Ex-Post Project Evaluation 2020:

SATREPS Package I

(Botswana, Thailand, Indonesia)

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JAPAN INTERNATIONAL COOPERATION AGENCY

OPMAC Corporation

Foundation for Advanced Studies on International Development

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* Since the analysis for this ex-post evaluation was commenced in FY2021, the title of each report from the next page onward starts with "FY2021 Ex-post Evaluation Report".

Botswana

FY2021 Ex-Post Evaluation Report of Technical Cooperation Project

"Information-based Optimization of Jatropha Biomass Energy Production in the Frost- and Drought-Prone Regions of Botswana"

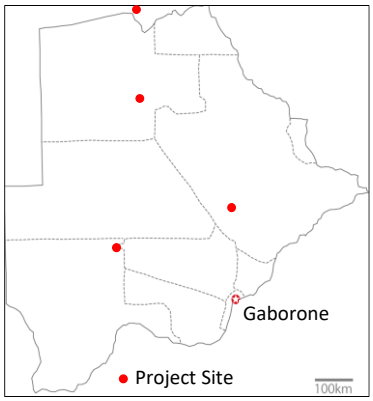
External Evaluator: Keishi Miyazaki, OPMAC Corporation

0. Summary

The project aimed to accumulate the technical knowledge and experience necessary to produce Jatropha biodiesel in Botswana on a commercial basis by conducting research in five areas: (i) the establishment of a Jatropha farming protocol suitable for the climate of Botswana, (ii) the establishment of bases for developing high yield and stress tolerant-Jatropha varieties, (iii) research on the characteristics of jatropha oil and development utilization methods, (iv) development of technologies to utilize non-oil Jatropha biomass, and (v) evaluation of the impact of Jatropha production and biomass from environmental, social and economic perspectives. This is in line with the Botswana's development policies and needs, as well as with Japan's assistance policy, and thus its relevance is high. In all five areas, research outputs were produced according to the plan and the project purpose was mostly achieved. Regarding the initiatives for social implementation which were set as the overall goals, three out of seven initiatives have been already completed or are on-going, while the remaining four have been not implemented yet. The project has made a certain contribution to improving the research capacity of the implementing agencies in Botswana, and there were generally no problems with the operation and maintenance of equipment. No negative impact on the natural environment was observed and there was no land acquisition or resettlement of people. Since this project has to some extent achieved the project purpose and overall goal, the effectiveness and impact of the project are fair. Both the project cost and project period were within the plan. Therefore, the efficiency of the project is high. No major problems have been observed in the policy background or in the institutional/ organizational, technical, or financial aspects. Therefore, the sustainability of the project effects is high.

In light of the above, this project is evaluated to be highly satisfactory.

1. Project Description



Project Locations

Jatropha cultivated on the pilot farm

1.1 Background

Botswana had seen tremendous economic growth since its independence in 1966. However, its economy had largely been driven by mineral resources such as diamonds, and domestic consumption, including oil, has been heavily dependent on imports. Meanwhile, Botswana's harsh weather conditions and low agricultural profitability had left much land unused. In such circumstances, the Government of Botswana decided to embark on the domestic production of biofuels with a view to increasing energy self-sufficiency, mitigating climate change and promoting the sustainable use of energy, and the government made clear its intention to actively explore and utilize renewable energy sources in *the Tenth National Development Plan* (2009-2016). Also, the Government of Botswana had been considering increasing the energy consumption from renewable energy sources to 30% of total energy consumption by 2030. In this connection, the production of biodiesel using Jatropha was seen as high potential. However, many challenges needed to be overcome to achieve the commercial production of Jatropha biodiesel such as developing varieties adapted to low rainfall and drought, establishing a Jatropha cultivation method and assessing its toxicity. Meanwhile, Botswana's research experience in the field of Jatropha research was extremely limited, and there was a need to conduct joint research with Japan, a world pioneer in this field.

1.2 Project Outline

Overall Goal		None
Project Purpose		Technical knowledge and experience to produce Jatropha biodiesel in Botswana on commercial basis is accumulated.
Outputs	Output 1	Jatropha farming protocol[1] suitable for the climate of Botswana is established.

[1] This includes management of tree pruning, windbreaks, water, and fertilizer timing to overcome winter droughts and cold damage.

	Output 2	Bases for developing high yield and stress tolerant-Jatropha varieties are established[2].
	Output 3	Characteristics of Jatropha oil production become clear.
	Output 4	Technologies to utilize non-oil Jatropha biomass are developed.
	Output 5	Impact of Jatropha production and biomass use is evaluated environmentally, socially and economically.
Total cost (Japanese Side)		288 million yen
Period of Cooperation		April 2012 – April 2017
Target Area		Sebele (Gaborone), Kang, Serowe, Maun
Implementing Agency		Department of Energy (DOE)/Ministry of Mineral Resources, Green Technology and Energy Security (MMGE), Department of Agricultural Research (DAR)/Ministry of Agriculture (MOA), University of Botswana
Other Relevant Agencies/ Organizations		None
Consultant/ Organization in Japan		Tottori University, University of the Ryukyus, Institute of Physical and Chemical Research (RIKEN)
Related Projects		Technical Cooperation, "Sustainable Production of Biodiesel from Jatropha in Mozambique" (July 2011 – June 2016)

1.3 Outline of the Terminal Evaluation

1.3.1 Achievement Status of Project Purpose at the Terminal Evaluation

It was judged that the project purpose was partially achieved. Four academic papers on Jatropha biodiesel had been published, three were under review in academic journals and four were being drafted. Drafts for technical knowledge and experience, the so called "technical protocol" on Jatropha cultivation methods, the development of transgenic Jatropha, the utilization of non-oil Jatropha, etc. were complete. On the other hand, only one researcher was able to obtain a master's/PhD degree during the project implementation period.

1.3.2 Achievement Status of Overall Goal at the Terminal Evaluation

(Including other impacts.)

[2] As it has aimed for the establishment of a methodology for efficient variety development, it is not envisaged that the project will lead to the development of new varieties.

An overall goal was not set in this project.

1.3.3 Recommendations from the Terminal Evaluation

The following recommendations were proposed:

(1) Development of a road map for social implementation of the project
(2) Contribution to the National Energy Policy
(3) Preparation of rules and regulations for genetic engineering
(4) Continuous utilization of facility/equipment provided through project implementation.

2. Outline of the Evaluation Study

2.1 External Evaluator

Keishi Miyazaki, OPMAC Corporation

2.2 Duration of Evaluation Study

This ex-post evaluation study was conducted with the following schedule.

Duration of the Study: July 2021 - January 2023

Duration of the Field Study: November 1 – November 14, 2021

2.3 Constraints during the Evaluation Study

This project is categorized as Science and Technology Research Partnership for Sustainable Development (SATREPS)[3]. Usually, the ex-post evaluations of SATREPS projects are undertaken by the internal evaluation. However, the ex-post evaluation of this target project was made by an external evaluator since the JICA Evaluation Department considered that useful insights could be gained through interviews with stakeholders in Japan, etc. It should be noted that this ex-post evaluation applied the previous evaluation criteria (five evaluation criteria) due to the timing of the introduction of the new evaluation criteria.

3. Results of the Evaluation (Overall Rating: A[4])

3.1 Relevance (Rating: ③[5])

[3] SATREPS are implemented by the Japan Science and Technology Agency (JST), the Japan Agency for Medical Research and Development (AMED) and JICA, with support from the Ministry of Foreign Affairs and the Ministry of Education, Culture, Sports, Science and Technology, to promote science and technology cooperation and science and technology diplomacy with developing countries through the collaboration of Japan's excellent science and technology and ODA. The aim of SATREPS is to acquire new knowledge and technologies and create innovations that will lead to solutions to global issues such as the environment, carbon neutrality, bioresources, disaster prevention and infectious diseases, as well as to improve the independent research and development capacity of developing countries and to build a sustainable system of activities that will contribute to solving these issues.

[4] A: Highly satisfactory, B: Satisfactory, C: Partially satisfactory, D: Unsatisfactory

[5] ③: High, ②: Fair, ①: Low

3.1.1 Consistency with the Development Plan of Botswana

At the time of the ex-ante evaluation, *the Tenth National Development Plan* (2009-2016) focused on key areas such as building a knowledge society, breaking away from dependence on mining and promoting industrial diversification, improving public services, promoting private sector growth, information communication and research, human resource development, public safety and security measures, infrastructure development and conservation, and investment in the service sector. The Plan included the active development and utilization of renewable energy sources from the perspective of improving energy self-sufficiency, mitigating climate change and promoting the sustainable use of energy. In addition, *the National Energy Policy* which was being developed at that time was considering the inclusion of a target to increase energy consumption from renewable energy sources to 30% of total energy consumption by 2030, and in this connection, the production of biodiesel from Jatropha was seen as a promising option.

At the time of the ex-post evaluation, *the Eleventh National Development Plan* (2017-2023), formulated on the basis of *VISION 2036*, which sets out long-term development strategy until 2036, identified priority areas such as the promotion of industrial diversification, human resources development, social development, sustainable use of natural resources and the implementation of an efficient management and evaluation system. This included the development of renewable energy, including the use of Jatropha. In addition, *the National Energy Policy of Botswana* (2020-2040) sets targets to reduce carbon dioxide emissions by 15% by 2030 and 36% by 2036 compared to 2010, in which the potential of Jatropha as a biofuel resource is mentioned.

3.1.2 Consistency with the Development Needs of Botswana

At the time of the ex-ante evaluation, Botswana's harsh weather conditions and low agricultural profitability left a lot of land unused, and the production of biodiesel from Jatropha on unused land was seen as promising[6]. However, for the commercial production of Jatropha biodiesel a number of challenges had to be overcome. These included developing varieties adapted to low rainfall and drought, establishing cultivation systems and assessing toxicity. In 2010, DOE/MMGE, with the help of Japanese Jatropha researchers, identified the challenges for Jatropha biodiesel production and decided that the selection and breeding of varieties suitable for Botswana's dry and cold environment and the establishment of cultivation methods should be a top priority. On the other hand, DAR/MOA and University of Botswana had researchers with knowledge in the relevant fields and some research facilities, but very little research experience in this field, and in

[6] Jatropha is inedible and therefore has the advantage that biodiesel can be extracted purely as energy, without competing with food and available bioethanol feedstocks such as maize.

order to make the commercial production of Jatropha biodiesel possible in the future, joint research with Japan, a world leader in the field of Jatropha research, was required.

At the time of the ex-post evaluation, it was confirmed that though the project, the project has made some achievements in the development of transgenic Jatropha seeds and cultivation methods that are stress tolerant in the climatic conditions of Botswana. However, there are still some issues to be resolved before promotion of full-scale cultivation of Jatropha, including continued research on cultivation methods, genome breeding research, and the establishment of domestic laws in related fields. Based on the above, DOE/MMGE changed its policy to the development of biodiesel through the use of non-Jatropha biomass[7], as it recognized that full-scale cultivation of Jatropha under Botswana's climatic conditions would leave some issues to be resolved. In response, DOE/MMGE, DAR/MOA and University of Botswana signed a Memorandum of Understanding to implement the "Biofuels Production Project[8]" (April 2018 - March 2023), utilizing various biomasses available in Botswana. This research project aims to continue and advance the development of biodiesel based on the research results of the SATREPS project, while extending the scope of the research to the development of biodiesel from waste biomass, including resource crops, tallow and waste cooking found in Botswana, rather than being limited to the development of Jatropha biodiesel. The research project is financed by the Government of Botswana, with a budget of approximately 14.2 million Pula (approximately 142 million yen[9]) over four years, which will be used for research and travel expenses (e.g., travel expenses to collect materials for biodiesel) for DAR/MOA and University of Botswana. Meanwhile, Japanese researchers, DAR/MOA, and University of Botswana continue to focus on the usefulness and potential of Jatropha as a biofuel resource, and DAR/MOA has expressed its willingness to continue research on the development of cultivation methods and variety improvement adapted to Botswana's climate conditions.

3.1.3 Consistency with Japan's ODA Policy

At the time of the ex-ante evaluation, *Japan's ODA policy for Botswana* identified "Support for infrastructure development for economic growth" and "Promotion for development in impoverished areas" as priority areas for cooperation, and stated that cooperation would be provided to help the country break away from its resource-dependent economic and industrial structure and achieve sustainable economic growth. In addition, at

[7] Biomass is the concept that expresses the quantity (mass) of biological resources (bio) and is defined as "renewable, organic resources of biological origin, excluding fossil resources". Biomass can be classified according to its status: (1) waste biomass (e.g., livestock waste, food waste, sewage sludge, manure sludge), (2) unused biomass (e.g., rice straw, wheat straw, rice husks, forest residues), (3) resource crops (e.g., sugar cane, corn and other starch resources, rapeseed oil resources, willow, poplar, etc.) (Source: website of Kyushu Regional Agricultural Administration Office, https://www.maff.go.jp/kyusyu/kikaku/baiomasu/teigitou.html).
[8] The Biofuels Production Project is implemented under the budget of Botswana government.
[9] Exchange rate used: BWP 1 = JPY 10.

the Fourth Tokyo International Conference on African Development (TICAD IV) in May 2008 and on other occasions, Japan expressed its intention to strengthen cooperation with African countries in their efforts to combat climate change, and this project was positioned as a concrete measure to support such efforts.

Furthermore, this project, which aimed to support the realization of a stable and sustainable energy supply in the Southern African region, was positioned as a "Regional Resource and Energy Supply System Development Program" in *JICA's country operation programs*.

3.1.4 Appropriateness of the Project Plan and Approach

The Project Design Matrix (PDM) at the time of the ex-ante evaluation set four indicators (Indicator 5.1 to Indicator 5.4) in Outcome 5. However, in the PDM used during the terminal evaluation, Indicator 5.3, "Impacts on land use, industry, employment, etc., are determined when the commercial use of Jatropha is assumed" was deleted, so it was not a subject of the evaluation judgement. However, the reason why Indicator 5.3 was deleted could not be confirmed.

In addition, Indicator 2 of the project purpose, "At least 6 researchers obtain a master/ PhD degree related to Jatropha", was not generated as a result of the activities of Outcomes 1-5 and therefore it is considered that Indicator 2 was not necessarily appropriate as an indicator to measure the achievement status of the project purpose. Rather, it would have been logistically appropriate to add the provision of scholarships to young Botswana researchers (master's and PhD students) engaged in Jatropha research, to give research guidance to them as project activities and use them as outcome indicators. However, it is considered that the appropriateness of the project plan and approach was not a problem, since the problems with the above two indicators cannot be said to be factors that prevented the project from being effective.

This project was highly relevant to Botswana's development plan and development needs, as well as Japan's ODA policy. Therefore, its relevance is high.

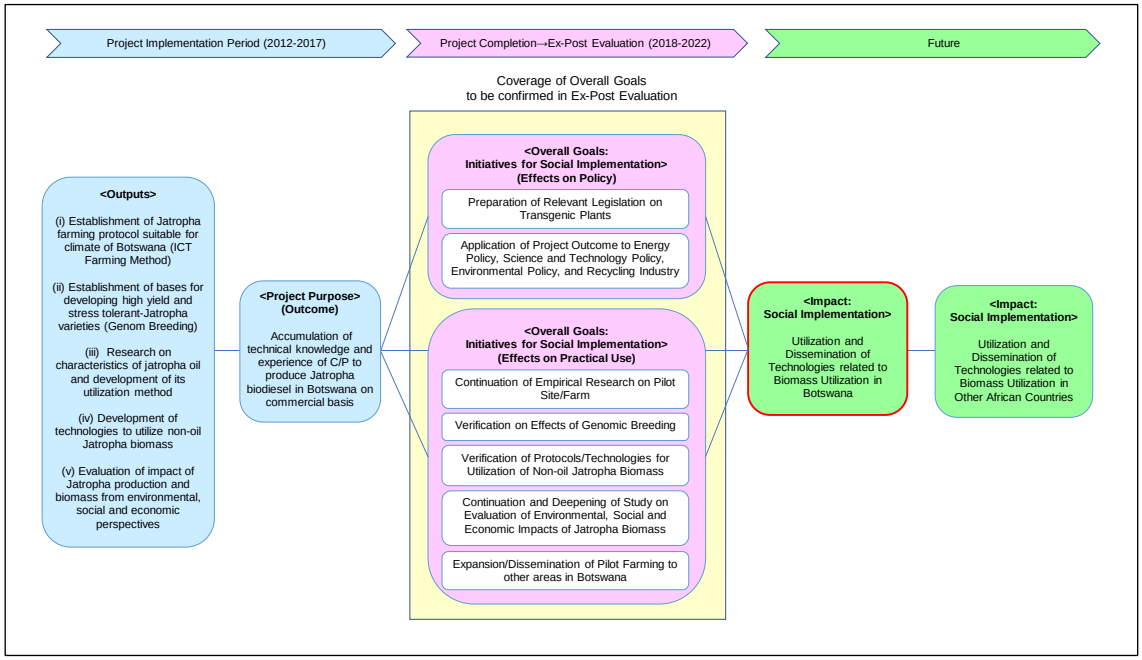
3.2 Effectiveness and Impact[10] (Rating: ②)

This project was a technical cooperation project conducted within the framework of SATREPS, which ultimately aimed to promote the social implementation of science and technology that responds to the issues and needs of the partner country, rather than merely providing support for basic or applied research. The social implementation aimed at by the project is the "Utilization and dissemination of technologies related to biomass utilization in

[10] The Sub-rating for Effectiveness is to be put with Consideration of Impact.

Botswana." [11] Several steps are necessary from the implementation of SATREPS to the realization of social implementation. For this reason, the "initiatives for social implementation" to be realized by 3-4 years after project completion were identified. These "initiatives for social implementation" were positioned as the overall goals of the project, and the achievement of the overall goals was analyzed from the viewpoint of whether or not various requirements were in place and whether progress was being made toward the realization of social implementation at the time of the ex-post evaluation.

The "initiatives for social implementation" are (i) Preparation of Relevant Legislation on Transgenic Plants, and (ii) Application of Project Outcome to Energy Policy, Science and Technology Policy, Environmental Policy, and the Recycling Industry as "Effect on Policy". They also include (iii) Continuation of Empirical Research on Pilot Sites/Farms, (iv) Verification of Effects of Genomic Breeding, (v) Verification of Protocols/Technologies for the Utilization of Non-oil Jatropha Biomass, (vi) Continuation and Deepening of Study on the Evaluation of Environmental, Social and Economic Impacts of Jatropha Biomass, and (vii) Expansion/Dissemination of Pilot Farming to other areas in Botswana as "Effect on Practical Use". The analytical framework used in this ex-post evaluation and the coverage of the overall goals to be confirmed in this ex-post evaluation is shown in Figure 1.



Source: Prepared by the Evaluator.

Figure 1 Evaluation Framework and Coverage of Overfall Goals

[11] It was assumed that initially the social implementation of this project was defined as "Commercial production and dissemination of Jatropha biodiesel." However, it was redefined in the ex-post evaluation as "Utilization and dissemination of technologies related to biomass utilization in Botswana" after the definition was confirmed with the researchers in Japan and Botswana.

3.2.1 Effectiveness

3.2.1.1 Project Outputs

(1) Output 1

Output 1 “Jatropha farming protocol suitable for the climate of Botswana is established” was achieved. In the four pilot farms in Sebele, Kang, Serowe and Maun, 76 indigenous accessions of Jatropha in Botswana and Jatropha in Ghanaian were planted, irrigation facilities and weather monitoring equipment were installed, and research on Jatropha cultivation was conducted. Based on the identification of the cold season through the analysis of weather data for the past five years, it was confirmed that irrigation twice a week from August to November while monitoring soil moisture would promote tree growth and flower bud differentiation, allowing seed harvesting before the winter (the frost season). In addition, for several superior accessions, it was possible to harvest more than 80 seeds per tree. Based on the above cultivation studies, a cultivation manual, “Jatropha Cultivation in Botswana”, was prepared.

(2) Output 2

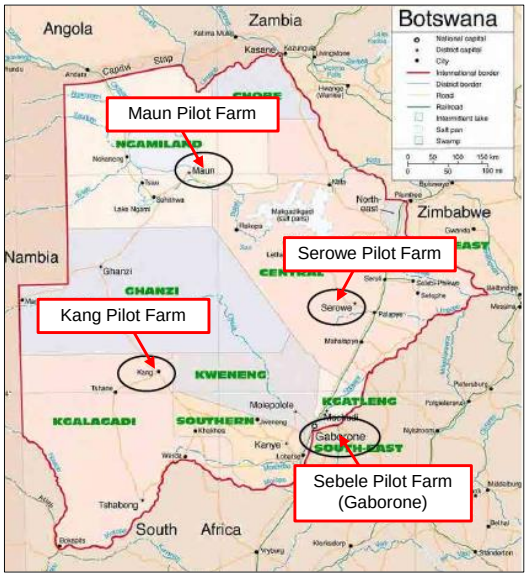
Output 2 “Bases for developing high yield and stress tolerant-Jatropha varieties are established” was achieved. The biomass productivity and seed productivity of all 76 accessions of Jatropha in Botswana planted in the Sebele pilot farm were assessed, and the accessions with high performance for each character were selected. Environmental stress tolerance was also evaluated based on biomass and seed productivity. In addition, genome analysis and databasing were conducted on five representative accessions of Jatropha in Botswana, and they were found to have high single nucleotide polymorphism (SNP). Based on this information, SNP markers were developed and the genotypes of all accessions of Jatropha in Botswana were analyzed, and successfully classified as a molecular phylogenetic tree. Following this, using a new transformation method developed at Tottori University, consisting of reduced pressure treatment and filter paper culture, three transgenic Jatropha varieties linked to high yield and stress tolerance were developed. Using this transgenic Jatropha, an environmental stress tolerance assessment was conducted at Tottori University, and it was confirmed that tolerance to low temperature stress had been improved. However, it was noted that it would take time for Outcome 2 to be disseminated to the Botswana side, as transgenic laws and regulations are not yet in place within Botswana and it was difficult to import the transgenic Jatropha varieties developed at Tottori University into Botswana. The transgenic Jatropha has been kept at Tottori University.

(3) Output 3

Output 3 “Characteristics of Jatropha oil production become clear” was achieved. As for the available 61 accessions of Jatropha harvested in Botswana, the oil content and oil composition of the seeds were analyzed, calorimetric data for typical accessions were obtained, and a database was constructed. 37 accessions that were harvested in the 2015 season out of the 76 accessions of Jatropha were analyzed for toxic compounds of Jatropha seeds, crude oil, and biodiesel. Basic fuel properties related to fuel specifications, such as the calorific value and viscosity of crude oil and biodiesel made from Jatropha seeds were measured, and combustion characteristics were determined using small generator and engine performance test equipment. Also, simulations of the electrification of non-electrified villages with small generators using biodiesel made from Jatropha were conducted, as well as the driving test of a vehicle using biodiesel. In addition, the yield efficiency of Jatropha biodiesel was calculated.

(4) Output 4

Output 4 “Technologies to utilize non-oil Jatropha biomass are developed” was achieved. The weight and composition of non-seed biomass (non-oil biomass) after oil squeezing, the shells of fruits, branches generated at harvest, etc. were analyzed to identify the characteristics of co-products (soil conditioners, raw fertilizer feedstock, solid fuel, catalysts). The results of the laboratory experiment on the application of Jatropha char to soil confirmed that soil treated with Jatropha char is likely to improve water holding capacity by more than 1.0% and water use efficiency by more than 0.5% compared to soil without Jatropha char. As a method of utilizing the non-oil biomass of Jatropha, technology has been developed to produce soil conditioners, solid fuels, solid fertilizers, etc. using biochar, and their effectiveness has been confirmed.



Source: Documents provided by JICA.

Figure 2 Map of Project Sites

(5) Output 5

Output 5 “Impact of Jatropha production and biomass use is evaluated environmentally, socially and economically” was achieved. A preliminary life cycle assessment of Jatropha production was conducted to estimate greenhouse gas emissions and reductions at various

stages of the Jatropha biodiesel project: the stages of cultivation, oil extraction, refining, distribution, and utilization. The results showed that in the Jatropha energy production and consumption process, reductions exceeded emissions by 63.4%. Secondly, an estimate of the reduction in petroleum fuel (diesel fuel) from Jatropha biodiesel production, a calculation of the reduction in wood fuel (firewood) from wood alternative fuel production, and an estimate of the number of households that could be supplied with a year's supply of firewood from wood alternative fuel were conducted. Following this, a cost-benefit analysis of the Jatropha biodiesel project was conducted by calculating the expenditure and revenue of the cultivation activities at the pilot farms and by constructing a scenario for generating profits using the model. In addition, a literature review of previously introduced Jatropha biodiesel projects in Sub-Saharan Africa was conducted, which supported the validity of the results of the above analysis.

3.2.1.2 Achievement of Project Purpose

The project purpose "Technical knowledge and experience to produce Jatropha biodiesel in Botswana on a commercial basis is accumulated" is judged as being mostly achieved. Table 1 shows the achievement status of each indicator.

Table 1 Achievement Status of Project Purpose

Project Purpose	Indicator	Actual Status
Project Purpose: Technical knowledge and experience to produce Jatropha biodiesel in Botswana on a commercial basis is accumulated	Indicator 1: At least 5 academic papers are published.	Mostly achieved. • Based on a literature review of projects previously introduced in Sub-Saharan Africa, an analysis of the requirements for, and issues connected to, the introduction of Jatropha biodiesel projects in Botswana from the perspectives of economic sustainability, energy policy, and socio-economic impacts was conducted. Four academic papers were submitted to international journals. • In addition to the above, 28 original papers (26 in international journals and 2 in domestic journals) and 13 publications were also presented. In addition, the results of the research were compiled as manuals, databases, etc.
	Indicator 2 At least 6 researchers obtain master's/PhD degrees related to Jatropha.	Not achieved. • Seven researchers received scholarships from the Botswana Government. Six started Jatropha research as graduate students at University of Botswana and one at the University of Botswana of Agriculture and Natural Resources (BUAN). However, the provision of the scholarships was significantly delayed due to delays in budget preparation by the Botswana Government. As a result, only one student was able to obtain a master's degree by project completion.
	Indicator 3 Technology protocols based on the Outputs of the Project are presented to the Botswana Government	Achieved. • Technical knowledge and protocols related to Jatropha cultivation methods, the development of transgenic Jatropha, and the utilization of non-oil biomass were compiled into a Technological Package and submitted to the Botswana Government.

Source: Documents provided by JICA.

Indicator 1 “At least 5 academic papers are published” was mostly achieved, Indicator 2 “At least 6 researchers obtain master’s/PhD degrees related to Jatropha” was not achieved, and Indicator 3 “Technology protocols based on the Outputs of the Project are presented to the Botswana Government” was achieved. The reason why Indicator 2 was not achieved was that the start of research for seven doctoral and master's degree graduate students was delayed due to a delay in their receiving scholarships from the Botswana Government, and as a result, only one graduate student was able to obtain a doctoral or master's degree by the time of project completion. However, it is questionable whether Indicator 2 was appropriate as an indicator of project purpose, since it was to be generated not as a result of joint research by universities and research institutions on the Japan-Botswana side conducted as activities for Outcomes 1-5, but through the research activity of Botswana graduate students based on technical knowledge and experience gained through the project. It would, rather, have been logistically appropriate to add the provision of scholarships to young Botswana researchers (master's and doctoral graduate students) on Jatropha research together with research guidance as project activities and use these as outcome indicators. On the other hand, Outcomes 1-5 are directly related to Indicators 1 and 3 of the project purpose, as the activities are carried out by both the Japanese and Botswana researchers, regardless of the schedule of the scholarship program for graduate students.

Based on the above, it was concluded that the project generally achieved its purpose, since (i) Outcomes 1-5 had been achieved by project completion, and (ii) Indicators 1 and 3 are directly related to Outcomes 1-5, and thus more weight was given to the achievement status of Indicators 1 and 3 in the evaluation judgment.

3.2.2 Impact

3.2.2.1 Achievement of Overall Goal

No overall goals were set for this project. Therefore, as mentioned earlier in this ex-post evaluation, “Initiatives for social implementation” that should be achieved by the third to fourth year after project completion were identified and positioned as the overall goals of the project. The degree of achievement of the overall goals was then judged from the perspective of whether various requirements were in place for social implementation and whether progress toward the realization of social implementation was being made as of the ex-post evaluation. Table 2 shows the results of the overall goals.

Tale 2 Achievement Status of the Overall Goals identified in the Ex-Post Evaluation

Overall Goals	Actual Status
(i) Preparation of Relevant Legislation on Transgenic Plants	• Legislation on transgenic plants is under discussion by the National Assembly and is expected to be approved by the end of 2022, according to the Ministry of Agriculture.
(ii) Application of Project Outcome to Energy Policy, Science and Technology Policy, Environmental Policy, and the Recycling Industry	• A guideline "Biofuel Guideline for Botswana" (May 2021) has already been prepared by the DOE/MMGE. This outlines the procedures for the production of biofuels, and is expected to be officially approved by the end of 2022. Once approved, the guidelines will be made available to the public.
(iii) Continuation of Empirical Research on Pilot Sites/Farms	• Since the project completion, no Jatropha has been cultivated in the four pilot farms in Sebele, Kang, Serowe, and Maun, with the exception of Sebele. Although the pilot farm in Sebele remains for the preservation of the accessions of Jatropha with high performance for biomass productivity and seed productivity selected from all 76 accessions of Jatropha in Botswana by the project, the cultivation of Jatropha has become difficult due to damage caused by frosts in winter and the theft of weather monitoring equipment installed on the pilot farm.
(iv) Verification of the Effects of Genomic Breeding	• At the time of the ex-post evaluation, the continuation of empirical research on the development of high-yielding and stress-tolerant Jatropha varieties (genomic breeding) by DAR/MOA had been substantially suspended due to the lack of the relevant legislation for transgenic plants required for the continuation of genomic research in Botswana, and a difficulty in importing the transgenic Jatropha varieties developed in Japan. DAR/MOA has shown its willingness to import the transgenic Jatropha varieties kept at Tottori University, and to resume empirical research on the effectiveness of genomic breeding after the passage of the legislation and to expand it from laboratory level to the field.
(v) Verification of the Protocols/Technologies for Utilization of Non-oil Jatropha Biomass	• DAR/MOA have continued an empirical study of agricultural fertilizer (compost) using biochar produced from Jatropha non-oil biomass. The empirical study researches the ratio of biochar which is appropriate to produce effective compost, this compost being provided free of charge to farmers as well as to vegetable growers at DAR/MOA's farms. Monitoring is being conducted to verify the effectiveness of the compost. According to DAR/MOA, this biochar has a high salt content, so when it is mixed with soil and used as compost, the content rate is limited to 10% or less. • Based on the results of this empirical study, DAR/MOA plans to disseminate knowledge on the production and use of Jatropha biochar to farmers in the future.
(vi) Continuation and Deepening of Study on Evaluation of the Environmental, Social and Economic Impacts of Jatropha Biomass	• Although the research results anticipated during project implementation were obtained, the same research has not been continued after project completion.
(vii) Expansion /Dissemination of Pilot Farming to other areas in Botswana	• Although, after project completion, Japanese cooperating organizations such as Tottori University applied for a second phase of this SATREPS project through JST in 2018-2019, the application was not accepted. In addition, the project team planned to conduct a village electrification project using Jatropha diesel and a land improvement project using Jatropha biochar through the grassroots technical cooperation project scheme and submitted an application to JICA. This application was not adopted because the project plan was not sufficient. The Botswana executing agencies and Japanese cooperating agencies are continuing to conduct project formulation studies, including review and refinement of the project plan, with the aim of adopting the project as a grass-roots technical cooperation project. However, the global outbreak of COVID-19 has made travel from Japan to Botswana difficult and field surveys have been suspended. • As described above, the Botswana executing agencies and the Japanese cooperating agencies had envisioned expanding and deploying the results of the empirical research obtained through this project to other areas in Botswana

Overall Goals	Actual Status
	through the implementation of a second phase of the SATREPS project and the utilization of the JICA grassroots technical cooperation project.

Source: The responses to the questionnaires with the Botswana executing agencies and the Japanese cooperating agencies, and interview results.

Utilization of Non-oil Jatropha Biomass

Raw material of Jatropha biochar (Jatropha trunk branches)

Compost production facility using Jatropha biochar.

Compost produced.

Three of the seven initiatives for social implementation based on the research results of this project have been implemented or are being implemented, and four have not yet been implemented. Therefore, it is judged that the project has achieved its overall goal at a limited level.

3.2.2.2 Continuation Status of Project Effects

(1) Utilization of Research Outputs

The continuation status of the five outputs (five research areas) of the project is shown in Table 3. As mentioned in "3.1.2 Consistency with the Development Needs of Botswana", after the project completion, the Botswana Government changed its policy to the development of biodiesel by utilizing biomass other than Jatropha. In response, DOE/MMGE, DAR/MOA, and University of Botswana are collaborating and cooperating in the "Biofuels Production Project" (April 2018 - March 2023), which will utilize various forms of biomass available in Botswana. The above events have affected the continuation and progress of each project output after its completion.

Output 1 was not being continued at the time of the ex-post evaluation. Research relating to Output 2 was inactive at the time of the ex-post evaluation, although there is still a possibility that it will be restarted after the enactment of the relevant legislation on transgenic plants in Botswana. Research relating to Output 3 is being undertaken by doctoral and postgraduate students of

Jatropha

Jatropha seeds

Jatropha seedling

Jatropha in Sebele pilot farm

University of Botswana, and is continuing to a certain extent. Meanwhile, the main focus of research activities is no longer limited to the production of biodiesel from Jatropha seeds, but has expanded to include research on the production and utilization of biodiesel from other available options such as Trichilia and other plant species, waste cooking oil, beef tallow, etc. University of Botswana is producing biodiesel from waste cooking oil and beef tallow, and conducting field driving tests using university diesel vehicles. As for Output 4, an empirical study of fertilizer (compost) using Jatropha biochar is continuing at DAR/MOA, and University of Botswana is also continuing research on the use of Jatropha non-oil biomass as a raw material for solid fuel (pellets). Output 5 was not continued after project completion. However, since the emphasis has shifted to the research and development of biodiesel feedstock other than Jatropha, the need to continue Output 5 at the time of the ex-post evaluation did not appear to be as high as initially assumed.

Table 3 Continuation Status of Research

Outputs	Continuation Status at Ex-Post Evaluation
Output 1 Jatropha farming protocol suitable for the climate of Botswana is established.	**[DAR/MOA]** • Since project completion, no Jatropha has been cultivated in the four pilot farms in Sebele, Kang, Serowe, and Maun, although there is an exception at Sebele where the pilot farm remains for the preservation of the accessions of Jatropha with high performance for biomass productivity and seed productivity selected from all 76 accessions of Jatropha in Botswana by the project. It has become difficult to grow Jatropha due to damage caused by frost in winter and the theft of weather monitoring equipment installed at the pilot farm. Sebele pilot farm has been managed by DAR/MOA continuously. • Meanwhile, DAR/MOA is conducting research on how to cultivate plants other than Jatropha (varieties such as Trichilia, Scythia, and Croton), which are available in Botswana as feedstock for biodiesel, and the research results of Output 1 are also helping in this research.
Output 2 Bases for developing high yield and stress tolerant-Jatropha varieties are established.	**[DAR/MOA]** • Since the Jatropha varieties developed by the project are not sufficiently stress tolerant to low temperatures, research on the genome breeding of Jatropha resistant to cold weather in winter should be continued. However, this research activity is being suspended until the enactment of related legislations on transgenic plants (the legislation is expected to be enacted by the end of 2022). • A map of Indigenous Potential Biomass was prepared. • The scope of research is being expanded from the development of biodiesel using Jatropha to research and development of biodiesel using plants other than Jatropha (varieties such as Trichilia, Scythia, and Croton). For example, research on Ethiopian mustard (the oil is not edible), and comparative analysis of the properties of Jatropha and other plant-derived oils.
Output 3 The characteristics of Jatropha oil production become clear.	**[University of Botswana]** • Jatropha-related research is being carried out by several PhD and master's students, and the research itself continues in part.

Outputs	Continuation Status at Ex-Post Evaluation
	• Meanwhile, the main focus of current research activities is not limited to the production of biodiesel from Jatropha seeds, but has expanded to include research on the production and utilization of biodiesel from other available options, such as other plant species such as Trichilia, waste cooking oil, and beef tallow (research on biomass utilization not limited to Jatropha). • A machinery (Bio-Prob 380 EX processor) has been developed to extract biodiesel from waste cooking oil, beef tallow, etc., enabling the production of 380 liters of biodiesel per batch. This biodiesel is actually used in the vehicles provided by the project, and University of Botswana aims to produce enough biodiesel to supply all the university's diesel vehicles in the future.  Bio-Prob 380 EX processor
Output 4 Technologies to utilize non-oil Jatropha biomass are developed	**[DAR/MOA]** • The empirical study on biochar production and fertilizer (compost) using biochar is ongoing. The compost is provided free of charge to farmers as well as to vegetable growers at DAR/MOA's farms, and monitoring is being conducted to verify the effectiveness of the compost. **[University of Botswana]** • Jatropha-related research, including studies on the use of Jatropha non-oil biomass as a feedstock for solid fuels (pellets), is being carried out by several doctoral and master's students at University of Botswana.
Output 5 Impact of Jatropha production and biomass use is evaluated environmentally, socially and economically.	**[University of Botswana]** • Although the research results anticipated during project implementation were obtained, the same research has not been continued after the completion of the project.

Source: The responses to the questionnaires with the Botswana executing agencies and the Japanese cooperating agencies, and interview results.

(2) Capacity Development of Researchers

University of Botswana recognizes that this project has made a significant contribution to the capacity building and development of researchers at the university. Based on the research results of this project, University of Botswana has selected a research theme for the doctoral and master's theses of graduate students in the Faculty of Engineering and Technology, and related research continues. Laboratory equipment provided to University of Botswana and DAR/MOA under this project has also been used in this research. According to DAR/MOA, conventional research areas were mainly crop cultivation and animal husbandry, but participation in the project has led to the expansion and advancement of DAR/MOA's research areas with the addition of biomass research.

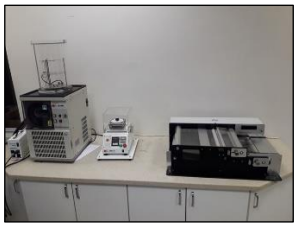
(3) Utilization, Operation, and Maintenance of the Equipment

The project provided various research and experiment equipment, including photosynthesis measuring equipment, denaturing gradient gel electrophoresis units, gel photography equipment, weather station units, leaf area meters, DNA electrophoresis equipment, freeze dry lyophilizers, and refrigerators for seed. These were still being used

for research at University of Botswana and DAR/MOA at the time of the post evaluation. There were no major issues in the maintenance of these items of equipment.

Equipment of DAR/MOA provided by the Project


Laboratory at DAR/MOA


leaf area meter


Protein Analyzer


High-temperature, high-pressure sterilizer

Equipment of University of Botswana provided by the Project


Laboratory at University of Botswana


Biodiesel Extraction Equipment


Biodiesel Extraction Equipment

Biodiesel Starter Kit

3.2.2.3 Other Positive and Negative Impacts

(1) Impact on Natural Environment

At the time of the ex-ante evaluation, it was recognized that the toxic substances and transgenic varieties of Jatropha handled in this project had a small but recognizable potential for adverse effects on the natural environment and human health. Therefore, it was planned that the project would incorporate into its activities research to characterize toxic substances and to conduct research on genetic modification in compliance with national and international regulations. This was carried out as planned. The research on transgenic (genome breeding research) was conducted mainly in Japan by Japanese collaborating institutions such as Shimane University, because Botswana had not yet developed the relevant legislation on transgenic plants.

During project implementation, the necessary environmental monitoring was carried out, and according to DAR/MOA, no negative impact of Jatropha was found either on the natural environment or on the health of project personnel on the pilot farms. Nor were any environmental impacts associated with transgenic observed.

(2) Resettlement of People and Land Acquisition

Since the four pilot farms, where the cultivation research on Jatropha was conducted, were located on land owned by MOA, there was no resettlement of people nor land acquisition associated with the project.

The project purpose was achieved through the implementation of the project. As for the initiatives for social implementation, which were set as the overall goals of the project, three out of seven have been implemented or are being implemented, and four have not yet been implemented. Regarding the continuation status of the project effects, Output 2, Output 3, and Output 4 were continued, while Output 1 and Output 5 were not continued. The project contributed to the development of the research capacity of researchers in the executing agencies in Botswana, and there were generally no problems in the utilization and maintenance of equipment. No negative impact on the natural environment, land acquisition, or resettlement of people was observed.

Based on the above, the project has produced positive project effects to some extent, therefore, the effectiveness and impact of the project is fair.

3.3 Efficiency (Rating: ③)

3.3.1 Inputs

Table 4 shows the comparison between the planned and actual inputs.

Table 4 Planned and Actual Inputs

Inputs	Plan	Actual
(1) Experts	• Long-term: Coordination, Cultivation (number of experts, man-month not stated) • Short-term: • Cultivation, Plan molecular breeding, Postharvest processing, No-oil biomass production, other specialties (number of experts, man-month not stated)	• Lon-term: 4 persons • Short-term: 15 persons
(2) Trainees received	N.A.	29 persons
(3) Equipment	N.A.	Vehicles, photosynthesis measurement devices, various measurement devices and equipment, etc.
(4) Operational costs	N.A.	Approximately 23.2 million yen
Japanese Side Total Project Cost	300 million yen	296 million yen
Botswana Side Total Project Cost	Amount not stated. (Personnel costs of the counterpart staff, labour costs of pilot farms, costs for laboratory equipment, costs for symposiums and workshops etc.)	Approximately 132 million yen (Personnel costs of the counterpart staff, fuel costs for project vehicles, labour costs of pilot farms and security guards, costs for dispatching long-term trainees, costs for workshops, meetings, training etc.)

Source: Documents provided by JICA.

3.3.1.1 Elements of Inputs

Nineteen experts/researchers (Lon-term: 4 persons, Short-term: 15 persons) were dispatched from Japan. The number of Botswana researchers received was 29.

As mentioned earlier, joint research in the five research areas was successfully conducted within the project period. A cultivation manual “Jatropha Cultivation in Botswana” was produced, together with a technical package, four academic papers were published in international journals, and a database was constructed. The equipment provided is generally well utilized and maintained.

The Botswana side made inputs of approximately 132 million yen for the personnel costs of the counterpart staff, costs for dispatching long-term trainees, costs for workshops, meetings, training etc., and it can be said that the project was implemented under the partnership of Botswana and Japan.

3.3.1.2 Project Cost

The actual project cost on the Japanese side was 296 million yen against the planned 300 million yen, which was within the plan (98% against plan).

3.3.1.3 Project Period

The actual project period was 60 months (April 2012 – April 2017) against the planned 60 months (March 2012 – March 2017), which was as planned (100% against plan).

Both the project cost and project period were within the plan. Therefore, efficiency of the project is high.

3.4 Sustainability (Rating: ③)

3.4.1 Policy and Political Commitment for the Sustainability of Project Effects

The development of renewable energy, including the use of Jatropha, is listed as a priority area in *the Eleventh National Development Plan (2017-2023)*, and *the National Energy Policy of Botswana (2020-2040)* also mentions the potential of Jatropha as a biofuel. In addition, legislation on transgenic plants, which is necessary for research on the genome breeding of Jatropha, is expected to be passed by the end of 2022. At the time of the ex-post evaluation, the Botswana Government’ policy has been promoting the development of biodiesel by utilizing biomass other than Jatropha as well, and DOE/MMGE, DAR/MOA, and University of Botswana will continue and develop the results of this SATREPS project through the ongoing “Biofuels Production Project” (2018-2023). Not limiting themselves to the development of Jatropha biodiesel, they are working to develop biodiesel using waste biomass, including resource crops indigenous to Botswana, tallow, and waste cooking oil,

as a continuation and expansion of the project outcomes.

Therefore, it can be seen that the policy and political commitment to sustain the project effects have been secured.

3.4.2 Institutional/Organizational Aspects for the Sustainability of Project Effects

In addition to its headquarters in Sebele, outside of Gaborone, DAR/MOA has numerous branches and offices throughout the country and is organized into four divisions: the Crop Research Division, the Livestock and Rangeland Research Division, the Support Services Division, and the Human Resources Division. The headquarters of DAR/MOA in Sebele has vast pilot farms and laboratory facilities for the chemical analysis of soil and other materials, DNA analysis, and so on. DAR/MOA also plays an important role as a seed provider for domestic agriculture, supplying 90% of the agricultural seeds used in the country. It is also responsible for the conservation of plant genetic resources and is in charge of biosafety, including the management of transgenic plants. At the time of the ex-post evaluation, 15 researchers were engaged in research related to the project at DAR/MOA.

University of Botswana, established in 1982, is a comprehensive university in Botswana. It has seven faculties: Business Administration, Education, Engineering and Technology, Health Sciences, Medicine, Humanities, and Social Sciences. Research on biodiesel, including Jatropha, is handled by the Faculty of Engineering and Technology, and at the time of the ex-post evaluation, six researchers (faculty members and doctoral and master's course graduate students) were engaged in related research. In addition, after project completion, there has been ongoing collaboration and cooperation with Tottori University and other cooperating institutions on the Japanese side, mainly on an individual basis.

Therefore, the institutional/organizational aspects to sustain the project effects has been secured.

3.4.3 Technical Aspects for the Sustainability of Project Effects

DAR/MOA has been engaged in collecting plant resources and cultivation experiments with Jatropha since the latter half of 2000. With the support of the “Biofuels Production Project” mentioned above, DAR/MOA has also been cultivating and conducting research on plants other than Jatropha (varieties such as Trichilia, Scythia, Croton, etc.), which can be used as raw materials for biofuels. DAR/MOA intends to continue the cultivation method (ICT farming) and molecular genome breeding of Jatropha suitable for the climate of Botswana after the relevant legislation on transgenic plants has been enacted, and to import the transgenic Jatropha varieties kept at Tottori University to Botswana, and therefore, the accessions of Jatropha with high performance for biomass productivity and seed

productivity selected from all 76 accessions of Jatropha in Botswana by the project is being preserved at the Sebele pilot farm. Research on the utilization technology of biochar made from Jatropha also continues. The laboratory equipment provided to DAR/MOA is in continuous use and is maintained generally in good condition.

University of Botswana earlier recognized the potential of circular energy and established the Clean Energy Research Centre (CERC) (a virtual research organization to which researchers related to the development and promotion of circular energy belong) to conduct interdisciplinary research that takes advantage of each researcher's expertise. The expertise of the individual researchers is high, and they have published many academic papers. With reference to the research results of this project, the Faculty of Engineering and Technology, University of Botswana, with the support of the "Biofuels Production Project", is also conducting research on biodiesel fuel using indigenous Botswana plants and other biomass (tallow, waste cooking oil, etc.). The university has developed equipment for producing biodiesel from tallow and waste cooking oil, and is also testing actual vehicles with fuel. The laboratory equipment provided to University of Botswana is in continuous use, and is also maintained generally in good condition.

Therefore, the technical aspect to sustain the project effects has been secured.

3.4.4 Financial Aspect for the Sustainability of Project Effects

University of Botswana received 2,080,000 Pula (approximately 21.4 million yen) in 2020 and 1,900,000 Pula (approximately 19.5 million yen) in 2021 from the "Biofuels Production Project". Similarly, DAR/MOA also received a research grant from the same project for the collection of plants that can be used for biofuels. Through the "Biofuels Production Project", DAR/MOA and Botswana will be provided with financial support for research into the development of biodiesel from biomass at least until 2023.

Therefore, it is judged that there are no major issues in the institutional/organizational aspects to sustain the project effects.

No major problems have been observed in the policy background nor in the institutional/ organizational, technical, financial aspects. Therefore, the sustainability of the project effects is high.

4. Conclusion, Lessons Learned and Recommendations

4.1 Conclusion

The project aimed to accumulate the technical knowledge and experience to produce Jatropha biodiesel in Botswana on a commercial basis by conducting research in five areas: (i) the establishment of a Jatropha farming protocol suitable for the climate of Botswana, (ii)

the establishment of bases for developing high yield and stress tolerant Jatropha varieties, (iii) research on the characteristics of jatropha oil and development of its utilization methods, (iv) development of technologies to utilize non-oil Jatropha biomass, and (v) evaluation of the impact of Jatropha production and biomass from environmental, social and economic perspectives. This is in line with the Botswana's development policies and needs, as well as with Japan's assistance policy, and thus its relevance is high. In all five areas, research outputs were produced according to the plan and the project purpose was mostly achieved. Regarding the initiatives for social implementation set as the overall goals, three out of seven initiatives have been already completed or are on-going, and the remaining four have been not implemented yet. The project has made a certain contribution to improving the research capacity of the implementing agencies in Botswana, and there were generally no problems with the operation and maintenance of equipment. No negative impact on the natural environment was observed, nor was land acquisition and the resettlement of people. Since this project has to some extent achieved the project purpose and overall goal, the effectiveness and impact of the project are fair. Both the project cost and project period were within the plan. Therefore, the efficiency of the project is high. No major problems have been observed in the policy background nor in the institutional/organizational, technical, and financial aspects. Therefore, the sustainability of the project effects is high.

In light of the above, this project is evaluated to be highly satisfactory.

4.2 Recommendations

4.2.1 Recommendations to the Implementing Agency

Since project completion, the pilot farm in Sebele (Gaborone), which is managed by DAR/MOA, has continued to grow Jatropha to preserve the accessions of Jatropha with high performance for biomass productivity and seed productivity selected from all 76 accessions of Jatropha in Botswana by the project. However, weather monitoring data cannot be collected and recorded due to the theft of the weather monitoring equipment provided by the project and installed at the pilot farm. It is desirable that MOA consider the re-procurement of weather monitoring equipment.

4.2.2 Recommendations to JICA

JICA has conducted projects related to research on biodiesel development using Jatropha (including SATREPS) in countries other than Botswana, such as Vietnam[12], Mozambique[13],

[12] Vietnam "Multi-beneficial measure for the mitigation of climate change in Vietnam and Indochina countries by development of biomass energy" (2011-2016).

[13] Mozambique "Sustainable Production of Biodiesel from Jatropha in Mozambique" (2011-2016).

and Thailand[14], However, there have not been many cases in which Jatropha biodiesel itself has been promoted and commercialized after project completion. The reasons for this include the difficulty of cultivating Jatropha due to differences in climatic conditions in different countries. Even when it is successfully cultivated, trends in market prices result in higher prices for Jatropha biodiesel compared to other biomass fuels and fossil fuels, reducing incentives for the production and sale of Jatropha biodiesel.

On the other hand, the knowledge and technology related to biodiesel production gained through research on Jatropha biodiesel are still being used in the respective countries after project completion. Therefore, for SATREPS projects related to research on biodiesel development, it is recommended that issues from project implementation to social implementation are analyzed across countries. Identification and analysis of how to devise measures that will lead to the social implementation aimed for by the SATREPS project should take place during project formulation, implementation, and after project completion.

4.3 Lessons Learned

(1) Necessity to reconfirm social implementation at the time of project planning and after project completion

The main focus of this project was research for the commercial production of biodiesel using Jatropha, and it is believed that it was initially thought that "Commercial production and dissemination of biodiesel using Jatropha" would be envisioned as a social implementation beyond the Outputs of the project. This would have taken such forms as (i) the establishment of a Jatropha farming protocol suitable for the climate of Botswana (ICT Farming Method), (ii) the establishment of bases for developing high yield and stress tolerant-Jatropha varieties (Genome Breeding), (iii) research on the characteristics of jatropha oil and development of its utilization method, (iv) development of technologies to utilize non-oil Jatropha biomass, and (v) evaluation of the impact of Jatropha production and biomass from environmental, social and economic perspectives.

Although, it was confirmed that through this project, the project has made some achievements in the development of transgenic Jatropha seeds and cultivation methods that are stress tolerant in the climatic conditions of Botswana, the needs became apparent for continued research on cultivation methods, genome breeding research, and the establishment of domestic laws in related fields before promotion of full-scale cultivation of Jatropha. The difficulties of growing Jatropha in Botswana were once again recognized. The energy policy of the Botswana government has also changed direction from the production of biodiesel from Jatropha to the production of biodiesel from biomass including Jatropha. For this

[14] Thailand "Innovation on Production and Automotive Utilization of Biofuels from Non-Food Biomass" (2010-2016).

reason, the social implementation of the project was redefined as the “Utilization and dissemination of technologies related to biomass utilization in Botswana”, broadly defined as the utilization of technologies for breeding bioresources and biodiesel production in this ex-post evaluation. While logically the above modification can be considered appropriate, the level of positioning of this project from the perspective of social implementation may have been relatively lower than originally envisioned. Thus, as a result of the implementation of SATREPS, there are cases in which the social implementation envisioned at the time of project planning should be reconfirmed, revised, or reviewed. Therefore, as well as at the time of project planning, the direction of the social implementation of the research results generated by the SATREPS should be discussed among project stakeholders during the project implementation period, and be revised or be amended as necessary.

In addition, it would have been recommendable if JICA and project stakeholders should have explained the significance of this project even more to the Botswana government department in charge of legalization and encouraged them to develop a domestic law on genetic modification throughout the project period.

(2) Necessity to identify and review Project Design Matrix (PDM) based on logic

Indicator 2 of the project purpose, “At least 6 researchers obtain a master/PhD degree related to Jatropha”, was not generated as a result of the activities of Outcomes 1-5. Thus, Indicator 2 was not necessarily appropriate as an indicator to measure the achievement status of the project purpose. Rather, it would have been logistically appropriate to add the provision of scholarships and research guidance for Jatropha research to young Botswana researchers (master's and PhD students) as a project activity, and also use this as an outcome indicator. Therefore, this ex-post evaluation made an evaluation judgement on the achievement status of the project purpose focusing on Indicator 1 and Indicator 3 of the three indicators. Since indicators of project purpose are important in measuring the effectiveness of a project, it is recommended that the relationship between, and the logic of, project outputs and project purpose be carefully checked regularly during the project implementation and the terminal evaluation, and that changes are made to the Project Design Matrix (PDM) and alternative indicators proposed as necessary.

(End.)

Kingdom of Thailand

FY2021 Ex-Post Evaluation Report of Technical Cooperation Project

"Development of Aquaculture Technology for Food Security and Food Strategy in the Next Generation"

External Evaluator: Junko Noguchi,
Foundation for Advanced Studies on International Development

0. Summary

The project aimed to develop new aquaculture technologies in Thailand by conducting research in five areas that complemented each other: molecular breeding, surrogate broodstock[1], infectious disease control, non-fish alternative meal diet, and detecting and reducing chemical hazards. This is in line with the Thai development policies and needs, as well as Japan's assistance policy, and thus the project relevance is high. In all five areas, research outputs were produced according to the plan. The developed technologies have been applied to the target fish species, and because of the joint research, the researchers' capacity has been improved and the research outputs have been publicly disseminated. Furthermore, efforts have been made to put the research outputs to practical use, and social implementation has been realized, such as the implementation of disease diagnosis services and the production and sale of non-fish alternative meal diets. In addition, several other positive impacts were confirmed, such as the early development and domestic and international approval of diagnostic methods for shrimp diseases that were prevalent, and the improvement of scientific literacy among farmers and private companies. Therefore, the effectiveness/impact of the project is high. The project period and cost are judged as commensurate with the outputs, and the efficiency is considered high. Regarding sustainability, the policy background and the institutional/organizational, technical, and financial aspects are all sufficient for the development of sustainable and high-quality aquaculture technologies and their social implementation. Thus, the project sustainability is high.

In light of the above, this project is evaluated to be highly satisfactory.

[1] Surrogate broodstock is a technique to produce gametes of a fish species for seed production by using a fish species for which a parent fish breeding method has been established as a surrogate parent fish.

1. Project Description

Project Locations

Research with the provided equipment at DOF
(Left: tabletop centrifuge, right: nitrogen evaporator)

1.1 Background

The fisheries industry has been one of Thailand's key industries, and Japan has been an extremely important export partner. At the same time, it was important for Japan that Thailand improved the quality and safety of its fishery products. The native black tiger shrimp, which had been a major fishery product until the early 2000s, was replaced by the nonnative whiteleg shrimp (Litopenaeus vannamei), whose production had declined significantly due to low productivity and the risk of disease outbreaks, among other factors. Diseases also became a major problem for whiteleg shrimp, and it was important to improve breeding techniques for aquatic animals that were resistant to disease and grew quickly. The main species of aquaculture in Southeast Asia were inexpensive tilapia, carp, catfish, and whiteleg shrimp, but to increase fishery production and exportation further, it was not enough to aim for quantitative expansion of these inexpensive cultured species; it was necessary to establish a new aquaculture system targeting high market-value fish. However, the private sector's investment in feed development and seed production for marketable fish had not progressed under the strain, which needed to be led by public institutions. Thus, technologies needed to be developed to improve the motivation of aquaculture companies and farmers for production and to stabilize productivity and the economy through aquaculture.

1.2 Project Outline

Overall Goal		None.
Project Purpose		Advanced technologies for sustainable aquaculture and high quality products are developed in species targeted.
Outputs	Output 1	Molecular markers for selective breeding at the molecular level

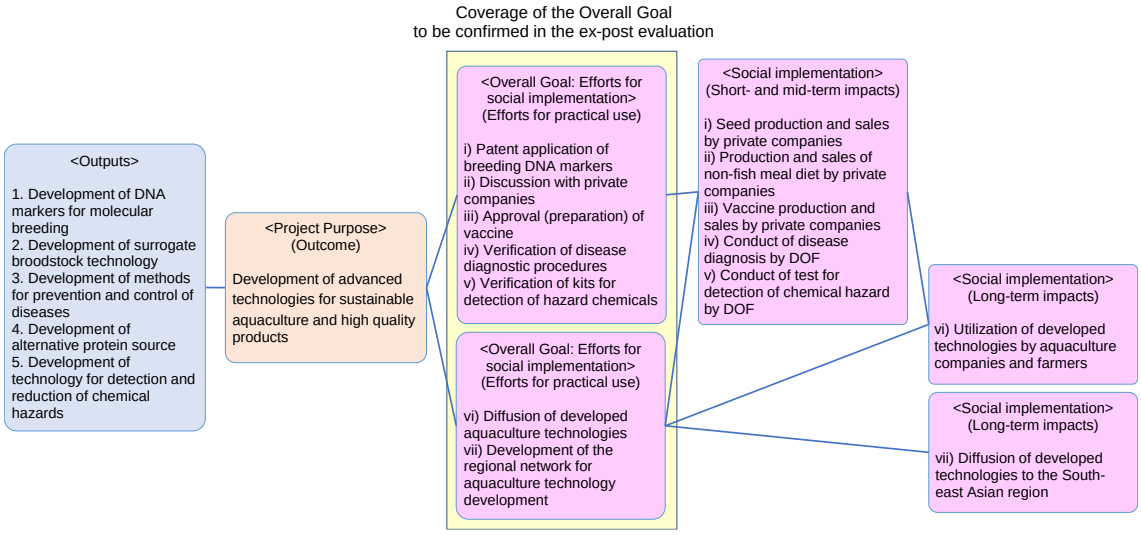
		(growth, disease and/or resistance, stress, etc.) are developed.
	Output 2	Surrogate broodstock technology for aquaculture is developed.
	Output 3	Practical methods for prevention and control of diseases are developed.
	Output 4	Alternative protein source replacing fish meal and broodstock diets are developed.
	Output 5	Technology for detection and reduction of chemical hazards in aquaculture system is developed.
Total cost (Japanese Side)		408 million yen
Period of Cooperation		May 2012 - May 2017
Target Area		Bangkok, Provinces of Krabi, Chonburi, Phetchaburi, Songkhla, Nakhon Si Thammarat, and Nakhon Ratchasima
Implementing Agency		Department of Fisheries (DOF) of the Ministry of Agriculture and Cooperatives, Kasetsart University (Faculty of Fisheries, Faculty of Science), Chulalongkorn University (Faculty of Science), Walailak University (School of Agricultural Technology)
Other Relevant Agencies/ Organizations		Suranaree University of Technology[2]
Organization in Japan		Tokyo University of Marine Science and Technology (TUMSAT), Japan International Research Center for Agricultural Sciences, Japan Fisheries Research and Education Agency
Related Projects		[Technical Cooperation Project (SATREPS)] "Utilization of Thailand Local Genetic Resources to Develop Novel Farmed Fish for Global Market" (2019-2024)

In the project, five outputs were set for each research area. Output 1 is the development of DNA markers for traits that are important in aquaculture, and the development of molecular breeding technology to select and breed individuals with such traits. As Output 2, surrogate broodstock technology was developed to raise eggs of a different species of large, high-quality fish in a fast-growing and robust fish species, which makes it possible to reduce the size of the parent fish, shorten the maturation period, and enables the selection and breeding of informative traits. It also makes it possible to conserve genetic resources. Output 3 is the development of technology for the control of infectious diseases, including vaccines, as countermeasures against fish diseases in aquaculture in conjunction with the production of highly disease-resistant families (Output 1). Output 4 is the development of protein-

[2] Suranaree University of Technology participated in the project as a cooperation agency. For data collection and analysis in the ex-post evaluation, it was treated as if it were an implementing agency.

enriched meal for aquaculture to reduce the use of fish meal, which is a natural resource, for the conservation of the ecosystem. Output 5 is the development of technology to detect and reduce hazards in feed and hatchery ponds to ensure food safety. Thus, “high-quality” aquaculture production is made possible by spawning and raising safe varieties (Output 5) with high commercial value (Outputs 1 and 3) in a shorter time and while using less space (Output 2). In addition, reducing the reliance on fish meal (Output 4) makes aquaculture production sustainable. Thus, to address interconnected issues, these elements (outputs) work in a complementary manner, leading to the Project Purpose: "Advanced technologies for sustainable aquaculture and high-quality products are developed in species targeted.”

Although the Overall Goal was not set, the Japan Science and Technology Agency (JST) stated in its terminal evaluation report that it was "to establish a new applied technology for industrialization of fish and shellfish (technology to cross the valley of death) that is expected to motivate farmers to increase their production and to create a new food bank for the world in Southeast Asia.”[3] Considering that the SATREPS project required the researchers to "establish a roadmap for social implementation" during the project period, the ex-post evaluation focused on the first half of the stated goal (establishment of applied technology) and set "efforts for social implementation" after the project completion as the expected Overall Goal. Specifically, seven efforts necessary for the social implementation of research outputs were assumed. The following figure shows the path of effects after the achievement of the Project Purpose.



Source: Prepared by the evaluator.

Figure 1: The Project Logic for Achieving Effects (Outputs to the Long-term Impacts)

[3] TUMSAT, *Completion Report of the Development of Aquaculture Technology for Food Security and Food Strategy in the Next Generation* (2017).

1.3 Outline of the Terminal Evaluation

1.3.1 Achievement Status of Project Purpose at the Terminal Evaluation

The Project Purpose was judged to have been achieved. Research activities progressed almost as planned, and notable research outputs were reported. Thai researchers acquired advanced knowledge and skills necessary for research, and joint papers were written. However, it was noted that only one of the nine target fish species had all the technologies developed and that further integration and completion of the technologies would be needed.

1.3.2 Achievement Status of Overall Goal at the Terminal Evaluation

The Overall Goal was not set in JICA's terminal evaluation. It was reported that some efforts were implemented for the social implementation.

1.3.3 Recommendations from the Terminal Evaluation

The following recommendations were made.

(1) Clarification and sharing of the vision of "the aquaculture technology for food security and food safety in the next generation"
(2) Confirmation of the activity progress by research area and the prospect of their practical utilization
(3) Discussion on the acquisition of the intellectual property rights
(4) Utilization of the research network developed through the project implementation
(5) Promotion and dissemination of research outcomes
(6) Technical assistance to the neighboring countries

2. Outline of the Evaluation Study

2.1 External Evaluator

Junko Noguchi, Foundation for Advanced Studies on International Development

2.2 Duration of Evaluation Study

This ex-post evaluation study was conducted with the following schedule.

Duration of the Study: July 2021 – January 2023

2.3 Constraints during the Evaluation Study

Due to the prevalence of COVID-19, the planned field survey was canceled and replaced by a remote survey through field survey assistants. At some of the implementing agencies, entering the facility and collecting information through face-to-face interviews and observations were not possible. For this reason, the survey method was switched to allow online interviews in addition to questionnaire surveys.

3. Results of the Evaluation (Overall Rating: A[4])

3.1 Relevance (Rating: ③[5])

3.1.1 Consistency with the Development Plan of Thailand

The project was relevant to Thailand's development policies at the time of ex-ante evaluation as well as the time of project completion.

The "10th National Economic and Social Development Plan" (NESDP) (2007-2011) identified value creation based on knowledge and innovation as one of the development strategies. The 11th NESDP (2012-2016) mentioned the importance of developing a profitable aquaculture industry and developing technologies to reduce aquaculture production costs. The 12th NESDP (2017-2021) also mentioned that in order to strengthen the competitiveness of the production and service sectors, farmer support that meets market demand, sustainable fishery production systems, and research and development using new technologies and equipment in the production process should be implemented. In addition, the Government of Thailand has stated in its "Kitchen of the World" plan that it would aim to increase food production and make it an export industry.

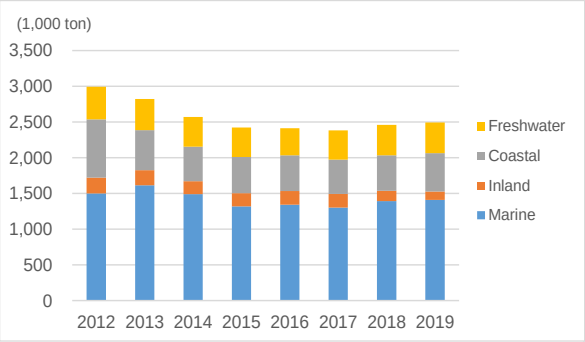
The "Strategic Plan" (2009-2012) of the Department of Fisheries (DOF), which serves as the basic policy for the fishery sector, identified (1) increasing production through aquaculture, (2) improving the quality of fishery products using farmed fish, (3) increasing fishery resources through aquaculture, and (4) strengthening research and development related to aquaculture, as major issues in the aquaculture sector. The same was true for the "Strategic Plans" (2013-2016) (2017-2021), which added the perspective of maintaining sustainability and diversity of fishery resources through fishery resource management.

3.1.2 Consistency with the Development Needs of Thailand

The project was consistent with Thailand's development needs at the time of both ex-ante evaluation and project completion. Annual per capita fish and shellfish consumption in Thailand was 33.7 kg in 2016, increasing on average by 11% from 2012 to 2016 compared to the previous year[6]. However, fishery and aquaculture production was on a decreasing trend from 2.99 million tons in 2012 to 2.38 million tons in 2017 (Figure 2). During the same period, aquaculture production was 1.27 million tons and 880,000 tons, respectively, and it was declining as well. The share of aquaculture production in the total production also decreased significantly from 43% to 37% over the same period. In terms of the fishery and aquaculture production value, it went from 174.3 billion baht in 2012 to 159.7 billion baht in 2017 (Figure 3). During the same period, the value of aquaculture

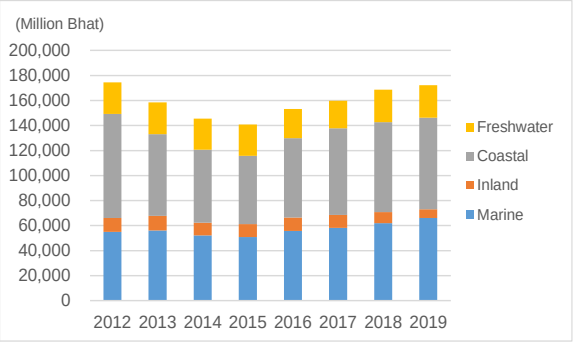
[4] A: Highly satisfactory, B: Satisfactory, C: Partially satisfactory, D: Unsatisfactory
[5] ③: High, ②: Fair, ①: Low
[6] Questionnaire survey with DOF.

production was 108.3 billion baht and 91.2 billion baht, accounting for 62% and 57% of the total value, respectively[7].



Source: Data from Fisheries Statistics of Thailand 2019.

Figure 2: Fishery and Aquaculture Production



Source: Data from Fisheries Statistics of Thailand 2019.

Figure 3: Fishery and Aquaculture Value

While fishery production was declining, exports were increasing (72.8 billion baht in 2012 and 190.1 billion baht in 2018). The increase in export value even when fishery production was not keeping pace with the increase in domestic consumption suggested a significant need existed for both export and domestic consumption of Thai fish and shellfish. In particular, for aquaculture production, which had shown a significant downward trend in both production volume and value, high-quality and efficient fishery production was needed to improve the market value and disease resistance. In addition, it was pointed out that economic activities, including aquaculture, had weakened key ecosystems such as mangroves, coral reefs, and seagrasses, and thus the maintenance and improvement of ecosystems needed to accompany aquaculture production.

3.1.3 Consistency with Japan's ODA Policy

The project was consistent with Japan's ODA Policy at the time of ex-ante evaluation.

The basic approach to cooperation with Thailand was to build a partnership-based cooperative relationship characterized by an emphasis on dialogue, mutual benefits, and other factors. One of the priority areas of technical cooperation was "strengthening competitiveness for sustainable growth." The project was in line with this priority area because it aimed to improve the productivity and safety of fish and shellfish, Thailand's main exports.

In light of the above, this project was highly relevant to Thailand's development plan and development needs, as well as Japan's ODA policy. Therefore, its relevance is high.

[7] Ministry of Agriculture and Cooperatives of Thailand (2021) *Fisheries Statistics of Thailand 2019*.

3.2 Effectiveness and Impact[8] (Rating: ③)

3.2.1 Effectiveness

3.2.1.1 Project Outputs

(1) Output 1

Research related to DNA marker development was conducted for all target fish species. As particularly significant results, 11 and two DNA markers were developed for tiger grouper and hybrid grouper, respectively. In addition, nine loci were obtained from informative DNA markers of grouper species for parental analysis, and evaluation of high-growth traits proceeded. Genetic linkage maps[9] showing 183 and 130 DNA markers were developed for tiger grouper and giant grouper, respectively. This research was the world's first case of genetic linkage mapping of grouper species and was a major achievement. Based on these maps, three families of tiger grouper and one family of hybrid grouper were produced. Regarding penaeid shrimp, seven and five DNA markers were also obtained for the analysis of the shrimp families of whiteleg shrimp and black tiger shrimp, respectively, and high-growth and disease-resistant families were established for black tiger shrimp. Other loci were identified using DNA samples from Asian seabass, and parental analysis was conducted to identify hypoxia tolerance, bacterial disease resistance, and high-growth traits.

The number of DNA markers developed, the number of genetic linkage maps created, and the number of lineages developed, all of which were set as indicators, exceeded the plan, and therefore Output 1 was achieved.

(2) Output 2

The surrogate broodstock technology was a new theme for the Thai side. Focusing on giant grouper[10] and Mekong giant catfish[11], which require seven to eight years to mature, research was conducted on the establishment of donor cell processing methods, the search for appropriate recipient species, transplantation operations, and related techniques (transplant cell tracking, etc.).

Indoor hatchery for research on surrogate broodstock technology
(Suranaree University of Technology)

[8] Sub-rating for Effectiveness is to be put with consideration of Impact.
[9] Map showing the location of genes on chromosomes.
[10] It is known that grouper species are slow-growing because they sexually mature as females and then change sex to males. Giant grouper needs seven to eight years to mature, whereas tiger grouper, also in the grouper family, matures in about two years.
[11] The Mekong giant catfish is one of the largest freshwater fish in the world, growing to about 2 m in length and in rare cases to 3 m and 300 kg in weight.

Once the surrogate broodstock technology is established, it will be possible to reduce the size of the parent fish, improve the efficiency of selection and breeding of families with useful traits by shortening the maturation period, and conserve genetic resources by freezing germ cells. The project aimed to clarify the range of combinations of donor and recipient among these. Cell transplantation methods and related techniques were developed for the combinations of giant grouper (donor) and tiger grouper (recipient) and Mekong giant catfish (donor) and striped catfish (recipient).

All of the indicators set for the establishment of cell transplantation methods, identification of recipient species, and establishment of donor-recipient compatibility were achieved, and therefore Output 2 was achieved.

(3) Output 3

Research on the prevention and control of infectious diseases (Output 3) focused on grouper, Asian seabass, and penaeid shrimp. Microarrays [12] were developed for black tiger shrimp and two species of penaeid shrimp, and gene catalogs for six species were developed (giant grouper, tiger grouper, Asian seabass, black tiger shrimp, whiteleg shrimp, and Nile tilapia). Profiling of disease-resistant shrimp species was obtained, and 11 candidate immune genes for black tiger shrimp were characterized. In addition, vaccines for *Vibrio parahaemolyticus* and the white spot syndrome virus (WSSV) were developed. After the beginning of this project, acute hepatopancreatic necrosis disease (AHPND) caused by *V. parahaemolyticus*, known as early mortality syndrome (EMS), occurred in shrimp farms in China and Southeast Asia including Thailand, and became a major problem. At the urgent request of the Thai side, research to address this disease was added to the project. The latest genomic analysis of the EMS/AHPND was conducted and a diagnostic procedure based on polymerase chain reaction [13] (PCR) testing was developed. This procedure was adopted as a standard procedure by DOF in 2014 and as a standard method by the World Organization for Animal Health (OIE) in September 2016 (Column 1). For grouper and Asian seabass, numerous immune-related genes were identified. For Nile tilapia, 10 candidate antigens

Breeding of Groupers and Asian Seabass
(Krabi Coastal Fisheries Research and Development Center)

[12] A DNA microarray is an analytical instrument in which a large number of DNA fragments are densely arranged on a plastic or grass substrate to measure the gene expression level in cells.
[13] A testing method in which the genes of the virus to be tested are amplified and detected using a chemical solution.

for pathogenic microorganisms were identified and a vaccine for group B streptococcus was developed and field-validated.

Indicators were linked to the development of microarrays, characterization of immune-related genes, characterization of candidate vaccine antigens, development of vaccines for pathogenic microorganisms, and development of disease control management methods. All of these activities were performed as planned or better, and thus Output 3 was achieved.

Column 1: Efforts for Rapid Adaptation of the Developed Technology

After EMS/AHPND became a problem in Thailand and other Southeast Asian countries, the University of Arizona first identified the pathogenic microorganism, and then the competition to develop a diagnostic method began among the research group at the Mahidol University in Thailand, the research group at the Cheng Kung University in Taiwan, and the research team in this project (DOF and TUMSAT). The three groups succeeded in developing the testing method at about the same time, but the research team in this project was the first to publish their results officially in a research paper. The research team in this project was successful in choosing a Japanese journal (*Fish Pathology of the Japanese Society of Fish Pathology*) as the submission destination, rather than an international journal, to avoid the possibility of peer review by competitors and a longer time to publication. The Fisheries Section of OIE meets regularly to collect information on outbreaks of infectious diseases from various countries. Because of the rapid spread of EMS/AHPND in the world after the outbreak, OIE identified it as a designated infectious disease. Diagnostic methods for EMS/AHPND were discussed at OIE and the methods of all three groups were adopted as standard methods.

Source: Prepared based on the interview result of TUMSAT.

(4) Output 4

Finding alternative protein sources for aquaculture (Output 4) was a goal aimed at ecosystem conservation by reducing the use of fish meal, a natural resource. The research targets were banana shrimp, whiteleg shrimp, and tiger grouper. A prototype broodstock diet for banana shrimp was developed. Several options were selected as alternative protein sources, and prototype diets were developed through feeding trials. For alternative broodstock diets for whiteleg shrimp, the optimum level of selected plant protein feed ingredients was determined, and PCR analysis was completed. Alternative diets were also developed for tiger grouper, and prototypes were evaluated.

As for indicators, diets for feeding trials and alternative protein sources were developed, and therefore Output 4 was achieved.

(5) Output 5

Output 5 was the development of the technology for the detection and reduction of

chemical hazards. In particular, to address the global problem of malachite green[14] (MG) residues, Thailand has spent a great deal of money and time monitoring the residues in fish and shellfish for export. However, this was not sufficient for domestic distribution, and the accumulation of MG in bottom sediment in hatchery ponds was considered a problem[15]. In the project, an ELISA (enzyme-linked immunosorbent assay)[16] analysis method for detecting leucomalachite green (LMG)[17] in feed, breeding water, and bottom sediment was validated and confirmed to be practicable under international standards. The analytical method demonstrated nearly three times better screening ability than conventional testing methods from the monitoring results of seabass and tiger grouper at aquaculture facilities. In addition, a prototype LMG detection kit was developed as a research output.

As for indicators, a prototype of an identification kit for the detection of chemical hazards and technologies for the reduction of chemical contamination was developed, and thus Output 5 was achieved.

3.2.1.2 Achievement of Project Purpose

The Project Purpose (advanced technologies for sustainable aquaculture and high-quality products are developed in species targeted) was achieved, as determined in the terminal evaluation. As mentioned above, traits suitable for aquaculture were identified through the development of DNA markers related to high-growth and disease resistance (Output 1), and research on surrogate broodstock was conducted to shorten the growing period (Output 2). Diagnosis methods and vaccines for the prevention and control of infectious diseases were developed (Output 3), and methods for detection and reduction of chemical hazards were developed (Output 5), which led to strengthening breeding techniques to ensure food security. In addition, the development of alternative protein sources to replace fish meal (Output 4) would contribute to the sustainability of fishery resources. These research outputs complement each other and work synergistically to improve the quality and sustainability of aquaculture (Project Purpose). In the terminal evaluation, clarifying and sharing the vision of "aquaculture technology for food security in the next generation" was recommended. In the ex-post evaluation, by asking DOF and four universities about this definition, it was confirmed that they had a common understanding of the relevance and complementarity between food security and the project's research.

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[14] Malachite green is a blue-green organic dye that was once widely used in aquaculture as an antimicrobial agent, but its use was banned after reports of carcinogenicity. Contamination by malachite green residing underground has been a problem. https://www.jst.go.jp/seika/bt2018-10.html (accessed on January 10, 2022).
[15] *JST Completion Report*, p.14.
[16] ELISA is an analytical method that provides the antigen or antibody of interest in a sample solution.
[17] Metabolites of malachite green.

Indicators of the Project Purpose were, as shown in the following table, (1) the number of targeted species, (2) the number of researchers who acquired skills, (3) the number of scientific papers that disseminate research results, and (4) the number of workshops and others that disseminate the research results. Regarding Indicator 1, it was pointed out in the terminal evaluation that "there was one target fish species for which all technologies were developed, and further integration and perfection of technologies is needed." However, target fish species were appropriate for research development in each area from the time of application of the project research[18], and the research was completed as planned. Indicators 2, 3, and 4 were achieved more than had been planned.

Table 1: Achievement of the Project Purpose

Project Purpose	Indicator	Actual
Advanced technologies for sustainable aquaculture and high quality products are developed in species targeted.	1. The number (at least 3) of species targeted on improved aquaculture technologies	Achieved. • New aquaculture technologies were developed for five research areas, targeting nine target species (giant grouper, tiger grouper, hybrid grouper, Asian seabass, black tiger shrimp, whiteleg shrimp, banana shrimp, Nile tilapia, and Mekong giant catfish).
	2. The number (at least 60% of members) of researchers who acquired skills of advanced aquaculture technologies.	Achieved. • 58 of 93 Thai researchers (62%) acquired the advanced technologies in training courses in Japan as of the time of terminal evaluation. It was judged by the terminal evaluation team that most of them were capable of utilizing and sustaining the acquired technologies.
	3. The number (at least 50) of scientific journals, technical reports, educational brochures, conference proceedings/abstracts, and/or newsletters.	Achieved. • Japanese and Thai researchers coauthored 75 scientific papers, among which Thai researchers prepared 35 papers as lead authors. No technical reports, educational brochures, or newsletters were developed.
	4. The number (at least 10) of workshops and/or seminars for education of skills and/or dissemination of project outputs.	Achieved. • 11 seminars, 11 conferences, and four symposiums and workshops were organized for the dissemination of research outputs (26 in total).

Source: Terminal Evaluation Report, questionnaire answer from DOF.

In light of the above, the project achieved its purpose.

3.2.2 Impact

3.2.2.1 Achievement of Overall Goal

As explained earlier, the project had no established Overall Goal, and thus in the ex-post evaluation, it was set as "making efforts for social implementation of the research outputs related to the development of aquaculture technologies targeted by the project."

[18] Interview with TUMSAT. Target species are clearly stated in the Implementation Report for JST from the first year.

As shown in the table below, efforts have been started for social implementation based on the project's research outputs, and therefore it is judged that the Overall Goal has been achieved.

Regarding the patent applications (1), DNA markers related to the growth traits of tiger groupers were considered valuable intellectual property and a contribution to future industries, and the Japanese researchers took the lead in patent applications. As for discussions with private companies (2), a vaccine for *Streptococcus pyogenes* in tilapia was developed, and discussions with Japanese veterinary pharmaceutical manufacturers were initiated along with field verification during the project period. Although the discussions were suspended due to the impact of COVID-19, the manufacturer has participated in the succeeding SATREPS project, "Utilization of Thailand Local Genetic Resources to Develop Novel Farmed Fish for Global Market" (hereinafter referred to as "the succeeding project"), and its relationship with Kasetsart University, the research institution on the Thai side, has continued. With regard to the approval of vaccine (3), because regulations for the approval of aquatic vaccine have not yet been established in Thailand, Kasetsart University has worked to obtain certification to meet Good Manufacturing Practice (GMP) industry standards to replace it. Regarding the verification of disease diagnostic procedures (4), as explained earlier, DOF adopted the EMS/AHPND diagnostic method as its standard method. It has been utilized not only for individual shrimp but also for research facilities. It is also used as a kit for detecting chemical hazards (5) in the water quality and sediments in hatchery ponds. For the diffusion of the developed technologies (6), non-fish meal diets were mainly disseminated to private companies and farmers. There are cases in which research outputs have been diffused to farmers during the prototype verification, cases in which they have been introduced to private companies and farmers through lectures and seminars, cases in which the technologies for feed production have been transferred to producing organizations, and so on. In another case, universities and distributors have provided developed fish diet and vaccines to distributors and farmers, not for the large-scale commercial purpose, but rather to return the research results to society and to generate research funds. To establish the regional network (7), DOF has shared the research outputs in international seminars. Among these efforts, ongoing efforts (2, 6, and 7) have been made by implementing agencies or in the succeeding project.

PCR test for EMS/AHPND diagnosis of shrimp (DOF)

Table 2: Achievement of the Overall Goal Expected in the Ex-post Evaluation

Topic	Achievement	Related output
(1) Patent application of DNA markers for breeding	Ongoing. • In 2016, TUMSAT and the Japan Fisheries Research and Education Agency applied for and registered a domestic patent in Japan for a "method of identifying brown-marbled grouper with growth genetic traits." • In 2017, TUMSAT and DOF applied for an international patent for a "method of identifying brown-marbled grouper with growth genetic traits." It was in the stage before the review at the time of ex-post evaluation. • In 2017, TUMSAT and DOF applied for a patent in Taiwan for a "method of identifying brown-marbled grouper with growth genetic traits." It was in the process of responding to the rejection by modifying it for the patent grant at the time of ex-post evaluation.	Output 1
(2) Discussion with private companies	Ongoing. • Discussions began in 2016 with a Japanese veterinary pharmaceutical manufacturer for the commercialization of a vaccine against type B hemolytic Streptococcus infections in tilapia. The discussions have been suspended due to COVID-19. The manufacturer is participating in the succeeding SATREPS project, and it has aimed to market the product in Thailand.	Output 3
(3) Approval (preparation) of vaccine	Ongoing. • Veterinary vaccines have not been manufactured following the standards required in the pharmaceutical manufacturing industry (Good Manufacturing Practice; GMP) in Thailand yet, and there has been no official registration system for veterinary vaccines. Only vaccines from overseas have been registered. The research team at Kasetsart University has established the GMP section within the faculty and has been in contact with the Food and Drug Administration for fish vaccine registration under its regulations. The research team has been working on obtaining GMP certification for the production of veterinary vaccines.	Output 3
(4) Verification of disease diagnostic procedures	Efforts completed. • The developed EMS/AHPND diagnosis procedure was adopted as a standard procedure of DOF. It was added to the diagnostic manual of the laboratory of DOF.	Output 3
(5) Verification of kits for detection of chemical hazards	Efforts completed. • The EMS/AHPND diagnostic method for shrimp has been applied not only to individual shrimp but also to water and sediment testing to select infected individuals and prevent disease. This has allowed individual infections to be prevented more than they were before.	Output 5
(6) Diffusion of developed aquaculture technologies	Ongoing. • Alternative protein sources for shrimp were disseminated to aquaculture companies in Thalang District, Phuket Province during the project period. • Since the time of project completion, Chulalongkorn University has been producing rALFPm3-added feed (not for commercial use) with a grant from the Agricultural Research Development Agency (ARDA) and support from the succeeding SATREPS project. • With advice from Japanese researchers during the project period, Kasetsart University, in collaboration with Ubon Ratchathani University, provided training to farmers on the use of fish vaccines and the effects of antibiotics on the environment and human health. Ubon Ratchathani University subsequently began to conduct lectures on vaccine development. • DOF conducted the following seminars for social implementation: 1) How to produce alternative diets replacing fish meal for grouper by the Coastal Aquaculture Research and Development Center (CARDC) of Phang-nga (2018-2019, for the Chaipattana Foundation). Because the market for grouper was small and private companies were not interested, technology transfer was provided to NGOs.	Outputs 3, 4

Topic	Achievement	Related output
	2) Grouper aquaculture and feed management (2018, for grouper farmers in Phuket Province). 3) EMS/AHPND diagnostic procedure for shrimp and their surrounding environment (2018-2019, for DOF laboratories). • Walailak University established a sector for the production and sales of probiotic products in 2017.	
(7) Development of the regional network for aquaculture technology development	Ongoing. • The Government of Thailand shared information about EMS/AHPND of shrimp in the international workshop in which the UN Food and Agriculture Organization members participated in July 2017. • DOF made a presentation at the 19th International Symposium on Nutrition and Feeding in Fish in December 2021 regarding the following: 1) Development of the non-fish meal and non-fish oil feed for Asian seabass. 2) Application of protein hydrolysate from discarded fish to banana shrimp feed.	Outputs 3, 4

Source: Terminal Evaluation Report, Completion Report of JST, questionnaire answers, and interview results of DOF, Kasetsart University, Chulalongkorn University, Walailak University, CARDC of Chonburi, TUMSAT.

Considering the situation above, efforts have continued for social implementation based on the project's research outputs. Thus, it is judged that the project has achieved the Overall Goal.

3.2.2.2 Other Positive and Negative Impacts

(1) Utilization of the Research Outputs

The research conducted by the project has continued in the five areas (Table 3). In addition, new research has begun. For example, the research on molecular breeding (Output 1) has continued which resulted in the creation of genetic linkage maps of giant grouper and tiger grouper consisting of 289 and 475 DNA markers, respectively[19]. The research on surrogate broodstock (Output 2) has continued, too, and the birth of Mekong giant catfish from the transplanted recipient catfish in 2019 was a great achievement (see the table below). Regarding the technology for detection and reduction of chemical hazards (Output 5), research has been conducted for the field verification of nitrofuran detection and mass production of detection kits has been conducted. Based on these research outputs, several papers have been published including ones coauthored with Japanese researchers.

[19] Interview with TUMSAT.

Table 3: Continuation of the Research Activities

Outputs		Continuity as of the Ex-post Evaluation
Output 1: Molecular markers for selective breeding at the molecular level (growth, disease resistance, stress) are developed.	Continuation of the research	• Research on molecular breeding of groupers has continued at TUMSAT and the DOF. Genetic linkage maps consisting of 289 and 475 DNA markers were created for giant grouper and tiger grouper, respectively. • For Asian seabass, joint research has continued at TUMSAT and the DOF to develop DNA markers. Several sequences of genetic information have been identified. Methods for the identification and selection of phenotype traits for parental analysis have been established. New families for the analysis have been identified and sustained at three local centers of the DOF. The National Center for Genetic Engineering and Biotechnology (BIOTECH) under the National Science and Technology Development Agency (NSTDA) has joined the research. • For the shrimp species, research was in progress at Walailak University, but an accident at the facility (power outage, generator failure) resulted in the total loss of black tiger and banana shrimp with WSSV-resistant and high-growth traits. However, later in 2019, individuals with the same traits were found again, and the breeding program has continued.
	Continuation of the research in the current SATREPS project	• Research to develop molecular markers for the detection of disease resistance and other informative traits of Asian seabass, to verify genetic diversity in banana shrimp, and to develop molecular markers for disease resistance has continued. • Sampling and genetic diversity analysis to confirm the genetic diversity of Asian seabass and banana shrimp has been ongoing. The development of molecular markers for the detection of disease resistance and other informative traits has been planned for novel farmed fish.
	Start of the new research based on the project output	• Molecular breeding techniques developed by the project have been used to select genetically diverse brooders, and breeding research on banana shrimp and seabass has been underway since 2020 at the DOF. • Based on the molecular breeding techniques of black tiger shrimp, research on whiteleg shrimp and tilapia breeding has been conducted at Walailak University.
Output 2: Surrogate broodstock technology for aquaculture is developed.	Continuation of the research	• TUMSAT and the DOF have continued research to establish donor-recipient relationships for giant grouper and tiger grouper. Giant grouper takes 7-8 years to reach maturity, and males are obtained through sex change after mature females grow further, so it takes time to raise and maintain parent fish. • TUMSAT and Suranaree University of Technology have continued research on Mekong giant catfish. In 2019, research results showed that the Mekong giant catfish had been successfully born from a transplanted recipient catfish (striped catfish). The genetic resources are stored at the DOF. • Research on surrogate broodstock technology has continued at the Suranaree University of Technology. Two graduates (PhD and MS) published scientific papers on germ cell transplantation.
	Continuation of the research in the current SATREPS project	• Research to develop germ cell transplantation techniques for the conservation of genetic diversity and genetic resources of Asian seabass, to improve germ cell technology of Thai native catfish, to conserve germ cells of banana shrimp and other species, and to develop cell transplantation techniques has continued. • The foundation of the germ cell transplantation system by identifying the maturation stage of the Asian seabass donor

Outputs		Continuity as of the Ex-post Evaluation
		and the developmental stage of a recipient suitable for transplantation, and verifying the efficiency of germ cell viability into the recipient gonads was established by March 2021. • Research on cryopreservation of testes and ovaries of catfish and seabass has been conducted at the Suranaree University of Technology.
	Start of the new research based on the project output	• Based on the research outputs on surrogate broodstock technology, Suranaree University of Technology conducted research on germ cell markers to identify germ cell formation, and four papers were produced on the same topic. • A new research project on genome editing and feeding of catfish has been considered using the technology and equipment obtained from the project.
Output3: Practical method for prevention and control of diseases are developed.	Continuation of the research	• For whiteleg shrimp, TUMSAT and a venture company from Tohoku University developed a kit in December 2017 utilizing technology from the Graduate School of Biomedical Engineering (dengue fever and other human infectious diseases, PCR-based testing methods) for early detection of infectious diseases in farmed shrimp through genetic testing. In this process, comparisons with conventional test results, etc., were made using samples examined locally by the DOF. Toward industrialization, tests were conducted in Indonesia and the Philippines (distributors) but have been suspended due to the prevalence of COVID-19. • Collaborative research between TUMSAT and Kasetsart University on vaccine development for Nile tilapia has continued. Regarding the said vaccine development, the researchers have been in contact with a Japanese pharmaceutical company and Thai food manufacturers (CP, Betagro). • The development of a bacterial vaccine has continued at Walailak University. • Research on shrimp immunity and antimicrobial peptides has been conducted at Chulalongkorn University.
	Continuation of the research in the current SATREPS project	• Research to develop vaccines and adjuvants for pathogenic biological infections of Asian seabass, vaccine evaluation methods, genetic tools for studying disease resistance in banana shrimp, and control methods for microbial infections in penaeid shrimp has been underway. • Sample preparation for the implementation of next-generation sequencing was conducted to study the biological defense response of banana shrimp to WSSV. Isolation of 13 phages from hatchery ponds was conducted to develop phage therapy methods for EMS/AHPND control and treatment in shrimp. • The genes for penaeid shrimp were cataloged, and cataloging of the gene for the banana shrimp was initiated.
	Start of the new research based on the project output	• Research has been conducted at Kasetsart University to characterize infectious disease pathogens in aquatic animals and to detect, prevent, and control diseases, including research on: 1) various diseases of freshwater and saltwater fish; 2) different types of vaccines to control bacterial diseases; 3) modules to detect bacterial diseases; and 4) probiotics for disease control in shrimp. • Chulalongkorn University has conducted research in collaboration with private companies on emerging infectious diseases of shrimp and molecular markers for breeding.
Output4: Alternative protein source replacing fish	Continuation of the research	• The DOF has continued evaluation of the prototype of fish meal replacement diets for tiger grouper.
	Continuation of	• Research has been underway to develop pre-shipment

Outputs		Continuity as of the Ex-post Evaluation
meal and broodstock diets are developed.	the research in the current SATREPS project	nutrient-enhanced feed and feeding methods for Asian seabass, the basic technology for the production of banana shrimp and other all-female shrimp, and efficient artificial breeding techniques for parent shrimp. • The scope of research was expanded to include not only feed development but also the development of feeding methods. By March 2021, research had been conducted on the growth effects of diets with progressively reduced fish oil in Asian seabass. • Research was conducted on the development of "artificial maturation diets for parent banana shrimp, new protein sources for shrimp larvae diets, and improved rearing methods.
	Start of the new research based on the project output	• The DOF has carried out research on the development of alternative protein sources for parent tiger grouper.
Output5: Technology for detection and reduction of chemical hazards in aquaculture system is developed.	Continuation of the research	• Research on the detection of malachite green residues, degradation products, and antibiotic residues has continued at Kasetsart University. In addition, a research exchange with the laboratory of a Japanese confectionery company has been underway regarding dye testing for hazards. • Field validation of nitrofurans detection and research for mass production of detection kits have been conducted at Kasetsart University.
	Continuation of the research in the current SATREPS project	• NA.
	Start of the new research based on the project output	• Research has been conducted at Kasetsart University on extending the detection system for various chemicals found in aquatic animals, including chloramphenicol.

Source: Questionnaire answers and interview results of the DOF, Chulalongkorn University, Kasetsart University, Walailak University, Suranaree University of Technology. JST Implementation Report of FY 2020 of "Utilization of Thailand Local Genetic Resources to Develop Novel Farmed Fish for Global Market."

(2) Capacity Development of Researchers

The DOF and the four universities have participated in the succeeding project as implementing agencies, and many of the researchers have continued the research (Table 4). Research on this project has continued as explained above, and new research has been started based on the project outputs.

Table 4: Continuity of Researchers in the Implementing Agencies

	Related Output	No. of researchers who participated in the project	No. of researchers who have continued working	No. of researchers who newly joined	No. of researchers who participate in the succeeding project
DOF	1, 2, 3, 4, 5	66	36	44	74
Chulalongkorn University	4	3	6	5	2
Kasetsart University	3, 5	7	3	6	16
Walailak University	1, 3	13	8	4	9
Suranaree University of Technology	2	6	1	3	12

Source: Questionnaire answers and interview results of the DOF, Chulalongkorn University, Kasetsart University, Walailak University, and the Suranaree University of Technology.

(3) Utilization, Operation, and Maintenance of the Equipment

The DOF and the four universities have continuously utilized the equipment provided by the project. The provided equipment has been managed using the list at the DOF. Regarding the equipment that has been set up at the local centers, the condition and the plan of operation and maintenance have been reported to the DOF every year. At the time of ex-post evaluation, only two pieces of PCR equipment had been broken at a local center. Since it is expensive to repair the two, the center has not fixed them and has used the other four pieces of PCR equipment, with which the research has been conducted without problems. At every agency, the provided equipment has been checked and utilized in the daily research.

3.2.2.3 Other Impacts

The following positive impacts have been confirmed, although it is difficult to separate the effects of this project from those of the succeeding project. No negative impacts on the natural environment have been reported. There was no land acquisition or resettlement.

(1) Realization of Social Implementation of the Research Outputs (positive impacts)

Social implementation expected in the short-, mid-, and long-term as results of the above-mentioned efforts is shown in Figure 1. Part of the expected social implementation has already been realized as shown in the following table. It was expected that non-fish alternative diet (2) and vaccines (3) would be produced for large-scale commercialization, but actually the university in charge of the research and an NGO trained by the DOF have sold the products on a small scale from which farmers have obtained benefits. Regarding the disease diagnosis (4) and detection of chemical hazards (5), as explained earlier, a diagnosis method was developed during the project period and officially disseminated nationwide by the DOF, thus realizing the social implementation of these research outputs early on.

Probiotics products developed by the project research outputs (Walailak University)

Table 5: Realization of Social Implementation

Topic	Efforts	Achievement
(1) Seed production and sales by private companies	• Patent application for DNA markers for breeding	Not realized. • It takes time to gain seed with the selected traits stably, and thus neither the DOF nor private companies have proceeded to production.
(2) Production and sale of non-fish alternative diet by private companies	• Discussion with pharmaceutical companies	Partially realized. • An NGO (Chaipattana Foundation) started the production of a non-fish alternative diet for grouper but suspended production and sale in 2019 due to its organizational restructuring and internal situations.
(3) Vaccine production and sales by private companies	• Approval (preparation) of vaccine	Partially realized. • Walailak University has produced probiotics products for shrimp and wholesaled them to three distributors in the southern region and one distributor in the northern region.
(4) Conduct of disease diagnosis by DOF	• Verification of disease diagnostic procedures	Realized. • The DOF has conducted 400 diagnoses of EMS/AHPND for aquaculture companies and farmers each year.
(5) Conduct of test for detection of chemical hazards by DOF	• Verification of kits for detection of chemical hazards	Realized. • The DOF has conducted tests of water quality and sediments in hatchery ponds based on the EMS/AHPND diagnosis procedure.
(6) Utilization of developed technologies by aquaculture companies and farmers	• Diffusion of developed aquaculture technologies	Partially realized. • Grouper aquaculture farmers purchased non-fish diets from the NGO and used them in the provinces of Phang-nga, Phuket, and Krabi. • Shrimp aquaculture farmers in the southern and northern regions have purchased probiotic products for shrimp from the distributors and used them.
(7) Dissemination of developed technologies to the Southeast Asian region.	• Development of the regional network	Not realized.

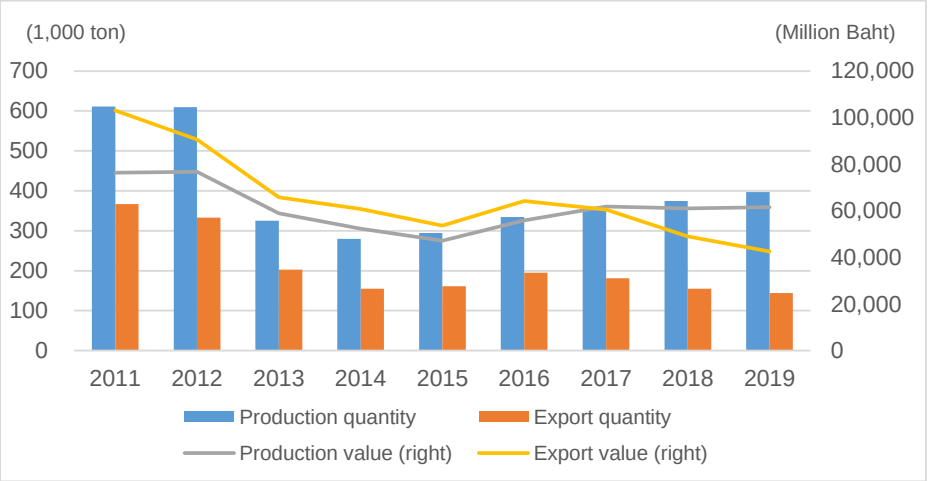
Source: Prepared based on the questionnaire answers and interview results from DOF, Kasetsart University, Walailak University, and Chaipattana Foundation.

(2) Positive Impacts Brought by the Developed Disease Diagnosis of Shrimp

As explained above, the project developed a method for the diagnosis of EMS/AHPND. After an outbreak of the disease, the production of shrimp drastically decreased in 2013, and since then it has been gradually recovering (Figure 4). Responsive research activities were added right after the outbreak of the disease, which resulted in the development of a diagnosis method at the early stage. This method was promoted nationwide at the initiative of the DOF. Shrimp is a major aquaculture product in Thailand, and it is thought that these efforts could prevent a large economic loss.

Aquaculture companies and farmers became to invest more in water quality management after the outbreak of EMS/AHPND, and the production cost increased, which has made them less competitive internationally, according to the DOF. Thus, some companies and farmers have given up shrimp aquaculture, and it was presumed that the

production of shrimp would not return to the pre-disease levels[20]. On the other hand, it is noteworthy that the scientific literacy of aquaculture companies and farmers has been improved through the nationwide promotion of the EMS/AHPND diagnosis method at the DOF's initiative (Column 2).



Source: Prepared based on data from DOF.

Figure 4: Production and Export of Shrimp

Column 2: Improvement of the Scientific Literacy of Aquaculture Companies and Farmers

Shrimp production has been recovering due to the development of the EMS/AHPND diagnostic method, but it has been estimated that it may not return to its previous level. On the other hand, the nationwide diffusion of this diagnostic method has improved the scientific literacy of aquaculture farmers, leading to improved management. First, unlike other countries, Thailand has promoted the EMS/AHPND diagnostic method throughout the country, which improved the scientific literacy of aquaculture farmers. Specifically, aquaculture companies and farmers had previously only waited for disease outbreaks to subside, but now that they understand the causes of the disease, they can avoid the risk factors. Understanding that disease response would reduce their profitability, farmers and companies made a business decision either to continue their business by improving quality and adding a safety perspective such as traceability and EMS diagnostics or to stop shrimp farming (switch to other species or switch to a different industry) without pursuing short-sighted profit. Compared to other neighboring countries, Thailand has a well-developed traceability system up to export. Some companies (e.g., Thai Union, a Thai seafood processing company) have been able to export to the United States by communicating the safety of their products. Second, farmers' understanding of EMS/AHPND enabled them to point out contamination at private aquaculture hatcheries, and this information was instantly disseminated. As a result, aquaculture hatcheries with inadequate contamination control measures were unable to continue their operations. In addition, as a consequence of prioritizing the sustainability of the aquaculture business, the area of shrimp hatcheries decreased as a result of avoiding overcrowded shrimp aquaculture, converting some of the ponds to reservoirs for water quality control, or shifting to other fish species. Thus, it is expected that shrimp production will remain at around 300,000 tons per year, but that the aquaculture industry as a whole will become more mature, and Thailand is expected to maintain a stable position in the global shrimp supply.

[20] Interview result of DOF.

Source: Prepared based on the interview results of DOF and a Japanese trading company.

(3) Positive Impact of the Joint Research

Networks between researchers and private companies were expanded through the project. For example, a university conducted joint research with a private company on vaccine development. The joint research was in line with the interests of both parties: the university benefited from verifying research results, getting financial support, and using the private company's facilities and equipment, while the private company benefited from the preparation of the advanced technology for commercialization. The project also invited private companies to seminars to promote exchanges. As another example, Japanese researchers introduced a Japanese cement manufacturing company to Walailak University. The company was engaged in the development and commercialization of materials in the field of water treatment and the development of technology to improve the environment of aquaculture ponds. The university conducted field verification of the company's water-quality-stabilizing materials for aquaculture[21]. The company has since commercialized the product, which has been sold in Thailand, Taiwan, and China.

(4) Positive Impact related to Biodiversity

At the time of project completion, the compatibility of the Mekong giant catfish (donor) and striped catfish (recipient) was under observation. After project completion, Suranaree University of Technology and TUMSAT continued joint research on the surrogate broodstock technology, and Mekong giant catfish were born from striped catfish. The genetic resources have been stored at the DOF. The International Union for Conservation of Nature and Natural Resources (IUCN) has listed the native Mekong giant catfish as a critically endangered species (CR),[22] and the project has contributed to the conservation of this rare species.

(5) Capacity Development of Young Japanese Researchers

Many Japanese associate professors, assistant professors, and researchers were dispatched to Thailand. Communication with Thai researchers and attending presentations in international seminars have led to the development of their capacity, as they have organized public seminars by themselves after they returned to Japan.

[21] It is a purification agent named Ceraclean to improve water and bottom sediment quality. It is used in aquaculture ponds and golf course ponds, as well as in natural lakes and mud flats. The company's website explains that the application of this product has proven effective in increasing the weight and survival rate of cultured shrimp. https://www.taiheiyo-cement.co.jp/service_product/ceraclean/cultivation.html (accessed on April 10th, 2022, Japanese pages only).

[22] CR is rated as facing an extremely high risk of extinction in the wild in the IUCN Red List.

This project has achieved the Project Purpose of developing technologies for sustainable aquaculture and high-quality products and the expected Overall Goal of carrying out efforts for social implementation. As a result, some social implementation has been realized, such as provision of disease diagnosis services and production and sales of non-fish meal diets. In addition, other positive impacts were confirmed. Therefore, effectiveness and impact of the project are high.

3.3 Efficiency (Rating: ③)

3.3.1 Inputs

The following table shows the comparison between the planned and actual inputs at the time of project completion.

Table 6: Planned and Actual Inputs

Inputs	Plan	Actual
(1) Experts	• Long-term: Coordinator (number of experts, PM not stated) • Short-term: Molecular breeding, surrogate breeding, immunology and vaccine development, alternative feed development, hazard factor analysis, etc. (number of experts, PM not stated)	• Long-term: 2 persons (66.37 PM) • Short-term: 17 persons (19.20 PM)
(2) Trainees received	NA.	58 persons
(3) Equipment	Laboratory analyzers, DNA analyzers, PCR equipment, high-performance liquid chromatography (amount not stated)	Analyzers for molecular breeding, DNA analyzers, PCR equipment, etc. (approximately 1.6 million yen)
(4) Operational costs	Information not available.	Approximately 60 million yen
Japanese Side Total Project Cost	353 million yen	408 million yen
Thai Side Total Project Cost	Amount not stated. (Personnel costs of the counterpart staff, project office, laboratory, and rearing tank of the implementing agencies, facility including hatchery pond, etc.)	151 million yen (Allocation of 116 counterpart staff, their personnel costs, consumables, reagents for analysis, office utilities, expert office space at DOF, laboratory of the implementing agencies)

Note: PM stands for person/month.
Source: JICA internal documents, questionnaire answer from DOF.

3.3.1.1 Elements of Inputs

Seventeen researchers (short-term experts) were dispatched from Japan. A total of 102 dispatches were made, and most of the dispatches were for a week or so at a time. The number of Thai researchers received was 58 (68 trips in total), but, as mentioned above, the research proceeded as planned, and 75 papers were jointly authored, which was more than planned. Therefore, it is judged that the joint research was implemented smoothly. In the project, 13 research groups were organized in five research areas, where 116 Thai

researchers participated. It was pointed out in the terminal evaluation that there was "insufficient information sharing due to the complicated implementation system." However, all groups held progress report meetings every year, and networks among researchers were created; this point was not considered a problem in the ex-post evaluation survey. All of the provided equipment except for two broken PCR machines have been utilized, which can be interpreted to mean that the equipment selection was appropriate.

The Thai side made inputs equivalent to 151 million yen, and it can be said that the project was implemented as a partnership.

3.3.1.2 Project Cost

The actual project cost on the Japanese side was 408 million yen against the planned 353 million yen. Reasons for exceeding the plan include (1) an increase in the number of researchers dispatched as research progressed, (2) the invitation of Thai researchers to the kick-off meeting, (3) a change from local purchase of reagents used for the analysis of DNA markers and immune-related genes to procurement in Japan, and (4) the hiring of project support personnel. In particular, the Thai side asked JICA and JST to take urgent action against EMS/AHPND, which became a major problem in Southeast Asia in early 2013. JICA and JST conducted a situational review and, as a result, joint research to respond to EMS/AHPND, which had not been originally planned, was added to the project scope. As it was an additional activity related to the technology for reducing infectious diseases (Output 3), the PDM was not revised accordingly. However, JICA and JST documents confirmed that the budget for FY2014 was increased and joint research was initiated[23]. This research activity led to the identification of the toxin gene and the development of a diagnostic method using PCR testing the following year (2014). Therefore, it is judged that the project cost was commensurate with the outputs of the added scope.

3.3.1.3 Project Period

The actual project period was 60 months (May 2012 to May 2017) against the planned 60 months (March 2012 to March 2017). It was as planned.

In light of the above, the project period was as planned, and it is judged that the project cost was commensurate with the produced outputs. Therefore, efficiency of the project is high.

[23] *JST Implementation Report of FY 2013*, JICA internal documents, and the Mid-term Review Report.

Column 3: Roles and Contribution of the Japanese Experts Who Encouraged Social Implementation

The project was aimed at the production of the developed vaccines and fish diets by private companies as part of the social implementation of the research results. The following two factors promoted efforts toward social implementation from the early stage. First, the project was implemented not only through research and information sharing by the implementing agencies but also through the involvement of private companies. Specifically, at the end of each fiscal year, an open meeting on the research results was held in Bangkok, and Thai companies and Japanese companies in Thailand related to the research field were invited to the meeting. The invited companies were those with which the Japanese and Thai researchers had previously had a cooperative relationship, and such companies were selected because the researchers felt comfortable conducting joint research within the project. The purpose of the meeting was not only to report the results of the project but also to introduce the developed technologies to the invited companies. In fact, an interested Japanese company started discussions with the implementing agency in Thailand regarding the commercialization of the vaccine under study, and the company has been participating in the succeeding project as a Japanese cooperation organization. Second, TUMSAT has long accepted exchange students from foreign countries, including Thailand, and the Japanese researchers who worked as experts in the project have continued joint research and exchange with former exchange students for more than 20 years. Many of the former exchange students have obtained key positions in the DOF, fishery-related research departments of universities, and research sections of private companies. Based on the network and relationship of trust with them, research activities proceeded smoothly in the project, and, as mentioned above, the project succeeded in involving organizations other than the implementing agencies in joint research activities.

Source: Prepared based on the results of interviews with the DOF and TUMSAT.

3.4 Sustainability (Rating: ③)

3.4.1 Policy and Political Commitment for the Sustainability of Project Effects

The development policies of the Government of Thailand have driven the development of sustainable, high-quality aquaculture technologies and their social implementation. Based on the government's plan, *Kitchen of the World*," the 12th NESDP (2017-2021) set forth a policy of promoting increased fish and shellfish production through technology development in the aquaculture industry. The *Strategic Plan* (2017-2021) of the DOF also set out four strategic objectives: (1) increasing productivity and strengthening farmers, (2) developing the quality of value-added fishery products, (3) sustainable fisheries and fishery resource management, and (4) organizational management of the DOF. Concerning each strategic objective, the goals are: research and development (R&D) and technological innovation to reduce production costs (1), R&D and technological innovation to create added value (2), R&D to improve the efficiency of fishery resource management (3), and strengthening the capacity of staff and international networking (4).

Thus, the policy and political commitment to sustain the project effects have been secured.

3.4.2 Institutional/Organizational Aspect for the Sustainability of Project Effects

The section in charge of research has been clearly positioned at each implementing agency, and the personnel to sustain the research has been secured (Table 7). Concerns were pointed out in the terminal evaluation about personnel transfers within the DOF. However, it was confirmed in the ex-post evaluation that, although there were transfers within the headquarters and between centers for promotion, the research results have been compiled in publications, reports, manuals, and so on., and no problems have occurred to date.

There are five R&D divisions related to aquaculture at the DOF. For promoting social implementation, a technical management group has been established in each division. Their main responsibilities include evaluation of the research results of each division and selection of the research outputs appropriate for social implementation. In addition, they have worked on the diffusion of aquaculture technologies, demonstration of aquaculture hatcheries, implementation of pilot projects, involvement of relevant stakeholders, and so on. There have been 15 to 20 staff members responsible for social implementation, and they have received support from local centers. According to the DOF, the number of staff has been sufficient. As for the four universities, the research group has been clearly positioned in the relevant department of each university. Some universities answered that the number of researchers was not sufficient to expand the research scope, but considering the status of research continuation and realization of effects, it is judged that there has not been a problem.

Table 7: Organizational Setting for Research in the Implementing Agencies

	Section-in-charge and number of the staff
DOF	• The DOF consists of four clusters. The aquaculture cluster has the following divisions: (1) Inland Aquaculture Research and Development Division (154 researchers) (2) Coastal Aquaculture Research and Development Division (124 researchers) (3) Aquatic Animal Genetics Research and Development Division (34 researchers) (4) Aquatic Animal Health Research and Development Division and (27 researchers) (5) Aquatic Animal Feed Research and Development Division. (28 researchers)
Chulalongkorn University	• The Program in Biochemistry and the Marine Science Department are responsible for aquaculture technology development. The number of the academic staff, including researchers, is 10. The “number of staff is not considered sufficient,” as there are various topics and species of aquatic animals.
Kasetsart University	• The Department of Aquaculture (Faculty of Fisheries) and the Department of Biochemistry (Faculty of Science) jointly operate five research sections: disease characterization, pathogen isolation and characterization, disease detection development, disease prevention and control, and development of the detection of food-contaminating chemicals. Each section has three to five professors and researchers. The number of staff is “not considered sufficient,” but there is a plan to increase the number of doctoral students by two to three in the 2022 academic year. • The university prepares scholarships and a fast-track program that allows completion in a short period to attract young students’ interests.
Walailak University	• The Center of Excellence for Shrimp is in charge of aquaculture research and development. It has four professors and five researchers and the number is considered

	Section-in-charge and number of the staff
	"sufficient." • The university provides scholarships but the number of doctoral students has been decreasing. The university has a plan to develop a curriculum for students from other regions in the country and from foreign countries.
Suranaree University of Technology	• Related research is conducted at the Program of Biotechnology for Aquaculture (master of sciences and PhD courses) under the School of Animal Technology and Innovation of the Institute of Agricultural Technology. Three responsible lecturers and five researchers are assigned to the program, and the number of the staff is considered "sufficient" for research on sustainable and quality aquaculture.

Source: Prepared based on the questionnaire answers and interview results of DOF, Chulalongkorn University, Kasetsart University, Walailak University, and Suranaree University of Technology.

All of the implementing agencies have been also participating in the succeeding project, and each has established a joint research relationship with other research institutions. The DOF has concluded agreements on R&D and dissemination with three national universities and the NSTDA and has been also conducting joint projects with aquaculture farmers, agricultural cooperatives, and the Thai Frozen Food Association. Furthermore, the universities have conducted joint research with other national universities and research institutes, overseas research institutes, and private companies. For example, Suranaree University of Technology has carried out joint research on aquaculture feed with the National Institute for Agriculture, Food and Environment at the University of Pau and Pays de l'Adour in France. Kasetsart University has worked with private companies for joint research and received funds from the Program Management Unit for Competitiveness (PMUC). Under this grant program, companies are required to pay 10% of the total research cost as a guarantee that they promise to utilize and commercialize the research results after the research.[24]

Taking the above into account, it is judged that the institutional and organizational aspects of the implementing agencies have been sufficient.

3.4.3 Technical Aspect for the Sustainability of Project Effects

As mentioned earlier, the project's ongoing and new research has continued in all research areas since project completion. In addition, collaborative research has been carried out in the areas of molecular breeding, control of infectious diseases, efficient feeding and rearing, and germ cell transplantation. These areas have much in common with Output 1, Output 3, Output 4, and Output 2 of this project, respectively.

For the DOF, research on surrogate broodstock technology was the first effort in this project, and since it needed specialized equipment, "advanced techniques are required

[24] PMUC (Program Management Unit for Competitiveness) is a research grant agency established under the Office of the National Higher Education Science Research and Innovation Policy Council (NXPO) of Thailand, with the aim of promoting the commercialization of research results. It provides grants according to the level of the research institution.

compared to other research areas, but in other areas, their techniques for continuing research have been sufficient." The DOF has worked on capacity building through seminars, workshops, and on-the-job training (OJT) for its staff, including new researchers at headquarters and researchers at local centers. The four universities have also been conducting OJT for new researchers and joint research with other institutions, in addition to research in the succeeding project. For example, in addition to participating in the succeeding project and other research projects with external funds, Chulalongkorn University has been maintaining research skills by conducting interactions among research groups within the university and providing short-term training for teachers, students, and post-doctoral researchers.

The research equipment has been utilized daily, as mentioned above.

In light of the above, considering the status of research continuation and equipment utilization, it is judged that techniques of the implementing agencies have been sufficient.

3.4.4 Financial Aspect for the Sustainability of Project Effects

The budget for research projects related to aquaculture and fisheries at the DOF is shown in the table below. The director, who took office in 2017, has placed a strong emphasis on research, and the budget has been increasing. In addition to this, the DOF has applied for research grants from external research institutions and has continued research. The headquarters and local centers have prepared the annual operational plan, in which the cost of repairing research equipment and purchasing supplies has been accounted for.

Table 8: Budgets for Research of DOF

Unit: Thai Bhat

	2017	2018	2019	2020	2021	2022 (plan)
Revenue	1,526,200	4,741,600	4,908,265	11,075,946	13,061,600	32,146,440
Expenditure	1,526,200	4,741,600	4,908,265	7,024,697	NA	NA

Source: Prepared based on the questionnaire answer form DOF.

Although strict financial data were not available from the four universities, the research budgets of three universities, including the budgets from the universities and research grants, have tended to remain about the same or increase slightly since the project completion. This budget has covered the operation and maintenance of research equipment. Chulalongkorn University had a research budget of about 8 million baht in 2017, which has decreased to 7 million baht since 2021. According to the university, more emphasis has been placed in recent years on applied research for adding value than on basic research on fish and shellfish diseases, and the government has expected more investment from the private sector in the shrimp aquaculture industry, as the government has relied much on the

private sector. Walailak University has generated about 600,000 baht per year (40% of development costs) from the sale of probiotic products. In addition, Kasetsart University has received income from paid services (laboratory experiments and research) for private companies.

Although some financial data could not be strictly confirmed, considering the status of research continuation and equipment utilization, it is judged that there has been no issue in the financial aspect of the implementing agencies.

No major problems have been observed in the policy background, the institutional/ organizational, technical, and financial aspects. Therefore, sustainability of the project effects is high.

4. Conclusion, Lessons Learned and Recommendations

4.1 Conclusion

The project aimed to develop new aquaculture technologies in Thailand by conducting research in five areas that complemented each other: molecular breeding, surrogate broodstock, infectious disease control, non-fish-meal alternative diet, and detecting and reducing chemical hazards. This is in line with the Thai development policies and needs, as well as Japan's assistance policy, and thus the project relevance is high. In all five areas, research outputs were produced according to the plan. The developed technologies have been applied to the target fish species, and because of the joint research, the researchers' capacity has been improved and the research results have been publicly disseminated. Furthermore, efforts have been made to put the research outputs to practical use, and social implementation has been realized, such as the implementation of disease diagnosis services and the production and sale of non-fish alternative meal diets. In addition, several other positive impacts were confirmed, such as the early development and domestic and international approval of diagnostic methods for shrimp diseases that were prevalent, and the improvement of scientific literacy among farmers and private companies. Therefore, the effectiveness/impact of the project is high. The project period and cost are judged as commensurate with the outputs, and the efficiency is considered high. Regarding sustainability, the policy background and the institutional/organizational, technical, and financial aspects are all sufficient for the development of sustainable and high-quality aquaculture technologies and their social implementation. Thus, the project sustainability is high.

In light of the above, this project is evaluated to be highly satisfactory.

4.2 Recommendations

4.2.1 Recommendations to the Implementing Agency

(1) The Chaipattana Foundation has suspended the production of non-fish meal diets for two years due to internal circumstances. The prospects for its resuming production do not appear to be great due to the lack of high consumers' demand for grouper in the southern region. The knowledge and technology for developing alternative feeds replacing fish meal for grouper can be applied to feeds for other fish species. It is recommended that the DOF continue the marketing research on alternative feeds, apply the knowledge and technology gained from the project to fish species with higher needs, and encourage NGOs or private companies with manufacturing systems for production.

(2) New research based on the research outputs of the project and in the succeeding project has been conducted. It is recommended that the DOF continue to disseminate the research outputs to other countries in international seminars or by publishing academic papers and drive research on aquaculture technologies in the Southeast Asia region.

4.2.2 Recommendations to JICA

None.

4.3 Lessons Learned

Involvement of research institutions and private companies with the basis and potential for social implementation

Efforts toward social implementation have been made since the project period and have been partially realized. In the project, not only the DOF, which is in charge of R&D and dissemination of aquaculture technologies, but also universities that have conducted research in the technological fields for sustainable and high-quality fishery production were selected as implementing agencies. The DOF is a government agency, and, under its direction, the shrimp disease diagnostic method that the project developed has been disseminated nationwide. In addition, because of its public status, the DOF cannot directly implement projects with private companies, but there are many local centers with research and dissemination functions, and thus the research outputs of the project (disease diagnosis, facility inspection, etc.) were able to reach farmers directly. On the other hand, by pursuing joint research with private companies, the universities were able not only to verify the research outputs but also to start discussions for future commercialization. This joint research was in line with the interests of both parties: the universities benefited from verifying research results, obtaining financial support, and using the private companies' facilities and equipment, while the private companies benefited from the preparation for commercialization of the universities' professional research. In this way, the SATREPS project could make efforts toward social implementation even during the project period by

involving private companies that could play an important role in social implementation and universities that have experience in commercialization.

(End.)

Indonesia

FY2021 Ex-Post Evaluation Report of Technical Cooperation Project

"Pilot Study for Carbon Sequestration and Monitoring in Gundih Area, Central Java Province, Indonesia"

External Evaluator: Keishi Miyazaki, OPMAC Corporation

0. Summary

The purpose of this project was to promote Carbon Dioxide Capture and Storage (CCS) programs in the Gundih gas field in Central Java, Indonesia, by conducting research on CO_2 storage evaluation technology, and CO_2 sequestration and monitoring technology, which is necessary for CCS technology application. This project was highly relevant to Indonesia's development plan and development needs, as well as to Japan's ODA policy. Therefore, its relevance is high. Three of the five outputs were achieved or nearly achieved and two were partially achieved. Since the overall goal has been achieved and six initiatives for social implementation have been implemented or were being implemented at the time of the ex-post evaluation, it is judged that the overall goal has been achieved. The project has contributed to improvement of the research capacity of the implementing agencies in Indonesia, and there were no problems in the utilization and maintenance of the equipment. No negative impact on the natural environment, land acquisition, or resettlement was observed. Therefore, the effectiveness and impact of the project is high, as the project has been effective as planned. Both the project cost and project period were within the plan, and the efficiency of the project is high. No major problems have been observed in the policy background and the institutional/organizational, technical, financial aspects. Therefore, the sustainability of the project effects is high.

In light of the above, the project is evaluated to be highly satisfactory.

1. Project Description

Project Location

A well planned for CO_2 injection in the Gundih gas field

1.1 Background

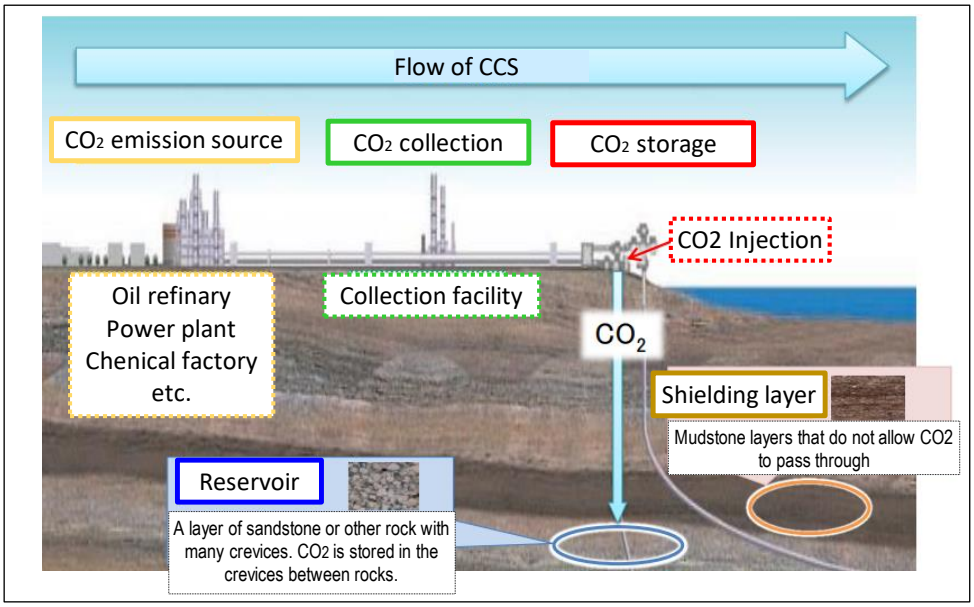
Indonesia was the world's third largest greenhouse gas emitter after China and the United States when CO_2 emissions from peatlands were included (3,143 million CO_2 equivalent tons, according to a report by Wetlands International), and there were concerns about the increase in greenhouse gas emissions associated with increased energy demand due to economic growth. In light of this, the second Yudhoyono administration, inaugurated in October 2009, positioned climate change measures as a key policy issue, setting a voluntary target of reducing greenhouse gas emissions by 26% compared to business as usual (BAU) by 2020, and establishing the *"Indonesia Climate Change Sectorial Roadmap"* (March 2010), a sectoral roadmap for adaptation and mitigation measures over a 20-year period from 2010 to 2029. The roadmap pointed out the possibility of CCS as one of the measures to reduce greenhouse gas emissions from coal-fired thermal power plants. However, research and studies on CCS had only just begun in Indonesia. In Japan, on the other hand, research and technological development related to CCS had been conducted since around 2000, and a certain level of technological development had been achieved through demonstration studies, particularly with regard to the development of technology for monitoring geologically sequestrated CO_2 behavior. Against this background, the Indonesian government requested that Japan conduct joint research for the development of CCS technology in Indonesia.

1.2 Project Outline

Overall Goal		Carbon Capture and Storage (CCS) programs in Indonesia are promoted for accelerating oil and gas development and production with zero CO_2 emission.
Project Purpose		Standard Operating Procedure (SOP) for CO_2 storage evaluation technology, CO_2 sequestration and monitoring technology, which is necessary for CCS technology application, is proposed for promoting CCS programs in onshore gas fields in Indonesia.
Outputs	Output 1	Detailed action plan of the project including implementation structure is completed for CO_2 sequestration and monitoring in the Gundih gas field.
	Output 2	Characterization/evaluation of CO_2 sequestration sites(s) and CO_2 storage are completed to proceed the activities under Outputs 3 and surface facility simulations.
	Output 3	Feasibility study including surface facility design and cost evaluation is completed for CO_2 sequestration and monitoring in the Gundih gas field.
	Output 4	Geophysical and geochemical technologies which can be

		applied for CO_2 sequestration and monitoring are evaluated in the actual storage to determine integrated technologies for storage evaluation and CO_2 monitoring.
	Output 5	SOP is prepared based on the analysis and the evaluation of the Gundih gas field CO_2 sequestration and monitoring.
Total cost (Japanese Side)		370 million yen
Period of Cooperation		September 2012-September 2017
Target Area		Bandung and Gundih gas field, Central Java Province
Implementing Agency		Bandung Institute of Technology (Institute Teknologi Bandung: ITB)
Other Relevant Agencies/ Organizations		Pertamina
Consultant/ Organization in Japan		Kyoto University, Waseda University, Kyushu University, Fukada Geological Institute
Related Projects		None

The main focus of the joint research in this project was the development and application of methods for selecting optimal CO_2 reservoirs based on geological and geophysical knowledge and monitoring the behavior of the geologically sequestrated CO2. At the same time, research on related CO_2 separation, capture, and injection methods, regulations, risk analysis, and social acceptability were also included. The CO_2 separation and recovery method was applied to a portion of the CO_2 released into the atmosphere as an associated gas during natural gas production at the Gundih gas field in Central Java, owned by the state-owned oil company Pertamina. The CO_2 was to be further liquefied and transported to a well owned by Pertamina, approximately 40 km from the gas field, for injection over a period of two years. Ultimately, the project aimed to develop and disseminate the SOP as a technical guide for geologically sequestrated CO_2 projects based on the results of the above study. On the other hand, it was planned that the drilling of the CO_2 injection well would be handled separately by the Indonesian side, since it was assumed that the cost may be as much as 1.5 billion yen which would be difficult for the project to handle.



Source: Ministry of Economy, Trade and Industry (METI).

Table 1　Flow of CCS (Image)

1.3 Outline of the Terminal Evaluation

1.3.1 Achievement Status of Project Purpose at the Terminal Evaluation

The project purpose was partially expected to be met.

Due to gas leakage found in the borehole where CO_2 injection was planned, monitoring of CO_2 behavior could not be conducted in the reservoir, and the CO_2 behavior could not be evaluated before the project was completed. Therefore, although preparation took place of a "Standard Operating Procedure (SOP) for Safe and Effective CO_2 Sequestration Technology in On-shore Areas," which summarized the results of the joint research, it was partially incomplete in terms of content. On the other hand, through the cooperation of Japanese and Indonesian researchers, advanced technology and methods were utilized to conduct baseline surveys, such as Time-Domain Electromagnetic (TDEM) and high-resolution seismic surveys, before CO_2 injection, and through the joint research, technology for CO_2 sequestration and monitoring in Indonesia were developed.

1.3.2 Achievement Status of Overall Goal at the Terminal Evaluation (Including Other Impacts)

The terminal evaluation did not make a determination on the level of achievement of the overall goal.

1.3.3 Recommendations from the Terminal Evaluation

The following items are recommendations from the terminal evaluation.

(1) Continuous coordination with main stakeholders in Indonesia, JICA, and the

Asian Development Bank (ADB)

(2) Public relations of CCS

(3) Utilization of equipment

(4) Establishment of a legal framework to encourage CCS

(5) Analysis of the contribution of CCS to the achievement of Nationally Determined Contributions (NDCs) of greenhouse gases

2. Outline of the Evaluation Study

2.1 External Evaluator

Keishi Miyazaki, OPMAC Corporation

2.2 Duration of Evaluation Study

This ex-post evaluation study was conducted with the following schedule.

Duration of the Study: July 2021 – January 2023

2.3 Constraints during the Evaluation Study

Due to the widespread of COVID-19, the planned field survey was cancelled and replaced by a remote survey with an Indonesian field survey assistant. Therefore, in addition to the questionnaire, online interviews were conducted in response to this situation.

This project is a Science and Technology Research Partnership for Sustainable Development (SATREPS[1]), and ex-post evaluation of SATREPS projects are usually conducted as an internal evaluation. JICA's Evaluation Department decided to conduct this project as an external ex-post evaluation, judging that valuable lessons could be learned from the evaluation survey process, such as interviews with domestic stakeholders. However, due to the timing of the introduction of the new evaluation criteria, this ex-post evaluation was conducted based on the old evaluation criteria (5 evaluation items).

3. Results of the Evaluation (Overall Rating: A[2])

3.1 Relevance (Rating: ③[3])

3.1.1 Consistency with the Development Plan of Indonesia

[1] SATREPS are implemented by the Japan Science and Technology Agency (JST), the Japan Agency for Medical Research and Development (AMED) and JICA, with support from the Ministry of Foreign Affairs and the Ministry of Education, Culture, Sports, Science and Technology, to promote science and technology cooperation and science and technology diplomacy with developing countries through collaboration with Japan's excellent science and technology and ODA. The aim of SATREPS is to acquire new knowledge and technology and create innovations that will lead to solutions to global issues such as the environment, carbon neutrality, bioresources, disaster prevention and infectious diseases, as well as to improve the independent research and development capacity of developing countries and build a sustainable system of activities that will contribute to solving these issues.

[2] A: Highly satisfactory, B: Satisfactory, C: Partially satisfactory, D: Unsatisfactory

[3] ③: High, ②: Fair, ①: Low

The second Yudhoyono administration, which took office in October 2009, set the goal of reducing greenhouse gas emissions by 26% by 2020 (41% with international support) compared to business as usual (BAU). *The National Medium-Term Development Plan (RPJM)* (2010-2014) identified "Environment and Disaster Management" as one of its priority areas. In order to continue to incorporate climate change issues in the RPJM, the Indonesian government made climate change measures a key policy issue for the administration, including the formulation of a sectoral roadmap for adaptation and mitigation measures over a 20-year period from 2010 to 2029, *the Climate Change Roadmap for the Republic of Indonesia* (March 2010). The roadmap identified climate change as an important policy issue for the Indonesian government. Increasing greenhouse gas emissions from coal-fired thermal power plants, on which the country depends for energy, were noted as a particular challenge, and CCS was considered as a potential mitigation measure.

At the time of the ex-post evaluation, *the National Medium Term Development Plan (RPJMN)* (2020-2024) identified increasing resilience to disasters and the addressing of climate change as priorities, with low-carbonization included as part of this. Specifically, items are categorized into (1) improving environmental quality, (2) improving resilience to disasters and climate change, and (3) low-carbon approaches, with numerical targets set for each. For (3) low-carbon approaches, the goal is to reduce greenhouse gas emissions by 27.3% by 2024 compared to BAU. Prior to the 26th Conference of the Parties (COP26) to the United Nations Framework Convention on Climate Change (UNFCCC) held in October-November 2021, Indonesia had announced *the Indonesia Long-Term Strategy for Low Carbon and Climate Resilience* in July of the same year, and stated that it would achieve carbon neutrality by 2060.

Based on the above, it can be seen that addressing climate change, including greenhouse gas reduction, was a priority in Indonesia's national development plan at the time of planning and ex-post evaluation, and therefore the project is consistent with the development plan of Indonesia.

3.1.2 Consistency with the Development Needs of Indonesia

At the time of the ex-ante evaluation, the Indonesian government had established the Directorate General of New Renewable Energy and Energy Conservation within the Ministry of Energy and Mineral Resources (MEMR) in February 2011 to promote new energy and energy conservation. The Directorate General announced *Vision 25/25*, which aimed to achieve a 25% share of new and renewable energy in primary energy by 2025, together with *the Clean Energy Initiative* to promote it. This initiative was a comprehensive guide to reducing CO_2 emissions from fossil fuel combustion, and CCS technology

development was to be promoted as one of the post-combustion measures for fossil fuels. On the other hand, research and studies on CCS had just begun in the country. ITB, one of the leading universities in Indonesia and the implementing agency of this project, had accumulated much knowledge in geology, geophysics, geochemistry, and other related fields but had limited experience in CCS research and surveys. Therefore, it was necessary for ITB, a leader in engineering technology in the country, to accumulate technical knowledge on CCS. Meanwhile, the Gundih gas field in Central Java, owned by the state-owned oil company Pertamina, which was the subject of this project's demonstration study, produced 20% CO_2 as an associated gas during natural gas production, and approximately 800 tons of CO_2 was emitted into the atmosphere daily.

At the time of the ex-post evaluation, the Government of Indonesia had set the goal of increasing crude oil production to 1 million barrels per day by 2030 and natural gas production to 12 BSCFD (1 billion standard cubic feet per day) by optimizing existing oil field production, discovering new reserves through exploration, and implementing enhanced oil recovery (EOR) and enhanced gas recovery (EGR) methods. CCS and Carbon Capture, Usage and Storage (CCUS) technology are essential for this. Therefore, the Government of Indonesia is in the process of formulating regulations to promote CCS/CCUS as a ministerial regulation of MEMR, which also refers to the SOP for the CO_2 sequestration technology developed in this project. The regulations focus on the use of CCS/CCUS[4] in the oil and gas sector through EOR, EGR, and enhanced coalbed methane recovery technology (ECBM), and the necessary framework from technical, legal, economic, and business perspectives has been discussed. In January 2022, *a Memorandum of Cooperation on the "Realization of Energy Transitions"* was signed between Japan's Ministry of Economy, Trade and Industry (METI) and MEMR. The MOU lists areas of cooperation as the development and deployment of technology that contribute to realistic energy transitions, such as hydrogen, fuel ammonia, carbon recycling, and CCS/CCUS, as well as support for efforts in multilateral forums to promote technical cooperation in these areas.

As described above, at the time of both planning and ex-post evaluation, there was a high need for research and technology development related to CCS in Indonesia, and this project is consistent with the development needs of Indonesia.

3.1.3 Consistency with Japan's ODA Policy

Japan's Country Assistance Program for the Republic of Indonesia at the time of the ex-

[4] For example, by injecting CO_2 into old oil and gas fields, the CO_2 is stored underground while the remaining crude oil and natural gas in the oil and gas fields is pushed out under pressure, thereby reducing CO_2 emissions and increasing oil and natural gas production.

ante evaluation included "Assistance to improve the capacity of the Asian region and the international community to respond to challenges" as one of the priority areas. Through this, Japan was to assist in "addressing global-scale issues such as environmental conservation and climate change." In addition, in the Ministry of Foreign Affairs' "*Rolling Plan for Indonesia"* (August 2010), the climate change countermeasures program was positioned as a "special issue." At the UN Climate Change Summit in September 2009, Japan announced financial and technical support for reducing CO_2 emissions in developing countries with CO_2 emission reduction targets of 25% below 1990 levels and 33.3% below 2005 levels by 2020. Efforts to reduce CO_2 emissions have been a national issue for both Japan and Indonesia.

Thus, it can be said that at the time of planning, the project and Japan's ODA policy were highly consistent.

Based on the above, this project was highly relevant to Indonesia's development plan and development needs, as well as Japan's ODA policy. Therefore, its relevance is high.

3.2 Effectiveness and Impacts[5] (Rating: ③)

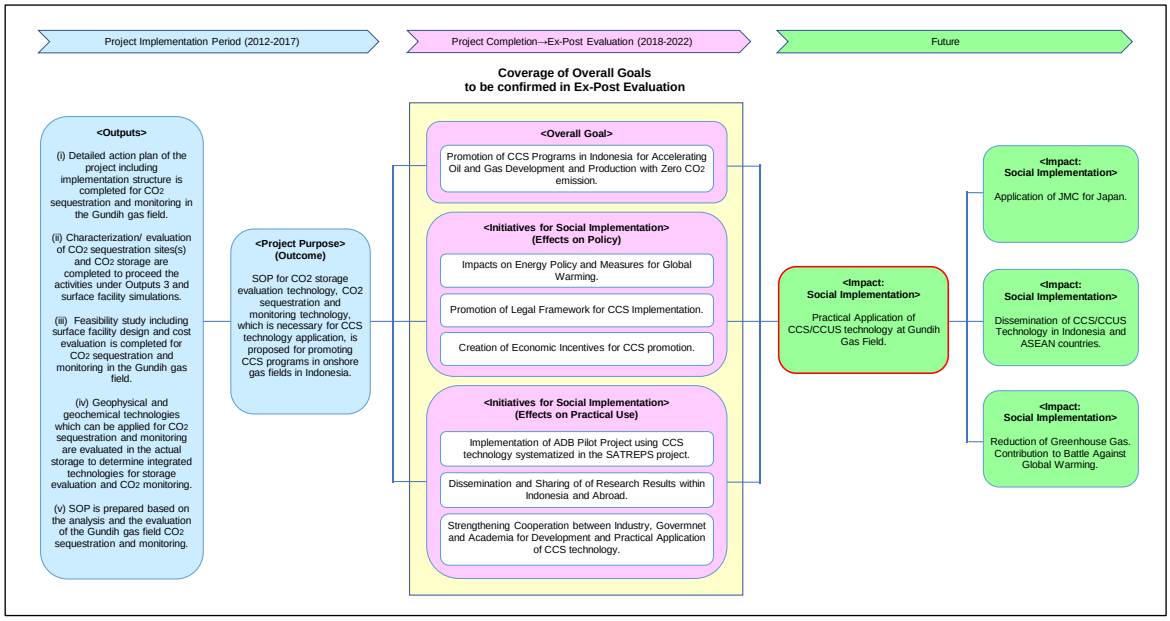
This project is a technical cooperation project conducted within the framework of SATREPS, and its ultimate goal is to promote the social implementation of science and technology that responds to the issues and needs of the partner country, rather than merely providing support for basic and applied research. The social implementation aimed at by this project is considered to be the "Practical application of CCS technology at the Gundih gas field," which will be followed by the "Utilization of Joint Crediting Mechanism (JCM) to achieve Japan's greenhouse gas reduction target," "Dissemination of CCS technology within Indonesia and ASEAN countries," and "Reduction of greenhouse gas emissions." It is necessary that several stages and processes are passed through from the execution of SATREPS to the realization of social implementation. Therefore, in this ex-post evaluation, "Initiatives for Social Implementation" that should be achieved within three to four years after the project completion were identified and defined as the coverage of overall goals to be confirmed. The coverage of overall goals includes the original overall goal of the project, "To promote CCS programs in Indonesia for accelerating oil and gas development and production with zero CO_2 emission."

"Initiatives for Social Implementation" were grouped under "Effects on Policy": (1) Impact on energy policy and measures for global warming in Indonesia, (2) Promotion of a legal framework for CCS implementation, (3) Creation of economic incentives for CCS promotion, and "Effects on Practical Use": (4) Implementation of ADB pilot projects using

[5] Sub-rating for Effectiveness is to be put with consideration of Impact.

the CCS technology systematized in the SATREPS project, (5) Dissemination and sharing of research results within Indonesia and abroad, and (6) Strengthening of cooperation between industry, government, and academia for the development and practical application of CCS technology.

The analytical framework used in this ex-post evaluation and the coverage of overall goals to be identified in this ex-post evaluation are shown in Figure 2.



Source: Created by the Evaluator

Figure 2 Evaluation Framework and Coverage of Overall Goals

3.2.1 Effectiveness

3.2.1.1 Project Output

(1) Output 1

Output 1, "Detailed action plan of the project including the implementation structure is completed for CO_2 sequestration and monitoring in the Gundih gas field" was achieved. At the start of the joint research, technical teams were formed for each technical topic and an annual operation plan was established. In addition, a detailed action plan for CO_2 sequestration and monitoring in the Gundih gas field was discussed and prepared.

(2) Output 2

Output 2, "Characterization/evaluation of CO_2 sequestration site(s) and CO_2 storage are completed to proceed the activities under output 3 and surface facility simulations" was achieved. Using the data on geological conditions, borehole and seismic exploration provided by Pertamina and geological data from field surveys, a database of geology and geophysics, and the physical property data for the Gundih gas field were compiled, and a

geological and reservoir model for CCS of the Gundih gas field was constructed in 2013. Simulation studies on CO_2 behavior were conducted on the geological and reservoir models with varying different parameters, and it was concluded that the reservoir would be safe from CO_2 leakage for a long period of time. In addition, a feasibility study, including surface facility design and cost evaluation, simulated the corrosion rate of the borehole during the CO_2 injection period, and the results were incorporated into the detailed design of the surface facilities.

For the "evaluation of CO_2 sequestration site(s) and CO_2 storage[6]," we reinterpreted the existing reflectometry geophysical data, conducted on-site borehole surveys and geological surveys, created a geological model, built a numerical reservoir model using that model, and conducted an injection simulation to precisely evaluate the injection site and characteristics of the reservoir. Also, the possibility of the reactivation of nearby faults was evaluated by focusing on changes in pore pressure in the reservoir due to injection. This was technology newly developed by this project.

(3) Output 3

Output 3, "Feasibility study including surface facility design and cost evaluation will be conducted for CO_2 sequestration and monitoring in the Gundih gas field" was mostly achieved. The feasibility study report on the surface facility design and directions for CO_2 sequestration and monitoring in the Gundih gas field was compiled, refined, and submitted to the relevant organizations in March 2015. The construction of the surface facility, the preparation of injection wells, and CO_2 capture, transport, and injection were not included in the scope of this project, but ADB showed interest and offered to fund the research, and therefore this feasibility study was conducted with financial support from ADB. A risk analysis study of the project was also conducted with funding from Norway.

(4) Output 4

Output 4, "Geophysical and geochemical technologies which can be applied to CO_2 sequestration and monitoring are evaluated in the actual storage to determine integrated technologies for CO_2 storage evaluation and monitoring," was partially achieved. The reason for the partial achievement was that although the evaluation of the CO_2 storage evaluation and monitoring method was completed up to the acquisition of data before CO_2 injection, the possibility of gas leakage in the existing borehole was pointed out (Jepon-1) where CO_2 injection was planned, making CO_2 injection difficult, and as a result, it was

[6] Storage evaluation is the determination of the geological, mechanical, and hydraulic properties of the strata into which CO_2 is injected from the surface, using geological, physical, and chemical tests and analytical methods. This allows an evaluation of the extent (amount and duration) to which CO_2 can be sequestered.

impossible to achieve an evaluation of the underground behavior of CO_2 by project completion. Meanwhile, with regard to CO_2 behavior monitoring and evaluation technology, the time-domain electromagnetic survey method, a reflectance geophysical survey using vibroseis seismic source, and a surface deformation measurement method using interferometric SAR (InSAR) were technology that were applied for the first time in Indonesia through this project.

(5) Output 5

Output 5, "SOP will be prepared based on the analysis and the evaluation of the Gundih gas field CO_2 sequestration and monitoring" was partially achieved. In addition to the research results of Outputs 1 to 4, the draft SOP for CO_2 sequestration and the monitoring of onshore gas fields was prepared by incorporating the results of a literature survey on CCS conducted around the world, a CCS demonstration experiment at Iwanohara in Nagaoka City conducted by the Research Institute of Innovative Technology for the Earth (RITE), and a large-scale CCS demonstration experiment in Tomakomai City conducted by METI of Japan. However, as mentioned above, since it was still impossible to perform CO_2 injection at the Gundih gas field at the time of project completion, the draft SOP was not finalized because it did not reflect the results of analysis and the evaluation of the monitoring of underground CO_2 behavior after CO_2 injection.

In addition to the activities described in Output 1 through 5 above, this project has been selected as a FY2015 "Program for Dissemination and Promotion of Global Warming Countermeasure Technology" by the New Energy and Industrial Technology Development Organization (NEDO). With the support of this NEDO program, a feasibility study for a Joint Crediting Mechanism (JCM), a bilateral trading of carbon credits that promoted by Japan, was conducted using this project as a case study.

3.2.1.2 Achievement of Project Purpose

The project purpose of "SOP for CO_2 storage evaluation technology, CO_2 sequestration and monitory technology, which is necessary for CCS technology application, is proposed for promoting CCS programs in onshore gas fields in Indonesia" is judged to have been partially achieved. The level of achievement for each indicator is shown in Table 1.

Table 1 Achievement of Project Purpose

Purpose	Indicator	Actual
[Project Purpose] SOP for CO_2 storage evaluation technology, CO_2 sequestration and monitory technology, which is necessary for	Indicator 1: A proposal of an SOP for safe and effective CO_2 sequestration technology in onshore is disseminated to 20	Partially Achieved • Although the SOP created through this project was shared with Indonesian government agencies, universities, local governments, companies, etc., monitoring of CO_2 behavior in the reservoir was not implemented as CO_2 injection could not be conducted

Purpose	Indicator	Actual
CCS technology application, is proposed for promoting CCS programs in onshore gas fields in Indonesia	organizations.	before project completion. Therefore, it was difficult to distribute the completed version of the manual because the monitoring results were not reflected in it.
	Indicator 2: Technologies for CO_2 sequestration and monitoring are developed with Indonesia researchers and engineers through collaborative work.	Achieved • Through collaborative work between Japanese and Indonesian researchers, a base line survey utilizing advanced methods and technology such as TDEM and high resolution seismic technology was completed before CO_2 injection, and monitoring technology for CO_2 movement has been developed.

Source: Provided by JICA

Indicator 1, "A proposal of a SOP for safe and effective CO_2 sequestration technology in onshore is disseminated to 20 organizations," was partially achieved, and Indicator 2, "Technologies for CO_2 sequestration and monitoring are developed with Indonesian researchers and engineers through the collaborative work" was fully achieved. Although the SOP developed in this project was distributed to each organization, the monitoring results of CO_2 movement in the reservoir were not reflected because CO_2 injection could not be conducted before project completion, and therefore the distributed SOPs were not a final version. Meanwhile, however, through the joint research of this project, technology and methods for the monitoring of CO_2 behavior using TDEM and high-resolution seismic surveys were developed.

Due to issues such as Pertamina's legal liability for CO_2 injection, this project was made a national project under the direct control of MEMR. After project completion, it was expected that the existing borehole (Jepon-1), which was identified as a possible gas leak, would be rehabilitated with continued ADB support, and CO_2 injection and CO_2 behavior would be monitored as an ADB pilot project.

Based on the above, the project achieved at a limited level its project purpose.

3.2.2 Impacts

3.2.2.1 Achievement of Overall Goal

As mentioned above, the project's overall goal was "to utilize and promote CCS programs in Indonesia for accelerating oil and gas development and production with zero CO_2 emissions." In addition to this, "Initiatives for Social Implementation" to be achieved within three to four years after project completion were included in the coverage of the overall goals to be confirmed in the ex-post evaluation and the degree of achievement of these goals was determined. Table 2 shows the results of the overall goals.

Table 2　Achievement of Overall Goal Assumed in the Ex-post Evaluation

Overall Goals	Actual
[Overall Goal] Promotion of CCS programs in Indonesia for accelerating oil and gas development and production with zero CO_2 emissions	Indicator: At least 5 CCS programs will be planned in Indonesia based on the SOPs proposed by this project.
	Achievement • The SOP proposed by this project provided technical guidance on matters related to CCS implementation from a broad perspective. This SOP was being used as a reference for the CCS/CCUS regulations that were being formulated at the time of the ex-post evaluation. • At the time of the ex-post evaluation, MEMR received applications from domestic and foreign companies for research and study projects for CCS/CCUS commercialization in Indonesia, 9 projects were approved, and research and preparatory works are underway. In five of these nine projects, ITB is conducting studies and research jointly with Indonesian and foreign companies, including Japanese companies, and SOP is being used as the basic information necessary for these studies and research projects.
[Effects on Policy] (1) Impact on energy policy and measures for global warming in Indonesia	• Based on the policy that CCS/CCUS could be one solution for energy transition in Indonesia, "Presidential Decree No. 98/2021 on the Instrument for the Economic Value of Carbon for Achieve Nationally Determined Contribution (NDC) Targets and Control of Carbon Emission in Development" was issued in 2021. This presidential decree provided an important legal basis for the government's efforts to reduce greenhouse gas emissions and achieve Indonesia's NDC. • The presidential decree mentions that the reduction of carbon emissions can be implemented by introducing engineering technology such as CCS/CCUS.
[Effects on Policy] (2) Promotion of a legal framework for CCS implementation	• In May 2017, the National Center of Excellence for CCS/CCUS was established at ITB under the leadership of MEMR, and the Center was ordered to draft new regulations to support CCS/CCUS in Indonesia. At the time of the ex-post evaluation, the Center was in the process of developing the new regulations with the aim of enacting them by the end of 2022. • The regulations are expected to address the rights of contractors to implement CCS or CCUS in their work areas; project approval and implementation mechanisms; economic incentives; measurements, reporting, and verification (MRV) requirements (for greenhouse gas emissions); health, safety, environmental, and social monitoring; decommissioning and transfer responsibilities after project completion. • The SOP proposed in the project includes technology for evaluating deep geological formations and monitoring underground CO_2 distribution and behavior. These technology and methods will be incorporated and utilized in the regulations.
[Effects on Policy] (3) Creation of economic incentives for CCS promotion	• The CCS/CCUS regulations mentioned above also consider a framework of economic incentives, including how to monetize carbon credits and distribute the proceeds, with a focus on the oil and gas companies that are the operators of CCS/CCUS projects.
[Effects on Practical Use] (4) Implementation of ADB pilot projects using the CCS technology systematized in the SATREPS project	• After completion of this project, the project became eligible for support from the ADB's Global Warming Prevention Program. With ADB support, a proposal and evaluation of a method for rehabilitating an existing borehole (Jepon-1) that was identified as a potential gas leak, and an updated feasibility study, which included the design of surface facilities, social acceptability and legal considerations, were conducted. As a result, it became clear that in order to implement the CCS pilot project, it would be necessary to drill a new injection well rather than rehabilitate and utilize the existing well. There was also a difference of opinion among the parties concerned regarding the handling of the hydrogen sulfide (whether hydrogen sulfide should be injected underground together with CO_2) generated in the process of separating and recovering CO_2 from associated gas. Ultimately, it was concluded that it would be difficult to drill new boreholes considering the scale of the ADB project budget (approximately 1.2 billion yen), and the ADB pilot project was canceled in the fall of 2019. • Subsequently, the Government of Indonesia, the Indonesian implementing agency, and the Japanese cooperating agencies requested that the Japanese government cooperate with the continuation of the CCS pilot project. As a

Overall Goals	Actual
	result, a review of the feasibility study conducted by ADB (FY2020) took place, a study to resolve issues (FY2021) was carried out under METI's scheme "Study on the Infrastructure Development Project for Acquisition of JCM Credits," and the basic design for the CCS pilot project (Pre-FEED) was completed. • Based on the above, it is planned that a CCS pilot project will be conducted in the Gundih gas field from FY2022 onward, utilizing NEDO's scheme "Program to Facilitate Private-Sector-Led Promotion of Low Carbon Technology Oversea" (NEDO-JMC). The project period for this pilot project is 5 years, with a budget of approximately 6-7 billion yen, and the schedule is as follows: detailed design of the pilot facilities (FEED) from 2022 to 2023; engineering, procurement, and construction (EPC) from 2023 to 2025; CO_2 injection and monitoring to start by 2026. • Many of the results from this project, such as the CO_2 behavior monitoring method, the injection method, and the basic design of the surface facilities, will serve as the basis for this pilot project.
[Effects on Practical Use] (5) Dissemination and sharing of research results within Indonesia and abroad	• The research results of this project are actively disseminated and shared by ITB and MEMR through presentations at international conferences, international symposiums, webinars, through academic papers, etc., both in Indonesia and abroad. • The ITB is also a member of the International Energy Agency Greenhouse Gas R&D Program (IEAGHG)[7] and, together with national representatives, mostly from developed countries, has proposed strategies for implementing CCS/CCUS, especially in developing countries. The two-week CCS/CCUS course organized by ITB and IEAGHG in 2020 was attended by 250 participants, with many ITB faculty members and Japanese researchers working on this project as instructors.
[Effects on Practical Use] (6) Strengthening of cooperation between industry, government, and academia for the development and practical application of CCS technology	• The National Center of Excellence for CCS/CCUS established at ITB is positioned as the research center for CCS/CCUS in Indonesia and also functions as a coordination window between industry and MEMR for CCS/CCUS projects in the country. It plays an important role in developing and promoting CCS/CCUS technology through collaboration between industry, government, and academia. • In addition to the National Center of Excellence for CCS/CCUS, the Center for Carbon Dioxide and Flared Gas Utilization was established at ITB in March 2020 to conduct research and consulting works as commercial activities related to CCS/CCUS. Through this new organization, ITB has more opportunities to directly engage in CCS/CCUS projects in collaboration with private companies.

Source: Questionnaire responses and interview results from the Indonesian implementing agencies and Japanese cooperating agencies.

The overall goal "to utilize and promote CCS programs in Indonesia for accelerating oil and gas development and production with zero CO_2 emissions" had been achieved at the time of the ex-post evaluation. The SOP proposed by the project was being used as a reference for the regulations on CCS/CCUS being developed at the time of the ex-post evaluation. In addition, at the time of the ex-post evaluation, of the nine projects approved by MEMR for the commercialization of CCS/CCUS, ITB was conducting joint research and studies with Indonesian and foreign companies, including Japanese companies, for

[7] IEAGHG was established in 1991 based on an agreement concluded under the International Energy Agency (IEA) to evaluate and promote greenhouse gas reduction technology, disseminate information on evaluation studies, and promote international cooperation. Currently, among the technology for reducing greenhouse gases, CCS is the main target of activities. Nineteen countries, including Japan and Indonesia, the European Commission (EU), the Organization of Petroleum Exporting Countries (OPEC), and 22 companies are participating. One of IEAGHG's main activities is the operation of the CCS expert network, the organization of workshops and large international conferences.

five projects, and the SOP was being used as basic information necessary for these studies and research.

Regarding "(1) Impact on energy policy and measures for global warming in Indonesia," in relation to this project, "Presidential Decree No. 98/2021 on the Instrument for the Economic Value of Carbon for Achieve NDC Targets and Control of Carbon Emission in Development" was issued in 2021, indicating the need to introduce engineering technology such as CCS/CCUS to reduce carbon emissions.

With regard to "(2) Promotion of legal framework for CCS implementation," the National Center of Excellence for CCS/CCUS established within ITB in 2017 is leading the process of developing regulations on CCS/CCUS (Ministry of Energy and Mineral Resources' Regulation) with the aim of enactment by the end of 2022. This is expected to address: the rights of contractors in the implementation of CCS or CCUS in their work areas; project approval and implementation mechanisms; economic incentives; measurements, reporting, and verification (MRV) requirements (for greenhouse gas emissions); health, safety, environmental, and social monitoring; decommissioning and transfer responsibility after project completion. The SOP proposed in this project will be incorporated into the regulations.

Regarding "(3) Creation of economic incentives for CCS promotion," in the regulations on CCS/CCUS, a framework of economic incentives is also discussed, including how to monetize carbon credits and distribute the proceeds, with a focus on oil and gas companies as operators of CCS/CCUS projects.

With regard to "(4) Implementation of ADB pilot projects using the CCS technology systematized in the SATREPS project," after the completion of this project, it was expected that this project would be eligible for ongoing ADB support for global warming countermeasures, and it was anticipated that ADB funding would be provided to rehabilitate the existing borehole (Jepon-1) that had been identified as a potential gas leak. This was to be followed by CO_2 injection and monitoring of CO_2 movement as a pilot project. However, due to the investigation, the drilling of a new borehole was required to implement the CCS pilot project. This was difficult to handle with the size of the anticipated ADB project budget, and thus the ADB pilot project was ultimately canceled in the fall of 2019. Subsequently, a review of the feasibility study conducted by ADB (FY2020) and a study to resolve issues (FY2021) were conducted under Japan's METI scheme "Study on the Infrastructure Development Project for Acquisition of JCM Credits," and the basic design for the CCS pilot project (Pre-FEED) was completed. The above studies were conducted by a consortium of Japanese plant engineering companies, electric power companies, engineering consultants, and ITB and Pertamina, which entered into a joint research agreement with the consortium. Based on the above, it is planned that a CCS

pilot project will be conducted in the Gundih gas field from FY2022 onwards, under the same implementation structure, utilizing NEDO's "Program to Facilitate Private-Sector-Led Promotion of Low Carbon Technology Overseas" (NEDO-JMC) scheme. The plan envisions the detailed design (FEED) of surface facilities (CO_2 capture facilities, CO_2 transport facilities, CO_2 injection facilities, etc.) from 2022 to 2023, followed by engineering, procurement, and construction (EPC) from 2023 to 2025, and CO_2 injection and monitoring to start by 2026.

Regarding "(5) Dissemination and sharing of research results within Indonesia and abroad," the research results of this project have been disseminated and shared within and outside of Indonesia by ITB and MEMR through presentations at international conferences, international symposia and webinars, and academic papers.

With regard to "(6) Strengthening of cooperation between industry, government, and academia for the development and practical application of CCS technology," industry-government-academia collaboration is underway to develop and promote CCS/CCUS technology, centering on the National Center for Excellence for CCS/CCUS which was established at ITB as a research center for CCS/CCUS in Indonesia. ITB has also established the Center for Carbon Dioxide and Flared Gas Utilization, and ITB itself is increasingly engaged in research and consulting work related to CCS/CCUS in cooperation with private companies.

From the above, it is clear that the overall goal of the project has been achieved, and the six initiatives for social implementation have been implemented or are being implemented. Therefore, the project has achieved overall goal.

3.2.2.2 Continuation of Project Effects

(1) Utilization and Continuation of Research Results

As explained in "3.2.2.1 Achievement of Overall Goal," after project completion, an updated feasibility study, which included the design of surface facilities, supported by ADB (FY2018-2019) and a basic design survey for the CCS pilot project by utilizing Japan's METI scheme (FY2020-2021) were conducted. The above studies are based on the research results of this project.

Meanwhile, although the SOP proposed in this project was not a complete version because it did not reflect the monitoring results of CO_2 movement in the reservoir, the proposed SOP will be integrated into the regulations on CCS/CCUS that are being developed. The ITB will not update the SOP in the future, as formulation of regulations is the top priority.

(2) Capacity Building of Researchers

Prior to the implementation of this project, research and study on CCS had just started in Indonesia, and ITB's research and study experience in the field of CCS was limited. Since then, through joint research with Japanese researchers through the project and training opportunities in Japan, ITB's research capabilities in the field of CCS have improved dramatically. The National Center for Excellence for CCS/CCUS, which was established at ITB as a result of the project, has ITB faculty members who were engaged in the project as core members, and human resource development related to CCS/CCUS in Indonesia is underway. In addition, ITB is expanding its research area from the CCS research undertaken in this project to research and demonstration of CCUS which effectively utilizes captured and stored carbon dioxide.

(3) Equipment Utilization and Maintenance Status

The project provided various types of research and survey equipment, including an earthquake survey system, a micro-earthquake monitoring system, receiver exchange units, electromagnetic method survey equipment, gravity monitoring meters, weather station survey equipment, GPS equipment, etc. This equipment continued to be used for educational and research purposes at ITB after project completion, and maintenance is generally satisfactory.

Pertamina Central Processing Plant at the Gundi gas field

New borehole for demonstration testing (Kedungtuban borehole)

Proposed site for surface facilities

Natural gas production plant

Pertamina staff

3.2.2.3 Other Positive and Negative Impacts

(1) Impacts on the Natural Environment

At the Pertamina Central Processing Plant (CPP) in the Gundih gas field, environmental monitoring activities as part of Labor, Health, Safety, and Environmental Protection (HSE) measures were conducted every three months during the implementation of this project, and emissions and waste were analyzed by a third party. According to the interview with the project officials, the CO_2 released into the atmosphere as an associated gas during natural gas production from the Gundih gas field contains a high percentage of hydrogen sulfide, and therefore the Central Production Facility uses desulfurization

equipment to remove the hydrogen sulfide. According to Pertamina, no negative impact on the natural environment associated with the project had been confirmed.

(2) Resettlement and Land Acquisition

Since the project site is located within the Pertamina CPP Gundih, no land acquisition or relocation of residents occurred as a result of implementation of the project. In the future, the drilling of a new demonstration borehole 4 km away from the CPP and the construction of a pipeline to transport CO_2 from the CPP to the borehole is to be implemented as part of the pilot project. However, the pipeline will be constructed along a right of way (ROW) already acquired by Pertamina, and therefore no new land acquisition or resettlement will occur.

The project purpose was partially achieved through the implementation of this project. The overall goal was achieved, and six initiatives for social implementation have been implemented or are being implemented. At the time of the ex-post evaluation, the research results were being utilized and the project effects were continuing. The project has contributed to the improvement of the research capacity of the researchers at the Indonesian implementing institution, and there were no problems in the utilization and maintenance of the equipment. No negative impact on the natural environment, land acquisition, or resettlement was observed.

In light of the above, the implementation of this project has produced the effects as planned. Therefore, effectiveness and impact of the project are high.

3.3 Efficiency (Rating: ③)

3.3.1 Inputs

A comparison of planned and actual results by inputs is shown in Table 3.

Table 3 Planned and Actual Inputs

Inputs	Plan	Actual (At Project Completion)
(1) Experts	• Long-term: 1 person (Coordination) • Short-term: 20 persons, approx. 80 man-months (Geology, Geological physics, Oil exploitation, etc.)	• Lon-term: 1 person • Short-term: 26 persons, total 27.4 man-months (Geology, Geological physics, Oil exploitation, etc.)
(2) Trainees received	N.A.	86 persons
(3) Equipment	Various measurement devices, computers and software for data analysis, etc. necessary for CO_2 monitoring work	Earthquake survey system, micro-earthquake monitoring system, receiver exchange units, electromagnetic method survey equipment, gravity monitoring meters, weather station survey equipment, GPS equipment, etc.
(4) Operational costs	N.A.	Approx. 51.6 million yen
Japanese Side Total Project Cost	401 million yen	357 million yen

Inputs	Plan	Actual (At Project Completion)
Indonesia Side Total Project Cost	N.A. (Personnel costs of the counterpart, etc.)	N.A. (Personnel costs of the counterpart staff, project office, travelling costs, costs for procurement of equipment (Gravimeters, ultrasonic velocity test equipment, multi-electrode geothermal systems, etc.)

Source: Documents provided by JICA.

3.3.1.1 Elements of Inputs

The number of experts (researchers) dispatched from Japan was 27 (1 long-term expert and 26 short-term experts). The number of trainees from Indonesia was 86. Joint research on CCS and monitoring in the Gundih gas field was successfully conducted within the project period, new technology and methods were developed, such as "CO_2 sequestration sites and storage evaluation" and "CO_2 behavior monitoring and evaluation," and the SOP was prepared. The equipment provided is generally well utilized and maintained. The project was implemented based on partnership, with the Indonesian side providing 29 counterparts from ITB and 4 from Pertamina to engage in the project, and the Indonesian side covering the counterpart personnel costs, project office, travel expenses, and equipment purchase costs.

3.3.1.2 Project Cost

The project cost on the Japan side was 357 million yen versus the planned 401 million yen, which was within the plan (89% of the plan).

3.3.1.3 Project Period

The project period was as planned (100%), with an actual of 60 months (September 2012 to September 2017) versus the planned 60 months (April 2012 to March 2017).

Both the project cost and project period were within the plan. Therefore, efficiency of the project is high.

3.4 Sustainability (Rating: ③)

3.4.1 Policy and Political Commitment for the Sustainability of Project Effects

The Indonesian government has set specific reduction targets for greenhouse gas emissions in its Nationally Determined Contribution (NDC) and Long-Term Low Emission Development Strategy, and CCS is positioned as one of the effective means to achieve these targets. For this reason, the Indonesian government is actively working to promote CCS/CCUS. This project was placed under the direct control of MEMR in 2017 and is positioned as a national project. In addition, regulations on CCS/CCUS, which are

necessary for promoting CCS/CCUS in Indonesia, are being developed.

Thus, the policy and political commitment necessary to sustain effectiveness has been secured.

3.4.2 Institutional/Organizational Aspects for the Sustainability of Project Effects

[MEMR]

MEMR is responsible for the overall resources and energy sector, which consists of four Directorates (Directorate General for New, Renewable Energy and Energy Conservation, Directorate General for Oil and Gas, Directorate General for Minerals and Coal, and Directorate General for Electricity) and three Agencies (Human Resource Development Agency of Energy and Mineral Resources, Research and Development Agency of Energy and Mineral Resources, and Geological Agency). Of these, the Oil and Natural Gas Engineering and Environment Bureau (10 staff) under the Directorate General of Oil and Gas is responsible for developing the regulations (ministerial regulations) on CCS/CCUS that are being developed. The Ministry has been cooperating with Japan's METI and has been building cooperative relationships in the energy sector for many years. In January 2022, a Memorandum of Cooperation on the realization of energy transition was signed with METI, and the two countries will continue to cooperate in developing and promoting CCS/CCUS technology.

[ITB]

ITB was established in 1959 in West Java Province as the first engineering university in Indonesia with 12 faculties and departments, 128 research programs, 111 research groups, 25 centers, 7 research centers, and 7 centers of excellence[8]. After project completion, research, development, the demonstration of CCS/CCUS technology in ITB have mainly been carried out through the National Center for Excellence for CCS/CCUS, established in 2017, and the Center for Carbon Dioxide and Flared Gas Utilization, established in 2020. The former is positioned as the center for research and development of CCS/CCUS in Indonesia, and the latter as the body for research and consulting services related to CCS/CCUS in collaboration with private companies. Both centers have about 45 staff members (who concurrently work in both organizations[9]), and many ITB faculty members involved in this project play essential roles in both centers as center directors and in other key roles.

As mentioned above, ITB and Pertamina have concluded a joint research agreement with

[8] A research center established at a university that centralizes excellent human resources and state-of-the-art facilities.

[9] Staff members work at either center depending on the nature of their work. Work at the National Center for Excellence for CCS/CCUS is on a volunteer (unpaid) basis.

the Japanese consortium. They are jointly conducting the basic design for the CCS pilot project (Pre-FEED) in FY2020-2021 under the METI scheme. The CCS pilot project in the Gundih gas field utilizing the NEDO scheme planned for FY2022 and onward will continue to be carried out under the same structure.

Since project completion, ITB has continued research and educational exchanges with Japanese partner institutions such as Kyoto University, Waseda University, Kyushu University, and the Fukada Geological Institute, and researchers in both countries frequently exchange information with each other. Japanese partner institutions also accept doctoral students and post-doctoral researchers from ITB. The team leaders of the Japanese researchers in this project continue to support ITB's research activities as overseas advisors to the National Center for Excellence for CCS/CCUS.

[Pertamina]

Pertamina is the largest state-owned oil and natural gas company, which was initially established in 1957 as the Oil and Gas Corporation. The shares in Pertamina are owned by the Indonesian government. The company is engaged in the exploitation, refining, domestic sales, and export of oil and natural gas in Indonesia. Pertamina has six sub-holding companies[10] under its holding company. Among them is the oil and gas exploration and production sub-holding company PT Pertamina Hulu Energi (PHE), which has 59 domestic and international subsidiaries, 8 joint ventures, and 2 subsidiaries. One of the subsidiary companies of PHE is Pertamina EP Cepu (PEPC), Zone 11, and this company owns the Gundih gas field.

In CPP Gundih, 10 employees (5 production staff, 3 mechanics, and 2 electrical equipment staff) have been assigned, and the maintenance and management of the facility is outsourced to contractors. As mentioned above, ITB and Pertamina have concluded a joint research agreement with the Japanese consortium and will continue to work on the CCS pilot project in the Gundih gas field.

Therefore, the institutional/organizational aspects necessary to sustain effectiveness are secured.

3.4.3 Technical Aspects for the Sustainability of Project Effects

[MEMR]

At the time of the ex-post evaluation, MEMR prepared draft regulations for CCS/CCUS through the National Center for Excellence for CCS/CCUS. These regulations are to be

[10] Pursuant to the Decrees of the Minister of SOE No. SK-198/MBU/06/2020 dated June 12, 2020, each subsidiary owned by the Pertamina Group was allocated to seven sectors and reorganized into "sub-holdings" and "corporations."

enacted and put into effect by the end of 2022, after consultation with stakeholders in each country and coordination among relevant ministries and agencies. The Ministry is also in charge of reviewing, approving, and monitoring CCS/CCUS projects in Indonesia, and is monitoring nine research projects for the commercialization of CCS/CCUS that had been approved at the time of ex-post evaluation.

[ITB]

The majority of ITB faculty and researchers engaged in the work of the National Center for Excellence for CCS/CCUS and the Center for Carbon Dioxide and Flared Gas Utilization were involved in the implementation of this project and are capable of continuing the research results of this project. Some ITB faculty and researchers will be lecturers at ITB having received their PhD. degrees from Kyushu University in 2021. Through the work of both centers, ITB has expanded its research area from CCS research for carbon capture and storage to the research and demonstration of CCUS for effectively utilizing captured and stored carbon dioxide. During the implementation of this project, the use and maintenance of the equipment provided were transferred from the Japanese side to ITB. The equipment continues to be used, and the maintenance status is generally satisfactory.

[Pertamina]

Pertamina is the owner and operator of the Gundih gas field and is providing ongoing technical assistance for the implementation of the project and subsequent studies, including providing data on wells, underground and surface facilities in the Gundih area. In addition, Pertamina has signed a memorandum of cooperation with a Japanese plant and engineering company to promote decarbonization business and explore new projects in the areas of hydrogen, ammonia, CCUS, and biogas. Pertamina is also working with a Japanese oil production company to evaluate the feasibility of a CCUS project in the Sukowati oil field using bilateral credits. In addition to this project, Pertamina has signed a memorandum of understanding with a major partner in international oil for joint research on the application of CCS/CCUS technology in South Sumatra, East Kalimantan, and West Java and is actively involved in the research, development, and promotion of CCS/CCUS technology in Indonesia. Pertamina is also conducting research on the production of blue hydrogen[11] in the CCUS process, and is moving toward the conclusion of a joint research agreement between Pertamina Corporate University and Kyushu University.

[11] A method of decomposing fossil fuels such as natural gas and coal into hydrogen and carbon dioxide by Steam Methane Reforming or Autothermal Reforming, and the carbon dioxide is captured before it is released into the atmosphere.

Therefore, the technical aspect necessary to sustain effectiveness has been secured.

3.4.4 Financial Aspects for the Sustainability of Project Effects

The Department of Energy and Mineral Resources and ITB budgets (2017-2021) related to CCS/CCUS are shown in Table 4.

Table 4 CCS/CCUS related Budget

Item	2017	2018	2019	2020	2021
Ministry of Energy and Mineral Resources (Directorate General for Oil and Gas)	IDR 636,089,000	IDR 620,618,000	IDR 25,108,000	IDR 249,375,000	IDR 491,252,000
ITB (Center for Carbon Dioxide and Flared Gas Utilization)	USD 200,000	USD 150,000	USD 150,000	USD 350,000	USD 350,000
Pertamina	N.A.	N.A.	N.A.	N.A.	N.A.

Source: Response to questionnaires for Energy and Mineral Resources and ITB.
Note 1: In addition to the above, ITB has other revenue from consulting fees from collaborating private companies.
Note 2: No information was provided by Pertamina.

The project was positioned as a national project under the direct control of MEMR. After project completion, progress was made to the basic design for a CCS pilot project (Pre-FEED) with funds from ADB and the METI. From FY2022 onward, the implementation of pilot project using NEDO funds is planned. At the time of this ex-post evaluation, the Japanese consortium, METI, and NEDO were discussing the project's feasibility. If the project is adopted as a publicly solicited NEDO project, NEDO will provide a five-year budget to implement the pilot project. Meanwhile, after the jurisdiction of the CCS pilot project in the Gundih gas field is transferred from PT Pertamina Hulu Energi (PHE), a sub-holding company, to Pertamina EP Cepu (PEPC), Zone 11, which manages and owns the Pertamina Central Production Facility where the gas field is located, Pertamina is considering the possibility of providing the gas field operating costs.

Therefore, it can be concluded that there is no problem regarding the finances necessary to sustain effectiveness.

No major problems have been observed in the policy background and the institutional/organizational, technical, financial aspects. Therefore, the sustainability of the project effects is high.

4. Conclusion, Lessons Learned and Recommendations

4.1 Conclusion

The purpose of this project was to promote Carbon Dioxide Capture and Storage (CCS)

programs in the Gundih gas field in Central Java, Indonesia by conducting research on CO_2 storage evaluation technology, and CO_2 sequestration and monitoring technology, which is necessary for CCS technology application. This project was highly relevant to Indonesia's development plan and development needs, as well as to Japan's ODA policy. Therefore, its relevance is high. Three of the five outputs were achieved or nearly achieved and two were partially achieved. Since the overall goal has been achieved and six initiatives for social implementation have been implemented or were being implemented at the time of the ex-post evaluation, it is judged that the overall goal has been achieved. The project has contributed to the improvement of the research capacity of the implementing agencies in Indonesia, and there were no problems in the utilization and maintenance of the equipment. No negative impact on the natural environment, land acquisition, or resettlement was observed. Therefore, the effectiveness and impact of the project is high, as the project has been as effective as planned. Both the project cost and project period were within the plan, and the efficiency of the project is high. No major problems have been observed in the policy background and the institutional/organizational, technical, financial aspects. Therefore, the sustainability of the project effects is high.

In light of the above, the project is evaluated to be highly satisfactory.

4.2 Recommendations

4.2.1 Recommendations to the Implementing Agency

MEMR is expected to continue to demonstrate leadership, including coordination with relevant ministries and agencies, to ensure that the regulations on CCS/CCUS, which are currently being formulated, can be enacted and put into effect during 2021 as planned.

4.2.2 Recommendations to JICA

None

4.3 Lessons Learned

(1) Establishment of cooperative relationships with governments of relevant countries and international organizations interested in the research fields and subjects during the implementation of the project to enhance the sustainability of the research results after completion

Although it was not planned at the start of the project, ADB and the Norwegian government showed an interest in the research area of the project, and using the research funds provided by ADB, the project proceeded with studies on the social receptivity of the residents in the injection area, CO_2 capture technology in the Gundih gas field, the transport of CO_2, the surface facilities for injection, and the legal regulations for CCS implementation.

In addition, Norway provided the funding for a risk analysis study of the project. Furthermore, this project was selected by NEDO as a "Program for Dissemination and Promotion of Global Warming Countermeasure Technology" in FY2015, and using funds from this NEDO program, a feasibility study for a Joint Crediting Mechanism (JCM) was conducted for the CCS project in the Gundih gas field as a case study. Thus, collaboration with ADB, Norway, and NEDO was promoted during project implementation. Meanwhile, MEMR and Japan's METI have had a long-standing cooperative relationship in the energy sector, and many Japanese companies have also invested and secured interests in the Indonesian energy sector. In this way, the development and commercialization of CCS/CCUS technology in Indonesia have been expected to contribute to the dissemination of Japan's superior low-carbon technology and systems, and to global greenhouse gas reduction as well as to greatly benefit Japan and Japanese companies from the perspective of securing their future emission credits. In light of the above, ADB and METI decided to finance the research portion of the project even after project completion, and research for the CCS pilot project in the Gundih gas field has continued.

It is highly likely that the collaboration which took place during project implementation between the governments of the countries concerned and international organizations interested in the research fields and subjects of the project leads to the continuation of the research results after project completion.

(End.)