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Evaluating the Effectiveness of Japan's Climate Change Mitigation and Clean Technology Development Policies

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ABSTRACT

The energy sector has been the highest contributor of greenhouse gases (GHG) emission in Japan. To reduce GHG emissions, the development and applications of cleaner technologies supported by effective policies are required. In this study, the effectiveness of Japanese government policies related to climate change mitigation especially in the technology development sector was analyzed. To do so, two methodologies; 1) results-based approach (RBA) and 2) case-based approach (CBA) will be combined to test the effectiveness of government policies. This combination was conducted to fill the missing data required to conduct the two methodologies. The merging of the two methodologies produced indexes where the proximity of the performance of each policy measured to it would determine its effectiveness. In order to verify the results, the number of projects related to the policy took place over the years was also observed. The results show that the most effective policies were related to the following technologies: 1) Energy management, 2) Biomass energy production, and 3) Electric power storage.

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1. INTRODUCTION

Clean technologies play a significant role in achieving both the medium and long-term targets of Greenhouse Gases (GHG) emission mitigation. In Japan, the energy sector accounts for the highest GHG emission with over 88% of the total annual GHG emission in 2016 (MOE, 2018). This strikingly high percentage of GHG emission from the energy sector has not changed much over several decades. The ability of Japan to meet its GHG emission mitigation target under the United Nations Framework Convention on Climate Change (UNFCCC) depends largely on the energy path pursues after the Fukushima nuclear disaster in March 2011 (Kuramochi, 2014).

The policies that support clean technology development projects are the product of assessments in determining how the government uses a systematic methodology to assist GHG emission mitigation (DOE, 2010; GAO, 2016; IEA, 2017). For example, the United States Department of Energy (US - DOE) conducts Technology Readiness Assessment (TRA) for its government technology development acquisition programs (DOE, 2015). In general, TRA helps in identifying development risks and potentials, prioritize subsidy allocation, and accelerate the development of promising clean energy technology. TRA has also been adopted by the Australian Renewable Energy Agency (ARENA) and the European Union (Héder, 2017). Japan has recently adopted and developed the Japanese version of TRA, named J-TRA (Ihara *et al.*, 2019; Ihara *et al.*, 2018; MOE, 2016; Pang *et al.*, 2019).

One way to evaluate the effectiveness of a policy is to use "results-based approach" (RBA). In this approach, the plans and targets are formulated prior the implementation of the policy then compared with the actual results after implementation. In the RBA method, the differences between actual results and targets values in tons of CO_2 from each sector are compared. In this case, the weaknesses of using RBA method are the following: 1) Evaluation cannot be conducted when the target and actual values are not available in the unit amount of CO_2 or other GHG emission chemical compounds; and 2) There is no appropriate verification to check the initial target and actual values.

Another way to evaluate the effectiveness of clean technology development policy is by the "case-based approach" (CBA). In this method, policy effectiveness is not measured quantitatively, but rather by organizing the projects into groups based on their phases and contents. Consequently, the policy can be revised in detail by referring to the evaluation results of the past projects.

Since both approaches have their own advantages and disadvantages, this paper aims to combine RBA and CBA, and develop a "Policy Evaluation Index". By doing so, all non-emission achievement targets in the Kyoto Protocol Target Achievement Plan (KPTAP) are quantified. The merging process used the least-squares method and Multiple Regression Analysis (MRA). The verification of the output indexes was conducted by plotting the number of the established technology development project in each category against the CO_2 emission mitigation performance of each technology development project categories. Two databases were utilized to serve this merging process: 1) The official report of the KPTAP and 2) Clean Technology Research and Development (R&D) database by Deloitte Tohmatsu Consulting (DTC) company. DTC has been assisting the MOE of Japan in reviewing clean technology R&D projects. The database used in this study is the archive of their assistance work.

2. METHODOLOGY

2.1. Development Framework

There are three main purposes in designing the policy evaluation index. Those are the following: 1) relevant and usable by the technology sector to create policies/measures in climate change mitigation; 2) appropriate and usable for the local and national government agencies to publish the climate change mitigation strategies information; 3) sufficient to help in creating policies and strategies in technology development.

The information about the CO_2 reduction amount from each technology are taken from the Progress Status of KPTAP report. Then, the information from these databases are screened, classified, and linked as technology categories. Finally, the CO_2 reduction target and the result of each technology category are compared, and the result is identified as Policy Evaluation Index. By reviewing the index, one can recognize what technical sectors must be strengthened in terms of their CO_2 reduction. The expected output of this approach is the knowledge of technology development projects in the actual states. From this output, the right policies can be introduced to support the development of the bottle-neck technical sectors.

2.2. Database Classification and Screening

2.2.1 R&D Database Classification and Screening

There are 42 technology development projects in the Deloitte's Clean Technology R&D database. These projects are classified into two major categories to reflect the supply side of energy. Projects without direct contribution to the reduction of GHG emission categorized as "others". The classified projects are sorted further to the following subcategories: 1) new/renewable energy; 2) energy storage and transportation; 3) power electronics; 4) transportation; 5) industry; 6) social system; and 7) consumer. Then, they are sorted into further subcategories based on the type of technology. The result of this third step classification is referred as the 3rd level screening categories. Each of the project is given an ID to identify their categories and subcategories. Among the 42 classified projects, only 37 are used for initial index calculation. The 5 temporarily eliminated projects are the following: 1) Those belonging to the "others" category; 2) The "social system" subcategory as they do not contribute directly to GHG emission reduction; and 3) Two projects overlap with each other with the same subcategories. These 4 projects will be reincluded once the initial indexes are identified.

2.2.2 Progress Status of KTPAP Database Classification and Screening

There are 196 technology categories belonging to a number of climate change mitigation policies that directly or indirectly contributes to the CO_2 reduction listed in the Progress Status of KPTAP database (MOE, 2016). In the preparation of building the Policy Evaluation Index, these categories were filtered out using the following conditions: 1) Those having available actual values of CO_2 reduction information from the year 2010 to 2012; 2) Those with a direct contribution to the promotion or performance improvement of clean technology equipment and systems. Categories met conditions 1 and 2 were eliminated and resulted in 27 remaining categories. The next step is to link these 27 categories with the subcategories in the 3rd classification level of the R&D database.

2.3. Linking the Two Databases

The linking process for most of the 27 technology categories found to be non-problematic as the naming is obvious. However, CO_2 data is only shown as a whole in 4 technology categories belonging to the "Promotion of high-efficiency energy-saving equipment" policy in the KPTAP. Furthermore, there is CO_2 amount from categories belonging to other policies included in the data. To estimate the actual CO_2 emission of each category in the "Promotion of high-efficiency energy-saving equipment" policy, 5 scenarios (CASE) were constructed and multiple regression analysis was conducted. The 5 CASEs are presented in **Table 1**.

Table 1. Assumptions made to calculate the CO_2 emission reduction improvement rate in CASE 1 to 5 measure with 3rd level classification subcategories in the R&D database

CASE	CO_2 Emission Reduction Improvement Rate Calculation Assumptions
1	Baseline scenario: As presented in the Kyoto database (The sum of CO_2 reduction from projects belonging to 2-7-34 to 2-7-36 subcategories are included together in the 2-7-38 subcategory)
2	The sum of CO_2 reduction from projects belonging to 2-7-34 to 2-7-36 subcategories are excluded from the baseline CO_2 reduction scenario data for the 2-7-38 subcategory
3	Amount of CO_2 reduction from projects belonging to 2-7-34 to 2-7-36 subcategories are prorated according to the crude oil reduction ratio in 2010
4	The general performance improvement index is incorporated in the calculation of the 2-7-34 to 2-7-36 CO_2 Emission Reduction Improvement Rate
5	Projects belonging to 2-7-34 to 2-7-36 are managed together as a separate classification category

Table 2 summarizes the actual number of projects in Japan for each category and the "CO_2 reduction effectiveness improvement rate" for each of the 3rd level classification category. "CO_2 reduction effectiveness improvement rate" (hereinafter referred to as the policy evaluation index or just index) was calculated from the increasing or decreasing trend of the CO_2 reduction amount from 2010 to 2012 using the least squares method. The policy evaluation index is then indicated as the effectiveness of a policy in contributing to the CO_2 emission reduction. Several things to note during the calculation of index are the following: 1) Actual values of CO_2 reduction for solar power generation, wind power generation, high-performance railways, and energy-saving houses and buildings were not available in 2012. Therefore, the actual values from 2010 to 2011 were used to calculate the "CO_2 reduction effectiveness improvement rate" for these categories; 2) Actual values of CO_2 reduction for some policies related to the use of biomass and waste energy were not available in 2012. Therefore, it is calculated using data from 2010 to 2011. In general, there are 11 categories from the 3rd level classification of the R&D database that could not be linked to the categories from the KPTAP. MRA was conducted in order to calculate the policy evaluation index of these 11 categories.

2.4 Completing the Missing Policy Evaluation Index using Multiple Regression Analysis

In order to perform MRA, the unknown policy evaluation index of the 11 categories were set as the target variable. There are 7 explanatory variables from R&D database such as: basic research, applied research, practical research, experimental implementation, initial dissemination and indirect contribution. From the independent variable of each project development phase (basic research, applied research, and others), the observed relationships are: 1) As the number of project increases, the policy evaluation index becomes higher; 2) Correlation with the number of projects is particularly high in the "experimental implementation" phase.

Table 2. CO_2 reduction effectiveness improvement rate (Policy Evaluation Index) for each of the 3rd level classification category

ID	3rd Level Classification Category	Number of Projects in Japan	Amount of CO_2 reduction (in ten thousand t-CO_2)			CO_2 reduction effectiveness improvement rate
			2010	2011	2012	
1-1-1	Solar power generation	211	111	112		0.48
1-1-2	Solar heat utilization	34	0	0	0	
1-1-3	Biomass and waste energy utilization	44	1405	1428	185	23.43
1-1-4	Biomass fuel production	223	0	0	0	
1-1-5	Bio-utilization technology	20	0	0	0	
1-1-6	Ocean energy power generation	22	0	0	0	
1-1-7	Hydrogen production	35	0	0	0	
1-1-8	Hydropower generation	45	0	0	0	
1-1-9	Coal utilization	11	0	0	0	
1-1-10	Geothermal power generation	45	0	0	0	
1-1-11	Natural gas utilization technology	3	0	0	0	
1-1-12	Wind power generation	51	142	142	-	0.61
1-1-13	Unutilized energy	103	0	0	0	
2-2-14	High-efficiency power transmission	8	0	0	0	
2-2-15	Hydrogen storage	27	0	0	0	
2-2-16	Hydrogen transportation and supply	41	0	0	0	
2-2-17	Heat storage	5	0	0	0	
2-2-18	Electric power storage	128	0	0	0	
2-2-19	Heat transportation	6	0	0	0	
2-3-20	High-performance devices	89	0	0	0	
2-3-21	High-performance power electronics	6	0	0	0	
2-4-22	Clean energy vehicles	87	2626	2994	3389	381.50
2-4-23	High-efficiency internal combustion engine vehicles	37	0	0	0	
2-4-24	High-performance aircrafts	13	215	202	236	10.50
2-4-25	High-performance ships	45	132	111	177	22.50
2-4-26	High-performance railways	27	94	107	-	13.00
2-5-27	Coproduction	2	0	0	0	
2-5-28	High-efficiency industrial furnaces and boilers	3	0	0	0	
2-5-29	Solar power generation	95	0	0	0	
2-6-30	Solar heat utilization	392	540	620	680	70.00
2-6-31	Biomass and waste energy utilization	41	0	0	0	
2-6-32	Biomass fuel production	50	0	0	0	
2-7-33	Bio-utilization technology	14	1288	1335	1459	85.50
2-7-34	Ocean energy power generation	2	0	0	0	
2-7-35	Hydrogen production	46	0	0	0	
2-7-36	Hydropower generation	25	0	0	0	
2-7-37	Coal utilization	4	0	0	0	
2-7-38	Geothermal power generation	67	3932	4293	4828	448.15
2-7-39	Natural gas utilization technology	6	0	0	0	
2-7-40	Wind power generation	62	3430	3930	-	500.00
2-7-41	Unutilized energy	85	0	0	0	

In other words, the greater the number of relevant policies/measures included in the category, the higher the policy evaluation index. The policy evaluation index for each category can be calculated with the multiple regression equation, the 5 initially eliminated 3rd level categories from the R&D databases are also included back in the analysis. The completed list of policy evaluation index is shown in **Table 3** with the exception of coal utilization, natural gas utilization, and co-production because these project types are not available in the R&D database. From this point on, since the two databases have been fully merged, "the 3rd level classification categories" from the R&D database is referred to just "technology category".

3. RESULTS AND DISCUSSION

3.1 Verification

To verify the developed policy evaluation index reflections in the reality, the values are plotted against the number of all-Japan-project belonging to each technological category. A positive correlation can be seen from the scatterplot with an R^2 value of 0.70 (**Figure 1**). However, there are anomalies identified. The following project categories either deviate significantly from the approximate straight line, has really high policy evaluation index, or has really low policy evaluation index: 1) energy management; 2) biomass fuel production; 3) electric power storage; 4) solar power generation; and 5) wind power generation. It is understood that projects such as energy-saving home appliances and commercial equipment, and clean energy vehicles are among the higher policy evaluation indexes.

Table 3. Policy Evaluation Index for each Technology Category

	Technology Category (From the R&D Database 3rd Level Classification Category)	Policy Evaluation Index	
		From Kyoto database	Calculated from multiple regression equation
1	Solar power generation	1.0	1.0
2	Solar heat utilization	-	235.3
3	Biomass and waste energy utilization	-69.2	-69.2
4	Biomass fuel production	-	1,716.8
5	Bio-utilization technology	-	15.9
6	Ocean energy power generation	-	233.3
7	Hydrogen production	-	44.7
8	Hydropower generation	-	300.3
9	Coal utilization	-	-
10	Geothermal power generation	-	1.7
11	Natural gas utilization technology	-	-
12	Wind power generation	6.5	6.5
13	Unutilized energy	-	543.5
14	High-efficiency power transmission	-	13.7
15	Hydrogen storage	-	-32.9
16	Hydrogen transportation and supply	-	87.6
17	Heat storage	-	8.3
18	Electric power storage	-	1,398.6
19	Heat transportation	-	44.1
20	High-performance devices	-	427.2
21	High-performance power electronics	-	-30.3
22	Clean energy vehicles	379.7	379.7
23	High-efficiency internal combustion engine vehicles	-	51.0
24	High-performance aircrafts	27.4	27.4
25	High-performance ships	143.1	143.1
26	High-performance railways	45.7	45.7
27	Coproduction	-	-
28	High-efficiency industrial furnaces and boilers	-	1.7
29	Energy-saving industrial processes	-	200.0
30	Energy management	-	2,990.4
31	New power supply systems	-	223.5
32	Advanced transportation systems	-	298.0
33	High-efficiency cogeneration	65.7	65.7
34	High-efficiency water heaters	281.4	79.8
35	High-efficiency air conditioners	281.4	1,027.1
36	High-efficiency lighting	281.4	345.5
37	High-efficiency heating equipment	-	15.8
38	Energy-saving home appliances and commercial equipment	281.4	281.4
40	Energy-saving houses and buildings	466.9	466.9
41	Fuel cells	-	149.7

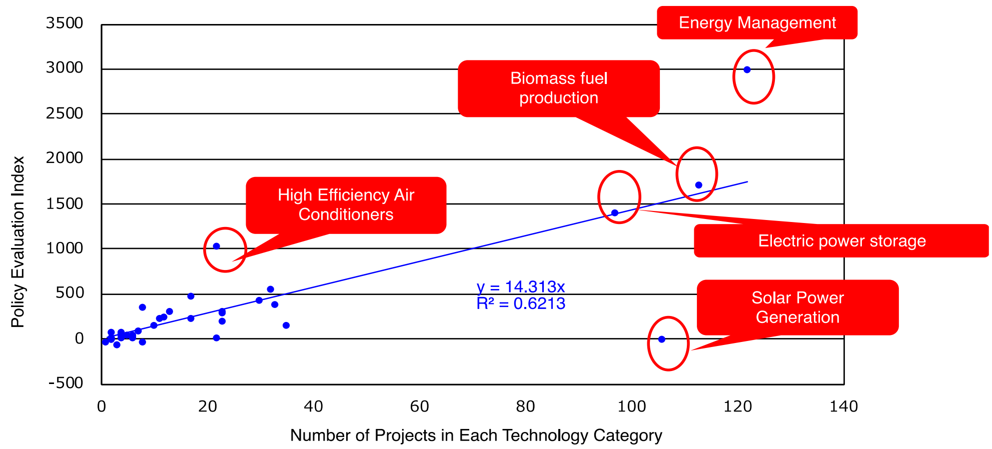

Figure 1. Relationship between the number of projects in each technology category with the policy evaluation index

On the other hand, projects on high-performance power electronics, hydrogen storage, biomass and waste energy utilization are among the lower policy evaluation indexes.

3.2 Interpretation and Discussion

In general, higher index correlates with a larger number of projects in different technology categories. However, there is an uncountable number of factors may influence the growth of technology development projects. For example, the number of technologies on solar power generation has increased with the introduction of Feed-In-Tariff in the field of renewable energy usage in 2012. In contrast, the technology is also considered to be already mature to a certain extent, this resulted in a low index. Another example is the biomass and waste energy utilization and bio-utilization technology categories. A lot of investments have been made for the technology development in these categories.

However, the market environment to utilize the technology is not ready due to the limited usage. These aspects such as the level of technology and market maturity may influence the progress of technology development. Therefore, the index should not be used as a fixed way to judge how policies give impact to technology development. However, the index can be used as a pointer to technology categories that require further attention and as approximation tool to show how the development of a certain technology category is positioned relative to the others.

Some technology categories have exceptionally high and exceptionally low values. The first one is energy management which is exceptionally high with an index value of 2,990.4 points. Factors that might have contributed to the high values are: 1) The number of projects in this category is quite high; 2) The popularization of “smart community” project in Japan; 3) Reconstruction of the Fukushima nuclear disaster affected area that adopts a number of more sustainable strategies. The second one with exceptionally high is biomass fuel production category with 1,716.8 index point. Some explanation of this high performance are the following: 1) The number of projects in this category is quite high with 113 projects; 2) From July 2010, the use of non-fossil energy resources by operators of electricity, oil, and gas as well as the effective use of fossil energy resources were mandated by the “Advancing Energy Supply Structure Act” (This act has resulted in the increase of biomass fuels mixed in gasoline to more than 3%). Following the increased demand for biofuels, projects related to the production of biomass fuels had increased significantly.

The third highest index technology category is electric power storage with 1,398.6 points. Some factors that might have influenced are: 1) The number of projects in this category is quite high with 97 projects; 2) There was a technology that has been dormant for a decade and suddenly came into use. This was the new type of battery power storage that was developed in 1991 under a national project called the "Moonlight Plan". Another project called the "Sunshine Project" distributed this technology between 1992 to 2002 but the popularity of this technology did not happen until suddenly in 2010 the number of projects related to this technology skyrocketed. There were 48 projects and half of them (24 projects) belong to the development project of Japan's New Energy and Industrial Technology Development Organization (NEDO) on complex electricity storage systems. The objective of this technology is to be used in smart communities. The development of this technology became active at the same time with the popularization of a smart community.

The fourth highest index technology category is the high-efficiency air conditioner with 1,027.1 points. Factors that have contributed to the high index value are: 1) Although the total number of projects throughout Japan is not so high with 44 projects, as many as 28 of them are in the practical research phase and so it has bigger impact in the CO_2 reduction; 2) In 2010, the revised "Energy Conservation Act" was released and within the act, the standard values for commercial air conditioners were improved. The majority of technology categories with small indexes (meaning, a small effect on CO_2 reduction), are either due to the small number of projects, having projects started outside the calculation period, or having projects that are in early development stages.

3.3 Policy re-organization and re-classification

Policies can be categorized to understand the nature, performance, and urgency after policy evaluation indexes for each of the categories are known and discussed. The technology categories belonging to various policies from the Kyoto database are sorted into 4 levels of effectiveness based on their performance on the CO_2 emission reduction (**Table 4**). Among the low performing policies are: 1) Promoting the installation of equipment and machinery with high energy-saving performance; 2) Implementation of thorough energy management; and 3) Introduction of the optimal use of renewable energy.

In the real world of policy implementation, some policies are cross-sectoral, while others are sectoral. The Japanese climate change mitigation policies (not only those from the Kyoto database) are summarized and categorized based on their sectors (industrial, business, housing, transport, energy conversion, and adsorption of GHG). Furthermore, to assist technical stakeholders to quickly identify whether policies in each sector includes technical measures and whether there is positive progress in the sector, the information is provided using the knowledge gained from the analysis and discussions in this study (**Table 5**). Policies that have no, or little progress are the “promotion of carbon logistics”, “reduction of carbon dioxide emission level in the power sector”, “promotion of Energy-saving measures in the petroleum products manufacturing sector”, “measures for forest sinks”, “measures for carbon sinks of farmland soil”, and “promotion of urban afforestation”.

Table 4. Range of index for each greenhouse gases emission mitigation policy

Policy		Technology Categories based on the Range of their Policy Evaluation Index			
		≤10	11 to 100	101 to 1000	≥1000
Promoting the installation of equipment and machinery with high energy-saving performance		High-performance power electronics	High-efficiency water heaters High-efficiency cogeneration High-efficiency heating equipment	High-efficiency lighting High-performance devices	High-efficiency air conditioners
Implementation of thorough energy management					Energy management
Energy-saving of buildings				Energy-saving houses and buildings	
Increasing the areas of energy utilization		Heat storage		New power supply systems	
Energy-saving for houses				Energy-saving houses and buildings	
Measures for individual automobiles			High-efficiency internal combustion engine vehicles	Clean energy vehicles	
Greening of the automobile transportation business by promoting the use automobiles that are environmentally friendly				Advanced transportation systems	
Measures for railroads, ships, and aircrafts			High-performance aircrafts High-performance railways	High-performance ships	
Promotion of low-carbon logistics					
Introduction of the optimal use of renewable energy	Renewable energy generation	Solar power generation Biomass and waste energy utilization		Ocean energy power generation Hydropower generation	
	Renewable energy heat.	Biomass and waste energy utilization	Bio-utilization technology	Solar heat utilization	Biomass fuel production
	Maximum utilization of electricity, heat and unutilized heat derived from renewable energy within the region		Heat transportation	Fuel cells	Electric power storage
Reduction of carbon dioxide emission level in the power sector	Highly efficient thermal power generation	Technology category exists but the number of projects is zero			
	Utilization of nuclear power generation that is confirmed as safe				
	Introduction of renewable energy to the maximum				
Promotion of Energy-saving measures in the petroleum products manufacturing sector					
Realization of the hydrogen society		Hydrogen storage	Hydrogen production Hydrogen transportation and supply		
Greenhouse effect gas measures and policies for carbon sinks	Measures for forest sinks Measures for carbon sinks of farmland soil Promotion of urban afforestation				

Table 5. Organization and progress situation of the climate change mitigation policies

Cross-Sectoral Policies	Sectoral Policies			
	Sectors	**Policies**	**Technical measures**	**Progress situation**
Promotion of the J credit system	Industrial sector	Promotion of voluntary initiatives in the industrial world		
Development of national movement		promotion of installation of equipment and machinery with high Energy-saving performance	√	√
		implementation of thorough energy management	√	√
		promotion of Energy-saving efforts with the cooperation among industries	√	√
Formation of low carbon cities, regional structure, and socioeconomic system	Business and other sectors	Promotion of voluntary initiatives in the industrial world	√	
		Energy-saving of buildings	√	√
		Promoting the installation of equipment and machinery with high energy-saving performance implementation through energy management	√	√
Realization of the hydrogen society		Increasing the areas of energy utilization, other measures, and policies	√	√
		Development of citizen movement, and initiatives by the public agencies		
Initiatives based on the guidelines for controlling the greenhouse gas emission effects	Housing sector	Development of citizen movement		
		Energy-saving for houses	√	√
		promoting the installation of equipment and machinery with high energy-saving performance	√	√
Promotion of environmental business activities		Implementation of thorough energy management, other measures, and policies	√	√
	Transportation sector	Promotion of voluntary initiatives in the industrial world		
Support for greening the tax system and making effective use of taxes to counter global warming		Measures for individual automobiles, measures for road traffic flow	√	
		Development of citizen movement		
		Greening of automobile transportation business by promoting the use of automobiles. that are environmentally friendly	√	
Greening of finances		Promoting the use of public transportation and bicycles		
		Measures for railways, ships, and aircraft and other measures and policies	√	
Emissions trading system within Japan		Promotion of low-carbon logistics		×
	Energy conversion sector	Promotion of voluntary initiatives in the industrial world		
		Introduction of renewable energy to the maximum	√	√
		Reduction of carbon dioxide emission level in the power sector	√	×
		Promotion of Energy-saving measures in the petroleum products manufacturing sector	√	×
	Absorption sources of greenhouse effect gas	Measures for forest sinks		×
		Measures for carbon sinks of farmland soil		×
		Promotion of urban afforestation		×

4. CONCLUSION

Policies have been evaluated by comparing the quantitative results, known as the RBA approach and by reviewing the achievement and progress status according to the type and nature of the policies or the CBA approach. A database of clean technology R&D belonging to the consultant of Japan's Ministry of Environment was screened and linked to the Kyoto database in order to fill the gap information from the Kyoto database, and to include the benefits from the CBA approach. The policy evaluation index for each technology category in the Kyoto database policy was successfully developed using the least-squares method and multiple regression analysis. The developed index was useful in pointing which technology category requires further attention. One finding was that there is a number of technology categories had a significant number of projects which stands out among the other technology development projects. These technology project categories are: 1) energy management; 2) biomass fuel production; and 3) electric power storage. Levels of indexes were found to be not only influenced by the number of projects in each technology category but also the stage of technology development and whether there are large incidental events such as the Fukushima nuclear disaster and sudden change in the market. Finally, the policies were classified according to their index levels and categorized them according to their sectors. From these classifications, the progress situation of each policy in terms of promoting development projects was able to be identified. Even though the effectiveness of each policy in different clean technology development categories have been identified, it is up to the government to decide on kind of changes and implementation actions will be taken to make real changes on the field.

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