegates and alternates) in TCPs was administered through SurveyMonkey. The survey questionnaire is described in Appendix A. The sample group was selected by collecting email addresses of representatives on 38 TCP websites. Among them, email addresses of the representatives could be gathered from the 18 TCP websites. The survey was administered for 5 weeks from the first week of November 2019. After three reminder emails and two interim reports before sending the reminder email, a total of 173 responses were received from the 511 representatives from 18 TCPs. The overall response rate was 34%. Details are described in the results section.

Figure 5 depicts the survey design for the study. A mixture research method was employed that included both quantitative and qualitative study, which deepened the understanding by collecting and analyzing numbers and words (Greene, et al., 1989). The general objective of the concurrent embedded design was a need to address different types of questions within research projects that require different methods (Creswell, et al., 2003).

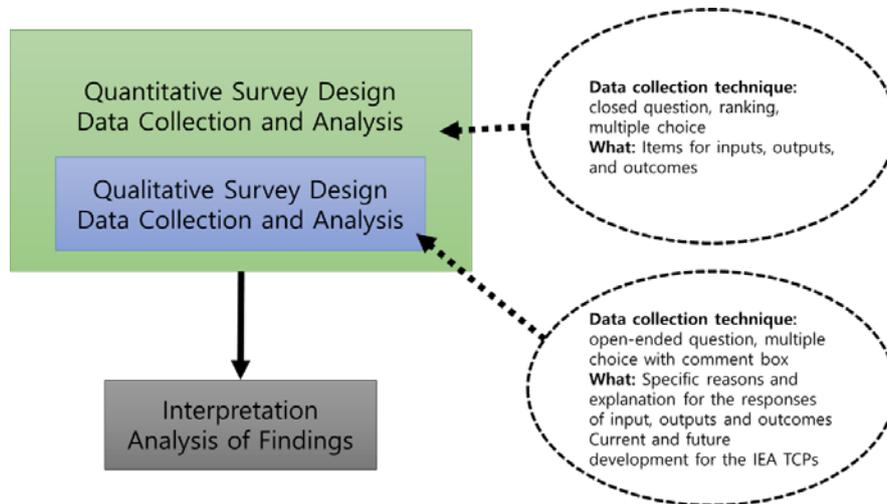


Figure 5. Mixed method of concurrent embedded design procedure (Source: (Creswell, et al., 2003); data collection technique designed by the authors)

Since we categorized the logical framework of IEA TCPs (Figure 4) from input to outcome, the survey was divided into four sections: 1) input variables: international/national goals, human/financial resources, IEA feedback, and central management organizations; 2) output variables: output channels for outcomes and overall output satisfaction; 3) outcome: policy adoption, technology deployment, economic benefit, and social acceptance; and 4) development and discussion of TCP activities. Question types ranged from

closed questions with two choices (yes/no) or five choices (highly unsatisfied to highly satisfied/not well to very well), multiple choice, preferences (ranking from 1–5), and open-ended question boxes for further description of their responses. Because representatives are affiliated in various fields, such as government, research, and business, the survey was designed to skip questions that were irrelevant/unrelated to the respondents.

For the input factors, cost sharing, human/financial resources, feedback from the IEA TCP governing bodies, and the importance of central management organizations were summarized. Since equal cost sharing is a rule to participate in TCPs, as described in Section 2.3.1, the question was to understand whether it is appropriate and the possible alternatives if it is inappropriate. Questions about human/financial resources were asked with sub-questions to learn about the sufficiency of the resources and additional information about fair/insufficient resource situations. Satisfaction of feedback from the governing bodies was asked about with a sub-question of what support is required for those who are not satisfied with the current governing bodies' performance. A question was asked to learn about the importance and necessity of central management organizations. This is because, when interviewing with the New Energy and Industrial Technology Development Organization (NEDO) in Japan, we came to understand that central management organizations, or so-called “centers,” operated in some TCPs. Regarding output factors, the effectiveness of output channels to share information and knowledge was asked about. Additionally, a question regarding overall output satisfaction of various outputs was asked with a sub-question about reasons for being satisfied or unsatisfied. This was to learn which specific areas the respondents were satisfied/unsatisfied with. In the outcome section, how output is reflected in one's country as a process of transiting from output to outcome was questioned. Outcome achievements categorized by policy adoption, technology deployment, economic benefit, and social acceptance were summarized with the reasons for reaching the outcome.

From the survey data, multiple regression correlations were built with a focus on the impact of input on the output satisfaction and outcome, respectively, and output channels on the outcome. However, not all respondents fully completed all questions because the survey was designed to skip irrelevant questions based on the respondents' status and occupation. It should be noted that those who did not make a full response to the factors employed in (Eq. 1–9), respectively, were removed, so that the number of responses in each equations were varied. A 95% confidential interval was applied. These regressions and their respective correlations describe the effectiveness of factors impacting the output or outcomes. For the input, output, and outcome question, there were two choices of closed questions (yes/no) and five choices (highly unsatisfied to highly satisfied/not well to very well). The answers were adjusted to have a maximum of 2 points. For example, the yes and no choices were changed to 2 and 1, respectively. The five choices were changed to 2, 1.75, 1.5, 1.25, and 1.

$$\begin{aligned} Output.Satisf. = & a + b_1 Input_{Intl} + b_2 Input_{Nat} + b_3 Input_{Human} + b_4 Input_{Finan} + b_5 Input_{Fb} \\ & + b_6 Input_{cmo} \quad (1) \end{aligned}$$

To find the correlations among the input–output satisfaction analysis (Eq. 1), six input factors were considered to find the correlation with output satisfaction (*Output.Satisf.*). Input factors were considered as follows: international goals (*InputIntl*), national goals (*InputNat*), human resources (*InputHuman*), financial resources (*InputFinan*), IEA feedback (*InputFb*), and central management organizations (*Inputcmo*).

$$\begin{aligned} Outcome_{i,j...} = & c + d_1 Output_{Conf.} + d_2 Output_{Report} + d_3 Output_{Newsletter} + d_4 Output_{Webinar} \\ & + d_5 Output_{Train} \quad (2) \end{aligned}$$

For the output channel and outcome analysis (Eq. 2), output channels consisted of five factors: conferences, symposiums, meetings, etc. (*OutputConf.*); reports like annual reports and technical reports, etc. (*OutputReport*); newsletters (*OutputNewsletter*); webinars (*OutputWebinar*); and training programs (*InputTrain*). Regarding output channels, the question was started with if each channel was performed in the TCP that the respondents belonged to. The sub-question for those who answered “Yes” was given to know how effective the respondent thought the channel was by scoring from 1–5. An answer of “No” was scored 0.

Outcomes ( $Outcome_{i,j...}$ ) had four factors, with  $i,j$  referring to policy adoption, technology deployment, economic benefit, and social acceptance.

$$Outcome_{i,j...} = e + f_1 Input_{Intl} + f_2 Input_{Natl} + f_3 Input_{Human} + f_4 Input_{Finan} + f_5 Input_{FB} + f_6 Input_{cmo} \quad (3)$$

The same factors of input and outcome were selected for the input–outcome analysis shown in (Eq. 3). Input factors and outcome factors were selected from (Eq. 1) and (Eq. 3), respectively.

It was hypothesized that the clearer the goal and the higher the implementing capacity, the better performance an international organization or group would have, as described in Table 3. Based on the hypothesis, a matrix was built by positioning the 18 TCPs according to the survey data. “Goal” indicates an international goal or national goal, while “implementing capacity” includes human resources, financial resources, and central management organizations.

		Goal	
		Clear	Unclear
Implementing capacity	High	High	Middle
	Low	Middle	Low

(Source: Prepared by the authors based on the authors' hypothesis)

$$P_{x,y,z...}^{AVR} = \frac{Int' l_{x,y,z...18}^{AVR} + Nat' l_{x,y,z...18}^{AVR}}{n_{x,y,z...18}} \quad (4)$$

$$IC_{x,y,z...}^{AVR} = \frac{Human_{x,y,z...18}^{AVR} + Finan_{x,y,z...18}^{AVR} + CMO_{x,y,z...18}^{AVR}}{n_{x,y,z...18}} \quad (5)$$

The matrix of the correlation between TCP goals ( $G_{x,y,z...}^{AVR}$ ) and TCP implementing capacity ( $IC_{x,y,z...}^{AVR}$ ) was built to visualize the TCP status based on the responses from the survey.  $x,y,z...18$  denotes the 18 TCPs for the survey samples. The sum of the average scores of international goals ( $Int' l_{x,y,z...}^{AVR}$ ) and average scores of national goals ( $Nat' l_{x,y,z...}^{AVR}$ ) divided by the valid responses of each TCP ( $n_{x,y,z...}$ ) was used to find the value of TCP goals shown in (Eq. 4). For each TCP capacity ( $TCP\ capacity_{x,y,z...}$ ), the average scores of human resources ( $Human_{x,y,z...}^{AVR}$ ), financial resources ( $Finan_{x,y,z...}^{AVR}$ ), and central management organizations ( $CMO_{x,y,z...}^{AVR}$ ) were considered with  $n_{x,y,z...}$ , as described in (Eq. 5).

$$Output.Satisf_{x,y,z...16}^{AVR} = g + h_1 G_{x,y,z...16}^{AVR} \quad (6)$$

$$Output.Satisf_{x,y,z...16}^{AVR} = g + h_1 IC_{x,y,z...16}^{AVR} \quad (7)$$

$$Outcome_{x,y,z...16}^{AVR} = g + h_1 G_{x,y,z...16}^{AVR} \quad (8)$$

$$Outcome_{x,y,z...16}^{AVR} = g + h_1 IC_{x,y,z...16}^{AVR} \quad (9)$$

Among the 18 TCPs, Enhanced Oil Recovery (EOR) and Fluidized Bed Conversion (FBC) are in the fossil fuel group that can be considered against energy transition. Hence, multiple regression analysis was performed to determine whether a clear goal and high implementing capacity could help reach better output and outcome by removing the two fossil fuel TCPs. (Eq. 6) and (Eq. 7) were to find the correlation between output satisfaction and goal/implementing capacity. The correlation between outcome and goal/implementing capacity was analyzed based on (Eq. 8) and (Eq. 9).

Lastly, questions about current and future developments of the IEA TCPs were given to the representatives to hear their opinions on the current status and what should be done for future TCPs. Political and economic relations on TCP activities were also asked about. Additionally, several questions about the necessity of other TCP in the IEA TCPs, of cooperation with other organizations, and of the wider recognition of the IEA TCPs were asked about to provide implications for the future development of IEA TCPs.

#### 4. Results

##### 4.1. Statistical analysis

For the past 5 years, it is a fact that the absolute number of countries and participants in TCPs has increased, proving the importance of IEA TCPs' role in energy technology cooperation.

Table 4. Statistical analysis of number of CPs and SPs (left) in all TCPs and of total entities in all TCPs (right)							
	2015 (39)		2019 (38)			2015 (39)	2019 (38)
	CPs	SPs	CPs	SPs			
Number of entities	457	92	472	95	Total number of entities	549	567
Average	14	1.23	14.82	1.55	Average	15.23	16.37
Median	13	0	14	0	Median	15	16
Standard deviation	6.97	3.12	7.35	3.14	Standard deviation	8.31	8.48
Maximum	27	18	28	17	Maximum	37	35
Minimum	3	0	3	0	Minimum	3	3

\*Total number of TCPs in parenthesis  
(Source: Prepared by the authors based on the analysis)

As describe in Table 4, 38 programs were in operation in 2019 because two programs ceased, and one program was newly established between 2015–2019. The average number of CPs and SPs, including the total participants, increased from 2015–2019. The median value of CPs increased by 1. The value of SPs does not show any change, as the participation by SPs is highly weighted in certain programs that participated in only 16 programs in 2019, such as Greenhouse Gas R&D (17), Clean Coal Center (7), Industrial Technologies and Systems (5), and Hydrogen (6), and the others include less than five SPs. Over 10 entities, 23 programs could be observed in 2015 but 24 programs in 2019. The standard deviation is to learn whether entities are evenly distributed across all TCPs. All standard deviations of CPs, SPs, and the total increased from 2015–2019, indicating that CPs and SPs participated in very broadly distributed programs in 2019. It can be inferred that entities that belong to CPs and SPs recognize low-carbon-intensive technology and systems for energy transition as important matters.

Table 5. Statistical analysis of number of IEA and non-IEA members in all TCPs (left) and of total states in all TCPs (right)							
	2015(39)		2019 (38)			2015 (39)	2019 (38)
	IEA	Non-IEA	IEA	Non-IEA			
Number of states	30	25	31	27	Total number of states	55	58
Average	15.23	3.68	15.23	3.52	Average	9.98	9.78
Median	18.00	1.00	19.0	2.00	Median	7.00	5.00
Standard deviation	10.21	4.60	10.07	4.66	Standard deviation	9.95	9.90
Maximum	36	20	37	22	Maximum	36	37
Minimum	0	1	0	1	Minimum	0	1
*Total number of TCPs in parenthesis (Source: Prepared by the authors based on the analysis)							

Table 5 provides statistics of country participation per program. It must be noted that entities encompass SPs and transnational groups, such as international organizations and interest parties. Statistical analysis considering country implicates how the individual countries take part in the TCPs for their sake in terms of carbon reduction, energy security, etc. The total of 30 members (IEA members plus the EC) in 2015 has become 31 members, as Mexico joined the IEA in 2018. Regarding non-IEA members, four non-IEA members (i.e., Argentina, Colombia, Namibia, and Saudi Arabia) have joined, while Qatar withdrew, and Mexico moved to the IEA member group. Since three countries (i.e., Luxemburg, Estonia, and Slovak Republic) did not participate in any program in 2015, the minimum value is recorded as zero in 2015, but it still does not change because of Luxemburg in 2019. The most active participant is the US in both 2015 and 2019 among the IEA members, whereas China joined 20 programs in 2015 and increased to 22 programs in 2019 among non-IEA members. More active participation of non-IEA members is observed in 2019, and it is considered that IEA TCPs had a breakthrough to encompass emerging countries, as it has been pointed out that IEA does not comprehend emerging countries such as China and India due to the agency's membership (Van de Graaf, 2012). It is noted that although the absolute value of country participation in TCPs increased from 2015–2019 (right side of Table 5), the standard deviation of total states slightly decreased by 0.05. This is because the decrease in standard deviation of IEA members offsets the increase in that of non-IEA members. The result shows that overall, states, particularly IEA member states, did not broadly participate in TCPs in 2019 compared to 2015 but rather slightly weighted toward certain programs. This trend of country participation declination per program can be argued that because IEA does not provide financial support, it would be too much of a burden for the countries participating in many programs. Second, clean technology simply is not effectively feasible in one's country due to the circumstantial changes and better viable technology appearance. Lastly, it can be considered that IEA member states, at the same time as OECD member states, are mostly developed countries that have relatively in-depth knowledge on clean technology. Through the collaboration, they may feel less likely to enjoy knowledge gain rather than have the high possibility of facing exposure of their novel knowledge of certain clean technology when it comes to the commercialization of clean technology (Urpelainen, 2013).

## 4.2. Survey analysis

### 4.2.1. Response

Technology Collaboration Programmes (TCPs)	Response	Survey sample	Response rate
Energy Efficient End-Use Equipment (4E)	3	15	20%
Advanced Fuel Cells (AFC)	9	27	33%
Advanced Motor Fuels (AMF)	11	31	35%
BioEnergy	12	42	29%
District Heating and Cooling (DHC)	10	22	45%
Demand-Side Management (DSM) <sup>a</sup>	7	34	21%
Energy in Building and Communities (EBC)	17	33	52%
Energy Storage (ECES)	8	23	35%
Enhanced Oil Recovery (EOR)	3	10	30%
Energy Technology Systems Analysis (ETSAP)	4	11	36%
Fluidized Bed Conversion (FBC)	14	29	48%
Hybrid and Electric Vehicles (HEV)	4	13	31%
Heat Pumping Technologies (HPT)	11	37	30%
High Temperature Superconductivity (HTS)	3	16	19%
Hydrogen	13	44	30%
Industrial Energy-Related Technologies and Systems (IETS)	9	18	50%
Photovoltaic Power Systems (PVPS)	20	66	30%
Solar heating and cooling (SHC)	15	40	38%
<b>TOTAL</b>	<b>173</b>	<b>511</b>	<b>Average: 34%</b>

<sup>a</sup> The name of the TCP was changed to User-Centered Energy Systems (Users TCP) in 2020  
(Source: Prepared by the authors based on the survey for the research)

As shown in Table 6, 173 responses were received. However, useful information for the analysis result was limited because the questions were not mandatory to respond to, as some questions were irrelevant or not related to respondents due to the various occupations of the representatives, such as in research, industry, or government. This led to performing analyses with different numbers of responses.

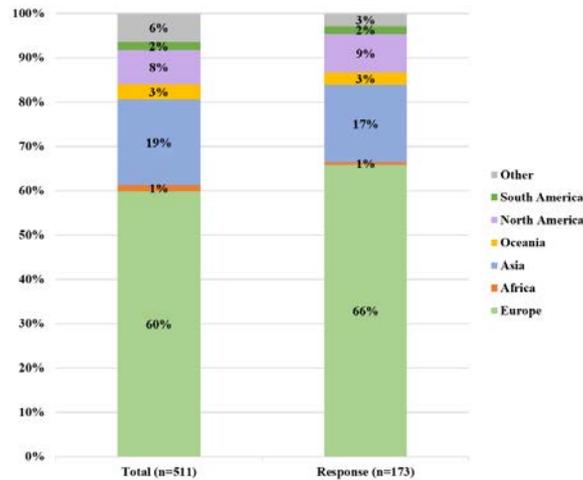


Figure 6. Survey sample and response by region  
(Source: Prepared by the authors based on the survey for the research)

According to the region (Figure 6), 60% of the total sample (n = 511) were from European countries, which was the largest number in the survey sample. Next was Asian countries (19%). North America took 8%, and others, such as NGOs, private companies, and interest groups, accounted for 6%. The response rate showed that more responses from the European countries (66%) and North America (9%) were received

when compared to the ratio of the sample, while Asian countries and others showed 17% and 3% lower, respectively, than the sample. By comparing the sample and the response, it can be said that a relatively similar ratio replied to the survey questionnaire.

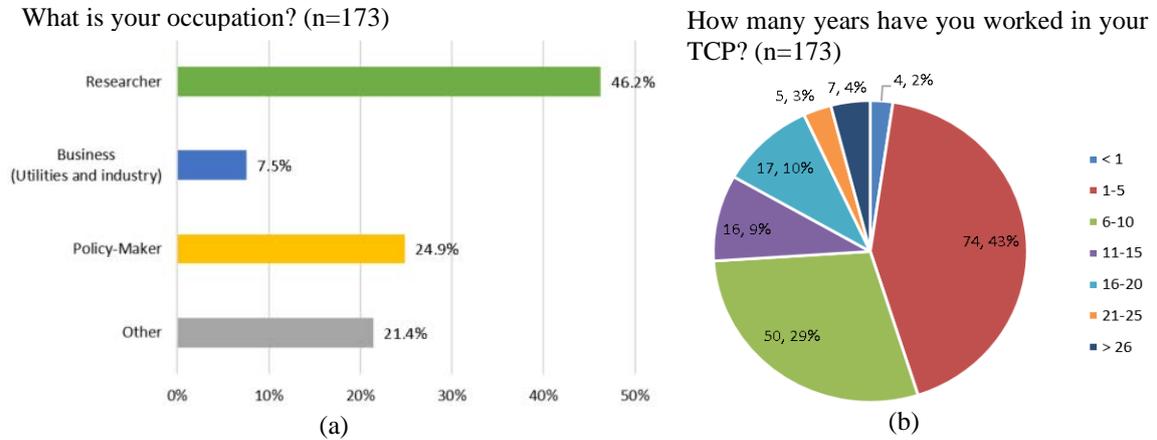


Figure 7. Respondents' (a) occupation and (b) working years in TPCs  
(Source: Prepared by the authors based on the survey for the research)

As described in Figure 7(a), 46.2% of respondents identified themselves as researchers, which was the most in the sample. Next was policymakers (24.9%) and other (21.4%). Those who chose “other” were working for NGOs and mostly the government sector (e.g., advisors, project managers, funding agencies/organizations). Most representatives had worked in their TCPs less than 10 years, as shown in Figure 7(b).

#### 4.2.2. (Input) Cost sharing

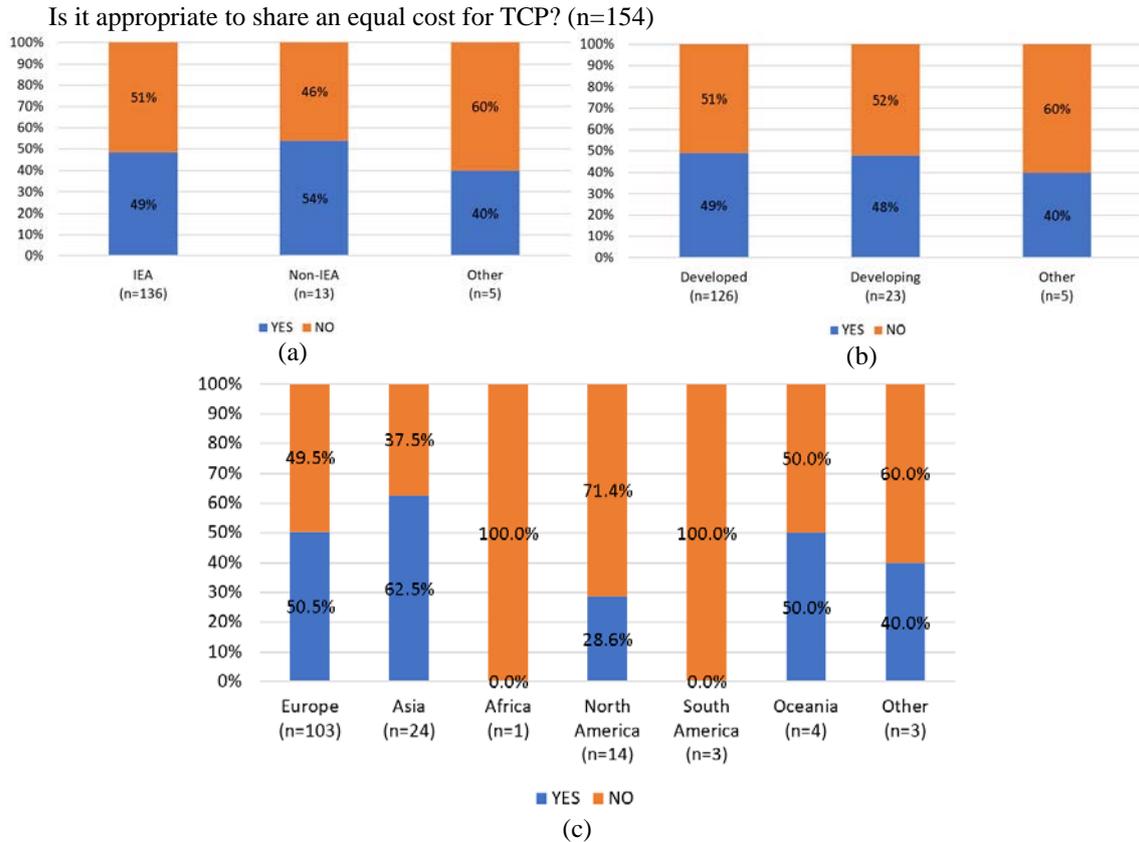


Figure 8. Response on cost sharing by (a) IEA/non-IEA members, (b) advanced/developing countries, and (c) region

(Source: Prepared by the authors based on the survey for the research)

Regarding equal cost sharing for TCP participation, results for both IEA/non-IEA members (Figure 8(a)) and advanced/developing economies (Figure 8(b)) did not lean too much to one side of either “Yes” or “No.” Advanced and developing economies were divided according to the United Nations (UN) report (UN, 2019). Most responses indicated that equal cost sharing was not an appropriate way for TCP participation. Only in the case of a non-IEA member, “Yes” outnumbered “No,” meaning that equal cost sharing was considered appropriate, because all “Yes” responses were from China. It is as well reflected in Figure 8(c) that “Yes” responses from Asian countries showed a higher share (63%) than “No” responses. Half from Europe and Oceania supported equal cost sharing, while more than half of North America responded “No.”

An open-ended question was asked to those against the equal cost sharing for alternative methods for cost sharing. Most respondents suggested the cost sharing should be considered according to the GDP and scale of economy in one’s country. Asia (except China), Africa, and Oceania responded with the same comments about GDP and the scale of economy. North/South America pointed out GDP as a factor but also suggested that national budget allocation for the TCP activities should be considered. South America proposed an interesting alternative that cost sharing should be done according to the GHG emission of each country. Others (NGOs, interest groups, etc.) were against equal cost sharing but stated it is better to continue the equal cost sharing because it would be difficult and time consuming to make a consensus for adjustment.

#### 4.2.3. (Input) Human and financial resources

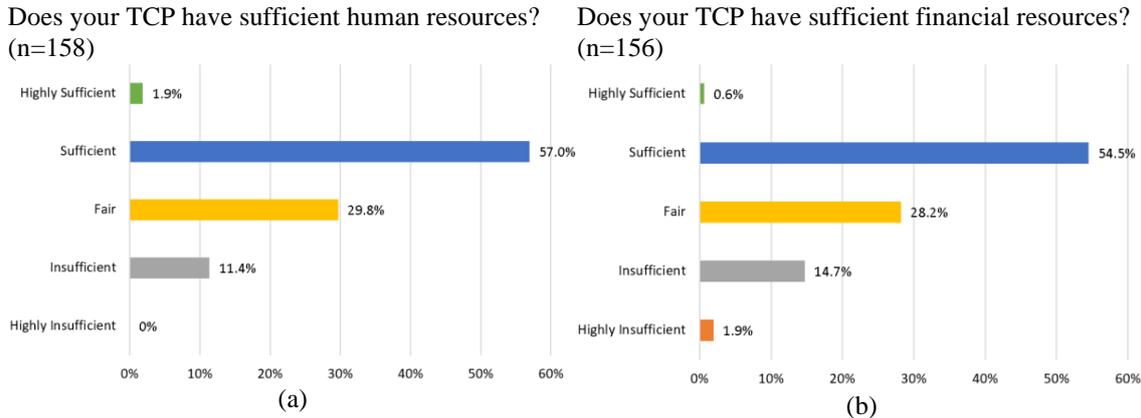


Figure 9. Sufficiency of (a) human resources and (b) financial resources  
(Source: Prepared by the authors based on the survey for the research)

As describe in Figure 9, over half of the respondents thought both human resources (58.9%) and financial resources (55.1%) are “highly sufficient/sufficient” for TCP operation. Approximately 30% of the respondents mentioned that human and financial resources are fairly sufficient. Only 11.4% expressed insufficiency in human resources, while 16.7% stated insufficiency in financial resources. It was found that the “insufficient/highly insufficient” responses were not from specific categories, such as advanced/developing economies or IEA/non-IEA members.

Based on the comments from those who answered insufficient/highly insufficient, it was found that human and financial resources are intertwined and that human resources cannot be sufficient unless financial resources are sufficient. There are many limits due to human and financial resources. Some TCPs’ activities are quite active such that more personnel would be better for support, while some told that increasing human resources would mean better performance and development of TCP activities. Additionally, extensive networks and increasing numbers of member countries are necessary to diffuse the results of TCPs for substantial impact worldwide.

It was told that some countries have a difficult time receiving funding due to economic crises. It can be inferred that the national economic situation highly affects funding issues, particularly for researchers. Hence, if national funding is not enough for the representatives, they have to be self-funded by NGOs. For those who do not have sufficient funding, there is no way to travel to participation meetings or even to participate in TCPs. Reponses say that more budgeting and funding can successfully reach other networks, policymakers, and industrial decision makers to undertake strategic studies or invest in promotional activities. From the perspective of administration, it was told that TCPs are quite administratively heavy, and therefore, more human resources could be utilized. This means that human resources would not be required much if the administration costs could be lowered.

#### 4.2.4. (Input) Feedback from the governing bodies

Do your governing bodies such as a Working Party (i.e., EUWP, WPFF, REWP, FPCC) give adequate feedback to help your TCP activities? (n = 148)

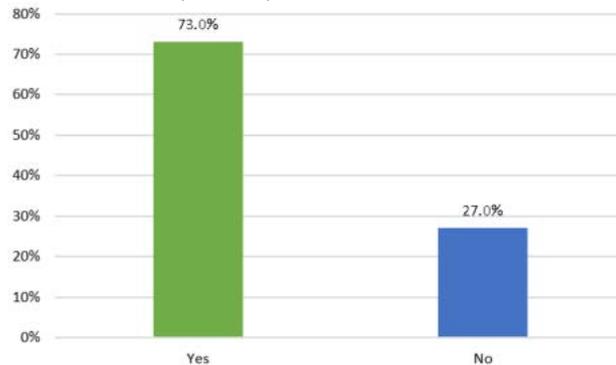


Figure 10. Satisfaction with the feedback from IEA governing bodies  
(Source: Prepared by the authors based on the survey for the research)

The results in Figure 10 show that 73% of respondents think the governing bodies of the working party/coordination provide adequate feedback to help TCP activities. On the other hand, inadequate feedback or lack of support from governing bodies were considered by 27% of respondents.

A sub-question—“What support from your governing bodies including feedback you need more of?”—was given to those who responded “No” to understanding their needs from the governing bodies. The responses demonstrated that three types of support from the governing bodies are highly necessary. First, the support representatives want clear and visible feedback and guidelines from the governing bodies. It was said that feedback and guidelines are rarely reported in ExCo meetings, and even if there are any, it is difficult to clearly identify feedback and information about support from governing bodies. Hence, more attention, effort, and consideration from governing bodies to integrate complementing tasks would increase the involvement and quality of work in TCPs.

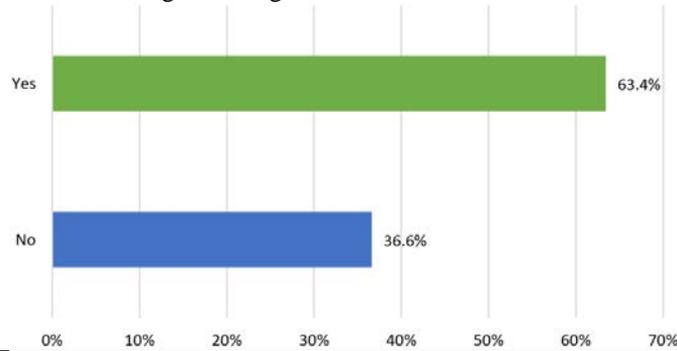
Second was insufficient information exchange and sharing. It is obvious that communication and national support are important to disseminate activities and results so that coordinating efforts among TCPs can be helpful for more active participation. Additionally, advice based on best practices from other TCPs and on operational and strategic issues would be appreciated. Identification of national R&D roadmaps would be helpful because the governing bodies have comprehensive knowledge.

The last was financial funding. It is a rule that the governing bodies do not provide financial support, but some representatives who participate in TCPs face difficulties acquiring research funding due to national economy situations, policies, etc. The funding issue is one of the most important for TCP activities learned about from the questions on the sufficiency of human and financial resources.

Others were mentioned as follows. Although feedback and guidelines are available, only written reports are available, meaning that no contacts or discussion can be made. A mismatch of timescales between a project agent and a policy analyst was mentioned because the policy analyst wanted quicker responses before projects were terminated with a clear result. The most negative comment was that the governing bodies should undertake a concrete positive action with a clear result in a practical way rather than a political way.

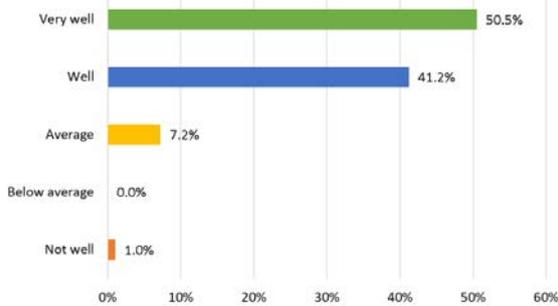
4.2.5. (Input) Importance of central management organization

Does your TCP have a central management organization such as so-called “Center”? (n = 153)



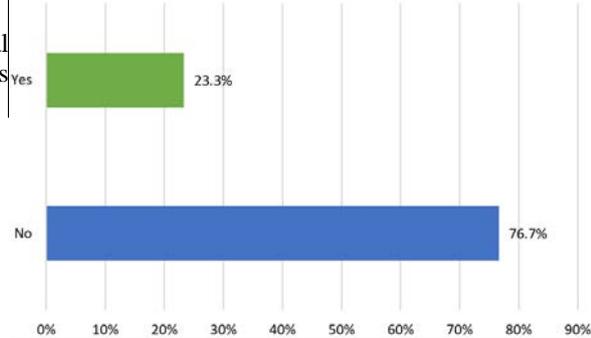
Yes

If Yes, how well do you think the central management organization (i.e., Center) is performing? (n = 97)

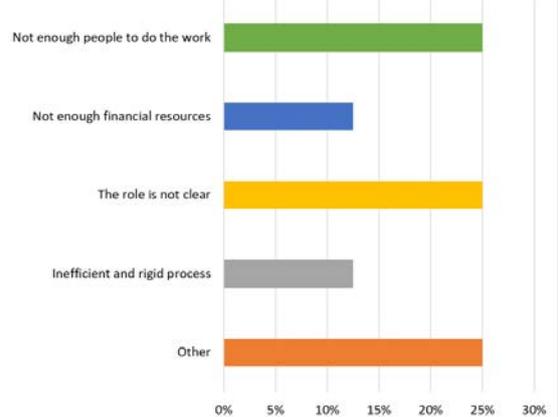


No

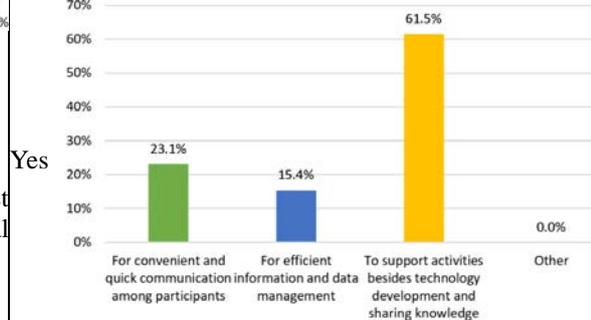
If No, do you think it is necessary to have a central management organization such as a “Center”? (n = 56)



If average or below what do you think the biggest issue affecting the performance of the central management organization of you TCP? (n = 8)

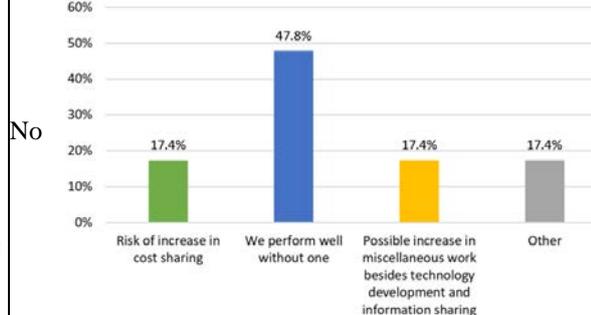


Why do you think it is necessary? (Choose the best answer) (n = 13)



Yes

Why do you think it is unnecessary? (Choose the best answer) (n = 46)



No

Figure 11. Response on the operation of central management centers (Source: Prepared by the authors based on the survey for the research)

For the active and supportive administration process within TCPs, some TCPs operate from a central management organization called a “center.” The series of questions provided an opportunity for further analysis. Based on responses for the centers’ existence, opinions on the centers’ performance and their reasoning for the necessity of the centers could be ascertained. A summary of the associated responses is outlined in Figure 11.

Regarding center existence, respondents who answered “Yes” (63.5%) showed high satisfaction (92%) with center performance. Only 8% of average or unsatisfied respondents stated reasons such as “lack of human force,” “unclear role of the center,” and “other.” Other was specified as poor performance of the general manager or chair management.

For those who did not have a central management organization (36.6%), most respondents (76.7%) mentioned that it is unnecessary to establish a center by reasoning that “we perform well without one” (47.8%), followed by “risk of increase in cost sharing,” “possible increase in miscellaneous work,” and “other” at 17.4%. “Other” is specified as the management is well done by the secretary and chairman, which can be put in the same context as “we perform well without one.” Those who thought a central management organization is required reasoned with “to support activities besides technology development and sharing knowledge” (61.5%), followed by “for convenient and quick communication among participants” (23.1%) and “for efficient information and data management” (15.4%).

#### 4.2.6. (Output) Output activities for knowledge and information sharing

Does your TCP regularly hold output activities to share information and knowledge? Yes

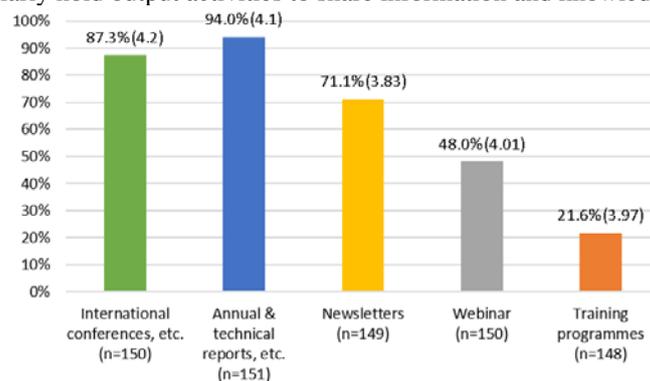


Figure 12. Output channels for knowledge and information sharing

Weighted score from “Yes” respondents described in parentheses

(Source: Prepared by the authors based on the survey for the research)

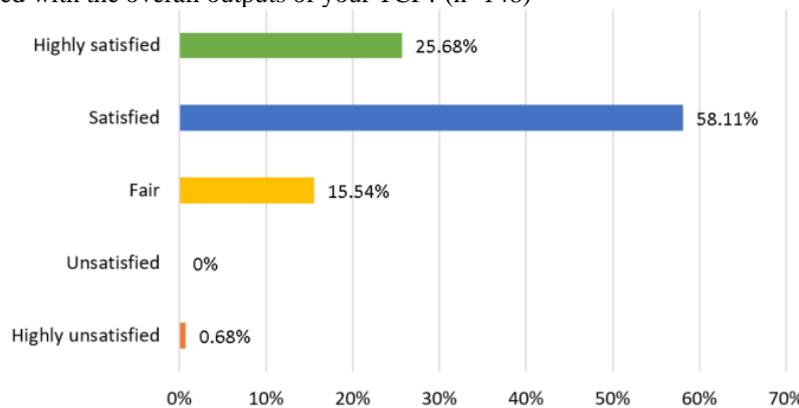
Regarding output channels for knowledge and information sharing (Figure 12), approximately 150 responses were collected on each. The question began with whether each activity was performed in the TCP respondents belonged to. The sub-question for those who answered “Yes” was given to know how effective the respondent thought the activity was by scoring from 1–5. Answers of “No” were scored 0. The result showed that various reports, such as annual reports and technical reports, were evaluated as the most effective, showing 94% of “Yes,” followed by international conferences, symposiums, congresses, etc. (87.3%). Roughly half of the respondents (48%) replied that webinars are conducted in their TCPs. Training programs were the least-mentioned activities (21.6%) conducted by the 18 TCPs. Regarding scores for the effectiveness of knowledge and information sharing, international conferences, reports, webinars, etc., were quite effective, showing a score above 4. However, training programs and newsletters could be regarded effective at only slightly below a score of 4.

An open-ended question was added for any other effective activities besides the five output channels. Varied activities were included. “Workshops” were mentioned the most frequently, held at various levels of individual annexes/projects of TCPs and international conferences, etc. Additionally, various types of

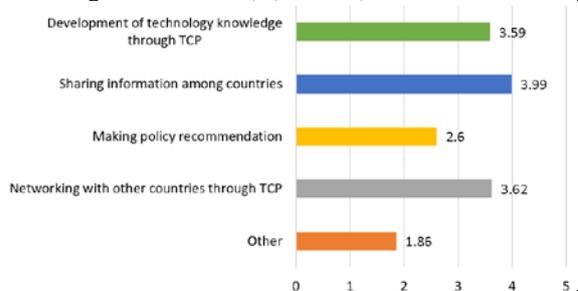
meetings, such as ExCO, outreach, technical, topical, and task meetings, are effective ways for sharing and understanding knowledge and information. National days and information/innovation days at national levels help to exchange information among national experts and TCP experts, which may lead to initiating a new joint annex/project. The utilization of media can be considered an efficient way, such as through joint publication, task webpages, and social media websites (e.g., Twitter, LinkedIn, and YouTube). For students and young researchers, holding an international student competition, such as the Solar Decathlon Europe 21 (SDE21), was suggested as an efficient way to spread knowledge and information. The establishment of liaisons with other international bodies with similar interests and key messages from prominent persons were also suggested for effective knowledge sharing.

#### 4.2.7. (Output) Output satisfaction

Are you satisfied with the overall outputs of your TCP? (n=148)



If *satisfied*, then please rank which areas you are most satisfied with (with most satisfied being 1 and 5 being least satisfied) (n = 122)



If *unsatisfied or fair*, which do you feel unsatisfied? (Multiple answers allowed) (n = 25)

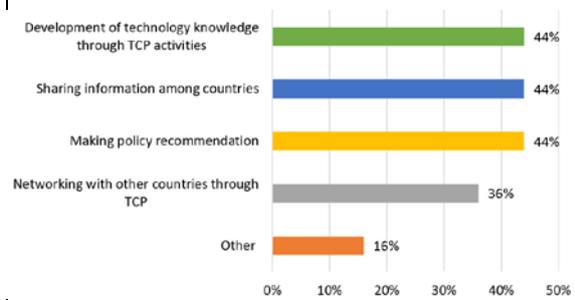


Figure 13. Response on overall output satisfaction (Source: Prepared by the authors based on the survey for the research)

Figure 13 describes that most respondents (84%) were satisfied with the overall output satisfaction. The ranking sub-question about which areas they are most satisfied with indicated that “sharing information among countries” acquired the highest scored of 3.99, followed by “networking with other country” (3.62) and “development of technology knowledge through TCP” (3.59). “Other” incorporates broadening their activities through collaboration with other organizations (e.g., IRENA), connecting among various research areas, and meeting young researchers with new and fresh views. Additionally, information acquirement about market development promoting satisfaction in output was mentioned in “other.”

On the other hand, a few respondents (16%) responded fair or unsatisfied about the overall output. They answered that fair or unsatisfied areas included “development of technology knowledge,” “sharing information,” and “making policy recommendation,” which accounted for 44%. Respondents specified “other” (16%) as follows: sharing information with the IEA central office, lack of running projects for their national sake, and long traveling time for meetings rather than web meetings.

#### 4.2.8. (Outcome) Transition from output to outcome

How has your TCP output been reflected in your country? (Multiple answers allowed) (n=132)

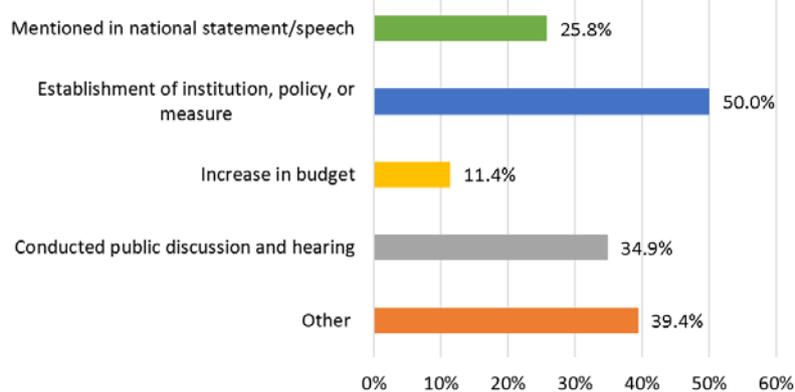
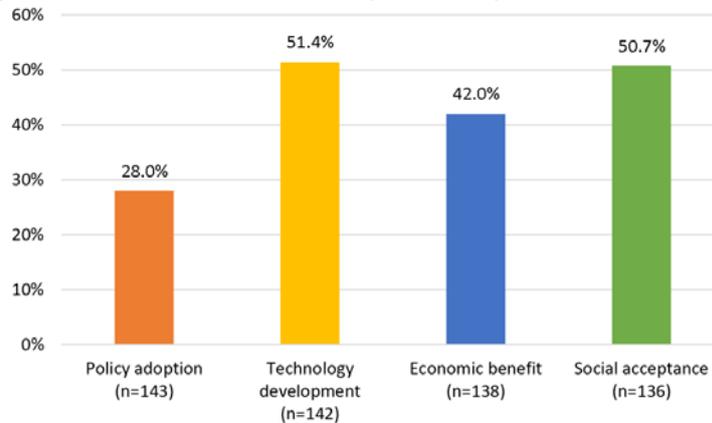


Figure 14. Response on reflection of TCP output in domestic activities  
(Source: Prepared by the authors based on the survey for the research)

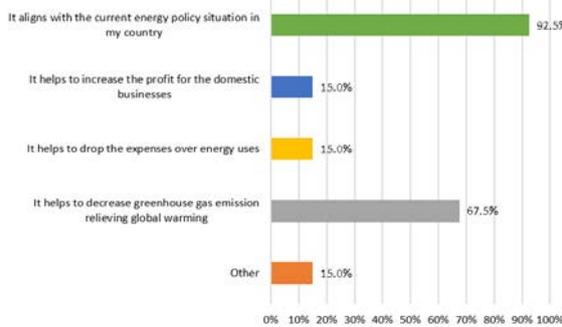
Another question was asked to understand the visualization of output in respondents' countries. As described in Figure 14, half of the respondents stated "Establishment of institution, policy, or measure" was reflected in their countries. Next was "other" (39.4%), conducted "public discussion and hearing" (34.9%), "mentioned in national statement/speech" (25.8%), and "increase in budget" (11.4%). Other included various activities performed in one's country mostly regarding domestic cooperation among institutions and companies being increased. Additionally, TCP output is reflected in the development of national energy roadmaps employing technology and modelling tools (e.g., TIMES). Acceptance of new technologies on a consumer and political level has increased. National workshops/events were held to present TCP work and seek new research opportunities with press releases.

4.2.9. (Outcome) Outcome achievement

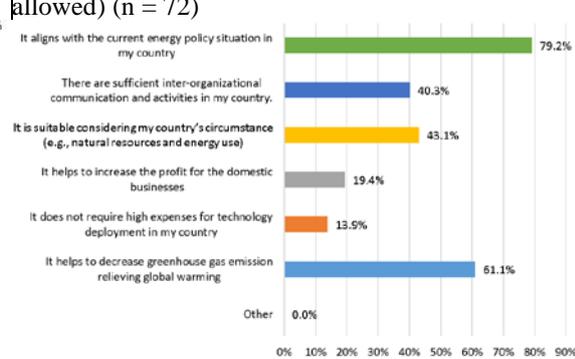
Has your TCP output been lead to the 4 outcomes in your country? Yes



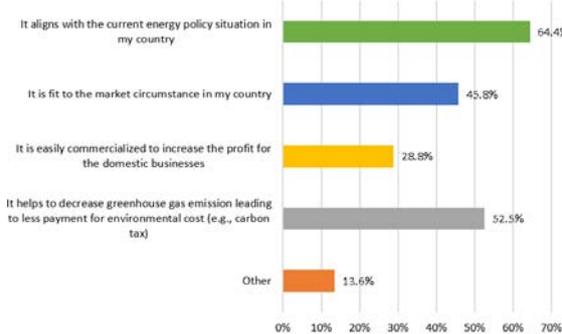
Why has your TCP output been adopted as policy in your country? (Multiple answers allowed) (n = 40)



Why has your TCP output led to the technology deployment in your country? (Multiple answers allowed) (n = 72)



What is the reason that the TCP output you participated in led to economic benefits in your country? (Multiple answers allowed) (n = 59)



What is the reason that your TCP output has led to social acceptance in your country? (Multiple answers allowed) (n = 97)

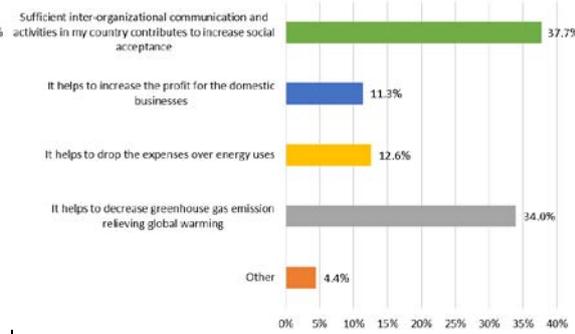


Figure 15. Response on outcome achievement  
(Source: Prepared by the authors based on the survey for the research)

Questions about outcome were provided to understand how much TCP output has led to four outcomes: policy adoption, technology deployment, economic benefit, and social acceptance (Figure 15). Over half of respondents stated that TCP output led to an increase in technology deployment and social acceptance in one's country. Policy adoption showed the least outcome (28%) from output. The main reason leading to outcome included "it aligns with the current energy policy situation in my country" (92.5%) and "it helps to decrease greenhouse gas (GHG) emission relieving global warming," which took first and second place, respectively, among all four outcomes.

In terms of policy adoption, current energy policy and GHG emission factors were the main reasons, while the profit increase of domestic business and the expense drop over energy users were relatively low (both 15%). It was found that domestic environment for technology deployment was important, such as “circumstance of natural resources and end-user” (43.1%) as well as “sufficient inter-organizational communication and activities” (40.3%), in addition to the current energy policy factor. The profit for domestic business and expenses for technology deployment factors showed relatively low importance for technology deployment. Regarding economic benefit outcome from TCP output, “market circumstance” (45.8%) and “easy commercialization of output” (28.8%) were observed. “Other” (13.6%) contained employment opportunities, technology export, saving R&D cost, and synergy effect by transnational cooperation. Lastly, “sufficient inter-organizational communication and activities” (37.7%) was the highest impact to increase social acceptance, followed by “GHG reduction” (34%). Next, factors increasing social acceptance were economic aspects of business profit (11.3%) and expense drops over end users (12.6%). Other (4.4%) indicated that TCP output led to an increase in the credibility of unfamiliar technologies, identifying weaknesses, and an increase in secure usage of the technology. It also increased focus on the energy user and behavior by seeing what other countries are doing.

#### 4.2.10. Regression analysis

##### 4.2.10.1. Input–Output analysis

Table 7. Multiple regression analysis on input–output satisfaction (n = 142)	
	Output satisfaction
International goals	−0.03 (0.12)
National goals	−0.1 (0.1)
Human resources	0.28*** (0.09)
Financial resources	−0.02 (0.08)
IEA feedback	0.05* (0.03)
Central management organizations	0.05* (0.03)
Standard errors in parentheses p-values * p < 0.10    ** p < 0.05    *** p < 0.01 No asterisk(*) p > 0.1 (Source: Prepared by the authors based on the survey for the research)	

Multiple regression analysis on the relationship between input and output is demonstrated in Table 7. It was found that human resources were the most important input, showing the highest coefficient ( $r = 0.28$ ) that lead to overall output satisfaction ( $p < 0.01$ ). Next were IEA feedback and central management organizations, where the correlation between the two factors and output satisfaction had a significant correlation coefficient of both 0.05 ( $P < 0.1$ ). Although international goals, national goals, and financial resources were regressed on output satisfaction, the probability value failed to reject the null hypothesis, showing  $p > 0.31$  for all three. The input–output analysis revealed a significant adjusted- $R^2$  value of 0.09, indicating that six input factors affect overall output satisfaction.

#### 4.2.10.2. Output–Outcome analysis

	Policy adoption	Technology deployment	Economic benefit	Social acceptance
Conferences, symposiums, etc.	-0.05 (0.07)	0.05 (0.08)	0.07 (0.08)	0.08 (0.07)
Reports	-0.12 (0.09)	0.04 (0.11)	0.19* (0.11)	0.14 (0.1)
Newsletters	-0.02 (0.05)	0.00 (0.06)	0.02 (0.06)	0.06 (0.06)
Webinars	0.05 (0.05)	-0.05 (0.06)	0.04 (0.06)	0.03 (0.05)
Training programs	0.11** (0.06)	0.09 (0.06)	0.01 (0.06)	0.13** (0.06)

Standard errors in parentheses  
p-values  
\* p < 0.10    \*\* p < 0.05    \*\*\* p < 0.01  
No asterisk(\*) p > 0.1  
(Source: Prepared by the authors based on the survey for the research)

For the output–outcome analysis (Table 8), training programs effectively affected policy adoption, with a coefficient of 0.11 ( $p < 0.05$ ). The second lowest p-value was “reports” at 0.21, failing to reject the null hypothesis. The other factors for policy adoption showing a p-value over 0.31 do not necessarily impact policy adoption, despite the negative coefficient. Next was technology deployment, with all factors showing  $p > 0.16$ , meaning this did not explain the influence on technology deployment. For economic benefit, various reports, such as annual reports and technical reports, had a significant coefficient of 0.19 ( $p < 0.1$ ). Training programs highly influenced social acceptance as well, with  $r = 0.13$  ( $p < 0.05$ ).

#### 4.2.10.3. Input–Outcome analysis

	Policy adoption	Technology deployment	Economic benefit	Social acceptance
International goals	0.22 (0.32)	-0.02 (0.36)	-0.11 (0.36)	-0.05 (0.36)
National goals	-0.09 (0.26)	0.16 (0.3)	0.40 (0.29)	-0.20 (0.29)
Human resources	0.14 (0.25)	0.34 (0.29)	0.10 (0.29)	0.58** (0.29)
Financial resources	-0.04 (0.22)	-0.28 (0.26)	0.13 (0.25)	-0.49* (0.25)
IEA feedback	0.15* (0.09)	0.10 (0.1)	0.08 (0.1)	0.01 (0.1)
Central management organizations	0.03 (0.08)	-0.01 (0.09)	-0.02 (0.09)	0.12 (0.09)

Standard errors in parentheses  
p-values  
\* p < 0.10    \*\* p < 0.05    \*\*\* p < 0.01  
No asterisk(\*) p > 0.1  
(Source: Prepared by the authors based on the survey for the research)

For the input–outcome analysis (Table 9), the results showed that IEA feedback and policy adoption had a significant correlation coefficient of 0.15 ( $p < 0.1$ ). The correlation between human resources and social acceptance was significant, with  $r = 0.58$ . It was found that financial resources and social acceptance showed a negative correlation coefficient of -0.49, which is a relatively high value. However, it is argued that financial resources are highly required to provide human resources and operate central management

organizations according to the survey result. Hence, it is argued to be an error value that cannot be interpreted.

4.2.10.4. Regression analysis by TCP

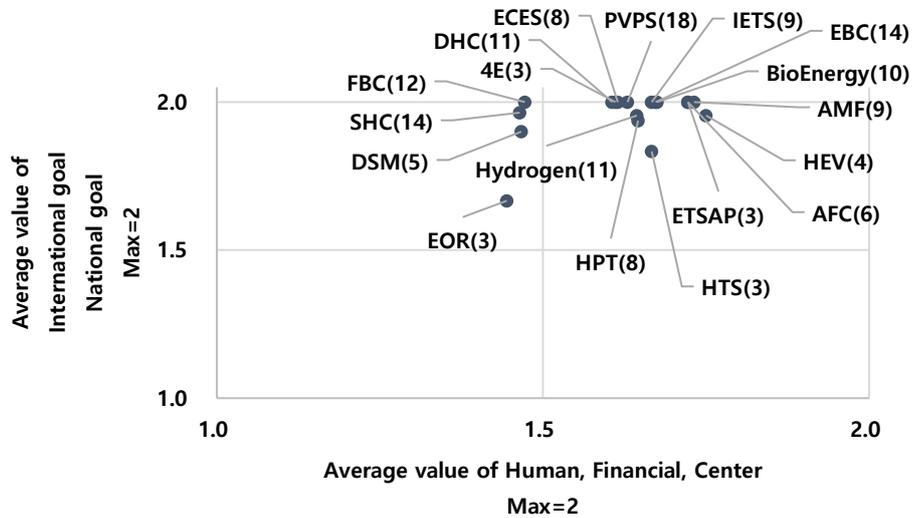


Figure 16. Matrix of correlation between goal/goals and implementing capacity

\*Number of responses in parentheses

(Source: Prepared by the authors based on the survey for the research)

Considering the correlation between goals and implementing capacity for the 18 TCPs, the results indicated that most TCPs are located in high goals and high capacity, as shown in Figure 16. The survey result determined that 97.7% (n = 170) and 97.6% (n = 164) of TCP respondents who participated aligned with international goals and national goals, respectively. EOR, DSM, SHC, and FBC showed relative lower values below 1.5 on implementing capacity (i.e., human resources, financial resources, and central management organizations). EOR in the fossil fuel group showed the lowest value on goals, despite a score above 1.5 on goals, as it is against the goals of GHG reduction. However, FBC in the fossil fuel group demonstrated a higher value on goals. It is argued that FBC deals with not only fossil fuels but also biomass, which can be a part of renewable technologies.

	Output satisfaction	Outcome
International goals, national goals	0.04 (0.37) p-value: 0.91	1.16 (0.91) p-value: 0.22
Human resources, financial resources, central management organizations	0.24 (0.21) p-value: 0.26	0.37 (0.55) p-value: 0.51
Standard errors in parentheses (Source: Prepared by the authors based on the survey for the research)		

Analysis for each TCP was performed and is shown in Table 10. Two TCPs, EOR and FBC, for the purpose of technology development of fossil fuels, were excluded from the 18 TCPs, and the remaining 16 TCPs for energy transition (in a broad sense) were analyzed. As a result, when the goal and goals (i.e., international and national goals) are clear, there is a tendency for better outputs and outcomes. Additionally, if the implementation capacity is high (i.e., it has human resources, financial resources, and a central management organization), it tends to be linked to better outputs and outcomes. However, it should be noted that the p-value ranged from 0.22–0.91, and the accuracy was not high.

#### 4.2.11. Current and future IEA TCPs

##### 4.2.11.1. Impact of political and economic relations among nations on TCP activity

According to the survey results, 32% of respondents (n = 150) replied that political and economic relations among countries affect the activities in their TCPs, while 68% think they do not impact their TCP activities. An open-ended question for further explanation was given to the 32% of respondents. It was said that there are always political and economic differences that have an impact on the collaboration among the participating countries. The activity level depends on national support for the reduction of funding and sources that can be done by a national policy. Participants are unwilling or unable to provide all of the necessary financial support to TCP tasks in case of economic problems. Hence, requests to negotiate to lower fees can be seen. It was mentioned that research directions and collaborative areas are different and are not relevant for all participating countries. Some countries' decisions of participation are affected by politicians and political situations, deterring them from harmonious cooperation.

Some respondents pointed out several negative cases of limited activities. Responses from ECES mentioned that Germany was not allowed to the TCP conference organization in 2018 in Turkey because Turkey put a strain on German–Turkish relations due to political reasons. It was said that geopolitical issues impact the collaboration from PVPS. In the case of Hydrogen and DHC, the US withdrew for some reasons, which the respondents thought to be political and economic issues. Additionally, it was mentioned that political and economic relations among countries participating in the IEA Bioenergy affect collaboration and knowledge sharing. Some countries work in a sensitive political environment, to which the 4E TCP has to relate, like avoiding some wordings or diminishing the edge of some activities.

In a positive way, it is a favorable circumstance to acquire some good ideas on new fuels and their effects. It was pointed out that cooperation is easier if countries are also aligned in other sectors, and the strategies and themes of interest depend on the interest of participating countries due to their connection to policymaking like 4E. The bonds with some countries are closer (language, shared history, collaboration), which positively affects cooperation willingness. For example, a strong cross-border relation between Flanders–Holland exists (Flanders being the northern, Dutch-speaking part of Belgium) in Hydrogen TCP.

##### 4.2.11.2. Future possible collaboration among TCPs

When asked about the evaluation of the current TCP activities, 88.57% of respondents said that TCP activities are sufficient, as in good (n = 140). Following that, most representatives (91.49%) replied that more fruitful output can be expected if they cooperate with other TCPs (n = 141). A sub-question was asked to those who answered “Yes” to know which TCP they have in mind for future cooperation with among TCPs. Of the respondents, 125 answered the sub-question.

Which TCP would be appropriate for your TCP to cooperate with? (Multiple answers allowed) (n=125)

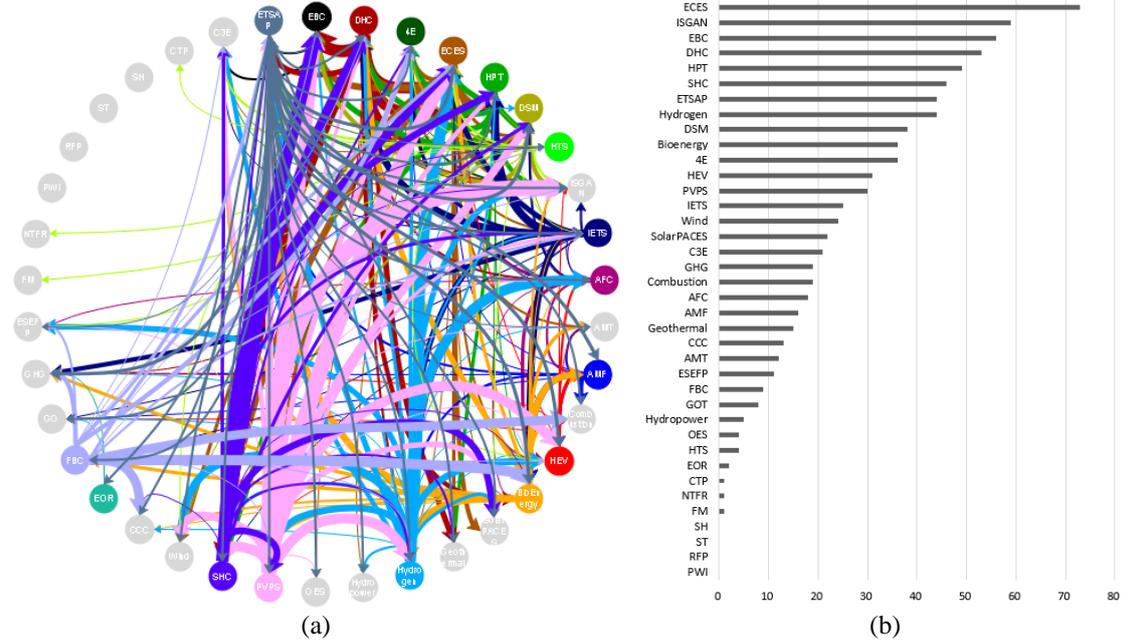


Figure 17. Response on collaboration partner each TCP wants (Source: Prepared by the authors based on the survey for the research)

Figure 17 shows wishful TCP partners for cooperation from among the 18 TCPs. Abbreviation of each TCP is explained in Table 6. In Figure 17(a), gray denotes exclusion of the survey, while the colored TCPs are the sampling groups for the survey. The thickness of the arrow indicates the number of respondents, meaning that the thicker the arrow is, the more respondents want to collaborate with them. It must be noted that the thicker arrows do not necessarily mean much stronger desire to cooperate than other TCPs. This is because the number of respondents varies depending on the sampling of each TCP. It indicates how much a TCP wants to cooperate with the other. For example, in the case of PVPS, the thickness of the arrow is comparatively thicker than other TCPs because PVPS has the largest number of samples and responses among the 18 TCPs. Since ISGAN, Hydrogen, and ECES show the thickest arrows from PVPS, most PVPS representatives hope to cooperate with them. It is the tendency that TCPs in the same group are willing to collaborate among them, such as building (EBC, DHC, 4E, ECES, and HPT), electricity (DSM, HTS, and ISGAN) and transportation (AFC, AMF, and HEV) groups. EOR and FBC, which are coal-related TCPs, want to collaborate with GHG, assuming that they are concerned on GHG emissions, as fossil fuel produces a large amount of GHG. Among TCPs, HTS particularly showed interest in fusion-related TCPs. In the case of ETSAP, because building modelling tools, such as TIMES and MARKEL, is the main purpose, ETSAP wants to cooperate with most TCPs.

The most interest in a TCP by the other TCPs was in ECES, followed by ISGAN, as described in Figure 17(b). It is argued that those two TCPs are related to balancing between supply and demand due to the acceleration of renewable energy. They are also important for charging/discharging transport as well as for smart operation of building. Considering the intermittent supply from renewable energy, collaboration with ECES and ISGAN would be helpful to optimize the energy mix at the national or sub-national level. Next is EBC and SHC, which are heating and cooling for buildings. It is considered that various energy sources can be applied with a broad configuration system using renewable and battery energies.

#### 4.2.11.3. Cooperation with other organizations

It was found that 71% of respondents mentioned that their TCPs are cooperating with other organizations, such as Mission Innovation and Clean Energy Ministerial (n = 138). Following that, the survey results about the necessity of cooperation with other organizations showed that 47.5% of respondents felt the necessity of cooperation with other organizations (n = 40), while more numbers of respondents (52.5%) did not think

it necessary to cooperate with other organizations. Lastly, when asked whether their TCPs have sufficient cooperation with other organizations, 54.74% out of the total 137 respondents answered that they have sufficient cooperation with other organizations. A sub-question was added for those who think that their TCPs have insufficient cooperation.

It was told that intensive cooperation with other organizations would open up opportunities for more funding. A higher level of cooperation would deliver stronger outcomes, although it does not seem easy. Respondents felt that when reaching to a higher level of cooperation, more resources and work would be needed, and it is necessary to cooperate more to be as efficient as possible. One suggested that liaisons should be created with organizations in cooperation for better communication. A response from HEV mentioned to consider CEM for electric mobile, while BioEnergy began to cooperate with the International Transport Forum. Not limited to international organizations, TCPs should commit to more engagement with other non-government programs and conferences, as well as key global discussions such as COPs. However, some responses say that cooperation would be positive although not necessary for the functioning of TCPs. Too many organizations covering parallel topics might make this too difficult to put into place. Therefore, it was mentioned that it is essential to understand what other relevant organizations are doing.

#### 4.2.11.4. Necessity of wide recognition of IEA TCPs with further explanation

Regarding the necessity of wide recognition of the TCPs, 78.1% of respondents from  $n = 137$  replied that TCPs should be more recognized, while 21.9% stated that wide recognition of TCPs is not necessary. Respondents who did not feel wider recognition was necessary commented that their TCPs are already well known on scientific and economic scales at both international and national levels. Additionally, there was an opinion from those who identified themselves as policymakers that broad recognition is not important because it is about multinational cooperation and specific activities with specialists.

Further explanation about the necessity of more recognition is described as having the following reasons. First, more participation can be expected from wide recognition. More people in TCP activities means massive communication and skill-building efforts to be able to share information and initiate collaborations. Additionally, greater recognition and dissemination can broaden important research areas for energy and climate policy. Since TCPs have a large amount of valuable knowledge and information to share, it would be much easier exposure for decision makers, equipment manufacturers, universities, and research centers who can enjoy the benefits. In addition, it could help increase the social acceptance of new technologies. Second, more communication by increasing participation due to wide recognition would increase the budget for TCP activities. This can be a breakthrough to overcome the limited national contributions to TCP activities due to the lack of financial support from the government. Third, linking to industry should be made through wide recognition. TCPs are quite recognized by research institutions but not the industrial sector. TCPs have already made good progress, but they are not generally seen as direct commercialization for useful benefit. It is a fact that TCPs' main purpose is not to develop new technologies for economic profit, but that is what businesses are motivated by. It would attract more business sectors to TCPs to fulfill funding issues.

Opinions from the representatives of each TCP and country were found. The recognition of BioEnergy is varied based on countries that need help among participants. Additionally, since media deliver too much information, BioEnergy should convey a number of important messages for the attention of decision makers. Insight, science, and knowledge should be provided by BioEnergy for discussion and policy on bioenergy. The business sector involved in fluidized bed conversion is fully recognized as FBC because many companies engage in it. PVPS is quite well known according to responses that PVPS is on active duty to inform results and opportunities. Hence, it was suggested that the IEA should treat PVPS better than others as PVPS is not only a technology but a driving force. In terms of IETS, only one TCP is available regarding industry where more attention is needed to be visible and appear at the national level. Hydrogen technologies recently received a broader political and industrial awareness that would move them to the next step from the pre-market phase in the future. AMF is constantly striving for increasing membership, such that it has a standing Committee on Outreach and Membership. 4E is highly specific and targeted to policymakers in the areas of energy. This is a limited scope of action for 4E, but it would be good for the

results of the TCP to be used more widely. The rebranding and relaunch of DSM is aimed at promoting a strategic aspect of energy policy worldwide.

#### 5. Limitations and uncertainties

- 1) For the statistical analyses, participation of entities and countries in IEA TCPs was compared in a short period of time, between 2015–2019. Although the results showed that the participation of overall entities and countries has increased, it was not able to look at the beginning of TCPs in the 1970s. Hence, it is difficult to conduct further in-depth investigation on the overall changes in entities and countries according to the flow of period.
- 2) In this survey, 18 TCPs were the sample group, and 20 TCPs were excluded due to unavailability of email addresses. The number of the sample was low, which can question the credibility. Additionally, not all email addresses of representatives could be acquired from the 18 TCPs, and some representatives registered on each TCP website were no longer representatives because of either resignation or transferring to other departments. The number in the sample for the survey based on the registered representatives on the websites outnumbered the real number of the sample for the survey.
- 3) When responding to the survey, some respondents quit in the middle of the survey. They also skipped questions because the questions were not adequate/related to the respondents due to their occupational status. Therefore, valid responses for each question came out with different numbers of answers.
- 4) The purpose of the survey was to hear the personal opinion and experiences of the representatives in TCPs. Because the analyses were fully based on subjective data from representatives, the results, particularly the regression analysis, can be a reference to the TCPs' future operation. It could possibly be different from the actual function of IEA TCPs.

#### 6. Discussion and conclusion

This study investigated international energy technology cooperation by employing IEA TCPs as a case study. The statistical and survey analyses revealed ample evidence for the essence of IEA TCPs. Returning to the questions at the beginning of the results section, general observations and conclusions can be drawn.

- 1) The statistical analysis: Results demonstrated that the standard deviation of participants per program and total absolute number of participants increased from 2015–2019, indicating that more numbers of entities, including private sectors, recognize the importance of clean energy technology and transition.
- 2) Input factor of the survey analysis: First, equal cost sharing is a controversial issue among representatives, whether it is considered appropriate or not. Alternative methods for cost sharing were mostly suggested as national GDP, the scale of economies, and national budget allocation. Second, the results showed that human/financial resources were sufficient for TCP operation. Those who thought they were insufficient mentioned that their TCP needed more human resources due to increases in the number of projects and activities in a positive way. However, the lack of financial resources causing the lack of human resources was observed. Heavy administration of TCPs uses high human/financial resources, and the lack of resources can be solved at a certain level by relieving the heavy administration. Third, most respondents were satisfied with the feedback from the governing bodies. Regarding more support from governing bodies, they wanted to clearly identify the feedback and guidelines from the governing bodies. Additionally, active interactions, such as discussions and financial support, were desirable. Lastly, central management organizations were evaluated as “well performed” by representatives having a “center” in their TCPs. Despite those who thought they did not have a central management organization, they did not feel it was necessary because they have performed well without one. In addition, they were worried about bearing the burden of miscellaneous work and cost to establish the central management organization, although various types of support can be expected.

- 3) Output factor of the survey analysis: Regarding output activities, the most common activities regularly held by the 18 TCPs were reports and international events (e.g., conferences, symposiums, and congresses), showing the high effectiveness of knowledge and information sharing according to the participants' evaluations. Newsletters, webinars, and training programs, which are types of one-sided knowledge delivery, were conducted less than reports and international events but were still evaluated as effective methods. Different levels of international and national workshops and various meetings were raised as other methods. Media utilization was suggested as well. In terms of output satisfaction, most respondents were satisfied with their TCP's overall output, particularly in development of technology knowledge, information sharing, and networking with other countries.
- 4) Outcome factors of the survey analysis: During the transition from output to outcome, establishment of institution, policy, and measure were the highest responses, followed by others specified as increase in domestic cooperation among institutions, companies, and universities leading to technology optimization and technology acceptance in their country. Among the four outcome achievements, technology deployment was the highest outcome countries achieved, while policy adoption was the lowest. The highest shared reason for reaching outcomes was the alignment of current energy policy situation in one's country and GHG reduction for climate action. The next reasons were economic aspects and benefits for end users for outcome achievement.
- 5) Regression analysis: Regression analysis results indicated that human resources, IEA feedback, and central management organizations were effective for output results in the input–output analysis. In the case of the output–outcome analysis, training programs were correlated with policy adoption and social acceptance, while various reports from TCPs showed correlation with economic benefit. For the input–outcome analysis, IEA feedback showed high and significant correlation with policy adoption, whereas human resources were important for social acceptance. Goal and implementing capacity were used in the regression analysis to understand the correlation with output and outcome, respectively, under the assumption that the clearer the goal and higher the implementing capacity each TCP has, the higher the correlation that appears. The results showed positive influence despite low reliability.
- 6) Current and future development:
 

Seeing the current situation of TCPs, political and economic relations among countries do not relatively impact TCP activities, according to the survey. However, there are some positive and negative cases driven by political and economic relations among countries due to geopolitical factors, domestic circumstance changes, and international relations among countries. Regarding current and future cooperation within TCPs and with other organizations such as MI and CEM, most representatives think there will be better output by collaborating with other TCPs. Additionally, cooperation with other organizations is also thought to be necessary because of more funding opportunities, stronger message delivery, higher chances of knowledge and information sharing, etc.

Scientific technology cooperation in IEA TCPs can expect rather more tangible outcomes than any organization for cooperation involved in economic and energy dialogues. Since IEA TCPs are more focused on energy technology cooperation, the deployment and application of clean technology is a second concern for the CEM, established at COP15 in Copenhagen in 2009, to accelerate clean energy transition and deployment (Diercks, et al., 2019). For this, the necessity of more practical experiments with enforcement are discussed for clean energy technology development and policy to emphasize socio-technical system changes (Scho & Steinmueller, 2018). From input to outcome, it is essential to broaden the public discussion and hearing to increase social acceptance. Unlike just focusing on technological development and related policy, recently, social and environmental issues have become significant. In these terms, public policies are important for a far broader range than is currently implemented in most countries to encourage the globalization of innovation (Archibugi & Iammarino, 1999). The evolution of IEA TCPs has been

successfully continued according to the needs of the period. Despite the limitations and uncertainties in this study, statistical analyses found that the awareness of low-carbon-intensive technologies has increased by confirming the increasing number of entities in TCPs. Concurrent embedded methods of quantitative and qualitative analysis for the survey found that overall, respondents were satisfied with the input and output and outcome of the TCP activities, although a minority had some opinions regarding the improvement of IEA TCPs for better performance. Clearer goals and higher implementing capacity would lead to better outputs and outcomes. Implications of the findings help encourage and boost the development of multilateral cooperation in various fields.

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Appendix A.

### **Survey on International Energy Agency (IEA) Technology Collaboration Programmes (TCPs)**

A “multilateral energy technology cooperation” is often a driver that leads to multilateral cooperation being successful. IEA TCPs are an interesting case study because they have a long history. For over 40 years, they have worked towards the achievement of energy and climate goals.

Purpose of the survey is to understand the current evidence on the roles and effectiveness of IEA TCPs in energy technology cooperation.

This survey may take about 15 minutes. Your reply will be greatly appreciated!

1. \*What is your occupation?
  - Researcher
  - Business (Utilities and industry)
  - Policy-maker
  - Other ( )
  
2. \*How many years have you worked in your TCP?  
( )
  
3. \*Is the TCP you participate in aligned with international goals? (*i.e.*, increase in energy efficiency and low-carbon energy technology in energy mix, deployment of CO<sub>2</sub> reduction technology, R&D on advanced technology, etc.)
  - Yes
  - No
  
- 3.1. Please explain your answer further. (If possible. Question without \* can be skipped)  
( )
  
4. \*Is the TCP you participate in aligned with national goals? (*i.e.*, increase in energy efficiency and introduce low-carbon energy technology into energy mix, deployment of CO<sub>2</sub> reduction technology, R&D on advanced technology, etc.)
  - Yes
  - No
  
- 4.1. Please explain your answer further. (If possible. Question without \* can be skipped)  
( )
  
5. \*Does your TCP have sufficient human resources?
  - Highly sufficient
  - Sufficient

- Fair
- Insufficient
- Highly insufficient

5.1. If fair or insufficient, please explain your answer further. (If possible. Question without \* can be skipped)  
( )

6. \*Does your TCP have sufficient financial resources?

- Highly sufficient
- Sufficient
- Fair
- Insufficient
- Highly insufficient

6.1. If fair or insufficient, please explain your answer further. (If possible. Question without \* can be skipped)  
( )

7. \*Do you think it would be appropriate for all participating countries to share an equal cost for the TCP?

- Yes
- No

7.1. If No, please describe alternatives for cost sharing. (If possible. Question without \* can be skipped)  
( )

8. \*Do your governing bodies such as a Working Party (*i.e.*, EUWP, WPF, REWP, FPCC) give adequate feedback to help your TCP activities?

- Yes
- No

8.1. If No, please specify what support from your governing bodies you need more of. (If possible. Question without \* can be skipped)  
( )

9. \*Does your TCP have a central management organization such as so-called "Center"?

- Yes
- No

9.1. \*If Yes, how well do you think the central management organization (*i.e.*, Center) is performing?

- Very well
- Well

- Average
- Below average
- Not well

9.1.1. \*If average or below, what do you think the biggest issue affecting the performance of the central management organization of your TCP?

- Not enough people to do the work
- Not enough financial resources
- The role is not clear
- Inefficient and rigid process
- Other ( )

9.2. \*If No, do you think it is necessary to have a central management organization such as a “Center”?

- Yes
- No

9.2.1. \*If Yes, why do you think it is necessary? (Choose the best answer)

- For convenient and quick communication among participants
- For efficient information and data management
- To support activities besides technology development and sharing knowledge
- Other ( )

9.2.2. \*If No, why do you think it is unnecessary? (Choose the best answer)

- Risk of increase in cost sharing
- We perform well without one
- Possible increase in miscellaneous work besides technology development and information sharing
- Other ( )

10. \*Does political and economic relations among some countries in your TCP affect the activity you participate in?

- Yes
- No

10.1. If Yes, please specify. (If possible. Question without \* can be skipped)  
( )

11. \*Does your TCP regularly hold **International conferences and forum, etc.** to share information and knowledge?

- Yes
- No

11.1. \*How are international conferences and forums effective for sharing and understanding of knowledge and information? (five stars for the most effectiveness)

☆ ☆ ☆ ☆ ☆

12. \*Does your TCP regularly issue **technical reports and annual reports** to share information and knowledge?

- Yes
- No

12.1. \*How are technical reports and annual reports effective for sharing and understanding of knowledge and information? (five stars for the most effectiveness)

☆ ☆ ☆ ☆ ☆

13. \*Does your TCP regularly issue **newsletters** to share information and knowledge?

- Yes
- No

13.1. \*How are newsletters effective for sharing and understanding of knowledge and information? (five stars for the most effectiveness)

☆ ☆ ☆ ☆ ☆

14. \*Does your TCP regularly hold webinar to share information and knowledge?

- Yes
- No

14.1. \*How are webinars effective for sharing and understanding of knowledge and information? (five stars for the most effectiveness)

☆ ☆ ☆ ☆ ☆

15. \*Does your TCP regularly hold training programmes to share information and knowledge?

- Yes
- No

15.1. \*How are training programs effective for sharing and understanding of knowledge and information? (five stars for the most effectiveness)

☆ ☆ ☆ ☆ ☆

15.2. If there is anything else that is effective for sharing and understanding of knowledge and information, please specify. (If possible. Question without \* can be skipped)

( )

16. \*Are you satisfied with the overall outputs of your TCP?

- Highly satisfied
- Satisfied
- Fair
- Unsatisfied

Highly unsatisfied

16.1. \*If satisfied then please rank which areas you are most satisfied with (with most satisfied being 1 and 5 being least satisfied. If not available, please check N/A)

( ) Development of technology knowledge through TCP N/A

( ) Sharing information among countries  
N/A

( ) Making policy recommendation  
N/A

( ) Networking with other countries through TCP  
N/A

( ) Other ( )  
N/A

16.1.1. If you include Other, please specify. (If possible. Question without \* can be skipped)

( )

16.2. \*If unsatisfied or fair, which do you feel unsatisfied? (Multiple answers allowed)

Development of technology knowledge through TCP activities

Sharing information among countries

Making policy recommendation

Networking with other countries through TCP

Other ( )

17. \*Has your TCP output been adopted as policy in your country?

Yes

No

17.1. \*Why has your TCP output been adopted as policy in your country? (Multiple answers allowed)

It aligns with the current energy policy situation in my country

It helps to increase the profit for the domestic businesses

It helps to drop the expenses over energy uses

It helps to decrease greenhouse gas emission relieving global warming

Other ( )

18. \*Has your TCP output led to the technology deployment in your country?

Yes

No

18.1. \*Why has your TCP output led to the technology deployment in your country? (Multiple answers allowed)

It aligns with the current energy policy situation in my country

There are sufficient inter-organizational communication and activities in my country.

- It is suitable considering my country's circumstance (e.g., natural resources and energy use)
- It helps to increase the profit for the domestic businesses
- It does not require high expenses for technology deployment in my country
- It helps to decrease greenhouse gas emission relieving global warming
- Other ( )

19. \*Has your TCP output led to economic benefits in your country?

- Yes
- No

19.1. \*What is the reason that the TCP output you participated in led to economic benefits in your country? (Multiple answers allowed)

- It aligns with the current energy policy situation in my country
- It is fit to the market circumstance in my country
- It is easily commercialized to increase the profit for the domestic businesses
- It helps to decrease greenhouse gas emission leading to less payment for environmental cost (e.g., carbon tax)
- Other ( )

20. \*Has your TCP output led to increase social acceptance of your TCP's technology in your country?

- Yes
- No

20.1. \*What is the reason that your TCP output has led to social acceptance in your country? (Multiple answers allowed)

- Sufficient inter-organizational communication and activities in my country contributes to increase social acceptance
- It helps to increase the profit for the domestic businesses
- It helps to drop the expenses over energy uses
- It helps to decrease greenhouse gas emission relieving global warming
- Other ( )

21. \*How has the outputs of your TCP been reflected in your country? (Multiple answers allowed)

- Mentioned in national statement/speech
- Establishment of institution, policy, or measure
- Increase in budget
- Conducted public discussion and hearing
- Other ( )

21.1. Please specify further (If possible. Question without \* can be skipped)

( )

22. \*Do you think that your TCP activity is sufficient as in good?

- Yes
- No

23. Do you think your TCP can produce a better output if you cooperate with other TCPs?

- Yes
- No

23.1. \*If Yes, which TCP would be appropriate for you to cooperate with? (Multiple answers allowed)

- Buildings and Communities (EBC TCP)
- District Heating and Cooling including Combined Heat and Power (DHC TCP)
- Energy Efficient End-Use Equipment (4E TCP)
- Energy Storage (ECES TCP)
- Heat Pumping Technologies (HPT TCP)
- Demand-Side Management (DSM TCP)
- High-Temperature Superconductivity (HTS TCP)
- Smart Grids (ISGAN TCP)
- Industrial Energy-Related Technologies and Systems (IETS TCP)
- Advanced Fuel Cells (AFC TCP)
- Advanced Materials for Transportation (AMT TCP)
- Advanced Motor Fuels (AMF TCP)
- Clean and Efficient Combustion (Combustion TCP)
- Hybrid and Electric Vehicles (HEV TCP)
- Bioenergy TCP
- Concentrated Solar Power (SolarPACES TCP)
- Geothermal TCP
- Hydrogen TCP
- Hydropower TCP
- Ocean Energy Systems (OES TCP)
- Photovoltaic Power Systems (PVPS TCP)
- Solar Heating and Cooling (SHC TCP)
- Wind Energy Systems (Wind TCP)
- Clean Coal Centre (CCC TCP)
- Enhanced Oil Recovery (EOR TCP)
- Fluidized Bed Conversion (FBC TCP)
- Gas and Oil Technologies (GOTCP)
- Greenhouse Gas R&D (GHG TCP)
- Environmental, Safety & Economy (ESEFP TCP)
- Fusion Materials (FM TCP)
- Nuclear Technology of Fusion Reactors (NTFR TCP)
- Plasma Wall Interaction (PWI TCP)
- Reversed Field Pinches (RFP TCP)
- Spherical Tori (ST TCP)
- Stellarator-Heliotron Concept (SH TCP)
- Tokamak Programmes (CTP TCP)
- Clean Energy Education and Empowerment (C3E TCP)
- Energy Technology Systems Analysis (ETSAP TCP)

24. \*Does your TCP cooperate with other organizations (e.g., Mission Innovation, Clean Energy Ministerial, etc.)?  
 Yes  
 No
25. \*Does your TCP need to cooperate with other organization (e.g., Mission Innovation, Clean Energy Ministerial, etc.)?  
 Yes  
 No
26. Please explain further about your answer. (If possible. Question without \* can be skipped)  
( )
27. \*Do you think you have sufficient cooperation with other organizations (e.g., Mission Innovation, Clean Energy Ministerial, etc.)?  
 Yes  
 No
- 27.1. If No, please explain further. (If possible. Question without \* can be skipped)  
( )
28. \*Is your TCP recognized well enough in your country?  
 Yes  
 No
29. \*Does your TCP need to be recognized more widely?  
 Yes  
 No
- 29.1. Please explain the reason about your answer. (If possible. Question without \* can be skipped)  
( )
30. Final comments and suggestion.  
( )