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Master’s Thesis

Analysis of Oceanographic Information as a Co-benefit of Ocean Renewable Energy Projects-A case study of Japan’s Ocean Current Power Project

(海洋エネルギーシステム導入によるコベネ フィットとしての海洋情報に関する研究 - 水中浮遊式の海流発電システムの事例研究)

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ANALYSIS OF OCEANOGRAPHIC INFORMATION AS A CO-BENEFIT OF OCEAN

RENEWABLE ENERGY PROJECTS

- A CASE STUDY OF JAPAN’S OCEAN CURRENT POWER PROJECT

ABSTRACT

Ocean renewable energy sources have been identified with a high potential which is in abundance globally (Huckerby et al., 2012). Ocean current energy is one such renewable energy where Japan has a potential to generate at least 5% of its electricity demand if 10% of the estimated power can be extracted from the Kuroshio Ocean Current (Takagi, 2014). With the post Fukushima social pressure, Japan is trying to improve its electricity generation from renewable energy sources. Ocean Current Power (OCP) project is one such initiative which tries to capture the power of Kuroshio Current to generate electricity (IHI Corporation, 2014).

Ocean renewable energy technologies are still in the development phase. Hence, there are many uncertainties such as potential impacts to the environment and existing industries. These uncertainties cause social acceptance issues, which becomes a threat to the deployment of the power projects. Potential social acceptability issues become more significant in Japan due to the lack of Marine Spatial Planning (MSP) and high socio-economic prominence given to the marine industries such as fisheries. This has been evident in the past coastal projects such as the JAXA’s space center development in Tanagashima, Offshore wind farm development in Yasuoka etc. Compensation schemes, the conventional way of handling the stakeholder opposition, causes a huge additional costs to the project developers. Additional project costs impacts the success of the ocean renewable energy projects which already very expensive.

Sharing the co-benefits of the power projects to achieve synergies among the stakeholders has been identified as a more sustainable way of improving the social acceptability. RIOE (2013), has proposed several negotiation options which can be used to build fisheries consensus for offshore wind power projects. One of the most applicable proposal to the OCP project is "sharing oceanographic information captured by the power plant's Condition Monitoring Systems (CMS) to the other stakeholders who is in need of such information". Similar type of oceanographic information sharing schemes have been used in other types of applications (such as the scientific ocean observation projects, shipping industry etc.). However this idea has not being used or tested in the ocean renewable energy sector. Hence the purpose of this research is to test the potential of the oceanographic information sharing scheme to achieve synergies among stakeholders in a context of ocean renewable energy projects. To test the hypothesis "The CMS of the ocean renewable energy project can satisfy the stakeholders' oceanographic information requirements", three specific research questions (R.Q.) were considered.

R.Q.1 – What oceanographic parameters are required by the stakeholders?

R.Q.2 – What oceanographic parameters can be generated by the plant's CMS?

R.Q.3 – What is the expected incremental costs and benefits to the stakeholders?

Japan's OCP project was selected as the case study and Shionomisaki area in the Wakayama prefecture, which is one of the project deployment sites, has been selected as the case study area. Fishermen, Fishery Union, Researchers and Project Developers have been selected as the main stakeholders considering the potential impacts to the industries and the socio-economic importance of the stakeholder groups in the area. Stakeholder interviews and focus group discussions have been used for primary data collection. Data from the similar information sharing systems, financial estimates of the OCP project and related market data etc. have been used as secondary data. Even though the secondary data has been used to validate and complement the primary data, a significant level of data unavailability and uncertainty was evident. Hence DS/AHP model, an evidence based decision making model (Beynon et al., 2000), which combines the standard Analytical Hierarchy Process (Saaty, 1987) and the Dempster Shafer Theory (Dempster, 1967, 1968; Shafer, 1976), was used as the final Multi Criteria Decision Making (MCDM) methodology. Since there were no calculation tool available to run DS/AHP model, a new DS/AHP software tool was also created using the C# programming language.

In addition to the monetary costs and benefits, qualitative criteria such as improvements to the existing oceanographic data sets and stakeholder engagement were used as decision criteria. From the results of the research question one and two, it was identified that most of the essential stakeholder information requirements can be fulfilled by the standard CMS. Considerable amount of other information requirements can be satisfied by doing incremental changes to the standard CMS. Hence, following scenarios were considered in the MCDM model.

Scenario 1 – No information sharing (Null hypothesis)

Scenario 2 – Sharing all the information required by the stakeholders

Scenario 3 – Sharing the information which is obtained for power plant operation

According to the worst case cost estimates, incremental startup cost and the annual maintenance cost (if incremental changes were to be implemented in the standard CMS) was estimated to be in the range of ¥130 – 190 million. Improvements in fishing area selection, travel cost reductions, improved fish migration pattern simulation etc. have been identified as the potential benefits. Willingness to Pay (WTP) of the fishery union is ranging from ¥100,000 – ¥500,000 /fisherman/year. Since the fishery union has more than 800 full time members and more than 2700 associate members, union's WTP is comparable to the annual additional costs. Sensitivity analysis done on the identified benefits shows the mentioned WTP range is reliable if the fisheries achieve at least 1%-5% income improvement and 'fuel and other cost' reductions. Researchers as well as the developers also identified qualitative benefits even though there were not enough data to estimate in monetary terms. The results of the DS/AHP decision making model shows that all the stakeholder groups selected the third scenario as the preferred scenario. The local government officials were also in favor of the proposal as they believed this can lead to more synergies among traditional and modern industries to revitalize the local economy. Hence this research outcomes proves the hypothesis, viability of the proposed information sharing scheme and its potential to generate benefits for all the stakeholders considered.

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I would like to express my sincere gratitude to my supervisor, Professor Ken Takagi for his patience and support during the two years of my master’s research and thesis writing. His constant guidance and advises helped me a lot to broaden my knowledge about the marine renewable energy in general as well as the ongoing Ocean Current Power(OCP) project specifically. He also helped a lot to conduct the field work in this research by helping me to build contacts with the key informants, financially supporting the field activities as well as guiding my field activities to get the expected results. I would also like to thank my co-supervisor, Associate Professor Hirotaka Matsuda for his guidance on vital areas of my research.

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DEDICATION

Effort, dedication, and commitment were fundamental elements for the completion of my master thesis, but even more important was the support of my family and friends. Today, I dedicate this important professional achievement to my family and friends because without their presence, support, love, and understanding, I would have never been able to achieve my goal.

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LIST OF ABBREVIATIONS

ADCP	- Acoustic Doppler Current Profiler
AHP	- Analytical Hierarchy Process
AWAC	- Acoustic Wave and Current (sensor)
CBA	- Cost Benefit Analysis
CISE	- Common Information Sharing Environment
CMS	- Condition Monitoring System
CO_2	- Carbon Dioxide
CORMP	- Coastal Ocean Research and Monitoring Program
CTD	- Conductivity Temperature Depth (sensor)
DS-AHP	- Dempster Shafer Analytical Hierarchy Process
DST	- Dempster Shafer Theory
DVL	- Doppler Velocity Log
EEZ	- Exclusive Economic Zone
EM	- Electromagnetic
ERS	- EuroGOOS Requirement Survey
EuroGOOS	- European (component of) Global Ocean Observation System
FEPC	- Federation of Electric power Companies (in Japan)
FINO	- *Forschungsplattformen in Nord- und Ostsee* (Research platforms in the North and Baltic Seas)
GHG	- Greenhouse Gas
GOOS	- Global Ocean Observation System
GPS	- Global Positioning System
GPSS	- Graduate Program in Sustainability Science

LIST OF ABBREVIATIONS (continued)

ICES	- International Council for the Exploration of the Sea
ICT	- Information and Communication Technology
IEA	- International Energy Agency
IPCC	- Intergovernmental Panel on Climate Change
JAXA	- Japan Aerospace Exploration Agency
LNG	- Liquid Natural Gas
MAFF	- Ministry of Agriculture, Forestry and Fisheries (in Japan)
MCDM	- Multi Criteria Decision Making
METI	- Ministry of Economy, Trade and Industry (in Japan)
MFSTEP	- Mediterranean Forecasting System Towards Environmental Predictions
MMO	- Marine Mammal Observation
MSP	- Marine Spatial Planning
NEDO	- New Energy and Industrial Technology Development Organization
NIMBY	- Not In My Back Yard
NOAA	- National Oceanic and Atmospheric Administration
OCP	- Ocean Current Power
R.Q.	- Research Question
RIOE	- Research Institute for Ocean Economics (in Japan)
SSS	- Sea Surface Salinity
SST	- Sea Surface Temperature
WGOOFE	- Working Group on operational Oceanographic products for Fisheries and Environment
WTP	- Willingness to pay

LIST OF UNITS OF MEASUREMENT

$	- Dollars (Currency of United States)
£	- Euro (Currency of European Union)
¥	- Yen (Currency of Japan)
%	- Percentage
GW	- Gigawatts
km	- Kilometers
kW	- Kilowatts
m	- Meters
m/s or ms^{-1}	- Meters per second
MW	- Megawatts
MWh	- Megawatt hours
n.mil	- Nautical miles
TWh	- Terawatt hours

1 INTRODUCTION

1.1 Sustainability and Ocean Renewable Energy in the global perspective

Sustainable energy is one of the most important and critical issues which has to be addressed in the global level. It is directly influencing the several other sustainability issues such as climate change, over dependency on non-renewable fossil fuels and improper wealth and resource distribution etc. According to IPCC (2014), Electricity and Heat production along contributes to about 25% of the global greenhouse gas (GHG) emissions (Figure 1.1).

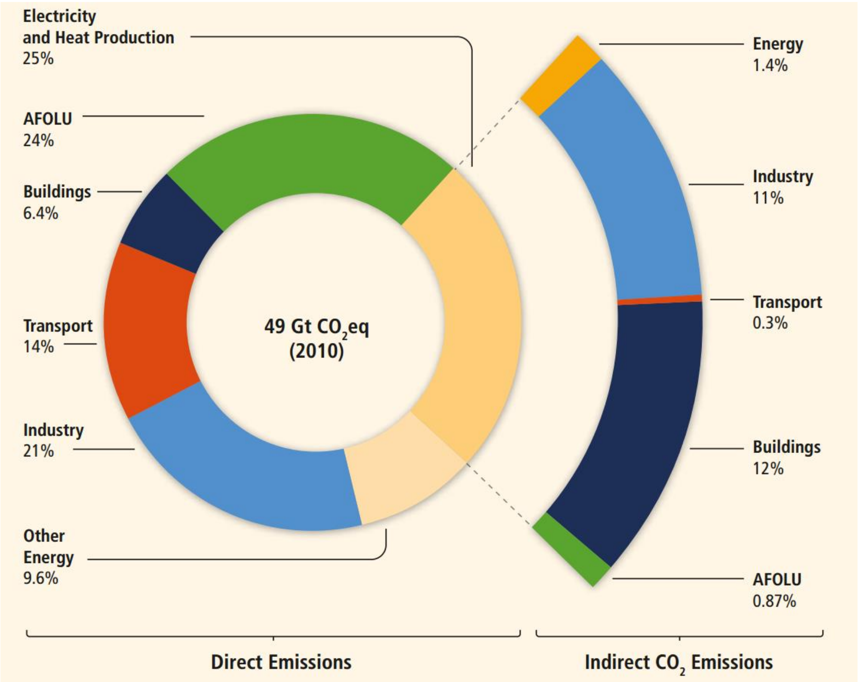

Figure 1.1 Greenhouse Gas Emissions by Economic Sectors in 2010.

Source-Mitigation of Climate Change: Climate Change 2014 by Intergovernmental Panel on Climate Change (IPCC), Technical Summary, page.14 (IPCC, 2014)

If the Electricity can be generated from a sustainable way with minimum amount of GHG emissions, it can help a lot to mitigate the climate change. With the new technologies such as electric transportation modes, more and more technology penetration to the primary industries, dependency on electricity is ever rising. With this current trends, the desire for sustainable electricity generation is ever increasing.

When defining the sustainable electricity generation, the most important factor is the ratio of non-renewable energy sources to renewable energy sources used in the energy mix. According to the Figure 1.2 from International Energy Agency (IEA), the total non-renewable fossil fuel based electricity production is about 67.4% and Nuclear based electricity production is about 10.6% while all the renewable energy sources (Hydro, Solar, Wind, Tidal Current etc.) contribution is only about 22% of the global electricity supply (IEA, 2015).

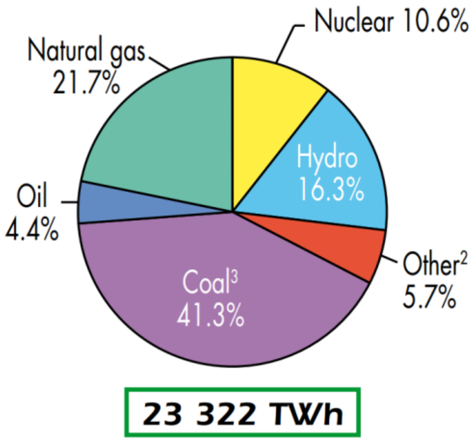

Figure 1.2 Fuel shares of global electricity generation in 2013 (Excluding pumped storage)

Source: Key World Energy Statistics 2015, IEA. Pg24

Despite this low level of penetration of the renewable energy into the global electricity generation mix, most countries with a very high electricity demand, target to achieve a higher percentage of renewable energy in their domestic electricity supply. For example, European Union has a target to achieve 20% of energy supply from renewable sources by 2020 (European Commission., n.d.) while Japan’s energy policy targets to achieve 22%-24% from renewable sources.(METI, 2014).

Renewable energy is not a new concept to the world. For example, the concept of electricity generation from solar radiation and wind energy has been there for decades. Due to the economic and technological barriers, these sources have not been able to compete with the traditional fossil fuels. Hence the true potential of these renewable sources has not been harnessed. With the technical developments, new renewable energy potentials have been identified and Ocean renewable energy is one such new frontier.

Previous research (VanZwieten et al., 2013) has estimated the power densities of the most powerful ocean currents in the world and ‘IEA-Ocean Energy Systems’ (Huckerby et al., 2012) have estimated the different ocean energy potentials globally as shown in the Figure 1.3. According to the previous research, the extractable amount of power from the ocean energy sources is significant. Having identified this huge potential, several countries have already started projects to harness energy from this untapped potential. By analyzing the similar cases in the past such as the gradual development of wind energy technology, we can expect ocean energy technologies also become popular as the technology develops. Hence, there is a very high possibility for ocean energy to become a major energy source in the future global energy mix which will ultimately contribute to for achieving a sustainable global energy supply.

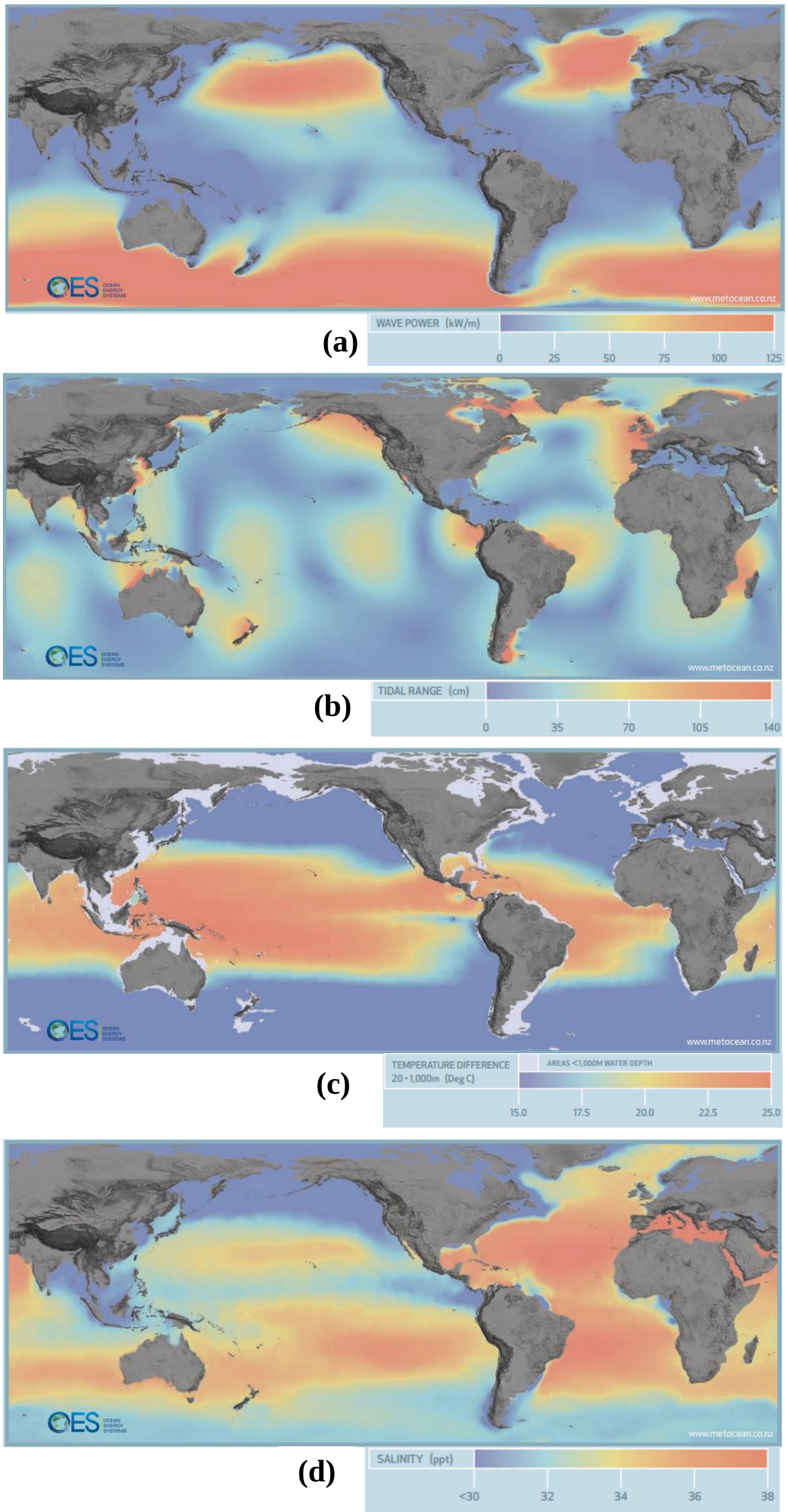

Figure 1.3 (a). Global Wave Power (b). Tidal power (c). Temperature difference (d). Salinity difference distribution

Source: "An International Vision for Ocean Energy" IEA-OES (2012)

1.2 Importance of Ocean Renewable Energy for Japan

Ocean renewable energy sources are very important to Japan, especially after Fukushima disaster. Figure 1.4 shows the Japan's primary energy supply percentage by source. It is clear that Japan has reduced the percentage of electricity generated from nuclear energy. And that gap has been almost filled by the Oil and Natural gas since the total demand has not been changed much from 2010 to 2012 (FEPC, 2014).

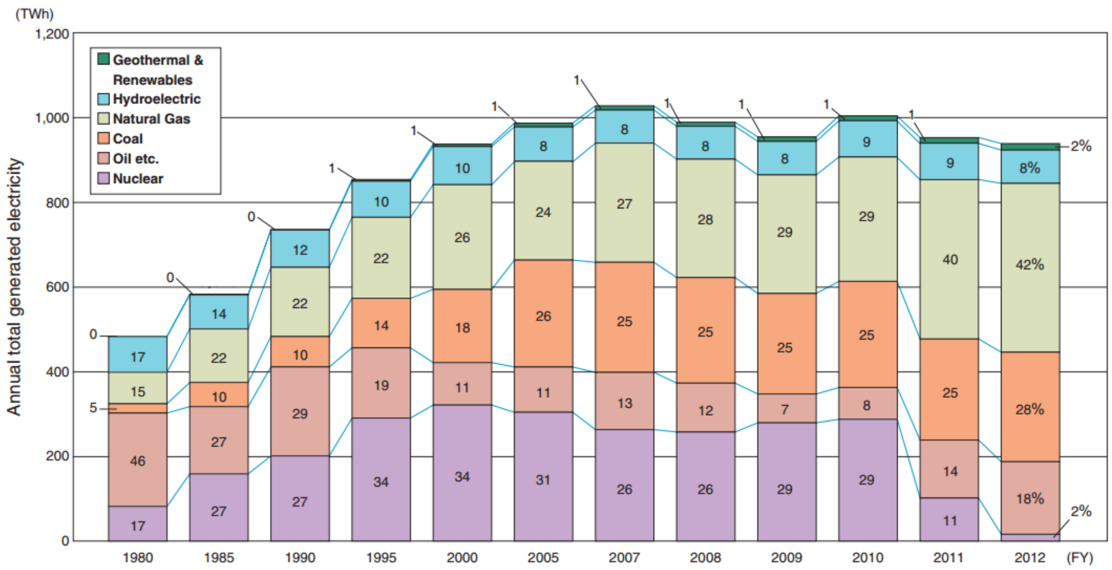

Figure 1.4 Historical Trend of Power Generation Volume by Source in Japan.

Source: The Federation of Electric power Companies (FECP) of Japan (2014)

Due to this shift in the power source, Japan has experience a rapid increase in the CO_2 emissions in the energy production as shown in Figure 1.5. And according to the strategic energy plan 2014 (METI, 2014), which is the fourth version of the Japan's energy policy, this energy shift has created a huge budget deficit in the Japanese economy while creating a considerable energy dependency towards fossil fuel exporting nations. Due to these factors, the latest energy policy target is to achieve 22%-24% electricity production by renewable sources.

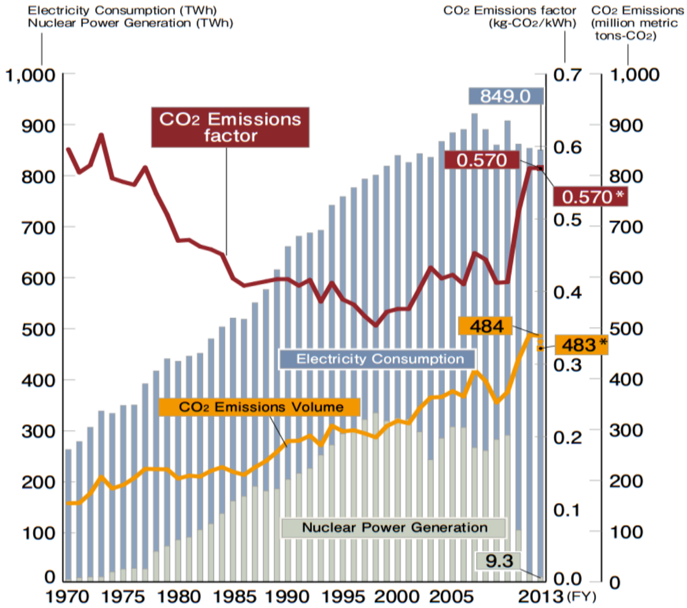

Figure 1.5 Historical trends in CO2 emission from power generation in Japan (Excluding self-generators)

Source: The Federation of Electric power Companies (FECP) of Japan (2014)

Table 1-1 describes the desired Japanese energy mix by 2030. However this requires reactivating most of the nuclear reactors which has been shut down due to post Fukushima public opposition towards nuclear energy. The reduced energy supply from the fossil fuels is planned to be recovered from the renewable energy sources. However, ocean energy is not been considered in this plan since the related technology is still in the very early development stages to give a reliable estimate.

Table 1-1 Japanese energy mix by 2030.

Technology		Desired energy mix by 2030
Non Renewable	Coal	26%
	Gas	27%
	Oil	3%
	Nuclear	20-22%
Renewable Sources	Hydro	8.8-9.2%
	Geothermal	1.0-1.1%
	Biomass	3.7-4.6%
	Wind	1.7%
	Solar	7%

Source: Strategic Energy Plan 2014 (METI Japan 2014)

Even though the technology has not been proven to be commercially viable by actual deployments, past researches such as (VanZwieten et al., 2013) have proved the high potential of Kuroshio Current which flows stably throughout the year closer to the Japans main land (Figure 1.7). In addition to this main ocean energy source, Japan also have considerable potential from the tidal energy as well. Hence marine current energy is the newest frontier of the Japanese electricity generation. On top of the above potentials, ocean energy sources are more predictable and stable than the conventional renewable sources such as solar power, wind power etc. which is intermittent by nature. Long term observations have proven that Kuroshio Current is stable in most of the areas while the tidal levels are predictable with higher accuracy. By the identification of the potentials of ocean energy sources, many countries have initiated different ocean renewable energy projects and the tenfold generation capacity growth in first decade of this century (Figure 1.6), is a clear evident of the booming industry.

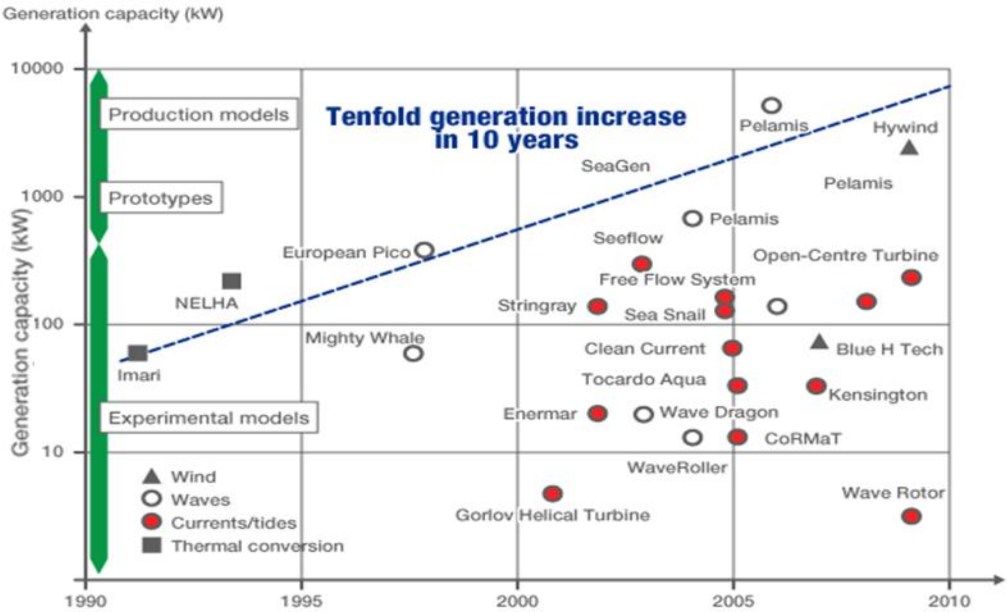

Figure 1.6 Number of Ocean Renewable Energy Projects Initiated from 1990-2010

Source：http://www.nippon.com/en/in-depth/a01203/ (last retrieved on 30th June, 2016)

It is important to notice that Japan led field in research and development of marine energy until the 90s however due to the availability of cheaper energy options, those initiatives had faded. However, few European countries continued their researches which resulted a significant improvement in the technology in the last decade making them the industry leaders. Following the post Fukushima energy crisis, Japan also followed the European trend of investing on Ocean renewable energy, because Japan has a significant power generation potential from tides, wind and ocean currents. Kuroshio ocean current is one of the most powerful and stable ocean current flowing near to the main land within the Exclusive Economic Zone (EEZ).

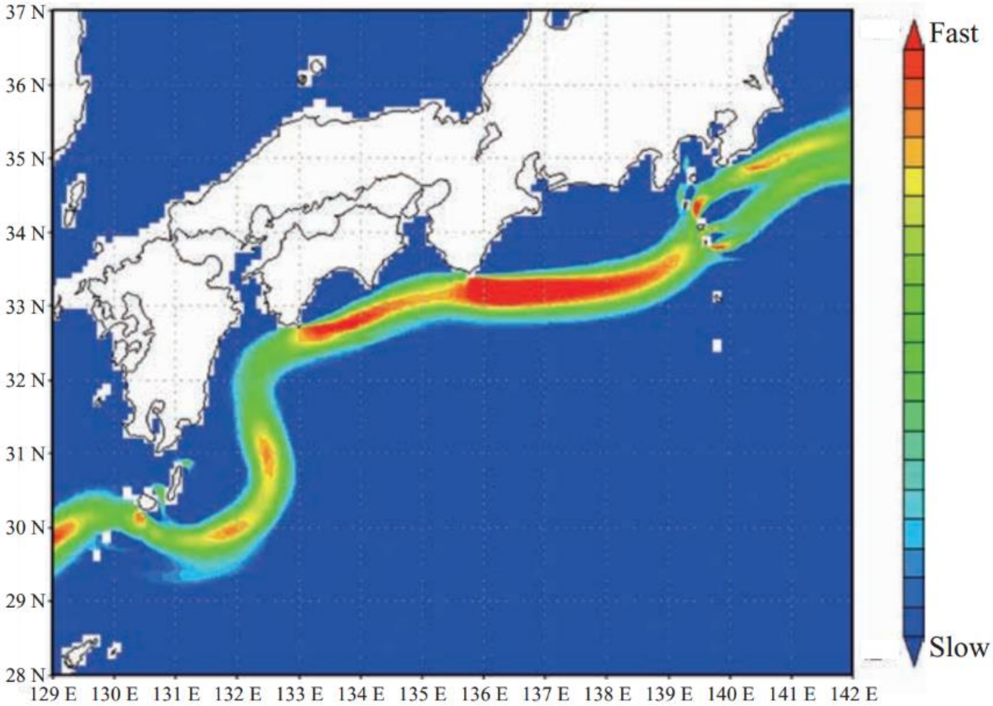

Figure 1.7 Estimated high power density areas of the Kuroshio Current Sources

Source: IHI Corporation

1.3 Japan’s Ocean Current Power (OCP) Project

Japans Kuroshio Current is estimated to have a huge potential, more than 200GW according to NEDO (2011), where the extractable amount is enough to supply at least 5% of the Japans national electricity demand. (Takagi, 2014). With the expectation of extracting this huge potential, a consortium led by ‘New Energy and Industrial Technology Development Organization (NEDO), IHI corporation, Toshiba corporation, Mitsui Global Strategic Studies (MGSSI) and the University of Tokyo (UoT), has started a demonstration research project of an ‘underwater floating type ocean current energy turbine system’ in 2011. The first deployment of this pilot project is planned in 2020. According to the preliminary plans, the main deployment will consist of 100 floating type twin turbine devices with power generation capacity of 200MW. Following conceptual diagrams in Figure 1.8 and Figure 1.9 illustrate the floating type turbine devices and the proposed underwater power plant.

Table 1-2 Design parameters of the proposed power plant

Design Parameter	Value
Number of turbines per unit	2
Number of units in the farm	100
Rated output of a turbine	1 MW
Diameter of a turbine	~40 m
Area of the power farm	~8 x 2.75 km
Expected cost of electricity	20 yen/kWh

Source: IHI Corporation

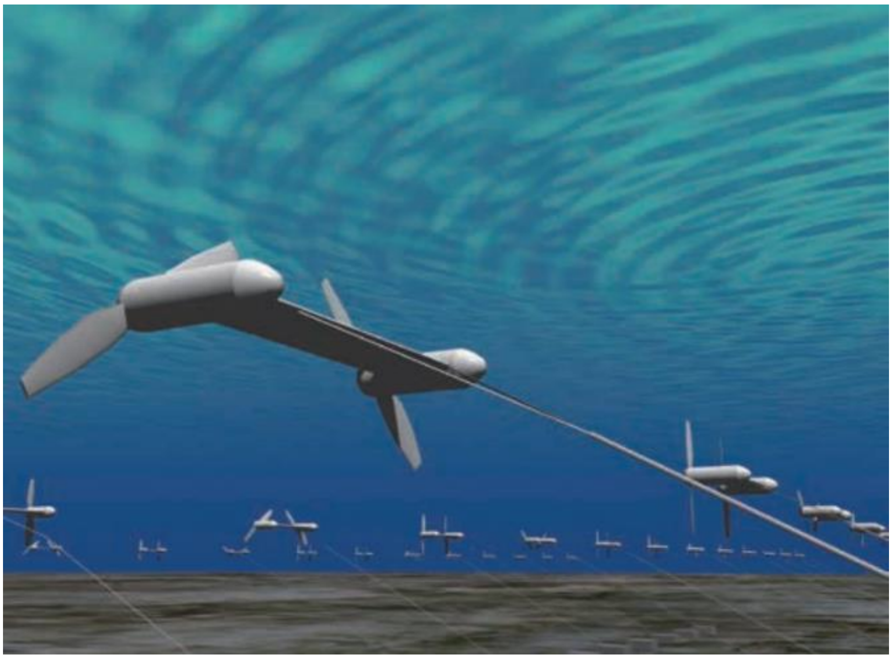

Figure 1.8 Proposed Ocean Current Power farm

Source: IHI Corporation

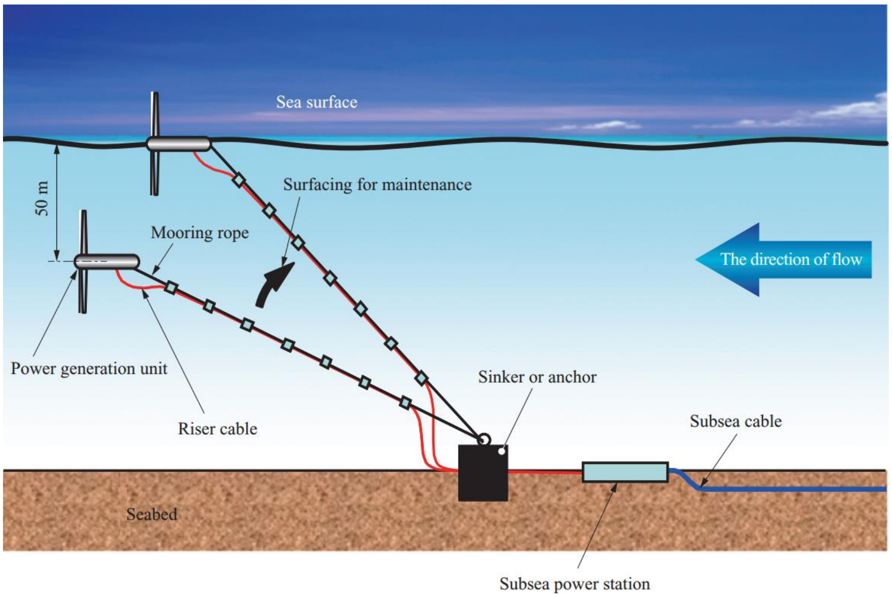

Figure 1.9 Conceptual diagram of the floating type turbine devices

Source: IHI Corporation

1.4 Previous examples and expected stakeholder opposition for ocean energy

Ocean is a common resource where many stakeholder groups use for their economic and recreational activities. In addition, some sea areas are rich in bio-diversity which is very sensitive to the anthropogenic eco system changes. Despite of those facts, there is very little spatial planning done for the general sea areas. Because of the lack of Marine Spatial Planning (MSP), it is very controversial to introduce new elements to the existing dynamics. There are major economic activities done in the considered ocean areas such as commercial fishing, Tourism and transport industry etc. Once the ocean renewable project is deployed, the prevailing economic activities might get impacted. These impacts are adverse to the prevailing industries according to the traditional view. For example, certain fishing methods get banned in the area, restrictions to shipping and recreational activities etc. (Sakaguchi, 2015).

One of the most frequently quoted example is the conflict and the resulting compensation scheme between the Japan Aerospace Exploration Agency (JAXA) and the local fishery union regarding the establishment of their largest space center in the Tanegashima Island. The local fisheries was against the project due to the potential adverse impacts to the surrounding fishing grounds. The project was deployed in the end after getting the consensus of the interested parties, which resulted a huge compensation scheme as well as restrictions on rocket launching days for more than 3 decades. (JAXA, 2010; SpaceDaily, 1997)

Similar to the perceived negative impacts to the prevailing industries, Not In My Back Yard (NIMBY) effect is also causing a significant stakeholder opposition for power projects. The term NIMBY is commonly used in previous literature with an implication of 'selfish' nature of local stakeholders while accepting the renewable energy in general. However, Burningham (2000) and Wolsink (2006) suggest that it is more complex and reasonable for stakeholders to oppose the project deployments in their locality.

Another major reason for high stakeholder opposition for marine renewable energy is the lack of experience and uncertainties due to the novelty of the technology. These uncertainties have caused a higher perceived risk than the perceived benefits for most of the local stakeholders.

Due to these reasons (highlighted from other types of renewable energy projects and from the past experiences especially from the coastal or offshore development projects), it is expected to have a significant stakeholder opposition for ocean renewable energy projects as well.

1.5 Legal situation with the OCP project deployment

According to the prime minister's Headquaters for Ocean Policy in Japan (2013), the deployment site selection of the ocean renewable energy project has to comply with several procedures and regulations. The existing legal system is scattered among different acts, laws and governmental bureaus. (Sakaguchi, 2015). According to the "United Nations Convention on the Law of the Sea", sea areas up to 200 nautical miles can be used for the resource extraction (Figure 1.10).

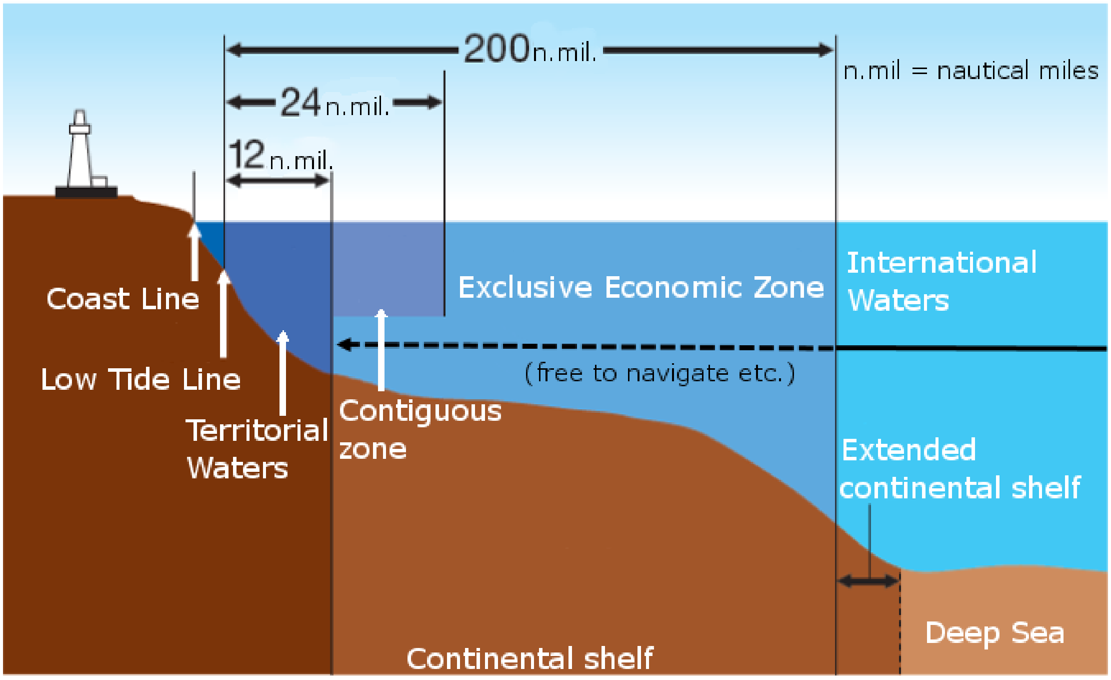

Figure 1.10 Explanation of Sea Areas defined by the United Nations Convention on the Law of the Sea

Source: http://www1.kaiho.mlit.go.jp/JODC/ryokai/zyoho/msk_idx.html [retrieved on 15th July, 2016]

However, according to the relevant laws in the Japanese context, part of the EEZ has been allocated for the fisheries with ‘Rights to Fish’ while most of the remaining area has been allocated with ‘Permission to Fish’. The sea areas with ‘Permission to Fish’ may be shared with other marine industries with the permission of the governor of the prefecture. According to the developers, the OCP project would be deployed in this shared sea area where the fisheries and other marine users can have a shared permission to continue their industrial activities. Hence there is no need to have a compensation for fisheries. However, it was also mentioned that fisheries can lead to a compensation scheme if it is proven that the OCP project effects fishery industry in the sea areas with ‘Right to Fish’. In addition, the national ocean policy headquarters requires the developers to get the prefectural governor’s, ministers’ (of the ministry of agriculture, forestry and fishery (MAFF) and the ministry of land, infrastructure and transport (MLIT)) and even the local fishery association’s approval depending on the changes or impacts occur to the existing sea areas with ‘Right to fish’ or within the ‘Low Tide Line’ etc. Generally it is not necessary to compensate or get the permission from the existing marine industries provided that OCP project are deployed in common sea areas and it is not proven that the OCP project has any impact on the other dedicated sea areas such the ‘Right to fish’ areas, conservation areas etc.

1.6 Problem identification and previous research findings

Even though the OCP project is being deployed in the common sea areas, the fisheries and other stakeholders perceive a considerable risk of having negative impacts from the project. In addition, according to previous research, existing marine industries and permission levels will also have to be adjusted in the OCP project deployment area according to the requirements of the project (Sakaguchi, 2015). According to Sakaguchi (2015), the main underlying reasons for potential stakeholder opposition has to be resolved by multi-dimensional adjustments to the existing socioeconomic and legal systems. However, consensus building by means of doing adjustments to the existing socio-economic and legislation involves a huge effort with respect to the expected increment of the stakeholder acceptability.

From the previous examples, especially from wind energy project deployments in Europe, the expert group on wind energy in International Energy Agency (IEA Wind, 2013) has identified several recommendations under 5 main themes, 1), Policy and Strategy (including Planning and support regimes), 2) Well-being and Quality of Life (including property value prices and landscape / ecosystems), 3) Distributional Design (including Costs and Benefits for the host communities), 4) Procedural Design (including Processes, Consultation and Involvement), 5) Implementation Strategies (e.g., Local Empowerment). Report explains the local community generally feel a sense of injustice or being exploited by national or multinational level corporates especially if the power projects are owned and managed by entities that are not permanent members of the local community because there is no direct economic or financial benefit for the local community. Rather most probably the local community has to bare the associated industrial and environmental costs. Hence it is recommended to look for strategies to create an equitable distribution of costs and benefits at the early stage of project development. Further it is emphasized that these strategies should not act as a bribe, but a means to achieve a balance of interests and fair distribution of positive and negative project impacts.

The main recommendations given under the theme of 'Distributional Design' by this expert group is, providing opportunity for local stakeholders to engage with the project, giving merits to the local economy, industries and community and improving the fairness, inclusivity and respect towards local requirements. From considering the relevant literature, the main strategies the developers have considered (in the previous onshore renewable energy project deployments) to win the public acceptance, can be summarized in the Table 1-3. These strategies have been adopted mostly during onshore wind power project deployments. In addition, cost effective strategies such as public involvement is relatively difficult and time consuming for the marine renewable energy projects. The main reason is the difficulty to identify the effected local stakeholder groups since many types of industrial activities happen in the marine areas where no Marine Spatial Planning (MSP) exists. Hence it is economically un-viable if the cost of the coping strategy increases with the number of stakeholders involved.

Hence the project developers have to consider about the relationship with cost and involved number of stakeholders, or have to create new strategies where the cost has an insignificant correlation with the number of stakeholders considered.

Table 1-3 Summary of the social acceptability improvement strategies from the literature

Main type	Examples
Financial Support	Profit / tax benefit used for local development
	Giving opportunity for local stakeholders to invest in the power project
	Ownership or shareholders of wind turbines, rented territory etc. (Brunt & Spooner, 1998)
Non-Financial incentives	Give value addition to the local tourism by Proposing a new combined visit to the existing tourist destinations and new power farm. (Jobert, Laborgne, & Mimler, 2007)
	Development of local infrastructure
Stakeholder Engagement	Project Information dissemination by public meetings (Jobert et al., 2007)
	Public participation in the project planning process, especially during the site selection (Bosley & Bosley, 1988)
	Involving local or third party stakeholders to monitor the project development/ post environmental impact (Jobert et al., 2007)
Getting the legislative / political support	Long term agreements with local governments, Mayors while lobbying for policy changes to support the project (Jobert et al., 2007)
	Change of (German) federal law which gave wind turbines privileged status where local communities refuse them totally. (Jobert et al., 2007)
Other	Isolating and dividing opposing stakeholders (Jobert et al., 2007)
	Selecting sites allocated for less attractive land use such as dumping sites (Jobert et al., 2007)

Source: Made by the author based on the literature

In the sustainability perspective, creating synergies among multiple local stakeholders or industries by means of project co-benefits, is the optimum distributional project design where all the stakeholders receive additional benefits with compared to standard project development process. Research Institute for Ocean Economics (RIOE), Japan (2013) has focused more into this concept with specific practical options to negotiate with fisheries when deploying offshore wind power projects as follows.

1. Providing real time oceanographic information
2. Use of wind Turbine foundations for
   a. Conservation breeding purposes
   b. Fishing operation purposes
3. Placing the Aquaculture facilities using the power plant's hard infrastructure
4. Placing Fixed Fishing Nets using the power plant's hard infrastructure
5. Combined use of leisure facilities
   a. Fishing parks
   b. Diving spots
6. Use of generated electrical power to,
   a. Supply electricity to the onshore facilities (e.g. Fish processing facilities etc.)
   b. Electric fishing boats
7. Fishery Engagement
   a. Use of fisheries (Boats) for power plant construction & maintenance activities
   b. Investment opportunities in the power plant project

Unlike offshore wind projects, (where static piles are the main subsea hard infrastructure developed), Ocean renewable energy projects (such as Tidal or Ocean current, Wave power conversion devices) has more dynamic devices in the water. For example, the infrastructure developed for the proposed Ocean Current Project is entirely submerged in the water. With this type of design limitations, the developers can only use the ‘Real time oceanographic information option’ (option 1) or the ‘sharing generated electricity option’ (option 6) as the non-monetary incentive scheme during the stakeholders negotiations. Engagement with stakeholders as described in Option 7 is also practically difficult since the identification of really effected stakeholders is difficult. Sharing of generated electricity is also economically unviable since the related costs are directly proportionate to the number of stakeholders considered. However the cost of the proposed option to provide oceanographic information is not proportionate to the number of stakeholders who receive the information due to the cheap or free information and communication technologies such as internet. Hence this option satisfies all the requirements discussed up to now. Further, this concept has not been tested or applied in the previous ocean renewable energy projects according to the literature.

1.7 The concept of Oceanographic Information sharing

According to the "National Geographic Society", Oceanography is the study of all aspects of the ocean from different disciplines such as Biological Oceanography, Physical Oceanography, Geological Oceanography, Chemical Oceanography etc. Oceanographic information refers to wide range of parameters which can be used to describe or forecast the marine conditions in different perspectives according to the respective discipline. Marine eco system is a highly inter-related, complex structure. Hence Oceanographic information is required by almost all the persons who directly use marine areas as well as coastal areas for their industrial of recreation activities or livelihood. In addition oceanographic information is required for policy implementation, controlling regulation of marine space usage, monitoring and assessing the anthropogenic impacts to marine eco-system and estimate the future global level impacts such as climate change as well. Hence, oceanographic information is directly or indirectly effects most of the population.

There are different oceanographic information sources developed to satisfy this information demand such as autonomous ocean monitoring platforms such as buoy systems, remote sensing using dedicated satellites, user-specific ocean monitoring systems in different industries such as weather forecasting, commercial shipping, fishery etc. However, it is practically impossible to satisfy all the oceanographic information demands due to many reasons such as the limited coverage (only a few percentage of the entire ocean areas have been explored up to now), significant variety in information demand from the users from different disciplines, very high cost of ocean observations and lack of information sharing especially between the industries. One of the very effective pragmatic approach to fill this gap is to share the observed oceanographic information with other users. In this approach, the total cost of ocean observation is reduced because sharing of information avoids the effort duplication made to obtain the same data for different user groups. This is the underlying concept of implementing oceanographic data sharing systems such as 'Global Ocean Observation System'("GOOS)" , 'Common Information Sharing Environment' (CISE (2010)) project in Europe etc.

According to CISE project, sharing of Oceanographic information across multiple sectors such as border control, safety and security, fisheries control, customs, environment or defense (of each member states) results major economic benefits to all related sectors by improving the data quality and availability (Figure 1.11), cost efficiency of data acquisition by removing the duplicate efforts to acquire data, better coordination and collaboration among different sectors and better management and regulation of maritime domains (European Commission Maritime affirs, 2014).

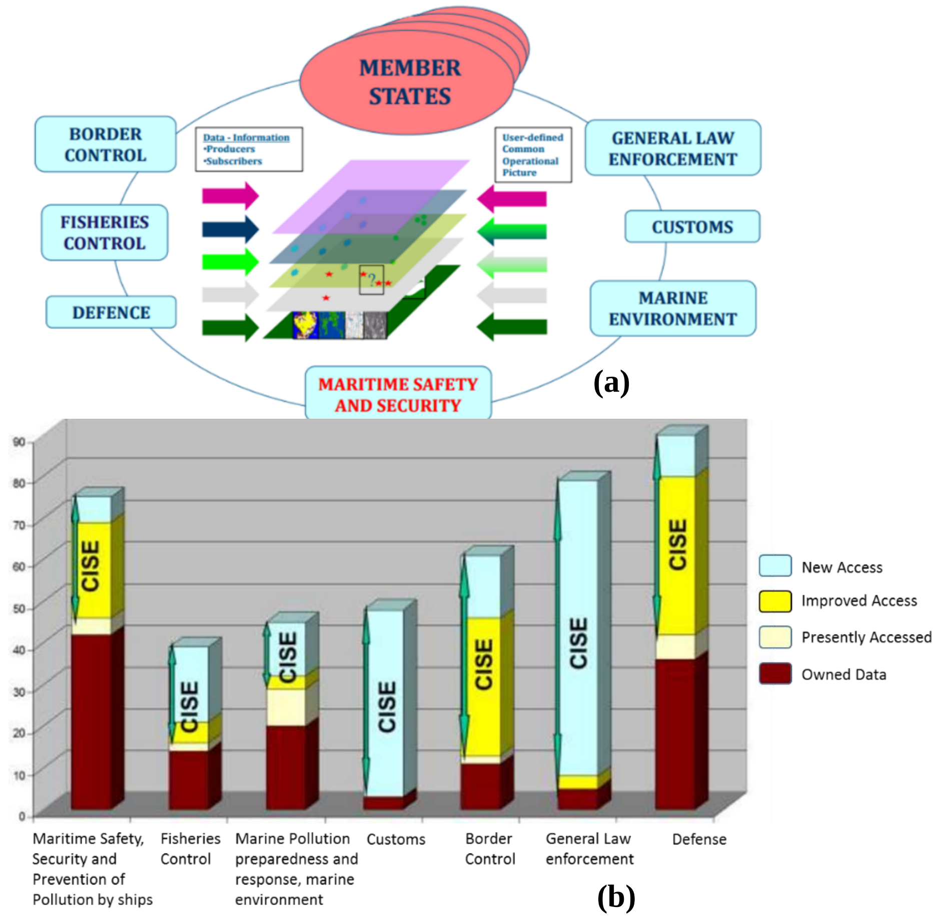

Figure 1.11 (a) Stakeholders of the CISE project. (b) Improvements of Oceanographic information availability by the CISE project

Source: European Commission Maritime affirs (2014) citing Garnier.B & Oliveri.F (2012)

In these oceanographic information sharing examples, the basic concept is achieving the common information sharing environment using the existing ocean observation systems. The option to share oceanographic information which RIOE (2013) has proposed can be described using the similar type of information sharing system where ocean renewable energy projects also becomes a data source for the common data sharing system since the condition monitoring system of the ocean renewable energy power plant can also supply oceanographic information.

1.8 Oceanographic Information as a Co-Benefit of Ocean Renewable Energy Projects

Ocean energy power plants have a separate sub system to monitor the operation condition of turbines to control the operating parameters remotely to suit the ambient environment conditions. This system is generally called the condition monitoring system (CMS). Condition monitoring system of the power plant monitor the operational parameters of the turbine devices as well as monitor the surrounding sea conditions. These information are being used for the smooth operation of the power plant and for preparing for future potential maintenance requirements (predictive maintenance). The intended purpose of the CMS is to operate the power plant smoothly at the optimum conditions with minimum manual interventions by sensing the surrounding environment and by adjusting the controlling parameters.

The operational parameters of the power plant as well as the conditions of the ambient surrounding sea condition can be used to estimate the surrounding sea conditions. Hence CMS of the ocean energy power plant can be considered as an oceanographic information source since it can generate different oceanographic parameters or indirect indicators of oceanographic parameters. In addition to acquiring these in-situ oceanographic data, the CMS can transmit those information to the on shore facilities real-time since all the power conversion devices are connected to the onshore control substations via subsea data transmission lines. Hence CMS can be considered as a source of real time, in situ oceanographic information which is highly demanded by the other marine industries such as fisheries, shipping etc. Hence the oceanographic information can be considered as a co-benefit of the condition monitoring system of the ocean renewable energy power plants.

1.9 Hypothesis, Research Objectives and Research Questions

This research is an in-depth analysis of the proposed option of sharing oceanographic information captured by the condition monitoring system to the other stakeholders in order to achieve synergies among stakeholders to enhance the local stakeholder acceptability. The hypothesis of this research is that the ocean renewable energy power plants' condition monitoring system can satisfy the local stakeholders' oceanographic information requirements. Hence the ocean renewable energy projects can be an oceanographic information source for other stakeholders once the related information is combined with existing data sources and shared among multiple stakeholders. Hence, ocean renewable energy projects can be used to improve the coverage and quality of the existing oceanographic information available for other marine industries and authorities as conceptually depicted in the Figure 1.12.

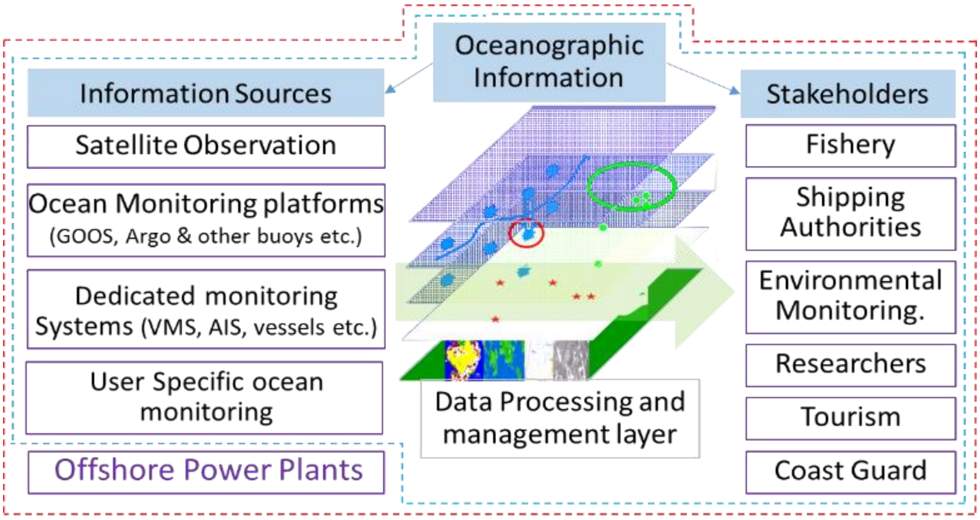

Figure 1.12 Concept of using the ocean power plant as an oceanographic information source for stakeholders other than plant operators

Source: Made by the author

The general objective of this research is to "Analyze the possibility of creating synergies among multiple stakeholders by an oceanographic information sharing scheme". To achieve this general objective, three specific research questions were selected;

1). what oceanographic parameters are required by the stakeholders?

2). what oceanographic parameters can be generated by the plant's CMS?

3). what is the expected incremental costs and benefits to the stakeholders?

From answering these specific research questions, it is expected to achieve the general objective as well as prove the hypothesis.

1.10 Importance of this research

This research is trying to analyze the practicality and potential of applying the proposed oceanographic information sharing scheme to achieve synergies among multiple stakeholders when developing ocean renewable energy projects in the context of Japan. According to the author's knowledge, this is the very first attempt to critically analyze this co-benefit sharing approach with respect to a real ocean energy project which is being developed. If the hypothesis is proven, the results of this research can be used for the real implementation of the proposed solution in order to enhance the local community acceptance as well as the net social benefits. In addition, the quantitative and qualitative results of this research will be useful for understanding the local community perspectives of future marine infrastructure development projects which will lead to better stakeholder management as well as better marine policy implementations.

2 METHODOLOGY

2.1 Case Study selection

The overarching methodology of this research is testing the hypothesis using an instrumental case study. Three research questions selected has to be evaluated in different aspects such as technical feasibility, social and industrial suitability and economic feasibility. To answer the three research questions in these aspects the stakeholder should possess a considerable amount knowledge or know-how about the proposal and the power project. Hence the basic criteria for the case study selection is the high knowledge level of the stakeholders. The next criteria is the existence of ocean renewable energy project in the area or probability of having an ocean renewable energy project in the future.

Several sea areas have been selected as demonstrational test fields for future ocean offshore renewable energy projects by the Prime ministers Headquater for Ocean Policy in Japan, (2014) (Figure 2.1). However there are very few projects being developed for these selected sea areas for the time being. The Japan's Ocean Current Power (OCP) project, which was described in the introduction is one such offshore renewable energy project. It has two potential test fields in the Toshima area in Kagoshima Prefecture and the Shionomisaki area in Wakayama Prefecture. Out of these two possible test sites, Shionomisaki area was selected as the case study area since it has the most favorable conditions for testing the research hypothesis as described in the Table 2-1.

Figure 2.1 Selected marine energy demonstration fields

Source: Made by the author based on the data from Prime ministers headquarters for Ocean Policy, Japan using google maps.

Table 2-1 Comparative analysis of characteristics of two potential sites allocated for ocean current energy projects

Criteria	Shionomisaki, Wakayama	Toshima, Kagoshima
Effected industrial activities	• Many offshore activities in Fisheries, Shipping and Transportation, Tourism sectors	• Less offshore activities (local fisheries is the main offshore industry)
Prior Stakeholder engagement & knowledge sharing activities	• Prefectural government has already started discussion among local stakeholders • Local revitalization program is already begun • Past RE project experiences.	• Very few stakeholder engagement activities are done. • Less knowledge about the projects due to the isolated nature of small island inhabitants
Positive aspects for the power plant deployment	• Convenient for installment and Maintenance of the power plant	• High cost of energy in the small islands • Less powerful voice of local stakeholders
Negative aspects for the power plant deployment	• Many conflicting offshore activities • Powerful voice of stakeholders	• Difficulty to achieve a consensus among stakeholders (many stakeholder groups in islands) • Inconvenient for installment and maintenance of the power plant

Source: created by the author based on the preliminary stakeholder interviews and Sakaguchi (2015)

2.2 Identification and selection of critical Stakeholders

Efficient identification of the stakeholders is one of the most important pre-requisite when solving the social acceptability issues of any marine renewable energy project. Mitchell et al., (1997) has described who should be counted as stakeholders based on the characteristics of power, legitimacy and urgency (Figure 2.2).

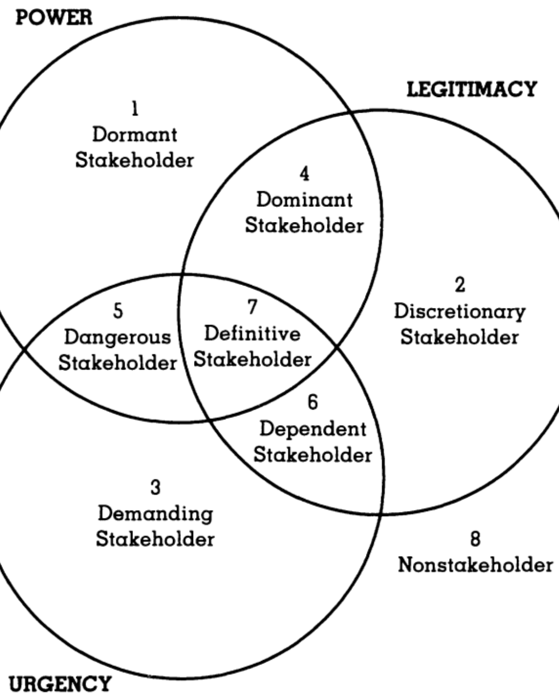

Figure 2.2 Stakeholder Topology by Mitchell et al., (1997)

This stakeholder identification model has been used by Johnson et al., (2013) in the case study of tidal power development in Maine, United States as shown in the Table 2-2.

Table 2-2 Stakeholders identified in the Tidal power project in Maine and their characteristics according to the Mitchell et al., (1997)

Stakeholder Group	Power	Legitimacy	Urgency	Stakeholder category
Commercial Fishermen	X	X	X	Definitive
Regulators	X	X	X	Definitive
Developers	-	X	X	Dependent
Native Tribes	X	X	-	Dominant
Scientists	X	-	X	Dangerous
Residents	X	X	-	Dominant
Property owners	X	X	-	Dominant
Recreational	-	X	-	Discretionary
Tourists	-	-	-	None

Source: Johnson et al., (2013)

By using these previous examples in the literature, the most relevant stakeholders were mapped in the Figure 2.3 in the context of Japan's Ocean Current Power (OCP) project in the Wakayama case study area based on the author's best estimates. Based on this stakeholder categorization and the level of oceanographic information requirements, Wakayama Higashi Fishery Union, Project Developers, Local government officials, Local fishermen, related Researchers were selected as the most appropriate stakeholders for this research. Shipping and transportation industry, Tourism industry national security and coast guard institutions as well as weather forecasting agencies such as meteorological department are also relevant stakeholders with respect to the oceanographic information supply is concerned. However these stakeholders were not incorporated in this research due to the resource limitations.

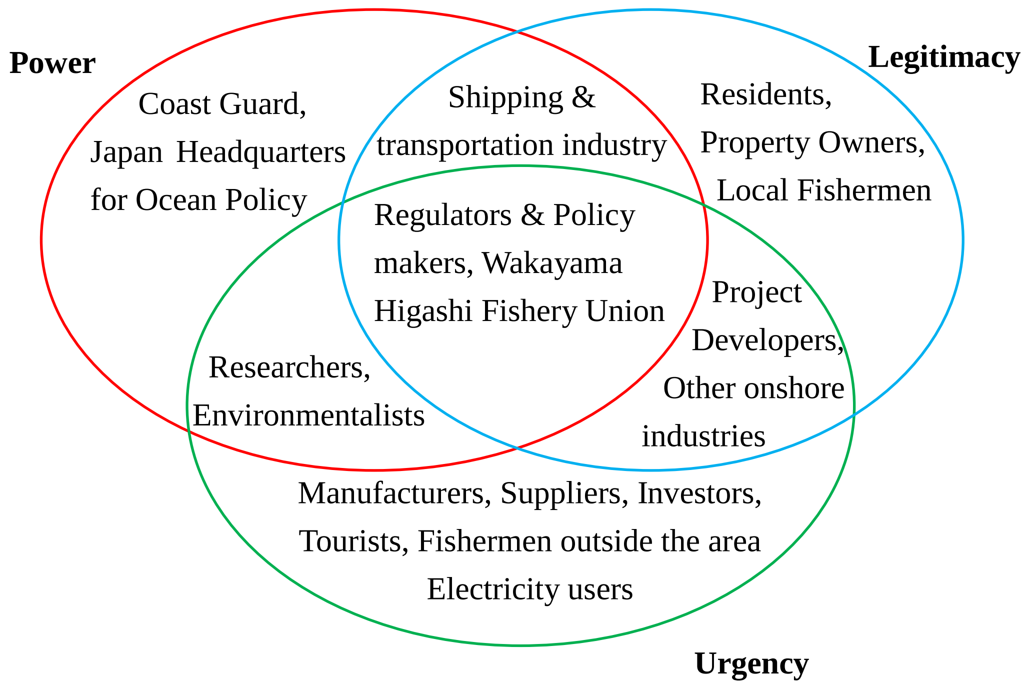

Figure 2.3 Stakeholder map for the OCP project in Wakayama test site deployment

Source: Made by the author

2.3 Research Flow

As the first step, first two research questions were considered independently to determine the stakeholders' oceanographic demand and the potential oceanographic parameters which can be obtained by the condition monitoring system of the power plant. In the third research question, financial costs and benefits were estimated for the potential information demand and supply scenarios according to the outcomes of the first and second research questions. As the final step, all the results of three main research questions were used to determine the best information sharing level according to the stakeholders' preference. Conceptual research flow is thus defined as the Figure 2.4.

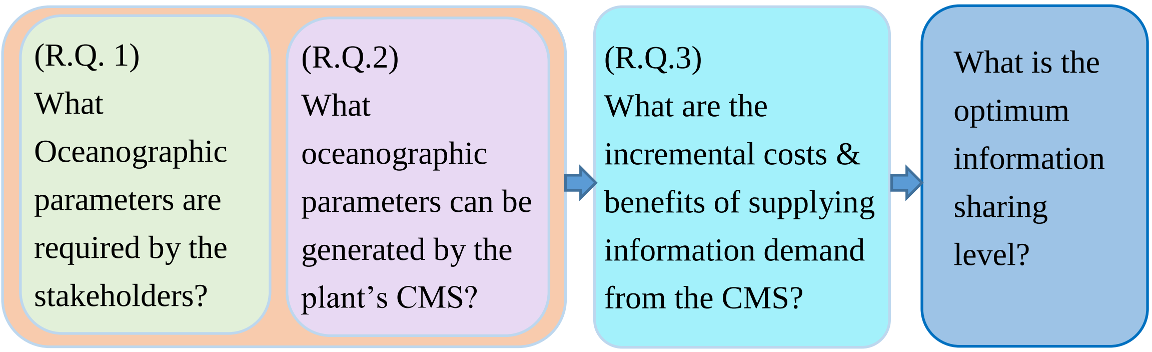

Figure 2.4 Conceptual research flow

Source: Made by the author

2.4 Data Collection Methods

Data from the case study area collected by the author (Primary Data) as well as the data from existing data sources and literature (Secondary Data) have been considered when answering the main research questions. Specific primary data collection methods and secondary data sources used for each research question are as follows.

2.4.1 Stakeholders' oceanographic information requirement (R.Q.1)

A similar type of stakeholder requirement survey has been conducted in the European context during the design stage of the EuroGOOS project (Fischer & Flemming, 1999). EuroGOOS represents the European participation in the Global Ocean Observing System (GOOS). EuroGOOS Requirement Survey (ERS) which was completed in 1998 was the most complete survey and analysis conducted at that time covering the full range of potential oceanographic information users by means of an open-ended survey. (Fischer & Flemming, 1999).

Different stakeholders require different oceanographic parameters for their industrial activities. The required data quality is different according to its usage even for the same oceanographic parameter. For example high resolution temperature distribution is required for short term planning for local fisheries. However for policy makers, high coverage is more important than the resolution of the same parameter for long term decision making such as selecting conservation areas etc. Hence in addition to the oceanographic parameter, following data quality characteristics are also considered when eliciting the stakeholders' data requirements.

I. Coverage – Monitoring area (Ocean basin, Coastal seas, Estuarine etc.)

II. Product Type – Type of Information required (Row data, processed data, Forecasts etc.)

III. Accuracy – Closeness of measured value and the real value (%)

IV. Precision – The degree of variance(%) between measurements for the same real parameter value

V. Temporal Resolution – How frequently the parameters should be monitored

VI. Spatial Resolution – The maximum allowed distance between two measuring points to be able to have reasonable estimation for the entire considered area.

VII. Vertical Resolution – The maximum difference of depth levels between two subsea parameter measuring points

VIII. Forecast Period – The minimum time period the forecast is valid with a reasonable accuracy

IX. Latency – The time delay between the information request and receive

X. Delivery Medium – How the information should be presented (Internet, Paper based, Fax etc.)

In addition, a separate grading was collected for each parameter, data quality combination selected by the stakeholders.

Grading of each information requirement are as follows.

① Might have some occasional use

② Might be useful, but it falls short of what the stakeholder needs

③ Useful Information

④ Good information which would be very useful for stakeholder's main activities

⑤ Ideal set of information which would meet the all the stakeholder requirements

Despite the comprehensiveness of the EuroGOOS Requirement Survey (ERS), the replication of it in this research context is not practical due to the lack of stakeholder expertise on the matter. Especially the local fisheries are not comfortable with the technical terms used in the ERS. More often, the local stakeholders used colloquial language to represent the same oceanographic parameter which is being used in their industrial activities. Hence clear explanation and guidance is needed to complete this information requirement survey. Hence key informant interviews and focus group discussions were selected as the main primary data collection methodology for answering the research question 1. However, a simpler version of this information requirement survey was created in Japanese (Appendix I) which was used as the guiding document during the stakeholder interactions. The results of the ERS were used as the secondary data (which is from the European context) to compare and validate the applicability of the primary data collected. Parameterization was done to the validated data at the end of analysis of the stakeholder's oceanographic information requirements. Additional questions were included in this guide document (Appendix I) in order to identify the current information availability with respect to each stakeholder, cost incurred in the current context to obtain those information and willingness to pay (WTP) for the specific oceanographic information parameters.

2.4.2 Condition Monitoring System's Information generation potential (R.Q.2)

The potential to obtain oceanographic information from the condition monitoring system (CMS) of the power plant depends on its configuration specifications. Generally the CMS monitors the critical operating parameters inside the nacelle of the turbine including the power take off equipment (Temperature, Oil Pressure etc.). In addition, it monitors the ambient conditions of the environment outside the nacelle which are directly related to the performance of the turbine (Current velocities, Temperature etc.). All these standard monitoring data is then transmitted to the onshore control center via the subsea fiber optic communication lines. However additional parameters can be monitored via the condition monitoring system if it is designed and configured with additional sensors and transmission capabilities. Hence, the potential of the CMS to generate oceanographic information is a broad question which should be analyzed according to the selected configuration of the power plant, environmental characteristics and other technical requirements. Hence, the CMS design specifications were used as the main secondary data to analyze the potential information supply. In addition, interviews and consultations with project development team was used to confirm the technical feasibility of having different CMS configurations to satisfy different oceanographic information requirements.

In addition to the power plant's design specifications, existing ocean observation systems (such as buoy systems, ocean observation platforms, user specific operational oceanographic data acquisition equipment and methods) were referred as other secondary data to validate the potential oceanographic information supply of the CMS of the power plant. Primary and secondary data collection was done for several scenarios such as, minimum development cost scenario, satisfying all the stakeholder requirements scenario etc. Similar to the first research question, parameterization was then conducted to summarize the results of second research question; 'what oceanographic information can be supplied by the condition monitoring system' according to the considered scenarios.

2.4.3 Incremental costs and benefits (R.Q. 3)

Primary data for estimating the total incremental costs of the proposed information sharing from power plant’s condition monitoring system to the other stakeholders were collected from the interviews with the project developers as well as analyzing available market data. The technical requirements (Type of sensors, data transmission equipment etc.) were confirmed by the project designer. In addition, total additional development cost is estimated using the interview results of the project developers and consulting equipment suppliers. Existing market pricing data were also collected by doing an online price survey for major oceanographic sensor manufacturers.

All these primary data was then compared with the secondary costing data obtained from the initial OCP project cost estimates, the costing data from the similar ocean observation systems and cost benefit analysis done for other ocean observation systems such as the Mediterranean Forecasting System Towards Environmental Predictions (MFSTEP) (Chiabai & Nunes, 2006).

Monetary value of stakeholder benefits which results from improved oceanographic information is relatively difficult to estimate by direct valuation methods. This is because the stakeholders do not have prior experiences of having such a rapid technological transition in recent history. Hence benefit estimation was done based on the qualitative improvements which the stakeholders identified during the focus group discussions and interviews. In addition, willingness to pay (WTP) study was done which gave an indirect indication of the stakeholders' benefits while sensitivity analysis was done to test the reliability. The primary data collected by the stakeholder interviews and focus group discussions (Table 2-3) were then compared with the secondary data obtained from the national and local level statistical data sets.

Table 2-3 Summary of the stakeholder interviews and focus group discussions

Stakeholder (group)	Description	Date & Place
Wakayama Prefectural Government officials (n=2)	Preliminary interview to understand, • The level of prior activities with respect to local stakeholder collaboration activities done with respect to the OCP project, during test site selection etc. • Problems identified & government attitude towards stakeholder acceptance of the project, • Similar experiences from previous projects, • Policy impacts of the proposed solution.	13th July, 2015 at the Kashiwa campus, The University of Tokyo.
Fisherman outside the case study area (n=1)	Key informant interview with a fisherman from Oshima (Tokyo) who has over 50 years' experience and who have been fishing in the Wakayama and Kagoshima area. General objectives are, • Understanding of fishing methods, fisheries perception of the OCP project and potential conflicts between fisheries and the OCP project • Preliminary understanding of local fishermen's oceanographic information requirements to short and mid-term planning activities.	29th Aug, 2015 at Oshima island, Tokyo.

President & other officials + local fishermen of Wakayama Higashi fishery Union and local government officials (n=6)	Semi structured interview and focus group discussions with administered questionnaire (Annex I & II) to understand, ● Knowledge and attitude towards the OCP project and its Wakayama deployment in the future ● Perceived impacts to local fisheries ● Fisheries oceanographic information requirements, existing information sources and prevailing cost of oceanographic information ● Potential benefits and Willingness to pay for the oceanographic information provided by the CMS according to the proposed information sharing. ● Preference levels of criteria & alternatives for the final multi criteria decision making.	14th & 15th Dec, 2015 at the head office of Wakayama Higashi Fishery Union, Kushimoto.
Officials of Wakayama prefecture fishery research and experiment station with local government officials (n=3)	Semi structured interview and focus group discussions with administered questionnaire (Annex I & II) to understand, ● Researchers oceanographic information requirements existing information sources and prevailing cost of oceanographic information ● Potential of improving the existing oceanographic data sets by the proposed information sharing system and the benefits of the additional information. ● Preference levels of criteria & alternatives for the final multi criteria decision making.	15th Dec, 2015 at Wakayama prefecture fishery research and experiment station, Kushimoto.
Academia related to fishery industry (n=1)	An interview with a senior professor from the Atmospheric and Ocean Research Institute (AORI) (who is working in the fishery related research areas) to understand, ● The oceanographic information requirements of the fishery & marine eco-system researches. ● Existing sources and cost of oceanographic information ● Potential benefits of the proposed information sharing scheme.	21st Jan, 2016 at the AORI, The University of Tokyo.

<table>
<tr><td>Researchers related to the other marine researches (n=1)</td><td>Informal interview with the researcher who is working with marine environment modeling to validate the oceanographic information requirements of for marine environment modelling and existing sources of oceanographic information</td><td>8th Feb 2016</td></tr>
<tr><td>Members of the OCP development team
(n=3)</td><td>Semi structured interviews with the researchers directly involved in the OCP development to understand,
● The general OCP project details and the conditions of the actual deployment area.
● The technical specifications of the standard CMS of the OCP project and possibility of obtaining the additional parameters requested by the other stakeholders.
● Cost estimates of the standard CMS and additional equipment needed to satisfy all the stakeholder information requirements. (Validation of the market data and other secondary data obtained with respect to the information generation capacity and cost)
● Preference levels of criteria & alternatives for the final multi criteria decision making.</td><td>2nd & 8th Feb, 14th Mar 2016 at the University of Tokyo.</td></tr>
</table>

Source: Made by the author

2.5 Data Analysis methods

2.5.1 Cost Benefit Analysis and the sensitivity analysis

From the results of the third research question, the incremental costs and stakeholder benefits were estimated using the primary data from stakeholder interviews and focus group discussions combined with secondary data. The cost benefits then compared using the standard cost benefit analysis methods (Boardman et.al 2006).

Due to the lack of stakeholder experience and knowledge, the estimation of costs and benefits raised considerable doubt. Since the data collection cannot be done with a large sample of stakeholders (due to the limited knowledge and experience stakeholder interactions required considerable amount of time and effort for explanations), the reliability of financial estimates were further reduced. To improve the reliability of the financial estimates, a sensitivity analysis was done based on the available primary data and the existing statistical data.

2.5.2 Multi criteria decision making (MCDM)

The acceptability of the proposed information sharing to achieve synergies among other stakeholders finally depends on the stakeholders' perceived preference. Stakeholders' perceived preference depends not only on the monetary cost benefit ratio. Generally, other non-monetary criteria also effects the stakeholders' decision. In most of the cases, these multiple criteria are conflicting to each other creating a situation where there should be a compromise on each criteria to come to the optimum decision. Hence, multi criteria decision making

(MCDM) approach (Kabir et al., 2014; Wang et al., 2009) (which is a commonly used decision support systems for this type of complex decision making scenarios), is the best approach to evaluate the different information sharing levels with respecting different conflicting criteria.

There are many types of methods available for multi-criteria decision making such as Analytic Hierarchy Process (AHP), Multi-Attribute Value Function Theory (MAVT), Multi-Attribute Utility Function Theory (MAUT), and Outranking methods, etc. The applicability of each method depends on the data availability, complexity of the problem, available sample size etc. Because of the limited number of respondents, any statistical method is not practical to analyze the data in this research.

2.5.3 Analytical Hierarchy Process (AHP)

Analytical Hierarchy Process (AHP) introduced by T. L. Saaty (1990) is a very common multi-criteria decision making model which is based on the additive synthesis. AHP has been used different complex decision making scenarios such as emission from power plants (Chatzimouratidis & Pilavachi, 2007), sustainability analysis of Hydrogen based transportation systems (Winebrake & Creswick, 2003), hydrogen energy technology (Lee et al., 2008), sea use management (Shiau, 2013) etc. AHP has been used in combination with other common data analysis methodologies such as cost benefit analysis since it can handle both quantitative and qualitative criteria when selecting the optimum alternatives. In addition, according the contextual requirements, the AHP methodology has been combined with other mathematical models such as fuzzy logic (which results Fuzzy AHP), Dempster Shafer Theory (which results DS-AHP) as well as other MCDM methods (Ho, 2008). Hence the basis of AHP can be applied to almost any sustainability related decision making process where number of criteria from different disciplines are being considered. A step by step methodology for the application of AHP is available in previous literature (Saaty, 1987) and following is the summary of basic steps of using the AHP for complex decision making processes.

Step 1: Defining the Problem and Goal

Step 2: Creating the hierarchy (Figure 2.5) from the Objective through the intermediate levels (Decision Criteria) to the lowest level Decision Alternatives

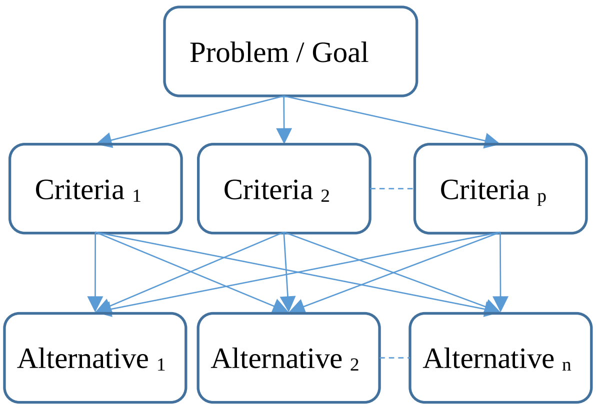

Figure 2.5 Conceptual Decision Hierarchy used in AHP

Step 3: Doing the pairwise comparison for each pairs in a hierarchy level with respect to the element in the immediately above hierarchy level

Step 4: Checking the consistency of the set of pairwise comparisons using the eigenvalues.

Step 5: Completing the hierarchical synthesis to weight the normalized eigenvectors by the weights of the criteria (The sum is taken over all weighted eigenvector entries corresponding to those in the next lower level of the hierarchy.)

Even though AHP is a straight forward process, it also has few limitations.

1. Number of pairwise comparisons required increases rapidly when the number of hierarchy levels, decision criteria or decision alternatives increases. It needs $n\ (n-1)/2$ pairwise comparison per each comparison group with ‘n’ elements in the lower hierarchy level.
2. All the comparisons are mandatory hence the decision maker’s knowledge limitations and uncertainties are not allowed.
3. Potential to have inconsistence comparisons. (The process can fail at the consistency check)

Due to the novelty of the proposed solution (i.e. getting information from the ocean renewable energy plant’s CMS to the other stakeholders), the respondents’ knowledge about the proposal is very limited. Since there are no prior examples, the uncertainties involved in the decision making process is also significant. Hence comparing the each decision alternatives with respect to the selected criteria is practically not successful using the standard AHP method. Hence an improved version of AHP which uses the Dempster Shafer Theory of evidence (Beynon et al., 2000) is used to evaluate the decision alternatives with respect to the selected decision criteria.

2.5.4 Dempster Shafer Theory and Analytical Hierarchy process (DS-AHP)

Dempster Shafer Theory (DS Theory) was initially developed by A.P. Dempster (Dempster, 1967, 1968) and then further developed by Glenn Shafer (Shafer, 1976). DS theory has been widely applied in Artificial Intelligence, pattern recognition (Le Hégarat-Mascle et al., 1997; Lee, 2007; Momani et al., 2007; Ranoeliarivao et al., 2013), risk assessment (Sadiq et al., 2006), sustainability evaluations and environment impact assessments (Wang et al., 2006) etc. DS theory has been combined with standard AHP (DS-AHP) to be able to use the AHP methodology with incomplete and uncertain data sets. (Beynon et al., 2001; Beynon et al., 2000; Beynon, 2002, 2005a, 2005b).

Due to the limitations of stakeholder knowledge and experience, the pairwise comparison of possible alternatives with respect to the selected criteria was not possible with the standard AHP. However, DS-AHP model was successful since it facilitates the data incompleteness and uncertainties.

2.5.4.1 DS-AHP theoretical background

DS-AHP model allows to assign measures of probability to focal elements (e.g. groups of decision alternatives) rather than comparing every possible element pairs within a single hierarchy level like in standard AHP. It also allows to assign a probability value for the set of all the decision alternatives which is called the frame of discernment (Θ). Basic probability assignment (bpa) is a function m: $2^{\Theta} \rightarrow [0,1]$ such that, $m(\emptyset) = 0$ and $\sum_{x \in 2^{\Theta}} m(x) = 1$. ($\emptyset$ is the empty set and 2^{Θ} is the power set of Θ). The assigned probability for the frame of discernment (Θ) represents the amount of (global) ignorance within the basic probability assignment. Since the Criteria comparison is straight forward, pairwise comparison and the standard AHP calculation is used to get the relative importance or the Weight of the criteria.

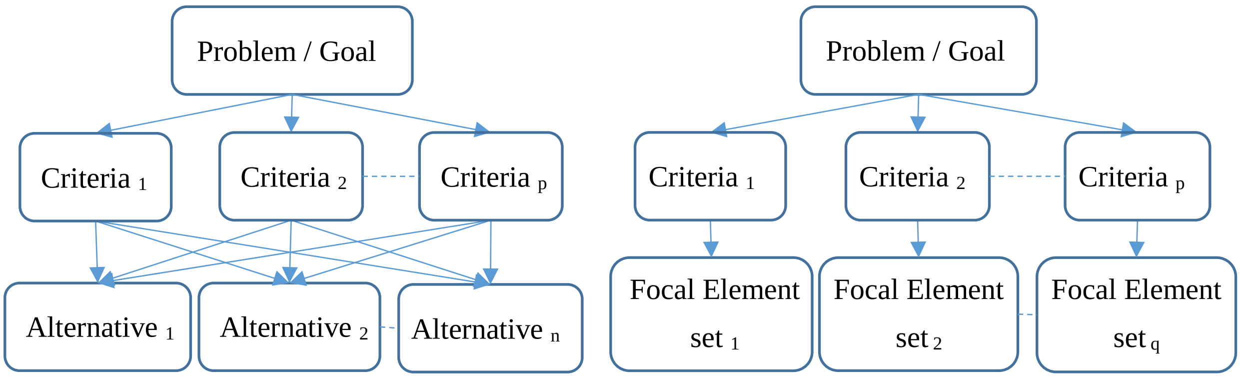

Figure 2.6 Comparison of Decision Hierarchy of AHP and DS-AHP

Source: Made by the author

Focal Element can be defined as a set of alternatives. It can be individual alternatives or group of alternatives. Group of alternatives can be considered as one alternative if the decision maker fails to distinguish their preference levels separately and if those alternatives can be treated equally with respect to the decision criteria considered. Hence the decision makers have the opportunity to avoid giving a preference rating for the alternatives with lack of knowledge or high uncertainty. In DS-AHP method, these group of alternatives (Focal elements) is given a preference rating (which represents the degree of favorable knowledge on each focal element) with compared to all possible alternatives (i.e. with compared to the frame of discernment (Θ)). This differs from the standard AHP method that makes pairwise comparisons between individual alternatives, where in DS-AHP method, each group of alternatives (Focal element) identified (according to the decision maker's knowledge) is compared to all possible alternatives in the frame of discernment (Beynon, 2002). Hence DS-AHP methods resolves the practical problem of decision makers' limited knowledge and high level of uncertainties when running the standard AHP model.

Once the focal elements are selected and given a preference rating with respect to the considered criteria, it is converted into a criteria-wise basic probability value which is also known as the basic probability assignment (bpa). The basic probability of each focal element with respect to the considered criteria is calculated using Eq(1), where $W_{C_i}$is the weight of the criteria C_i and a_y is the decision maker's preference level (1-6 scale was used in this research (Beynon, 2002)) given to the considered focal element (y). 'd' is the number of focal elements evaluated under the criteria C_i.

$$[C_i](y) = \frac{a_y\, W_{C_i}}{\sum_{j=1}^{d} a_i\, W_{C_i} + \sqrt{d}} \quad \& \quad [C_i](\Theta) = \frac{\sqrt{d}}{\sum_{j=1}^{d} a_i\, W_{C_i} + \sqrt{d}} \qquad Eq(1)$$

Dempster's rule of combination allow to combine the measures of evidence (bpa) from different sources. Dempster's evidence combination rule is given in Eq(2), where C_i and C_j are the sources of evidences. 'y' represents the estimated evidence from the combination of the sources C_i and C_j.

$$[C_i \oplus C_j](y) = \begin{cases} 0 & ;\ y = \phi \\ \left[\frac{\sum_{A_p \cap A_q = y} C_1(A_p)\, C_2(A_q)}{1 - \sum_{A_p \cap A_q = \phi} C_1(A_p)\, C_2(A_q)}\right] & ;\ y \neq \phi \end{cases} \qquad Eq(2)$$

In DS-AHP method, this is used to combine the probability values obtained with respect to each criteria and to compute the final probability value of each focal elements (y) with respect to all the criteria. The belief level, which represent the extent the decision maker believe the considered focal element is the preferable option, is calculated by the sum of final probabilities that are subsets of the probabilities in question using Eq(3).

$$Bel(y) = \sum_{B \subseteq y} m(B) \quad \forall y \subseteq \Theta \qquad Eq(3)$$

The Plausibility level, which represent the extent that the decision maker fail to disbelieve the considered alternative, is calculated using Eq(4).

$$Pls(y) = \sum_{B \cap y \neq \emptyset} m(B) \quad \forall y \subseteq \Theta \qquad Eq(4)$$

All the final assigned probabilities sum to unity and there is no belief in the empty set

(∅). However due to the summation of probabilities of the subsets, the summation of all the belief levels and the summation of all the plausibility levels does not add up to unity. Since DS-AHP model is an evidence based decision making model, belief level and the plausibility level represents the minimum and maximum level of preference of the considered alternative respectively.

Following are the steps used in the data collection for the DS-AHP method in this research and questionnaire in Appendix II was used as the guide document.

Step 1: Complete the pairwise comparisons using the standard AHP approach using the 9 scale relative importance level indicator. The consistency check should be done in this step. Once the pairwise comparison is completed, the relative weights of each criteria is possible to calculate.

Step 2: Identify and group the alternatives which can be given a preference value with respect to the each considered criteria. (Creation of criteria wise focal elements).

Step 3: Preference value for each focal element is given using the 2-6 preference scale with respect to the considered criteria.

Finally all the results from each decision maker (stakeholder groups in this research context) were combined using the DST to calculate the final group decision. (Beynon, 2005a). Decision makers are given a weight when aggregating their decisions to a group decision where 1). Equal weight scenario and 2). Weight proportional to the group size scenario were considered in this research.

2.5.4.2 DS-AHP software development

The actual number of calculation steps depends on the number of focal elements the decision maker evaluates and the number of alternatives considered within an evaluated focal element. Hence the calculation steps are (in the equations 1, 2, 3, and 4) are dynamically changing. Hence a dedicated computer software was needed to run this decision making model. Since the author could not find a freely available computer software, a new computer software tool was created using the C# programing language based on the .Net framework. Following are the screenshots of the main screens where the decision maker do the pairwise comparison for the criteria (Figure 2.7) and creation of criteria wise focal elements and giving the preference levels (Figure 2.8).

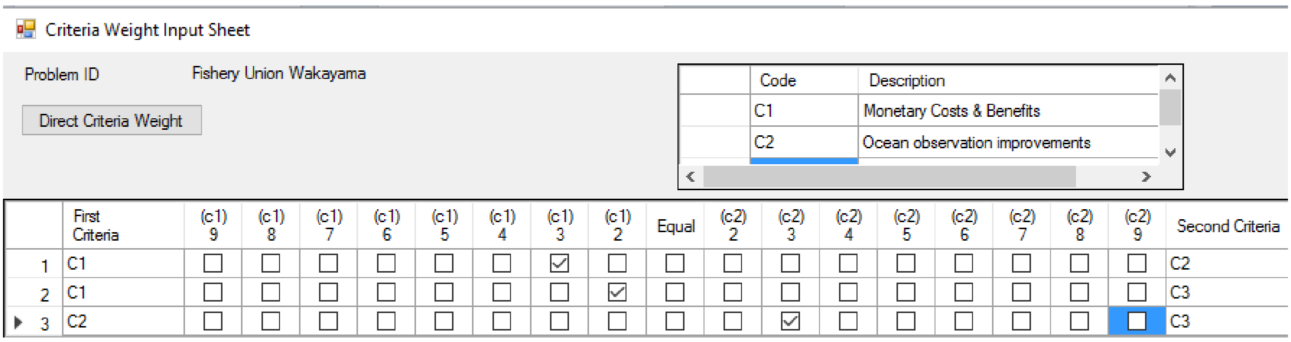

Figure 2.7 Screenshot of the pairwise comparison of Criteria

Source: Made by the author

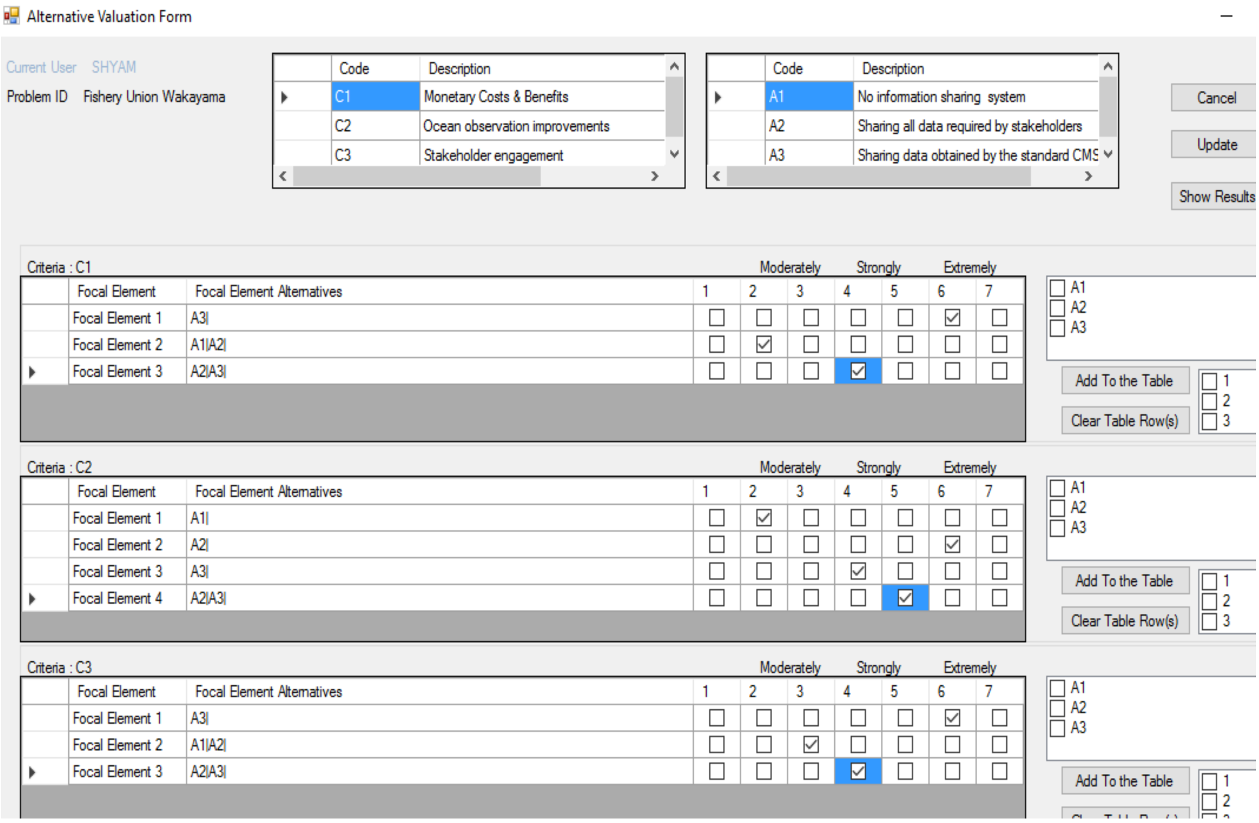

Figure 2.8 Screenshot of the criteria wise focal element creation and preference input screen

Source: Made by the author

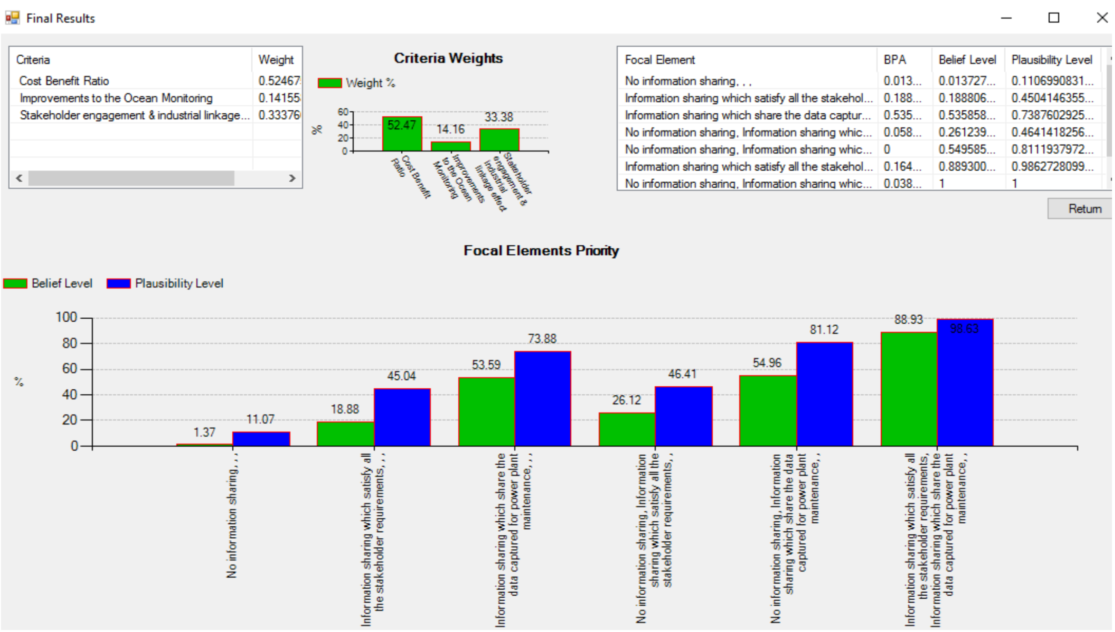

Figure 2.9 Result display screen

Source: Made by the author

A comprehensive description of the implementation of the DS-AHP software has been described in the Appendix III.

With the data collection and analysis methods, the complete research flow can be summarized as the research framework diagram in the Figure 2.10.

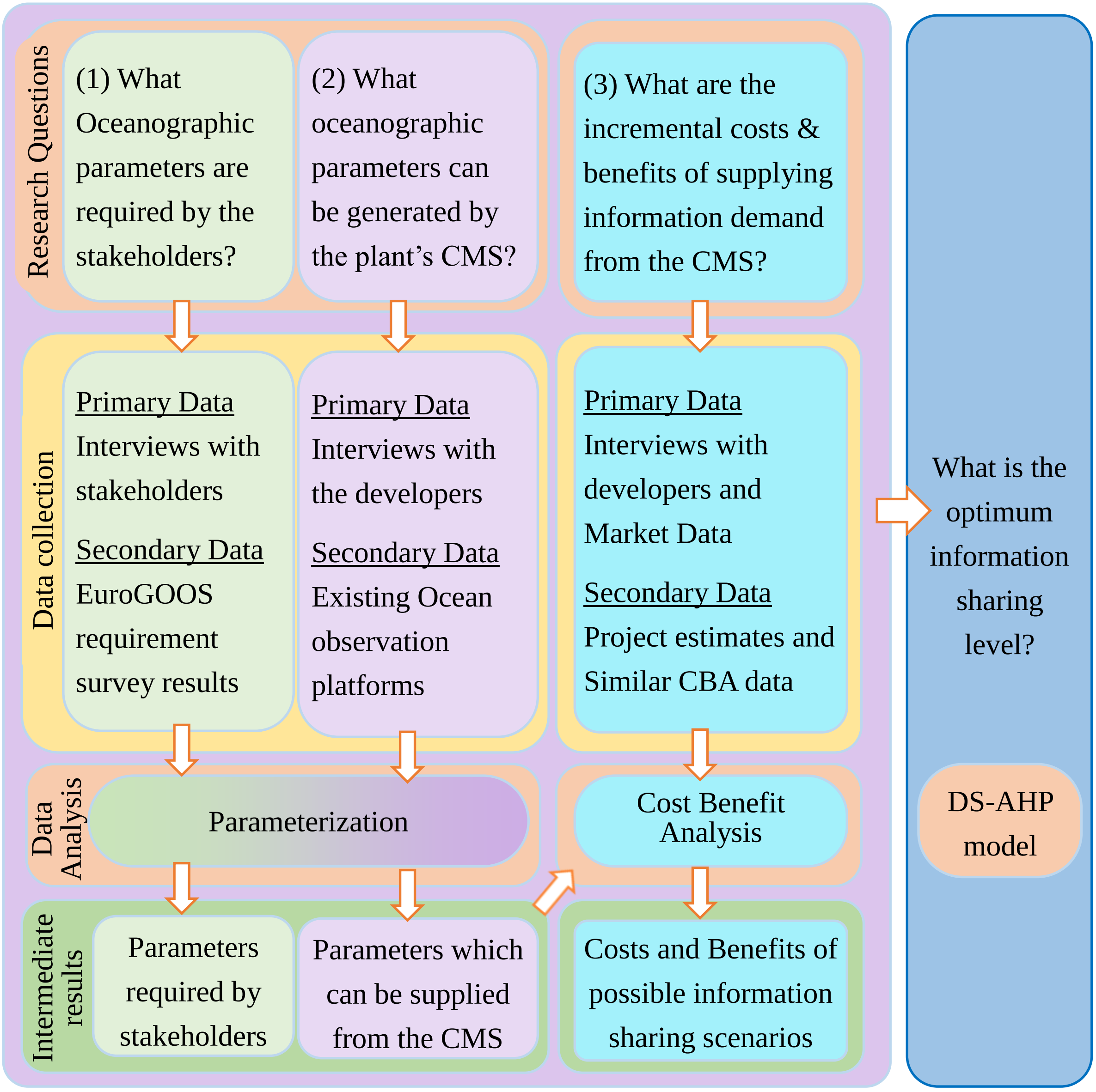

Figure 2.10 Research Framework and Methodology

Source: Made by the author

3 RESULTS AND DISCUSSION

The results of the primary and secondary data collection and analysis will be presented as a summary for each research question considered.

3.1 Stakeholders' oceanographic information requirements (R.Q 1)

3.1.1 Fisheries Information requirements for commercial fishing

Table 3-1 summarize the oceanographic information required by the fisheries according to the interview results.

Table 3-1 Oceanographic parameters required by the fisheries (Primary data)

	Oceanographic parameter	Parameter Category	Other remarks
1	Sea Surface Temperature (SST)	Surface Fields	10km spatial resolution
2	Temperature distribution along the depth (CTD Sections)	Deep ocean	50m vertical resolution
3	Ocean Current / Tidal velocity and direction	Surface Fields	In the Kuroshio Current path
4	Wave profile	Surface Fields	Weekly forecast
5	Wind profile	Surface Fields	Weekly forecast
6	Plankton levels	Biochemical	In the Kuroshio Current path
7	Underwater Video or the fish count	Optics	Near the fixed net setups
8	Underwater noise	Acoustics	-
9	Hourly mean sea level	Surface Topography	-
10	Coastal bathymetry	Coastal and Shelf	-
11	Suspended sediments	Biochemical	In the main fishing areas
12	Dissolved Oxygen level	Biochemical	In the main fishing areas

Source: Made by the author based on the interviews and focus group discussions

In addition, Fish and fish egg count, anthropogenic noise, upper ocean fresh water percentage, depth of photic zone have been mentioned as important parameters specially for mid and long term planning.

Most of the surface level oceanographic parameters (such as SSS, SST, Wave and Wind parameters) are available from existing oceanographic information providing systems. For example, Local fishery union gets the satellite information from JAXA and NOAA and more general information and warnings from meteorological department and coast guard services. However, data quality parameters such as resolution, accuracy etc. have not achieved the optimum level with respect to the fisheries' requirements. According to the fisheries, spatial and vertical resolution are the most important data quality criteria (according to the most cited frequency).

Most of the surface level parameters are currently available especially from the NOAA satellites. However, subsea parameters are not available. Hence fishermen has to visit the area and check the parameters from their traditional techniques. Some of them are still using primitive methods to check the subsea parameters such as sensing the depth wise temperature distribution by means of a rope. According to the fishermen, 10km spatial resolution is enough for estimating the sub-sea conditions and for the selection of their fishing grounds.

According to the fishery union and experienced fishermen, 50m vertical resolution is sufficient especially for depth wise temperature distribution parameter and ocean current velocities. However, 10m vertical resolution has also mentioned as the ideal requirement.

Table 3-2 gives the summary of the data quality parameters which was mentioned most frequently during the interviews and the focus group discussions.

Table 3-2 Summary of the other data quality requirements (Primary data)

Information quality	Ideal range (according to the frequency)
Coverage	Kuroshio current areas Coastal areas
Product type	Processed data / forecasts Statistics
Accuracy	1% 10%
Spatial resolution	10km
Vertical resolution	50m 10m
Temporal Resolution	Daily Six hours
Forecast period	Weekly Daily
Latency	Real-time Three hours
Delivery medium	Internet available for all the fisherman User specific information management systems

Source: Made by the author based on the interviews and focus group discussions

3.1.2 Researchers' Information requirements for Scientific Research

There is a visible parameter wise similarity of the researchers' oceanographic information requirements with respect to the fisheries requirements. However, the main difference is that researchers requested higher quality data in contrast to the fisheries. Table 3-3 gives the summary of the researchers' oceanographic information requirement according to the interviews.

In addition, research specific parameters such as sea surface acidity, ocean current parameters, bio chemical parameters such as Chlorophyll-A levels etc. were also mentioned during the interviews. Most of the data is currently obtained from research specific data acquisition activities (such as direct measurements during the field observations etc.) and buoy systems. Some data acquisition systems are scientific experimental systems rather than the commercial or industrial level equipment such as common ocean observation sensors. The information quality requirements are highly dependent on the requirement of the research done. Hence the there is a considerable variety in the required quality parameters. However, it is identified that the quality requirements of the researchers are beyond the fisheries data quality requirements.

Table 3-3 Oceanographic parameters frequently required by the Researchers (Primary data)

	Oceanographic parameter	Parameter Category
1	Sea Surface Temperature (SST) and salinity (SSS)	Surface Fields
2	Wave Profile	Surface Fields
3	Ocean Current and Tidal Profile	Surface Fields
4	Wind profile	Surface Fields
5	Phytoplankton & Zooplankton	Biochemical
6	Nitrate levels	Biochemical
7	Dissolved Oxygen levels	Biochemical
8	Marine Mammal Observation	Biochemical
9	Underwater noise and Passive acoustic monitoring	Acoustics
10	Fish species count and their migration / breeding patterns	Biochemical
11	Suspended sediments	Biochemical
12	Marine growth (Sea bed)	Biochemical

Source: Made by the author based on the interviews and focus group discussions

3.1.3 Comparison with the secondary data

The main secondary data source for the first research question is the EuroGOOS stakeholder information requirement survey (ERS) done in 1998. Responses from 155 companies and agencies (from Denmark, United Kingdom, Greece, Italy, Netherlands, and Spain) representing 'Research', 'Marine services', 'Environment', 'Building', 'Transport', 'Defense', 'Energy', 'Food', 'Equipment', 'Hinterland', 'Mineral' and 'Tourism' sectors have been collected for the ERS. (Figure 3.1).

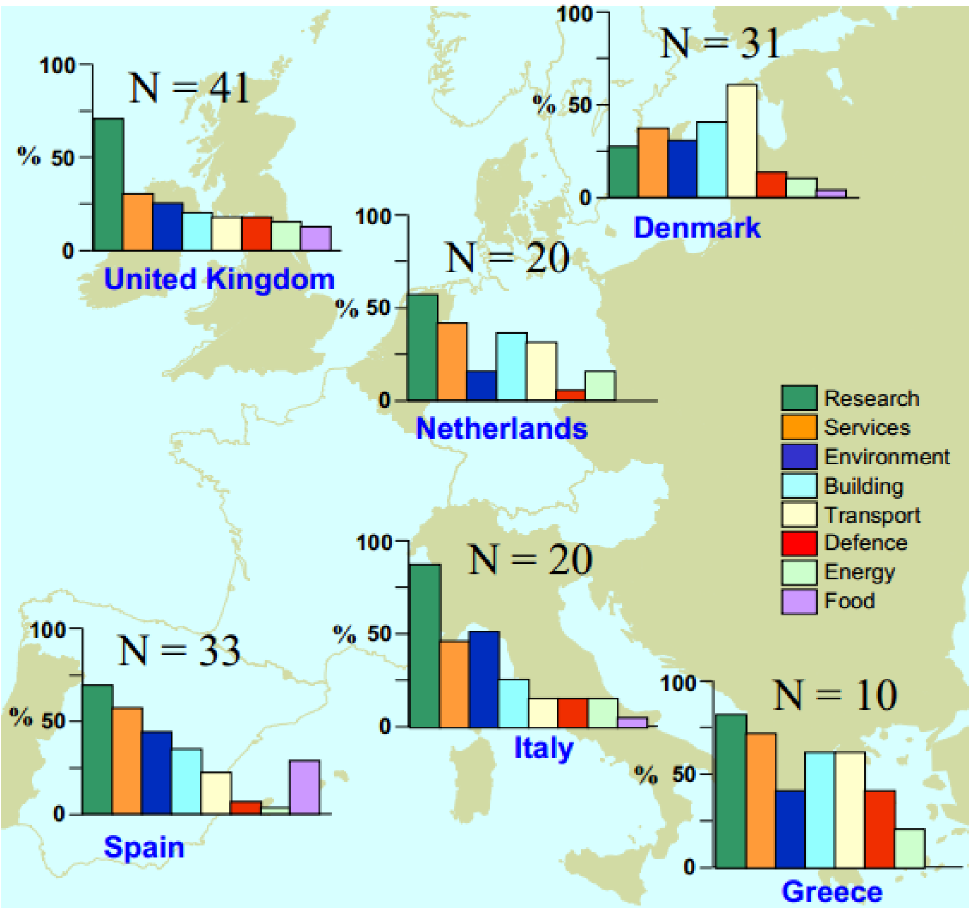

Figure 3.1 Distribution of ERS respondents by country and sector

Source: Fischer & Flemming, (1999)

The secondary data which can be compared with the results of the first research question is the ERS outcomes of the ‘Research’ and ‘Food’ sectors. Research applications includes Oceanography, Environmental sciences, Coastal & Ocean modelling, Climate change, Marine biology, Estuarine modelling, Acoustics, marine weather forecasting, Polar research, Fisheries, shipping/naval architecture etc. Food sector applications includes Fish farming, Fisheries, catching, Shellfish, Crustacea, Shellfisheries and Fishing gear (Fischer & Flemming, 1999). Hence the ERS results of ‘Research’ and ‘Food’ sectors can be considered as highly comparable secondary data for this research. The ERS results from these sectors have been summarized in Table 3-4 & Table 3-5.

Table 3-4 Oceanographic parameters frequently required by the Marine Food sector (Secondary data)

	Oceanographic parameter	Parameter Category
1	Current Direction	Surface Fields
2	Current Velocity	Surface Fields
3	Sea Surface Temperature (SST)	Surface Fields
4	Wave directions	Surface Fields
5	Wave Heights	Surface Fields
6	Sea surface wind stress	Surface Fields
7	Wave period	Surface Fields
8	Suspended sediments	Biochemical
9	Oxygen	Biochemical
10	Aquatic toxins	Biochemical
11	Wave spectrum	Surface Fields
12	Wave swell	Surface Fields
13	Coastline Map	Coastal and Shelf
14	Coastline bathymetry	Coastal and Shelf
15	Surface Currents	Upper layer fields
16	Phytoplankton	Biochemical
17	Human health risks	Biochemical
18	Pathogens	Biochemical
19	Pesticides and Herbicides	Biochemical

Source : Fischer & Flemming, (1999)

Table 3-5 Oceanographic parameters frequently required by the Marine Research sector (Secondary data)

	Oceanographic parameter	Parameter Category
1	Sea Surface Temperature (SST)	Surface Fields
2	Sea Surface Salinity (SSS)	Surface Fields
3	Current direction	Surface Fields
4	Current velocity	Surface Fields
5	Sea surface wind stress	Surface Fields
6	Upper ocean salinity	Upper layer fields
7	Bathymetry	Sea bed
8	Surface Currents	Upper layer fields
9	CTD Sections	Deep ocean
10	Phytoplankton	Biochemical
11	Wave direction spectrum	Surface Fields
12	Wave heights	Surface Fields
13	Wave spectrum	Surface Fields
14	Coastline bathymetry	Coastal and Shelf
15	Nitrate	Biochemical
16	Chlorophyll	Biochemical
17	Suspended sediments	Biochemical
18	Precipitation	Surface Fields
19	Wave period	Surface Fields
20	Coastline map	Coastal and Shelf

Source : Fischer & Flemming, (1999)

ERS results also gives the combined averaged product quality levels (Table 3-6). However, it is important to notice that the following product quality requirements are the combined average requirement of all the stakeholder groups / marine applications (not only the food and research applications).

Table 3-6 Summary of the data quality requirements (Secondary data)

Information quality	Ideal range (according to the frequency)
Coverage	Coastal areas Shelf seas
Product type	Processed data Statistics and row data
Accuracy	1% 10%
Spatial resolution	1 km 10 km
Vertical resolution	1m 10m
Temporal resolution	Six hours (Specially for surface fields) Daily
Forecast period	10 days 1month (specially for biochemical variables)

Source: Created by the author based on the ERS results (Fischer & Flemming, 1999)

Primary and secondary data comparison indicates there is a significant similarity of the European and Japanese case studies as shown in the Table 3-7. However following are the key differences between the primary and secondary data.

1) According to the primary data both fisheries and researchers require wind profiles however secondary data shows a less significant for the same.

2) Researchers and fisheries in this case study require more biochemical information especially on the fish count, fish breeding and migration patterns etc. in comparison with the secondary data. Qualitatively, this may be because of the ongoing research trend about the fish stock depletion in the Japanese waters.

3) Japanese stakeholders tends to show a higher interest on the marine environmental impacts specially caused by the marine renewable energy project deployments. This may be due to

the higher perceived risks because of the lack of prior experiences.

Table 3-7 Comparison of the primary and secondary data

	Oceanographic Information requirements (Primary data)	ERS results (Secondary data)	
	Required by Fisheries	Includes in the top 10	Includes in the top 20
1	Sea Surface Temperature (SST)	√	-
2	Temperature distribution along the depth (CTD Sections)	x	x
3	Ocean Current / Tidal velocity and direction	√	-
4	Wave profile	√	-
5	Wind profile	x	x
6	Plankton levels	-	√
7	Underwater Video or the fish count	x	x
8	Underwater noise	x	x
9	Hourly mean sea level	x	x
10	Coastal bathymetry	-	√
11	Suspended sediments	√	-
12	Dissolved Oxygen level	√	-
	Required by Researchers		
1	Sea Surface Temperature (SST) and salinity (SSS)	√	-
2	Wave Profile	-	√
3	Ocean Current and Tidal Profile	√	-
4	Wind profile	x	x
5	Phytoplankton & Zooplankton	√	-
6	Nitrate levels	-	√
7	Dissolved Oxygen levels	x	x
8	Marine Mammal Observation	x	x
9	Underwater noise and Passive acoustic monitoring	x	x
10	Fish species count and their migration/breeding patterns	x	x
11	Suspended sediments	-	√
12	Marine growth (Sea bed)	x	x

Source: Made by the author

The other qualitative reasons for the difference among the primary data and the secondary data may be the differences of the data collection methodology where the secondary data was collected through an comprehensive questionnaire focusing the large scale (155) organizations and the primary data was collected through a simplified survey sheet used as a guide document in a context of interviews and focus group discussions. In addition, the number of respondents in the primary data collection is very low and not representing national level large scale organizations.

A similar survey done by the ‘Working Group on operational Oceanographic products for Fisheries and Environment’ (WGOOFE) of the ‘International Council for the Exploration of the Sea’ (ICES) was also considered as a secondary data for validating the stakeholders’ oceanographic information requirements. This survey was also done in the European context specially focusing the fisheries and environmental monitoring related information requirements. However the main respondents of the questionnaire survey are the scientists work closely with the industry. As a summary, this survey gives the oceanographic parameter requirements shown in the main graph of the Figure 3.2 as the stakeholders’ information requirement. In addition this survey also indicates that a mismatch existed between user (environmental and fisheries scientists) requirements and the perceived requirements identified by the producers of oceanographic data products (ICES WGOOFE, 2009).

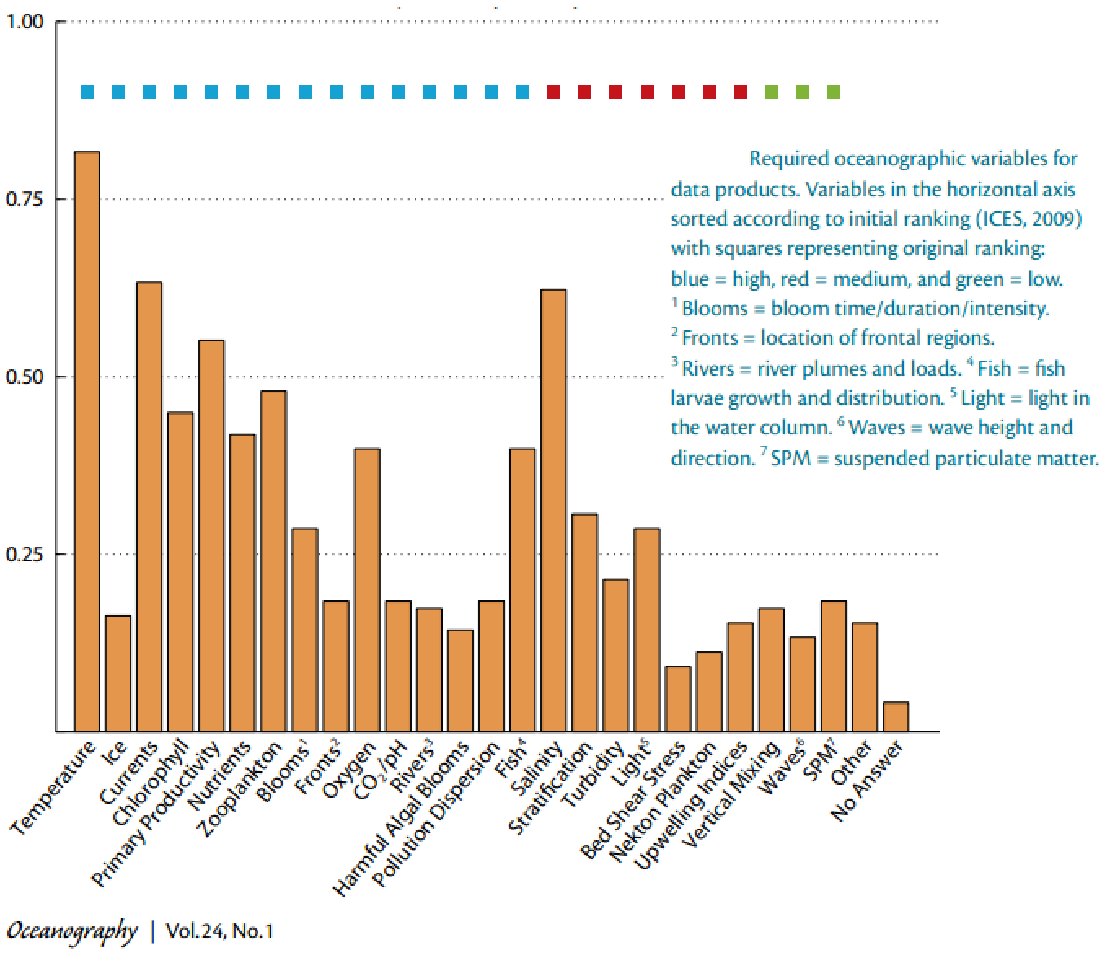

Figure 3.2 Stakeholders' operational oceanographic information requirements

Source : (Berx et al., 2011)

3.2 Information Generation capacity of the CMS (R.Q 2)

3.2.1 Oceanographic information obtained from the standard CMS

Table 3-8 summarize the oceanographic information which can be monitored by the standard condition monitoring system based on the existing design specifications and the developer interviews.

Table 3-8 Oceanographic parameters which can be monitored by the standard CMS (Primary data)

Monitoring Area	Monitoring Parameters	Attributable oceanographic parameter
Around the Turbine (at an average depth of 50m)	Ambient temperature	Water temperature at an average depth of 50m
	Turbine Rotation speed	Indirect indication of Ocean current velocity at depth 50m
	Current and Tidal velocity by ADCP, DVL, EM velocity meter	Direct measurement of current and tidal velocity
	Wave height by ADCPs	Wave heights
	Underwater video	Fish species and fish count
	Marine growth on the devices	Indirect measurement of biofouling rate & other related biochemical parameters
	Micro-fouling Macro-fouling	
	Marine mammal observation by underwater TV camera, passive acoustic monitoring, fish detectors or fish finders, Hydrophones and ADCPs	Marine Mammal observation (Dolphins and whales)
		Underwater noise
		Fish species and fish count
Around the sinkers and Anchors	Marine growth	Marine growth (Sea bed)
	Micro fouling Macro fouling	Indirect measurement of biofouling rate & related biochemical parameters
	Underwater video	Fish and Crustacea detection

Source: Made by the author based on the interviews

According to the developers, the first OCP project deployment is planning to do a comprehensive environmental impact monitoring. This is because OCP project is the first large scale ocean renewable energy project which will be deployed in the Japanese Kuroshio current areas. In addition there has been a prior agreement with the fishery associations to monitor and evaluate the impact of the OCP devices to the fish density in the deployment area. The major product quality levels are depending on the layout of the power plant itself because most of the sensors should be connected to the main device itself. According to the previous research (such as Sakaguchi 2015), the spatial resolution of power conversion devices are less than 1km. Hence spatial resolution can be improved up to 1km provided that each power conversion device is equipped with all the sensors mentioned in the condition monitoring specifications. However, the design specification has not been finalized yet. The main turbine is expected to be around 50 m below the sea surface and the power conversion devices has to potential to be deployed at depth range from 200 m up to 1000 m. (Figure 3.3).

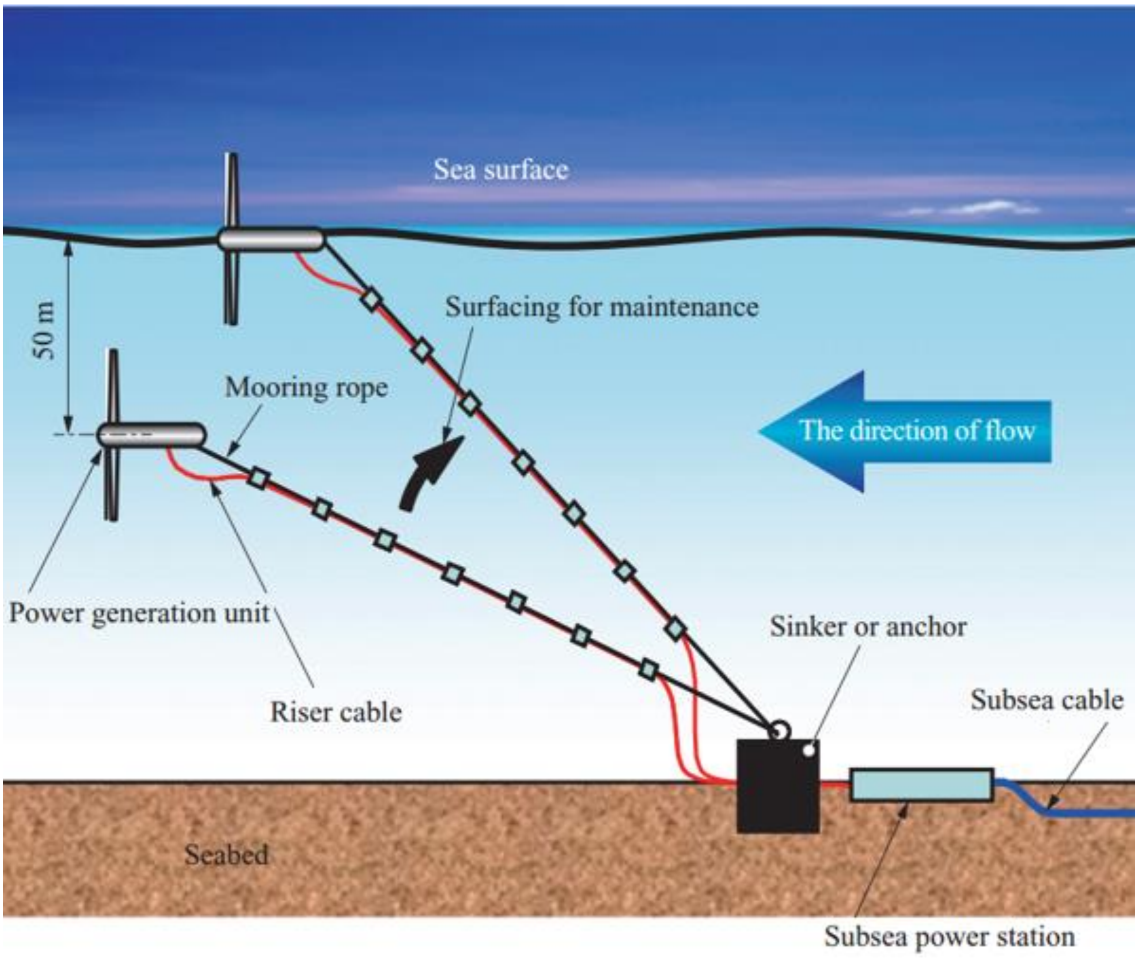

Figure 3.3 Design of the floating type turbine of the OCP project

Source: IHI Corporation

Since the design specifications of the condition monitoring system has not been completed yet, the exact details about the data quality levels are not available. However the Table 3-9 gives the summary of the potential data quality levels according to the results of the developer interviews.

Table 3-9 Summary of the possible data quality levels of the CMS (Primary data)

Information quality	Maximum potential data quality
Coverage	Depends on the coverage area of the power plant. The estimated plant area is 3km x 10km across the Kuroshio current path. (First deployment)
Product type	Depends on the type of sensors and the data processing and management strategy. Row data as well as processed data for some parameters may be available.
Accuracy	Highly depends on the type of sensors used.
Spatial resolution	Depends on the layout of the sensors within the power plant. Spatial resolution up to 1km should be possible.
Vertical resolution	Depends on the depth and power plant configuration. Parameters around 50m depth and sea bed level are possible
Temporal Resolution	Depends on the type of sensors used
Forecast period	Depends on the type of sensors and forecast models used
Latency	Real time communication between the power devices and onshore control room is possible. Latency of the oceanographic parameters depends on the data acquisition methods used.
Delivery medium	Depends on the data management strategy. Most probable delivery medium would be internet.

Source: Made by the author based on the interviews

3.2.2 Potential of having additional Oceanographic Information

The next step of answering the second research question is analyzing the possibility of improving the standard CMS such that highest number of stakeholder requested oceanographic parameters can be monitored. The main infrastructure available for improving the CMS is the existence of the physical structure where additional sensors can be mounted, existence of the fiber optic communication network with a very high bandwidth for the data communication and availability of the power supply which can be used to support the additional sensors. Hence, in this section, the possibility of improving the monitoring capability by utilizing these existing infrastructure of the power plant is considered by doing incremental changes to the sensor network. Table 3-10 summarize the results of the developer interviews and the researcher interviews for the potential improvements which can be made to the standard CMS by doing incremental changes to its sensor network.

According to the researcher interviews, one of the most valuable improvement which can be made to the standard CMS is the improving its connectivity such that specific research oriented monitoring equipment can be mounted on the devices and share the fiber optic network to transmit those data to the onshore facilities. One of such proposal was to mount the fish detector signal receivers[*] on the mooring line so that the researchers do not need expensive hard infrastructure to capture the fish migration pattern in the Kuroshio Current. If these receivers can be mounted on the mooring line, a significant amount of Kuroshio Current cross section can be covered hence the effectiveness is said to be improved significantly. Similarly, mounting the water samplers** (a transparent tube which captures the samples) to monitor the suspended sediments and cameras to capture the image and send those data to the laboratories would enhance the ongoing researches significantly.

Table 3-10 Additional parameters and quality improvements by doing incremental changes to the standard CMS

	Incremental Change to standard CMS	Monitoring Improvement
1	Adding CTDs on the mooring line at an optimum depth levels	Able to monitor the depth wise temperature distribution (CTD Sections)
2	Mounting the fish detection receivers on the mooring line*	Fish detection and migration patterns can be identified
3	Mounting the water sampler tubes** (and cameras) on the non-moving device	Most of the bio-chemical parameters such as suspended sediments, plankton levels etc. are obtained by sample testing. (The researchers proposal to automate the process is sending an image of the sample to the laboratories)

Source: Made by the author based on the interviews

According the interviews, most of the stakeholder information requirements can be monitored by improving the standard CMS (by adding more sensors). In addition to the high cost, the design limitations of the OCP was also considered when trying to achieve the highest level of ocean monitoring which satisfy most of the information requirements of the stakeholders. For example, atmospheric measurements (such as wind profile, precipitation etc.)

are not possible within the OCP design requirements however, those parameters can also be considered in other type of ocean renewable energy projects.

3.2.3 Comparison with the secondary data

The main secondary data source for the second research question is the existing ocean observation system specifications. Existing ocean observation systems and the CMS of the power plant can be comparable because of the similarities of ocean monitoring methodologies. However, design limitations of the power plant is also considered when comparing ocean monitoring potential of the power plant's CMS with the existing ocean monitoring systems. The main offshore observation systems referred in this research are,

i. FINO (Forschungsplattformen in Nord- und Ostsee Nr. 1, 2, 3 - Research platforms in the North and Baltic Seas 1, 2 and 3) in Germany. (http://www.fino-offshore.de/en/ [retrieved on 1st July, 2016].)

ii. Existing integrated marine observation data portals and other literature

3.2.3.1 FINO 1, 2, and 3

FINO ocean monitoring platforms have been constructed by the Federal Government of Germany in 2002 with the intention of investigating the conditions for offshore wind power generation in North Sea and Baltic Sea. Scientific studies conducted on these platforms includes measurement of wind strength, wind direction and turbulence in relation to height, measurement of wave height and wave propagation, measurement of the strength of sea currents, analyzing the seabed subsurface conditions and lightning measurements. In addition, these research platforms monitor oceanographic parameters (such as Current measurements, Oxygen measurements, Wave and Surface Current measurements, Temperature and Salinity measurements etc.), meteorological parameters (such as wind velocity, air temperature, humidity, precipitation and air pressure, radiation levels etc.). Although these infrastructure are made purely for scientific applications, the data acquisition methodologies (Table 3-11) can be compared with the OCP project's CMS.

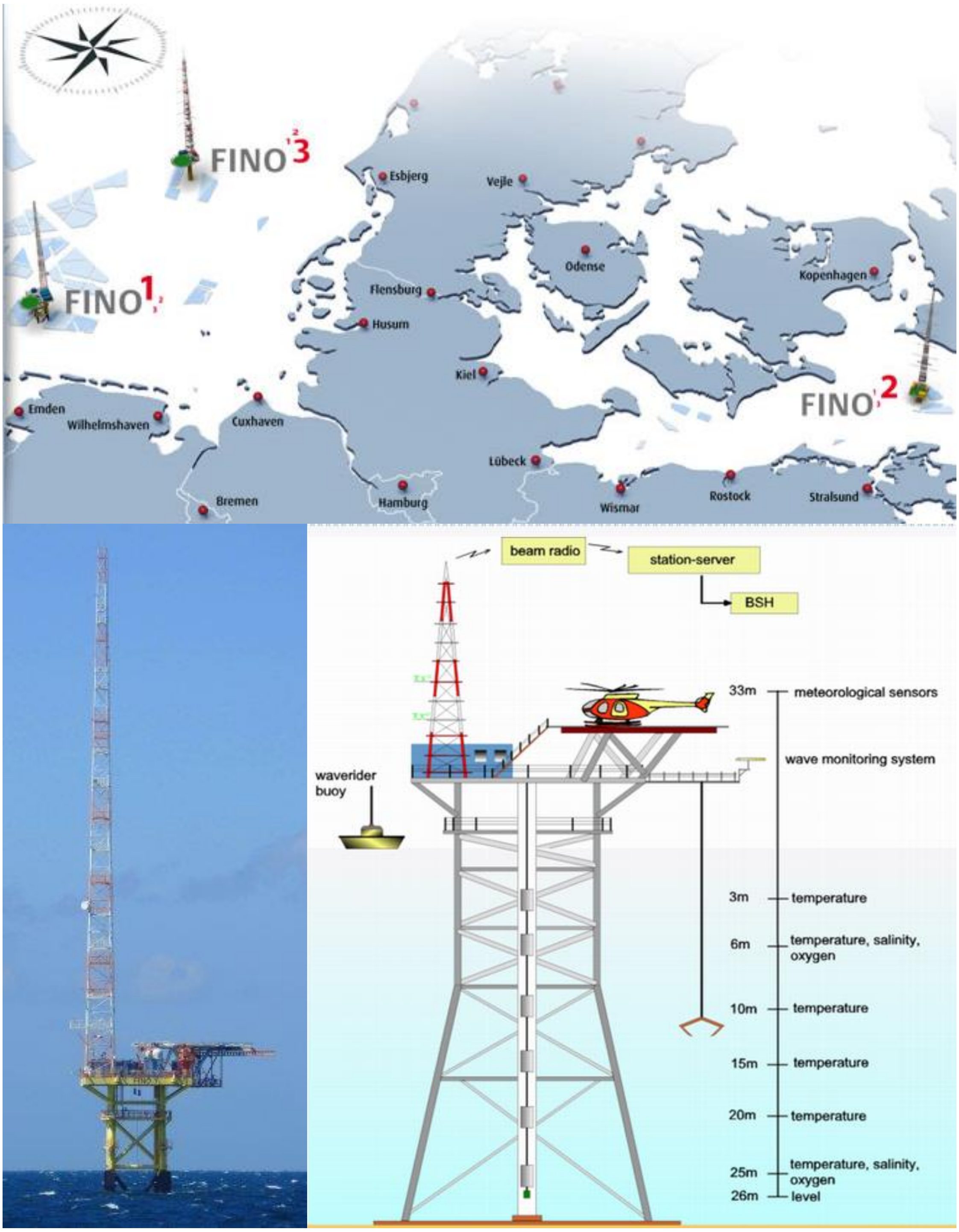

Figure 3.4 Location of FINO platforms and general details of data acquisition methods

Source: http://www.fino-offshore.de/en/ [last retrieved on 30th June, 2016]

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Table 3-11 Summary of parameters monitored by FINO1 and its applicability to the CMS

Measured Parameter	Data Acquisition method	Applicability to the CMS of the OCP
Ocean Current measurements	On line monitoring by a bottom mounted Nortek Acoustic Wave And Current Meter (AWAC) Acoustic Doppler Current Profiler (ADCP)	Highly applicable and already in the standard CMS configuration.
Temperature and salinity	'Sea Bird Electronics 37 (SBE37) Microcat' & 'Sea & Sun / T40' thermistors have been used	Realtime communication is available but have to deploy several sensors in different depth levels.
The Wave and Surface Current	nautical X-Band radar, Nortek Acoustic Wave And Current Meter (AWAC) ADCP	X-band radar is not suitable for CMS, but bottom mounted ADCP may be suitable.
Wind Parameters	Measured by cup anemometer, ultrasonic anemometers and wind vanes	Wind parameters are not suitable with OCP design

Source:http://www.bsh.de/en/Marine_data/Observations/MARNET_monitoring_network/FINO_1/index.jsp, http://www.seabird.com/sbe37si-microcat-ctd [last retrieved on 30th June, 2016]

As a summary, water temperature measurements (CTD sections) and ocean current measurements and biochemical parameters such as salinity and dissolved oxygen level can be monitored by commercially viable methods.

3.2.3.2 Existing integrated marine observation data portals and other literature

Due to the huge economic benefits, most the ocean observation data in Europe are being shared among its members and stakeholders and thus provided as integrated data sets from different sources. “Copernicus Marine Environment Monitoring Service” is one such integrated data portal which has many oceanographic data monitored commercially. Table 3-12 gives a summary of such commercially monitored oceanographic parameters.

Table 3-12 commercially available, in-situ, near real time oceanographic data sources and parameters monitored

Monitored Parameters	Data Set	Data sources/ suppliers
• **Mass concentration of chlorophyll A in sea water** • **Moles of oxygen per unit mass in sea water** • **Sea surface height above sea level** • **Sea water salinity** • **Sea water temperature** • **Sea water x velocity** • **Sea water y velocity**	Global ocean in-situ near real time observations (INSITU_GLO_NRT_OBSERVATIONS_013_030)	Argo, GOSUD, OceanSITES
	Arctic ocean- in situ near real time observations (INSITU_ARC_NRT_ OBSERVATIONS _013_031)	Arctic ROOS members
	Baltic sea- in situ near real time observations (INSITU_BAL_NRT_OBSERVATIONS_013_032)	BOOS members
	Atlantic- European north west shelf- ocean in-situ near real time observations (INSITU_NWS_NRT_OBSERVATIONS_013_036)	NOOS members
	Atlantic iberian biscay irish ocean- in-situ near real time observations (INSITU_IBI_NRT_OBSERVATIONS_013_033)	IBI-ROOS members
	Mediterranean sea- in-situ near real time observations (INSITU_MED_NRT_OBSERVATIONS_013_035)	MONGOOS members
	Black sea- in-situ near real time observations (INSITU_BS_NRT_OBSERVATIONS_013_034)	Black Sea GOOS members

Source: Copernicus marine environment monitoring service

Similar to the European Copernicus data portal, the CORMP (Coastal Ocean Research Monitoring Program) data portal which is a member of IOOS (Integrated Ocean Observation Systems) share the observations done in the east coast of the United States. The Sources of CORMP data portal provides data on Wind speed and direction, Conductivity, Ocean current velocities, water temperature and salinity, Wave direction, height and periods, air temperature and pressure (CORMP, n.d.). One of the similar project in the East Asian context is the underwater environmental monitoring project in the offshore wind farm in the western sea of Taiwan. (Chan et al., 2013). Wave profile, Ocean current profile, water temperature and salinity, mean sea level, dissolved oxygen content, underwater acoustics and benthonic measurements have been considered as the monitoring parameters. Acoustic Doppler current profiler (ADCP) by Teledyne RD Instruments (Teledyne Rd Instruments™), Sea-Bird Electronics (SBE) 37 CTD (Sea Bird Electronics™), and a TC-4032 hydrophone manufactured by Teledyne Reson (RESON Teledyne™) have been used as the main equipment.

Although selected references does not represent a significant portion of existing ocean monitoring programs, the secondary data analyzed is sufficient to indicate that the most commonly requested physical oceanographic parameters (such as Water temperature, Ocean current velocities, Wave and Wind profiles, underwater acoustics etc.) are being monitored in the commercial applications. In additions, few biochemical parameters (such as salinity, dissolved oxygen levels, chlorophyll etc.) are also viable to monitor in commercial applications according to the secondary data. However, real time, in-situ monitoring of fish species, plankton levels as well as other biochemical parameters highlighted in the first research question was not found to be already existing in commercial applications. Rather those parameters are monitored in scientific research applications. Long term Marine Mammal Observation (MMO) has been done for previous offshore energy projects (MeyGen, 2011) even though it's not a commercial application.

By analyzing the results obtained for the first and second research questions, potential information demand (from stakeholders) and supply (from the CMS) can be matched and summarized as the Table 3-13.

Table 3-13 summary of the stakeholders' information demands, information gap and potential of CMS to fill the gap

	Oceanographic parameter in demand	Information Gap (in the case study area)	Potential supply of the CMS	Additional requirements to match the requirement
1	Sea Surface Temperature (SST)	Available from satellite data	Temperature at 50 m depth	-
2	Vertical temperature distribution (CTD Sections)	Not available from data existing sources	Available	Additional CTDs are required
3	Sea Surface Salinity (SSS)	Available from satellite data	Salinity at 50 m depth	Additional sensors required
4	Ocean current and Tidal velocity	Coverage and availability of real-time data is limited	Available	-

5	Wind profile	Coverage and availability of real-time data is limited	Not Available	-
6	Wave Profile	Coverage and availability of real-time data is limited	Available	-
7	Phytoplankton & Zooplankton levels	Very limited information exists	Not available	remote sensing equipment can be supported
8	Fish count / Underwater video	Almost No Information exists	Underwater video is available	Fish counting methods should be used with video
9	Underwater noise and Passive acoustic monitoring	Very limited information exists	Available	-
10	Marine Mammal Observation	Almost No Information exists	Available	-
11	Dissolved Oxygen levels	Very limited information exists	Available	Additional sensors required
12	Nitrate levels	Almost No Information exists	Not available	Remote sensing equipment can be supported
13	Suspended sediments	Very limited information exists	Available	Additional sensors required
14	Fish species count and their migration / breeding patterns	Almost No Information exists	Fish migration pattern available	Additional signal receivers required
15	Marine growth (Sea bed)	Almost No Information exists	Available	-
16	Hourly mean sea level	Available with data quality limitations	Available	Additional sensors required
17	Coastal bathymetry	Available	Not available	-

Source: Made by the author

3.3 Costs and Benefits of the proposed Information sharing scheme (R.Q 3)

According to the interviews with the Wakayama prefectural government officials, qualitative elements to be considered when evaluating the costs and benefits of the proposed information sharing scheme has been summarized in the Table 3-14. However, these are qualitative factors given considering all possible beneficiaries in the local community in general.

Table 3-14 Key benefits (Drivers) and costs (Barriers) identified by the local government officials

	Potential Benefits or key drivers	Potential Costs or key barriers
1	Improved the efficiency and safety of offshore operations	Additional financial costs to the OCP project development and deployment
2	Opportunity for new local industries such as monitoring & forecasting, suppliers etc.	Difficulty to coordinate with all the possible stakeholders
3	Better resource management & planning	Potential data management issues
4	Effective in gaining the stakeholder support for project development	Potential over exploitation of natural resources
5	Potential for local economic development by other indirect means	Potential impacts to the local and traditional socio-economic activities

Source: Made by the author based on interview results

Costs and benefits of the information is highly dependent on the oceanographic parameters and data quality levels of those parameters. Due to the lack of prior experiences, the monetary value of the incremental costs and benefits is very hard to obtain from the stakeholders. Hence estimation methods and other indirect indicators have been used to complete the monetary evaluation of the proposal. These estimations are based on the qualitative data obtained from the stakeholder interviews and focus group discussions combined with the secondary data available from the literature and other sources.

3.3.1 Benefits of oceanographic information

The main benefits of the oceanographic information (especially from the Kuroshio current areas) for the local fisheries are as follows.

i. Improving the productivity by efficient fishing ground selection

According to the interviews with local fisheries, Kuroshio current velocity and the water temperature is the most important criteria for selecting the efficient fishing grounds. It is highlighted that experienced fishermen can estimate the fish catch up to a 10 km range if the fisherman gets the accurate information about the water temperature. Currently, only the sea surface temperature (SST) is available from the NOAA satellite observations. Fishermen use traditional methods (such as estimating the depth wise temperature distribution by means of a rope etc.) to estimate the water temperatures in the deeper water layers. Since the CMS can provide the depth wise temperature distribution with a very high spatial resolution, the main existing information gap can be fulfilled by the proposed information sharing scheme. Since the local fisheries believes that they can estimate the fishery productivity in relatively a large area if they were provided with accurate temperature distributions and current velocities of a single point, their perceived benefits of these particular parameters are very high with respect to the other parameters.

ii. Operational cost reduction by reduced transportation requirements

The only existing guidance for selecting the fishing ground is the sea surface temperature (SST) which is observed by the satellites. The spatial resolution and the accuracy limitations results a higher travel requirements. According to the fishery statistics, 20%-30% of the operational costs attributes to the transport related costs such as fuel costs etc. (MAFF 2013). Transportation requirements can be reduced if the fisheries can get accurate in-situ, real-time data remotely, i.e. without visiting the area. Additionally, improved knowledge about the sea conditions can results efficient and safe route selections when reaching to the most efficient fishing grounds.

iii. Improving the reliability of the fish migration pattern estimates

Estimation of the fish migration patterns is an important research topic in the Japanese fisheries because the fisheries are facing a considerable fish catch decline. Lack of understanding of the fish migration patterns is said to be a main barrier to do an effective and sustainable fishing in the area. Improved oceanographic information (such as temperature variances, Current velocities, plankton levels etc.) helps local fishermen to understand the fish migration patterns. It is said that experienced fishermen can estimate the fish migration patterns if they can understand the basic Kuroshio Current conditions. Hence local fisheries have a high perceived long term benefit of estimating the fish migration by the proposed information sharing scheme.

iv. Reducing the operational costs by reducing the damages and related risks

The main operational risk and major contributor to the human and property damages is the unexpected weather conditions (including the both subsea, surface level and atmospheric). Lack of environmental monitoring parameters (with the required quality levels) and inaccuracies of the existing weather prediction models are the main reasons of failing to forecast the weather conditions. According to the interviews done with the researchers, oceanographic parameters discussed in the section 3.2 is very useful for forecasting the subsea conditions using the existing weather prediction models.

From the fisheries perspective, one of the greatest human threats are caused by the rough sea surface conditions caused by waves and winds. One of the major property damages are caused by rapid currents also known as ‘Kyucho’. According to the researchers and the literature, Kuroshio current parameters are essential for predicting the Kyucho events. (Isobe et al., 2012; Matsuyama et al., 1999). Such devastating Kyucho event (such as the one occurred in 1994 in the

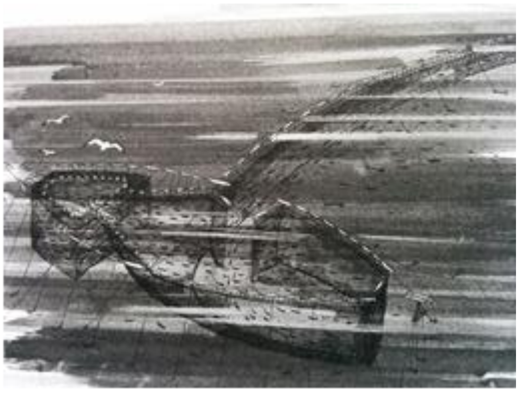

Figure 3.5 General overview of a fixed net set up

Source - Fisheries Experimental Station, Wakayama Prefecture

Sagami bay area) causes huge damage to the fishery properties such as set nets. (Ishidoya, 2008; Matsuyama et al., 1999). According to the interviews, the set nets / Fixed nets deployed generally costs around 3-10 million US dollars (Figure 3.5). According to the researchers, oceanographic information provided by the proposed information sharing scheme can be useful when predicting future Kyucho events. Hence the fisheries perceived value of reducing the damages to these set nets is significant. Even though it is difficult to estimate in monetary terms, the incremental value of reducing the human risks by improving the accuracy of the weather prediction is also highlighted as a main benefit of the proposed information sharing scheme.

According to the interviews done with the researchers, the main benefits of the oceanographic information (especially from the Kuroshio Current areas) for the researchers who are working with related research are as follows.

i. Improving the understanding and accuracy of the fish migration and breeding patterns

Due to the fish catch decline experienced within the last decade in Japanese coastal areas, one of the main research themes related to fisheries is the understanding the fish breeding and migration patterns. However, for most of these researches, the data collection is done using the manual sample collection and oceanographic parameter monitoring methodologies which is done during the field surveys as shown in the Figure 3.6.

Figure 3.6 Manual data collection for researches

Source: Fisheries Experimental Station, Wakayama Prefecture.

In addition to the manual data collection, very limited in-situ data is obtained automatically for understanding the fish migration and breeding patterns by means of signal transmitters and receivers. The transmitters are put inside a large fish sample and receivers are set covering the expected fish migration paths (Figure 3.7). Although these transmitters and receiver units are relatively cheap, the cost of setting up the receivers in the migration path is expensive. Hence they have been deployed in the areas with a minimum cross section of migrations paths such as estuaries. However,

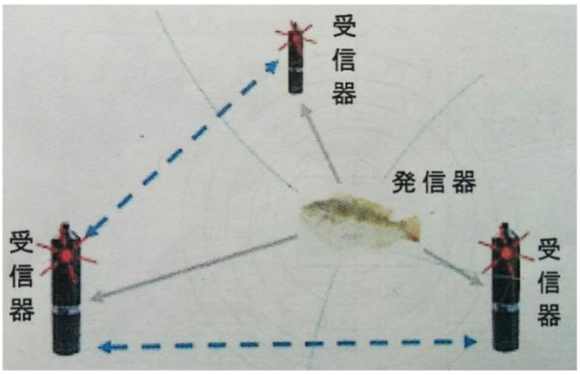

Figure 3.7 Transmitter receiver setup used in fisheries research

Source - Fisheries Experimental Station, Wakayama Prefecture the researchers need to set up those receivers across the Kuroshio Current path.

According to the interview results, biggest advantage of the using the co-benefits of the OCP project is that the researchers can use the structure as well as the communication lines of the power plant to setup and operate their research related sensors & equipment.

Researchers believe that the fish detectors and signal receivers can be easily mounted on the mooring lines of the power plant so that they can cover a large cross section of the Kuroshio current path with a lower cost.

ii. Improved Environmental impact monitoring

According to the researchers, additional oceanographic parameters and improved quality of existing oceanographic parameters available by the proposed information sharing scheme would enhance the subsea environment monitoring capabilities. According to the developers, environmental impact monitoring has been a major consideration where they had an agreement to put extra effort to do additional monitoring in the first deployment. With this proposal, the same or more improved level of subsea environmental monitoring will be available which is considered very valuable by the researchers.

iii. Improving the existing data sets which is used for modelling

Most of the other types of researchers are based on the numerical modeling and other simulation techniques. Real ocean observations are required as initial conditions of these models as well as to validate the results. According to the researchers, satellite observations are the most frequently used information. However, more detailed oceanographic information are also required for improving the simulation outcomes. In-situ observations from existing buoy systems and other ocean monitoring platforms are the next level of detailed information available to the researchers. Since this proposal adds another in-situ oceanographic data source, both parameter wise and data quality wise improvement to the existing data sets is expected.

3.3.2 Stakeholders' willingness to pay for the information

In order to do the cost benefit analysis, the benefits of the oceanographic information discussed in the previous section has to be comparable with the cost estimates which is done in monetary terms. However, direct monetary evaluation of the benefits is practically unfeasible due to lack of data and uncertainties. Kaiser and Pulsipher (2004) points out the difficulty to establish a direct link between improved observation systems and cost savings and lack of clarity about which form of observation system, or combination of forms, will enhance the value of the existing configuration the most and even quantifying the value of existing observation systems is subject to significant uncertainty etc. as the practical limitations of evaluating the value of oceanographic information. In addition, the stakeholders' limited knowledge and experience to give reliable data to estimate the benefits in monetary terms has also evident in this research as a major barrier to do a direct economic valuation of the proposed information sharing scheme.

Hence indirect indicators such as prevailing cost of information, willingness to pay (WTP) (Boardman et.al. 2006) for the information (based on the stakeholders/ perceived benefit levels) has been used for estimating the benefits in this research. Even with these indirect indicators, researchers' benefits of information is harder to estimate due to the reasons such as,

1. Monetary value of the on-going research itself is harder to measure. Hence the impact of new information is much harder to estimate in monetary terms.

2. Most of the researches considered in this field survey is financed by public funds and hence the market value of existing information and willingness to pay for new information was not available from the key informants interviewed.

However, the values for the existing cost of information and willingness to pay from the Wakayama Higashi Fishery union was available. According to the interviews and the focus group discussions done with the representatives of fishery union and individual fisherman, the average willingness to pay for the additional information proposed in this research is about 0.25 million yen annually. In addition, it is mentioned that the Wakayama Higashi Fishery Union has incurred about 20 million yen for obtaining oceanographic information for the fisheries. Further, fishermen have to option to obtain very few parameters from existing data providers and they should pay 20,000 yen annually for such an option. Fishery research and experiment station has incurred about 0.8 million yen annually for obtaining information from other sources. According to the interviews and the focus group discussions with the heads of the Wakayama Higashi fishery union, it is mentioned that the fisheries will be willing to pay from 100,000 yen per fisherman per year and it may increase up to 500,000 yen per fisherman annually if they can get all the oceanographic data required.

3.3.3 Sensitivity analysis of the stakeholder benefits

Due to the high level of uncertainty in the financial estimates obtained by the stakeholder interviews and focus group discussions as mentioned in the previous section, a separate sensitivity analysis was conducted using secondary data to validate the reliability of the primary data. The secondary data used is the statistical records of Japanese fishery (MAFF, 2013) and the literature on estimating the benefits of oceanographic information (Chiabai & Nunes, 2006; Kaiser & Pulsipher, 2004; Kite-Powel & Colgan, 2001). For the sensitivity analysis of the monetary evaluation of the benefits of oceanographic information following criteria has been considered.

Table 3-15 Indicators for estimating the fisheries benefits for the sensitivity analysis

Main Benefits	Supporting arguments	Indicators
Annual income improvements	Better stock predictions Increase in fishing days	Average landing quantity and number of fishing days (Kaiser et.al 2004)
Annual fuel cost reductions	Reduced transportation requirements	Number of trips & transit times (Kaiser et.al 2004)
Annual repair & depreciation cost reduction	Reduced operating costs due to better fishing area and route selection	Average operating costs (Kaiser et.al 2004)
Other benefits including safety improvements, insurance cost reductions etc.	Damage reduction from better knowledge on local sea conditions	Average insurance costs, damages (Stel & Mannix, 1996)

Source: Made by the author

Sensitivity analysis done on the base values obtained from the fishery statistics (MAFF, 2013) and Table 3-16 gives the summary of the existing fishery statistics and financial elements used for the sensitivity analysis according to criteria selected in the Table 3-15.

Table 3-16 Sensitivity Analysis of potential stakeholder benefits

Annual Figures per fisherman	2006-2012 Average values		Potential to have Impact*
	¥ (in millions)	% of income	
Fishery Income	**6.28**		✓
Fishery cost	**4.00**		
Labor Cost	0.48	11.90%	x
Equipment Cost	0.32	8.08%	x
Repair Cost	0.28	6.91%	✓
Fuel Cost	0.78	19.42%	✓
Sales Commissions	0.39	9.68%	x
Depreciation	0.64	15.91%	✓
Others	1.12	28.10%	✓
Fishery Net Earnings	**2.28**	36.22%	
Non Fishery Net Earnings	0.13		

*Based on the literature and the best guess according to the authors' estimates.

Source: Made by the author based on (MAFF 2013)

Figure 3.8 represents the total estimated fishery benefit levels assuming a same level of percentage improvement for all the selected criteria. According to this sensitivity analysis, the potential monetary value of additional oceanographic information in the range of ¥100,000 to ¥500,000 per fisherman per year represents the combined improvement range 1.1% and 5.5% respectively. Although these estimations are subjected to high level of uncertainties, it is clear that the willingness to pay obtained by the primary data collection is also in the same range.

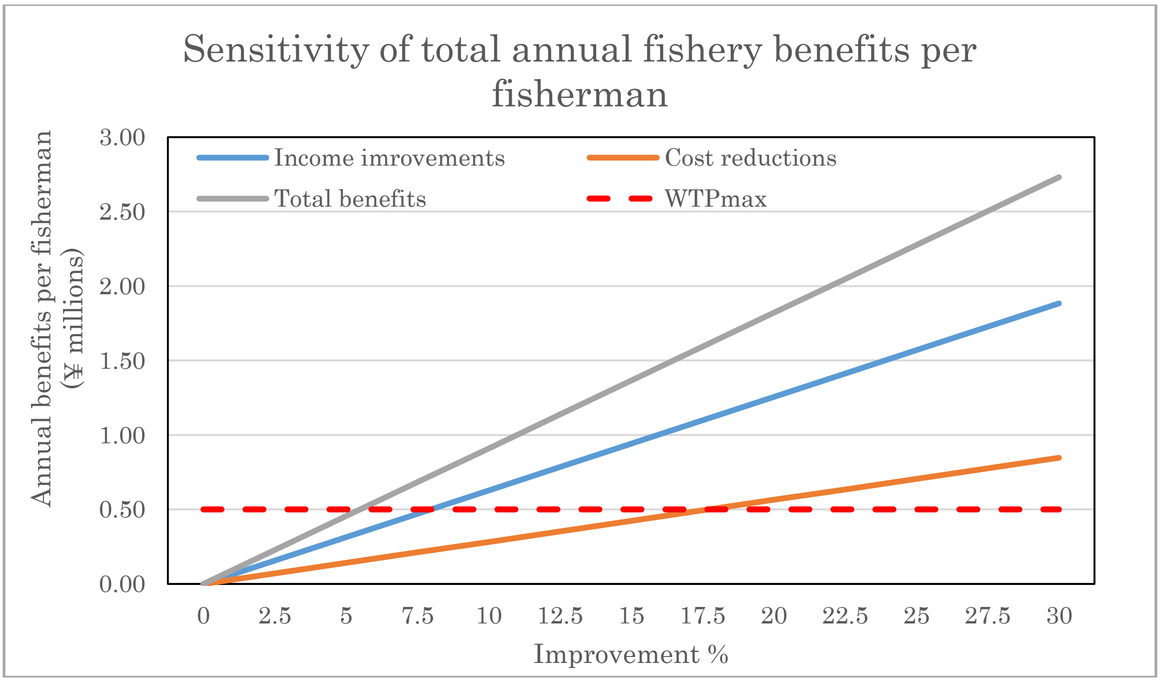

Figure 3.8 Sensitivity analysis

Source : Created by the author assuming productivity improvements and fishing days has a direct impact on the fishery income, Travel requirements and transit times are directly proportional to fuel costs and all the considered improvements happen with a same percentage.

In order to improve the results, detailed sensitivity analysis was done to test the different scenarios where the total benefits were assumed to be from three independent indicators, i.e. Income improvements, Fuel cost reductions and depreciation, repair and other cost reductions (considered as one category). The results of this three independent variable sensitivity analysis is given in the Appendix V.

3.3.4 Estimation of the incremental cost of the proposed information sharing scheme

According to the basic information sharing proposal (obtaining information from the power plant's CMS and distributing the relevant information to the required stakeholders) additional operations such as additional data processing, information management and distribution etc. should be performed in addition to the basic tasks of operating the power plant. However, due to the existence of sophisticated information distribution channels among local stakeholders as well as relatively insignificant cost of data distribution through the modern Information and Communication Technologies (ICT), it is assumed that these additional tasks involves insignificant additional costs specially to the project developers. However, this assumption is not valid if it involves even an incremental change to the standard CMS of the power plant. This is because the underwater monitoring is very expensive and involves a significant maintenance costs.

According to the results of the initial research questions, it was identified that there is an opportunity to improve the standard condition monitoring system so that a higher level of stakeholders' oceanographic information requirements can be satisfied by the CMS. The potential returns of such an additional investments is clearly indicated by the significant change of the fisheries willingness to pay amount. Hence, incremental changes to the CMS that results additional information availability is considered in the incremental cost estimation.

3.3.4.1 Identifying the Costs attributable to the CMS

Mitsui Global Strategic Studies Institute (MGSSI), a member of the OCP project development consortium, has done a very basic cost estimates considering three OCP deployment scenarios. A very basic summary of those financial estimates for the most general deployment scenario (One hundred 2 MW devices, deployed in 1000 m water depth, 50 km offshore) is given in the Table 3-17.

Table 3-17 Summary of the OCP project cost estimates for a hundred 2MW devices deployed in 1000m depth at 50km offshore

Items	Cost (£'000)
Capex	
Equipment costs*	1,267,963
Installation Costs	134,181
General Expenditure	31,349
General Capex Contingency (18%)	258,029
	1,691,521
Opex	
Annual O&M costs**	40,766
General Contingency (16%)	6,523
	47,289

Source: MGSSI financial estimates

*From the total capital expenditure, £42,822,670 is estimated for the standard CMS equipment (approximately 3% of total capex).

** Breakdown of the annual Operation and maintenance costs (% of total annual cost)

1. Subsea Cable Test/Inspection £167,960 (0.41%)
2. Annual inspection of nacelles/rotors £1,179,200 (2.89%)
3. Mooring inspection £90,840 (0.22%)
4. Scheduled replacements/repairs £2,289,000 (5.62%)
5. Unscheduled repairs £2,313,430 (5.68%)
6. Management and engineering costs £34,725,839 (85.18%)

(Sum of individual values may not be equal to the respective totals due to rounding off errors)

From these financial estimates, Operation and maintenance cost attributable only to the CMS is not available. It also represents the practical scenario since most of the maintenance activities are planned according to the condition of the independent subsystems of the power plant. Even though the CMS is also a subsystem, it is more integrated within the other sub systems, hence separate maintenance cost estimation for CMS is not practical. However, the maintenance cost of the CMS can be estimated by referring to the existing offshore / underwater monitoring systems since, maintenance activities done on those platforms are attributable mostly to the monitoring equipment and data transmission network.

Chiabai and Nunes (2006) has given a comprehensive cost breakdown estimation of the Mediterranean forecasting system towards environmental predictions (MFSTEP) as shown in the Figure 3.9.

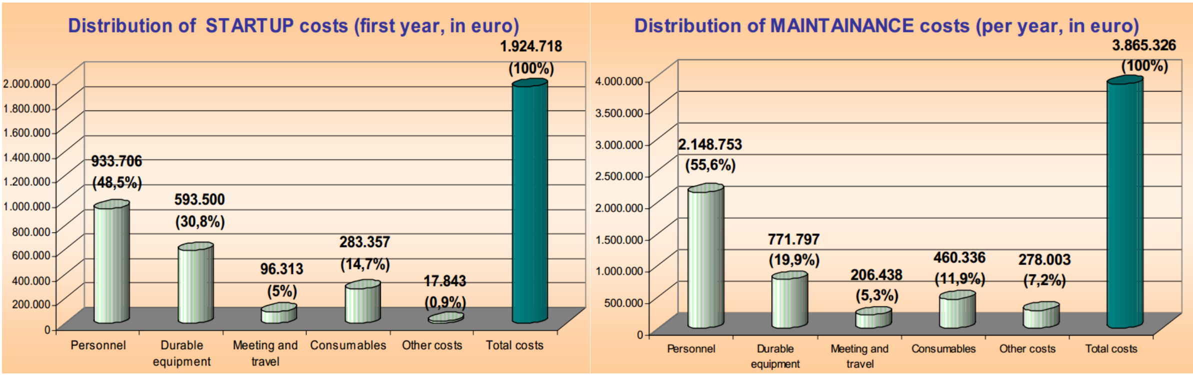

Figure 3.9 Summary of cost estimates of MFSTEP

Source: Chiabai & Nunes, (2006)

By analyzing the startup costs and annual maintenance costs of the MFSTEP ocean monitoring system, it can be highlighted that the annual maintenance cost is almost twice the startup cost and more than half of the annual maintenance cost is for the personnel costs (Administration cost, researchers' cost, training and technical staff cost etc.). However, in this research context, a very insignificant additional personnel cost can be expected due to the incremental changed done to the CMS, since the operation and maintenance of the CMS is done by the power plant operators as a part of their routine power plant maintenance activity. Hence it can be assumed that the incremental annual maintenance cost is equal to the incremental startup cost of the CMS within a context of an ocean renewable energy power plant.

With these assumptions, from the MGSSI costing estimates, it can be estimated that the startup & annual operating cost of the standard CMS is approximately 42.8 million euros each.

3.3.4.2 Estimation of incremental costs attributable to the CMS

To estimate the worst case scenario, 10% of the standard costs was estimated as the incremental additional costs which may be resulting from adding more sensors to the standard CMS. Hence the additional startup cost in the worst case scenario is estimates to be 4.28 million Euros which is approximately 480 million yen. And the same amount is expected to incur annually as additional operation and maintenance costs.

To obtain the most probable additional costs, number of additional sensors required was calculated based on a proposed sensor layout plan which is shown in the Figure 3.10.

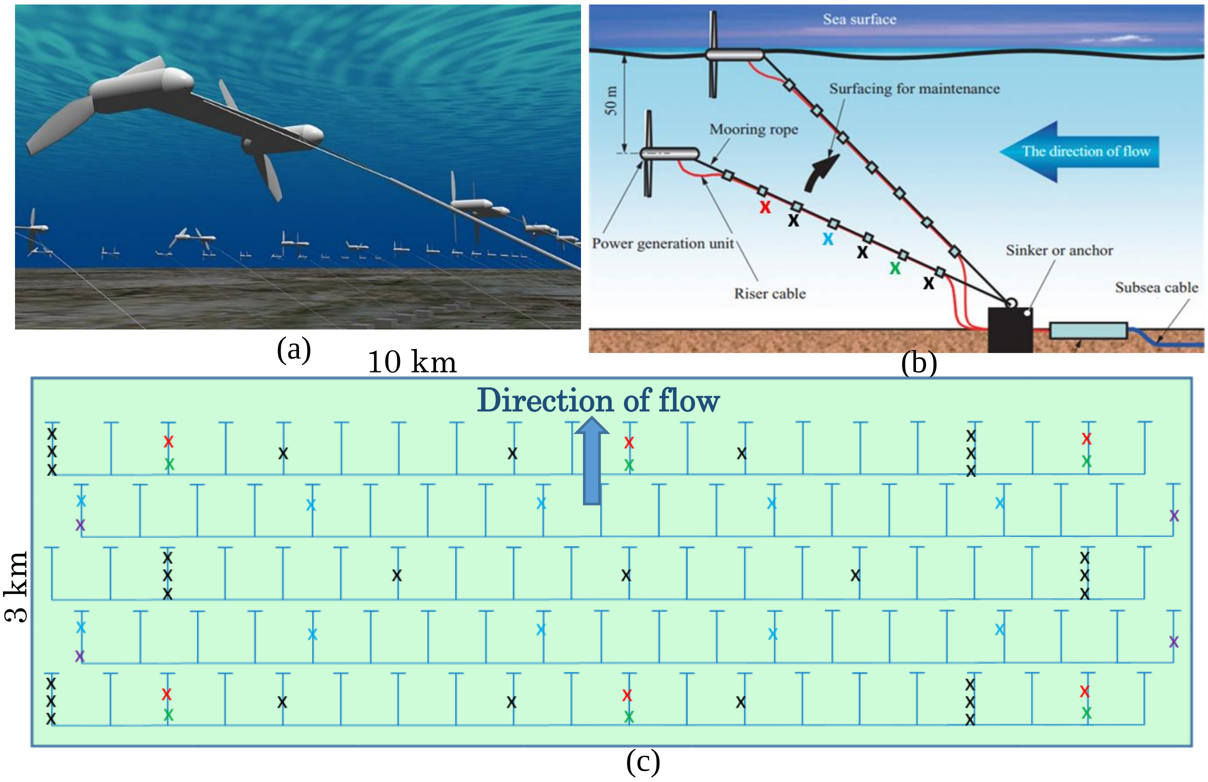

Figure 3.10 (a) Virtual reality of OCP plant (b). Side view of a twin turbine energy convertor with additional sensors on mooring line, nacelle and the sinkers, (c). Plan view of the turbine farm with the additional sensor layout

x =CTD
x =ADCP
x =Video cameras and Hydrophones
x =Fish detectors
x =Bio-chemical sensors

Source: Created by the author based on the interviews done with the stakeholders and project details from IHI Corporation.

According to the sensor layout plan (which was designed considering the stakeholders' most important oceanographic information requirements), additional sensor costs were estimated using the market data as shown in the Table 3-18.

Table 3-18 Additional sensor cost estimation

Sensor (Generic type)	Unit cost (highest range of different pricing data)	Units required	Total cost (¥ millions)
CTD	¥ 700,000 - ¥ 1,000,000	27	18.9 – 27.0
Acoustic Doppler Current Profiler	¥ 5,000,000-¥ 7,500,000	6	30.0 – 45.0
Underwater Video systems	¥1,000,000 - ¥ 1,500,000	6	6.0 – 9.0
Hydrophone, Passive acoustic monitoring equipment	¥ 500,000 - ¥ 700,000	6	3.0 – 4.2
Fish Detector	¥ 250,000 - ¥ 300,000	10	2.5 – 3.0
Biochemical sensors (Chlorophyll A, sampler, particle counter)	¥ 1,500,000 - ¥ 2,000,000	4	6.0 – 8.0
Connectors and other additional equipment	Assuming 100% of the sensor costs		66.4-96.2
			132.8 – 192.4

Source: Created by the author based on the developer interview results and market data

However, it should be noted that these costing estimates are based on a very limited market data, hence the final values incorporates a high level of uncertainty. However these costing can represent the worst case scenario hence used in the option evaluation process done at the end of the data analysis of this research.

3.4 Scenario creation and criteria selection for the MCDM model

According to the preliminary results of the three main research questions, it was highlighted that the CMS of the OCP power plant has a potential to satisfy most of the stakeholders' oceanographic information requirements. However, standard CMS cannot satisfy all the information requirements. Hence the scenarios for the final MCDM model was selected based on the level of information sharing considered.

<u>Scenario 1 – No information sharing</u>

This is representing the null hypothesis where no oceanographic information sharing is done from CMS to the other stakeholders. Since this is the null hypothesis, no incremental costs or benefits are involved in this scenario.

<u>Scenario 2 - Sharing all the information required by the stakeholders</u>

This represent the highest level of information sharing possible with incremental changes to the standard CMS. Hence this involves higher stakeholder benefits as well as costs.

<u>Scenario 3 - Sharing the information which is obtained for the power plant maintenance by the standard CMS</u>

Last scenario represent the hypothesis in a moderate level of information sharing where no changes are done to the standard CMS, which obtains the information required to maintain the power plant. This scenario involves negligible amount of additional costs for the data dissemination process. However the stakeholder benefits are also reduced with compared to the second scenario.

From the stakeholder interviews it was identified that other qualitative characteristics are also being considered (in addition to the monetary cost benefits) when evaluating scenarios. For example stakeholders from the fisheries were considered about the potential impacts to the fisheries from the OCP project and stakeholder collaboration options. In contrast, the researchers' were focusing about environmental impacts and potential opportunities to improve the existing under water environment monitoring capabilities. Since the local government looking towards regional revitalization, the government officials were interested in the stakeholder collaboration options as well as local economy development opportunities. According to the developers' perspectives improving the stakeholder collaboration at the minimum cost is the best scenario. By considering the stakeholders' conflicting interests, two additional criteria, which basically represents the non-monetary costs and benefits of the proposal, has been added for selecting the best scenario from the MCDM model. Figure 3.11 shows the final MCDM hierarchy with the selected scenarios and criteria.

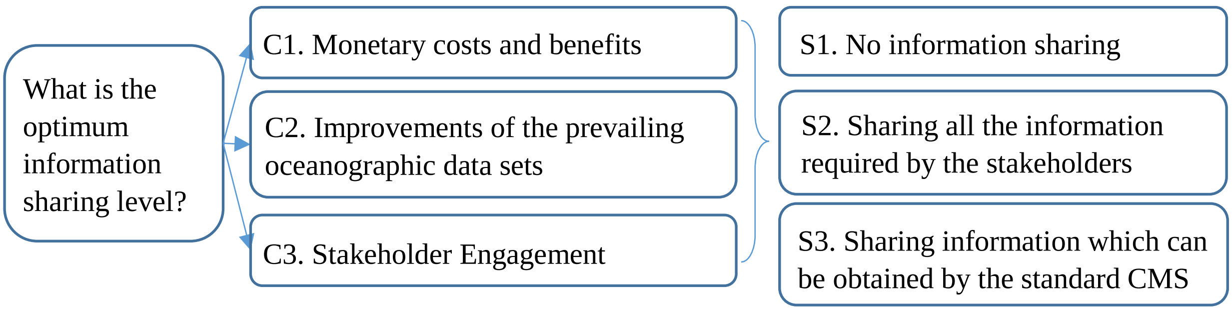

Figure 3.11 MCDM hierarchy used for DS-AHP model

Source: Made by the author

3.5 DS-AHP results and preferred Information sharing levels

As described in the methodology section, the results of the DS-AHP model is given in two steps for each stakeholder group. As the first step relative importance of selected criteria is calculated from the standard AHP model. As the second step belief level and the plausibility level of each scenario is calculated according to the DS-AHP model.

3.5.1 Local Fishermen

Table 3-19 is the summary of the local fishermen's pairwise comparison of the criteria done according to the standard AHP process. Figure 3.12 shows the criteria weights obtained by this pairwise comparison results.

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Table 3-19 Basic criteria matrix - local fishermen

	C1	C2	C3
Monetary costs and benefits - C1	1	6	1
Improvements of the prevailing data sets - C2	1/6	1	1/5
Stakeholder engagement - C3	1	5	1

Source: Created by the author by using the standard AHP model

These criteria weights represents the local fishermen's priorities when selecting the best options. It is noticeable that local fishermen values stakeholder engagement since this proposal is made within the context of power plant development. However, their main interest is to get economic benefits from the oceanographic information rather than the indirect benefits which results from the improvements of ocean monitoring and forecasting by improved data sets.

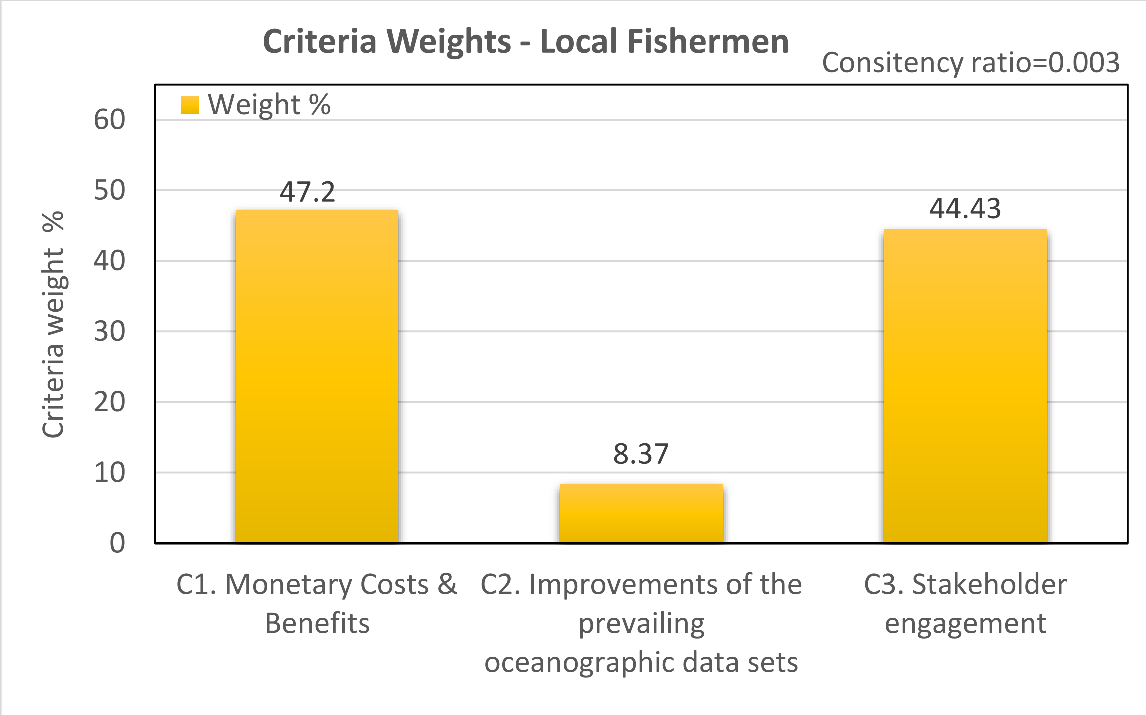

Figure 3.12 Criteria weights according to the local fishermen

Source: Created by the author by using the standard AHP model

Table 3-20 gives the summary of the scenario preferences with respect to each criteria given by the local fishermen and Figure 3.13 gives the combined scenario preferences.

Table 3-20 Criteria wise scenario preference levels of scenario(s) - local fishermen

Criteria	Scenarios in the Focal element	Preference Level
C1. Monetary costs and benefits	S1.	4
	S3.	5
	S1 & S3	5
C2. Improvements of the prevailing oceanographic data sets	S1	2
	S2	6
	S2 & S3	5
C3. Stakeholder engagement	S1	2
	S3	5
	S2 & S3	6
	S1 & S2	3

Source: Created by the author by using the DS-AHP model

Due to the high valuation given to the monetary costs benefits and stakeholder engagement, local fishermen prefers the third scenario, which is the moderate level of information sharing (Figure 3.13). Because the local fishermen believe the Ocean current data and the water temperature data which is available from the standard condition monitoring system, provides the highest economic benefits. Other parameters which can be obtained from the additional sensors will cause higher incremental costs than the economic benefits.

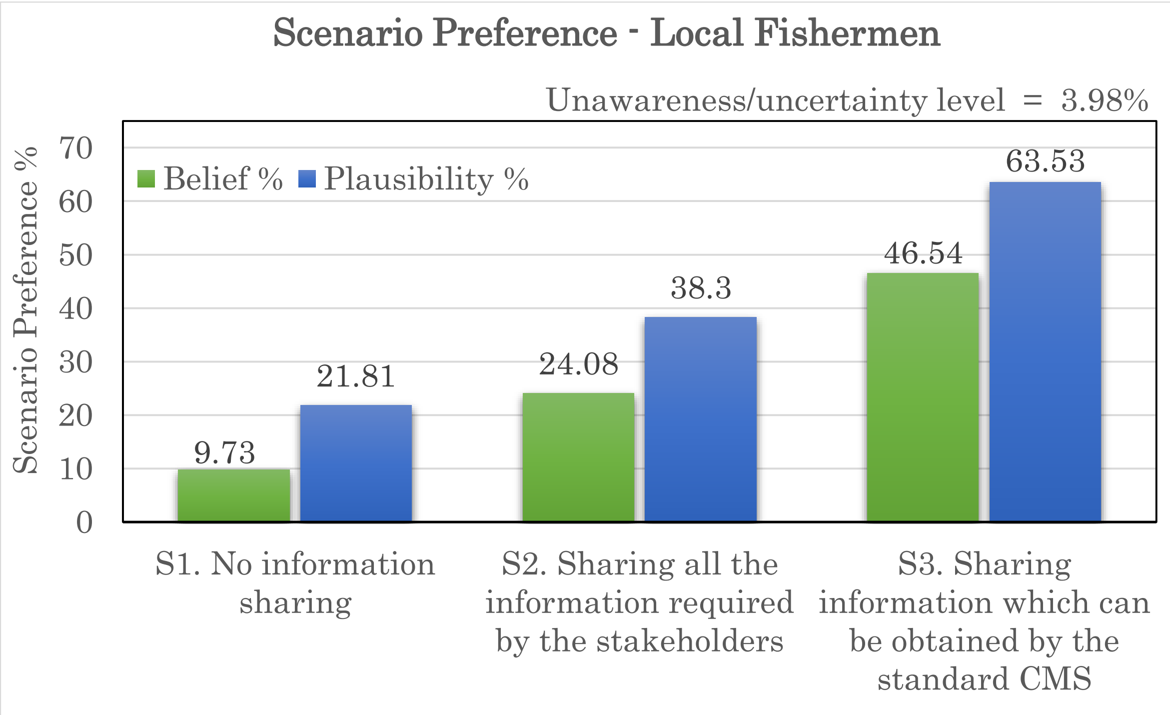

Figure 3.13 Belief and Plausibility levels of the scenarios according to the local fishermen

Source: Created by the author by using the DS-AHP model

3.5.2 Fishery Union

Table 3-21 is the summary of the fishery union's pairwise comparison of the criteria done according to the standard AHP process. Figure 3.14 shows the criteria weights obtained by this pairwise comparison results.

Table 3-21 Basic criteria matrix - fishery union

	C1	C2	C3
Monetary costs and benefits - C1	1	3	2
Improvements of the prevailing data sets - C2	1/3	1	1/3
Stakeholder engagement - C3	1/2	3	1

Source: Created by the author by using the standard AHP model

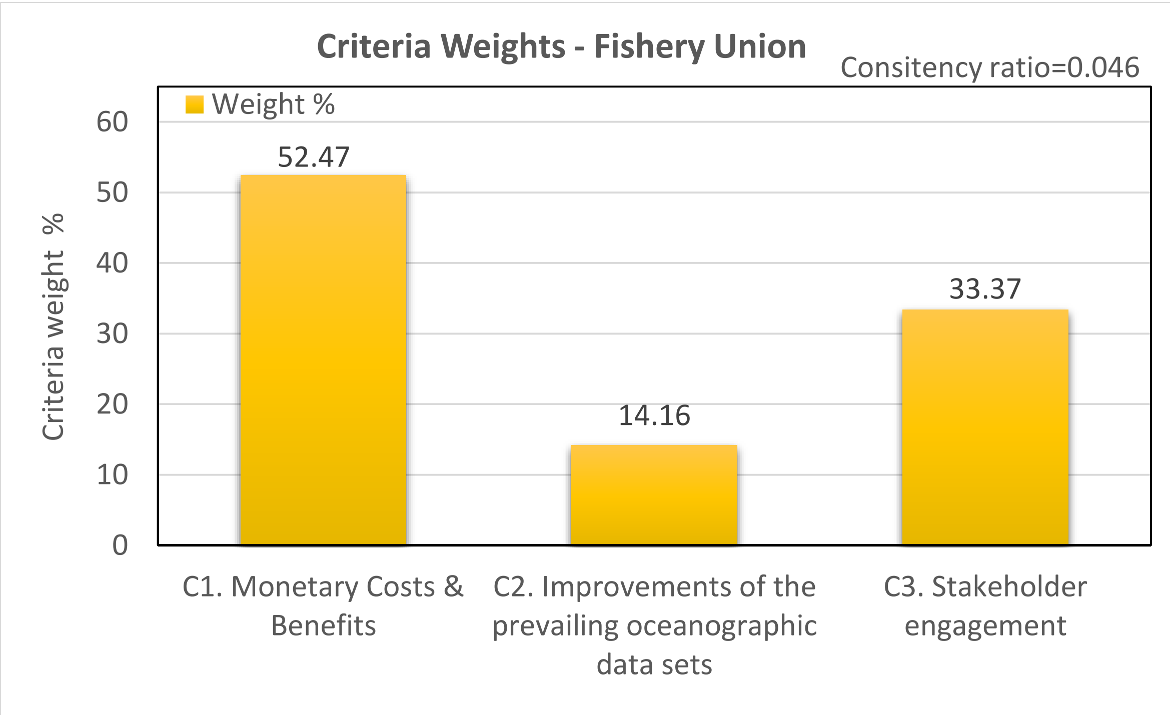

Figure 3.14 Criteria weights according to the Wakayama Higashi Fishery Union

Source: Created by the author by using the standard AHP model

According to the criteria weights obtained by the interviews with the fishery union leaders, it is clear that fishery union also follows the trend of the local fishermen. However, there is relatively a higher weight given to the monetary evaluation and slightly less weight for the stakeholder engagement. This may be due to the reason that fishery union is the most probable cost bearer of this kind of project and the sole representative of the local fisheries with regards to the business agreements with other industries. This has been the same in the previous and existing projects such as the collaboration with JAXA, local research center and other information and equipment providers.

Table 3-22 gives the summary of the scenario preferences with respect to each criteria given by the fishery union leaders and Figure 3.15 gives the combined scenario preferences.

Table 3-22 Criteria wise scenario preference levels of scenario(s) - Fishery Union

Criteria	Scenarios in the Focal element	Preference Level
C1. Monetary costs and benefits	S3	6
	S1 & S2	2
	S2 & S3	4
C2. Improvements of the prevailing oceanographic data sets	S1	2
	S2	6
	S3	4
	S2 & S3	5
C3. Stakeholder engagement	S3	6
	S1 & S2	3
	S2 & S3	4

Source: Created by the author by using the DS-AHP model

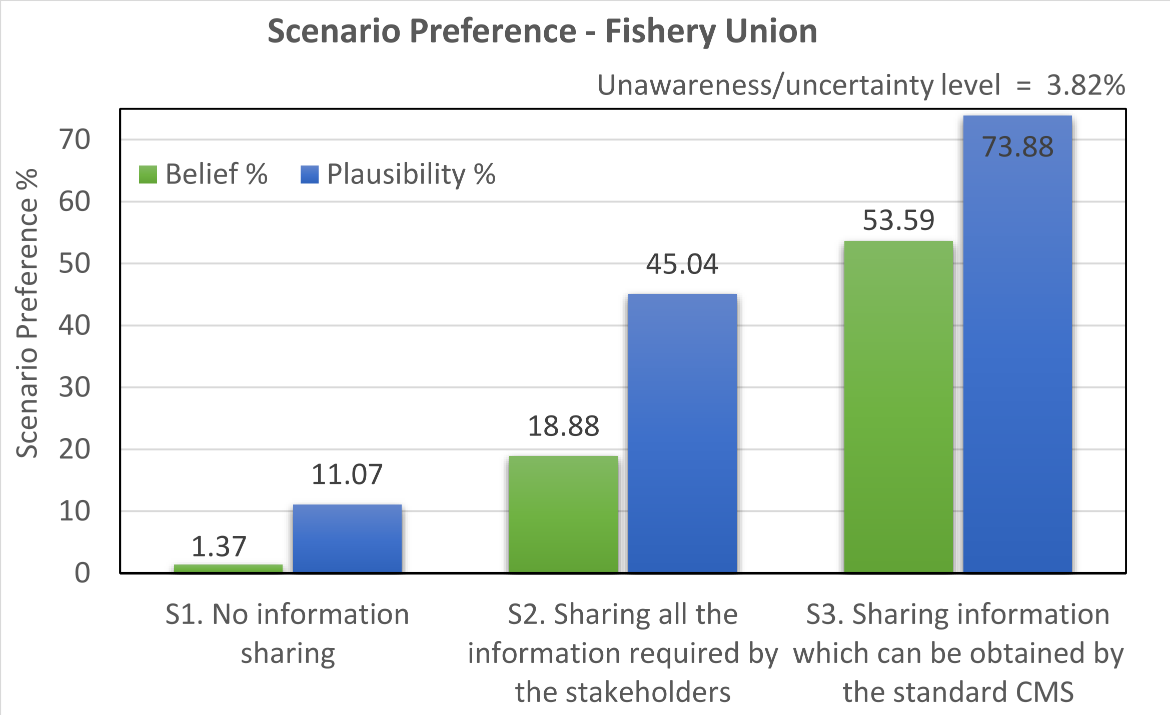

Figure 3.15 Belief and Plausibility levels of the scenarios according to the Wakayama Higashi Fishery Union

Source: Created by the author by using the DS-AHP model

Fishery union also prefers the third scenario since they believe obtaining the information without incurring additional costs to the main power plant project is the scenario with the highest net profits to the both fisheries as well as the developer. However, according to the willingness to pay analysis results in the section 3.3.2, the fishery union also have indicated that they will be willing to pay a very high price up to half a million yen per year per fisherman, if they can get all the required information. But the fishery union prefers the third scenario over the second scenario by a greater margin with compared to the local fisheries. This may be due to the very high level of perceived cost of changing the standard CMS.

3.5.3 Researchers

Table 3-23 is the summary of the researchers' pairwise comparison of the criteria done according to the standard AHP process. Figure 3.16 shows the criteria weights obtained by this pairwise comparison results.

Table 3-23 Basic criteria matrix - Researchers

	C1	C2	C3
Monetary costs and benefits - C1	1	1	5
Improvements of the prevailing data sets - C2	1	1	6
Stakeholder engagement - C3	1/5	1/6	1

Source: Created by the author by using the standard AHP model

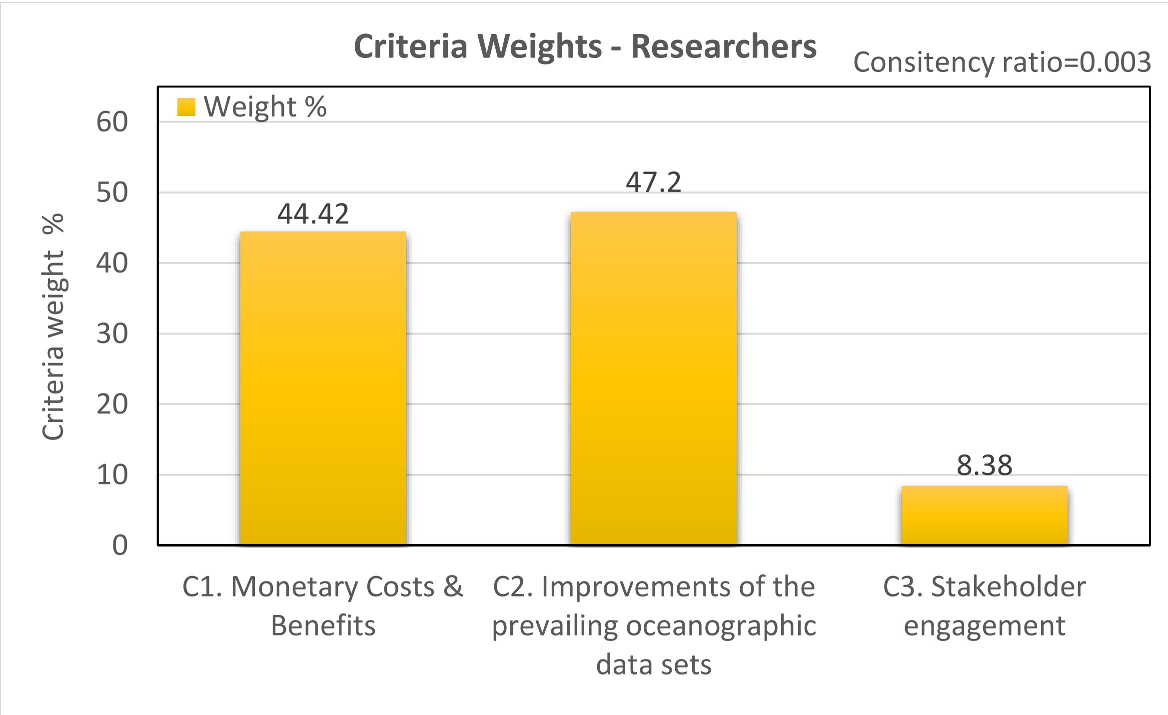

Figure 3.16 Criteria weights according to the Researchers

Source: Created by the author by using the standard AHP model

In contrast to the stakeholders from the fishery industry, the researchers who are working with scientific researches gives the highest priority to the benefits which can be obtained from improving the existing ocean monitoring capabilities and improving the quality of existing oceanographic data sets. Further, researchers give a very low priority towards stakeholder engagement which is highly valued by the fisheries as well as the developers. Qualitatively, this may be due to the higher perceived future benefits of the ongoing research activities which cannot be valued in monetary terms in the present context. Further, the researchers who are involved with modelling and forecasting generally do not have to have high level of collaboration with other marine users such as fisheries. At the same time, the researchers are mostly working under the public entities which make them harder to interact with local level stakeholders.

It is also clear that researchers' oceanographic information requirement is significantly different from the fisheries. The researchers' requirements are for scientific purposes where the direct industrial benefits are not clear at least in the research phase. However, researchers also consider about the cost of information as well.

Table 3-24 gives the summary of the scenario preferences with respect to each criteria given by the researcher and Figure 3.17 gives the combined scenario preferences.

Table 3-24 Criteria wise scenario preference levels of scenario(s) - Researchers

Criteria	Scenarios in the Focal element	Preference Level
C1. Monetary costs and benefits	S2	3
	S3	5
	S2 & S3	4
C2. Improvements of the prevailing oceanographic data sets	S1	2
	S2	5
	S3	4
	S2 & S3	6
C3. Stakeholder engagement	S1	2
	S3	5
	S1 & S2	3
	S2 & S3	5

Source: Created by the author by using the DS-AHP model

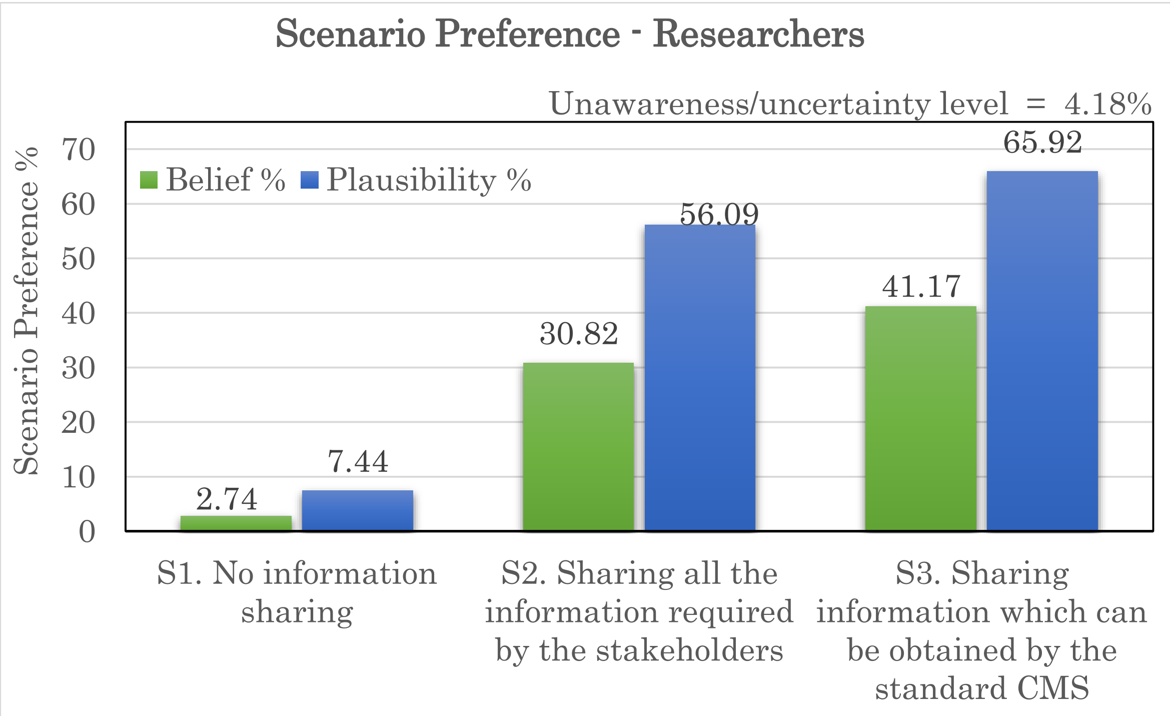

Figure 3.17 Belief and Plausibility levels of the scenarios according to the Researchers

Source: Created by the author by using the DS-AHP model

According to the combined preference results, researchers marginally prefers the third scenario over the second scenario (Figure 3.17). However it noticeable that the researchers have a very high preference towards the highest level of information sharing (scenario 2) because of their higher valuation of oceanographic information.

3.5.4 Developers

Table 3-25 gives the summary of the developer's pairwise comparison of the criteria done according to the standard AHP process. Figure 3.18 shows the criteria weights obtained by this pairwise comparison results.

Table 3-25 Basic criteria matrix - Developer

	C1	C2	C3
Monetary costs and benefits - C1	1	8	1/2
Improvements of the prevailing data sets - C2	1/8	1	1/6
Stakeholder engagement - C3	2	6	1

Source: Created by the author by using the standard AHP model

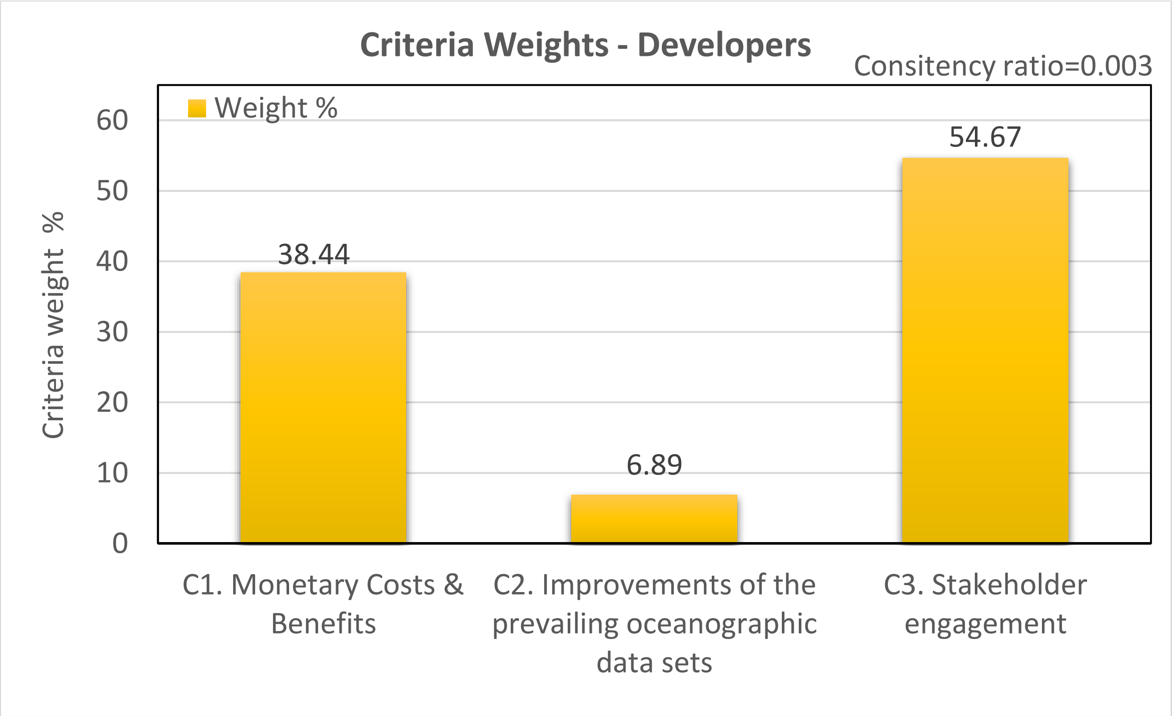

Figure 3.18 Criteria weights according to the Developers

Source: Created by the author by using the standard AHP model

According to the criteria valuation results of the developers in Figure 3.18, there is a clear contrast of the criteria evaluation of the developers when compared to the fisheries or the researchers. Developers gives relatively a very high weight for the stakeholder engagement when evaluating the three scenarios in this research. In contrast, future benefits of improving the existing oceanographic data sets which cannot be measured in monetary terms in the current context have the least weight. However, developers also give a considerable weight to the monetary costs and benefits as well. This criteria valuation may be due to the higher perceived risk of potential stakeholder opposition which may cause much higher costs with respect to the additional costs discussed in the cost benefit analysis. In addition, developers have a better knowledge about the potential additional costs related to the information sharing scheme discussed in this research. Table 3-26 gives the summary of the scenario preferences with respect to each criteria given by the developer's and Figure 3.19 gives the combined scenario preferences.

Table 3-26 Criteria wise scenario preference levels of scenario(s) - Developer

Criteria	Scenarios in the Focal element	Preference Level
C1. Monetary costs and benefits	S1	6
	S2 & S3	2
C2. Improvements of the prevailing oceanographic data sets	S2	6
	S3	5
	S1 & S3	3
	S2 & S3	6
C3. Stakeholder engagement	S2	5
	S3	5
	S2 & S3	6

Source: Created by the author by using the DS-AHP model

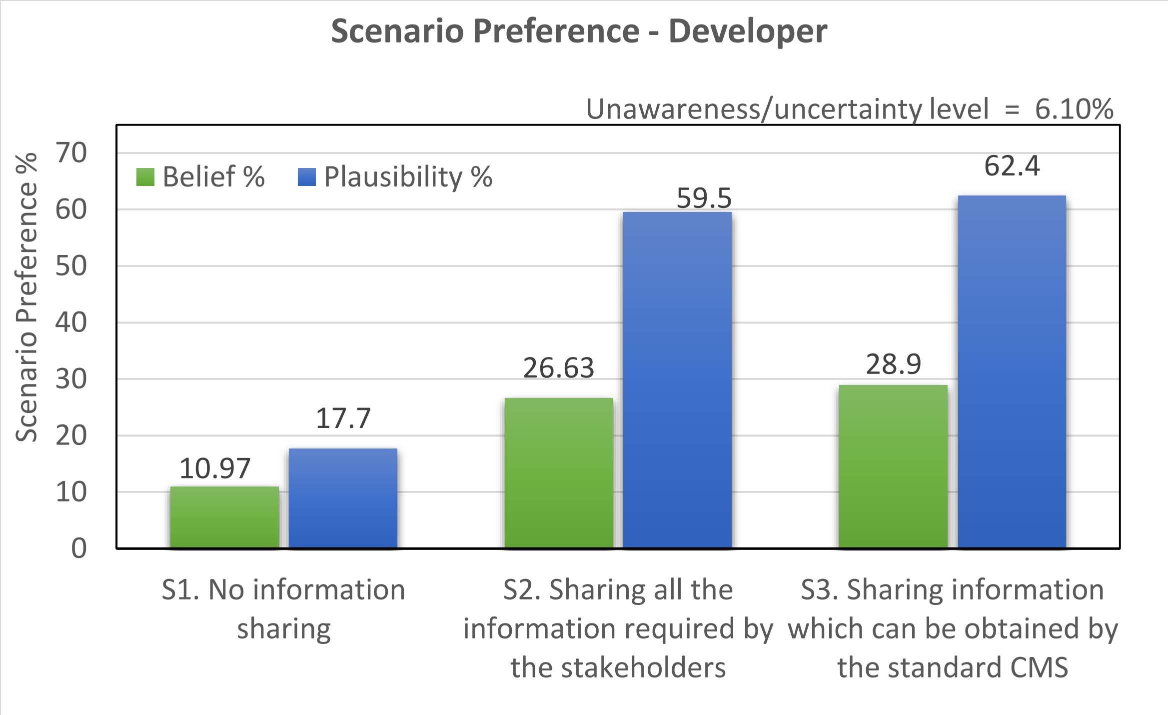

Figure 3.19 Belief and Plausibility levels of the scenarios according to the Developers

Source: Created by the author by using the DS-AHP model

The developers have given very high ranks for both information sharing scenarios (S2 & S3) with respect to the criteria 'stakeholder engagement' (Table 3-26) while giving the highest weight for the same criteria (Figure 3.18). This is an indication that developers are looking into the proposed information sharing scheme as a way of improving the public acceptance of the OCP project. Even though the developers have given a significant weight to the monetary costs benefit ratio, the preference level difference between the highest and moderate level information sharing scenarios (S2 & S3) is insignificant. This may be due to the perception that related cost difference is also insignificant with respect to the total project costing, and/or the benefits of enhancing the stakeholder engagement exceeds the incremental costs.

4 CONCLUSION

This section gives the summary of the results given in the previous section and tries to analyze the implications as a whole. According the results summary, the final recommendations which can be obtained from this research will be discussed specially with the qualitative inputs got from the stakeholder interactions on practically implementing the proposed solution. And finally, the limitations of this research and possible future improvements will be discussed.

4.1 Summary of the results

From analyzing the results of the first and second research questions, it was identified that most of the physical oceanographic parameters which are in high demand, can be obtained from the CMS of the OCP power plant with minimum additional costs as per the scenario 3. Most of the biochemical parameters also possible to with incremental changes to the standard CMS (Scenario 2). Most of the other underwater environmental monitoring parameters (Such as Marine Mammal Observation etc.) are being monitored in the first deployment due to the existing agreement with the stakeholders even though those parameters are not essential monitoring parameter for the power plant operation.

From the results of the economic analysis in the third research question, stakeholder benefit levels were estimated using indirect indicators. The main indicator used was the Willingness to Pay (WTP) which also considered the existing stakeholder cost of information and the nature of the additional information available. The fishery unions' WTP pay for the proposed information is varying from ¥100,000 to ¥500,000 per fisherman per year. According to the sensitivity analysis which was done based on the industry average base values indicates at least 1.1% to 5.5% improvement of the considered economic factors is required in order to match with the WTP of the fisheries. The highest possible cost was also estimated in two methods. The worst case cost estimated using the existing project cost estimates with the assumption of 10% additional CMS cost resulted approximately 480 million yen as the incremental startup cost. However, incremental costs required for the additional equipment based on the worst case market prices were estimated from 132 to 193 million yen

Based on the intermediate results of the three research questions, stakeholder perception was evaluated using the DS-AHP model where the summary of the criteria evaluation results are shown in the Figure 4.1. According to the criteria evaluation of the four stakeholder groups, a clear difference was indicated between the fishery industry, academic and scientific researchers and the project developers.

Figure 4.2 shows the summary of the scenario evaluation made by the four stakeholder groups. Despite the variations in preference levels, all the stakeholders preferred the third scenario which is the information sharing scheme without changing the standard CMS.

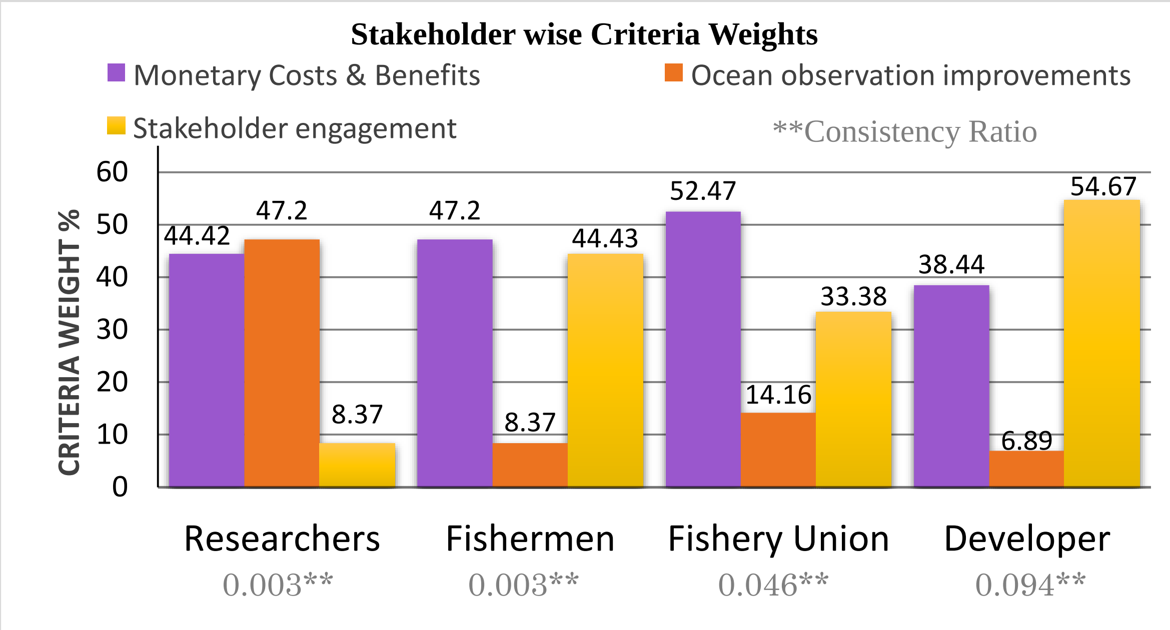

Figure 4.1 Summary of Stakeholder wise criteria evaluation

** Consistency ratio

Source: Created by the author by using the standard AHP model

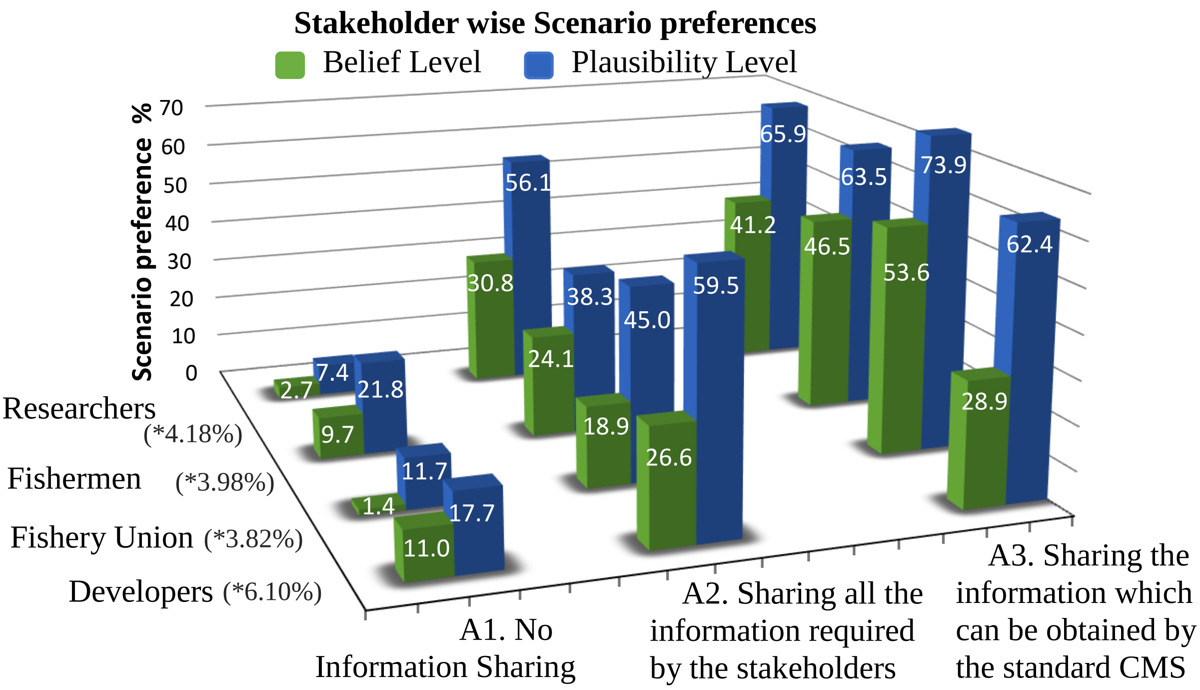

Figure 4.2 Summary of Stakeholder wise Scenario evaluation

* Unawareness / Uncertainty level

Source: Created by the author by using the DS-AHP model

Qualitatively, this criteria evaluation and scenario evaluation can be impacted by the asymmetry of knowledge. The project developers have a very good knowledge about the potential incremental costs related to the proposed information sharing scheme. In addition the developers have a high perceived risk about the potential stakeholder opposition situations and the costs related to solve the stakeholder opposition problems. Similarly, researchers have a very good knowledge about the future benefits of improving the oceanographic information quality and availability. However the researchers have a very less perceived value for the stakeholder collaboration strategies.

Figure 4.3 shows the aggregation of stakeholder wise scenario preferences giving an equal weight (25%) to each stakeholder group (Local fishermen, Fishery union, Researchers and developers). Figure 4.4 shows the same aggregation by giving weight proportional to the group size (i.e. the number of respondents in each stakeholder group). However in this research, both these weighting methods resulted an approximately similar weights. In addition, all the individual stakeholders prefers the third scenario (S3) amidst the different preference levels. Due to both these factors, the third scenario (S3) was highlighted as the final group decision regarding the optimum level of information sharing.

Summary of all the DS-AHP results are given in the Appendix IV.

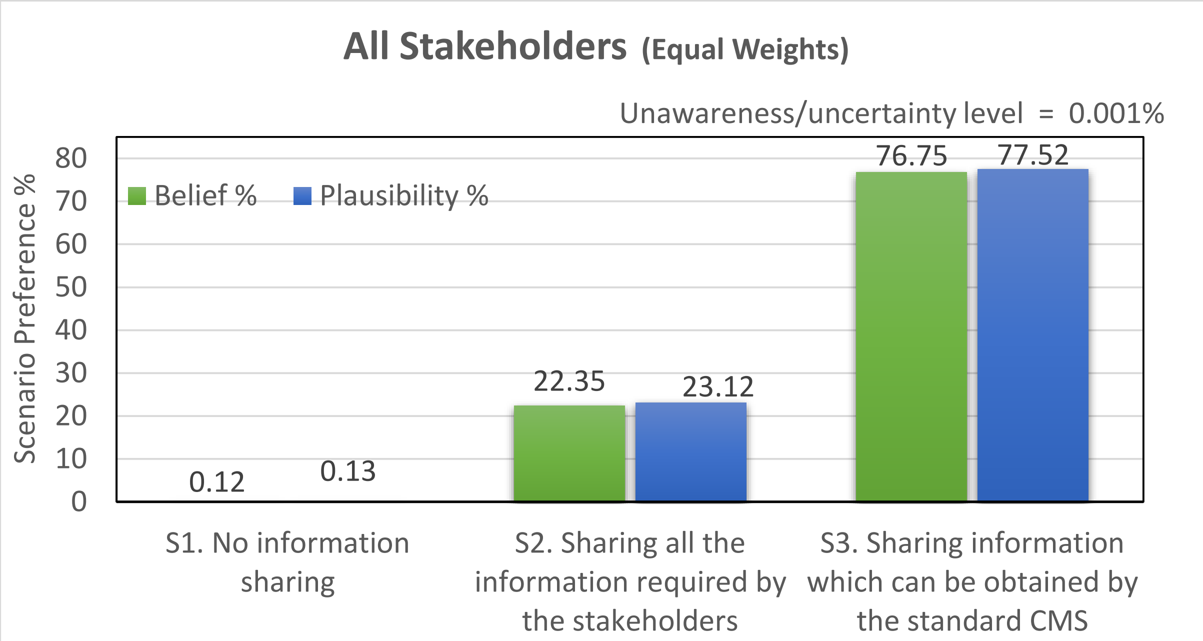

Figure 4.3 Group decision on the final scenario evaluation (giving equal weight to all the stakeholder groups)

Source: made by the author using the DS-AHP group decision making model

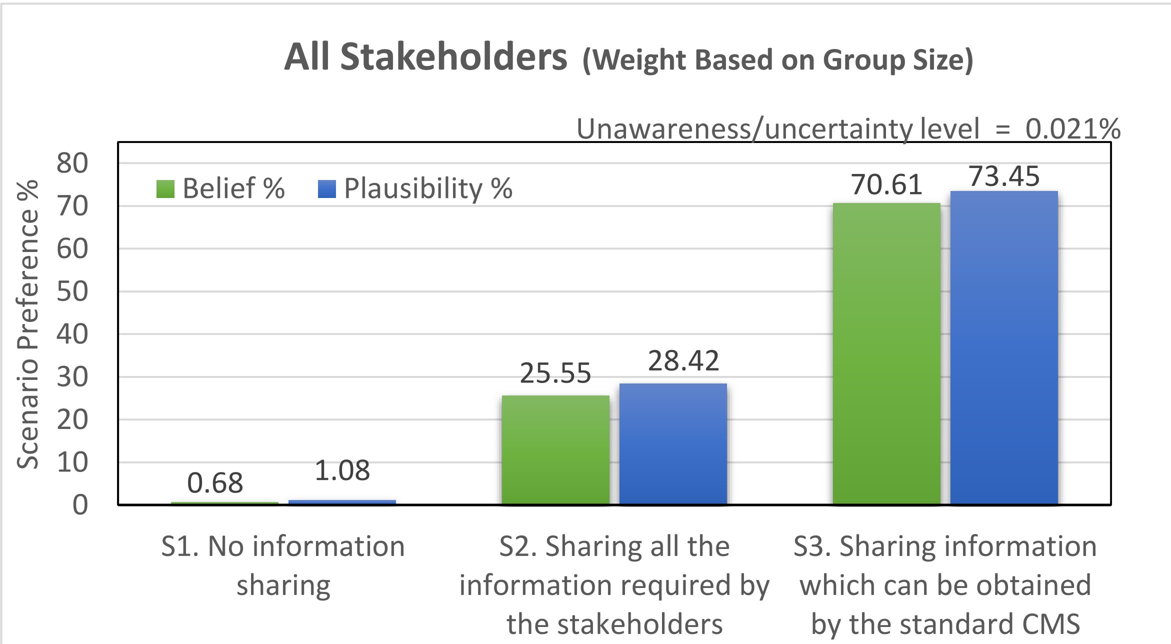

Figure 4.4 Group decision on the final scenario evaluation (giving weight promotional to the group size)

Source: made by the author using the DS-AHP group decision making model

4.2 Recommendations from the research outcomes

Based on the outcomes of this research it is identified that the proposed information sharing scheme has the potential to create synergies among local stakeholders of the OCP project. Hence, the implementation of the proposed system as described in the third scenario (S3) during the first deployment of the OCP project is recommended. The actual level of incremental costs and benefit levels should be estimated based on the results of the first deployment.

In addition, following recommendations were identified that can contribute to the improvement of the stakeholder acceptability via implementing the proposed information sharing scheme.

The successful implementation of the proposed information sharing system depends on the level of collaboration between different stakeholders such as the project developers, local industries such as fisheries, financial and governing institutes, researchers and existing ocean monitoring agencies etc. In the current context, all of these stakeholders do not get involved in collaborative projects as the one proposed in this research. However, in order to make this proposal a reality, an unprecedented level of multi-stakeholder collaboration is required. Unless there is a good collaboration among stakeholders, the level of information sharing may not become optimum in the long run considering all the possible beneficiaries.

Local government should take the initiative to implement the proposal as they are the most suitable entity to manage the stakeholder collaboration. Because, the local government has the highest potential to get the involvement of all the stakeholders and to strike a balance between all the stakeholder interests aiming the long term, sustainable development of the region. Government initiation should happen not only at the stakeholder collaboration level, but also on the policy and long term strategy level. According to the author's knowledge, these stakeholders are being governed by different governing entities and policies. For example, the development project is financed and managed with the initiation of NEDO, which is governed by the ministry of economy, trade and industry (METI) while the fisheries industry is governed by the ministry of agriculture, forestry and fisheries (MAFF) and the other related organizations are governed by separate entities. (Japan meteorological agency is governed by the ministry of land, infrastructure, transport and tourism-MLITT, Researchers and other research organizations are mostly governed by the ministry of education, culture, sports, science and technology (MEXT) etc.). Most of the projects done in these organizations are financed and controlled within the same higher level organization or the ministry. However, this type of proposal needs multi-agency collaboration and the local government is the most suitable entity in managing and implementing in the local level.

Even for the third scenario which is the moderate level of information sharing with minimum additional costs, considerable amount of investment has to be put in the initial level.

Since it is very unlikely for individual stakeholders to make this initial investment, it is recommended that the public funding should be used for the initial implementation. Adams et al. (2000) identified the regional level indirect benefits and highlighted a rational behind using public funding for improving ocean monitoring such as, 1). Once produced, information is almost costless to distribute and the total benefit of the information are greatest if made available to anyone who might benefit from it. Hence oceanographic information has the characteristics of a 'public good'. 2). Investment returns are both uncertain and dependent on others' actions. In addition, the investments required are too large for most of the individuals. Hence individuals would only invest in those parts that are of direct benefit to them, and the overall system benefits would not be realized. Hence it is difficult for private organizations to negotiate a solution that produce the highest benefits. 3). Some of the potential benefits of oceanographic information are likely to be derived from its use in determining national and local level policies that effect everyone in the region. In general it is expected to achieve a balanced distribution of costs and benefits by government initiation and usage of public funding.

Achieving long term sustainability with improved set of information is also important. The proposed information sharing system would have a huge impact on the existing industries and eco-system if the generated information is not used in sustainable resource utilization. For example, improved oceanographic information can lead to long term unsustainable fishing such as over fishing etc. However, the same information can be used for improving the long term sustainability of the fisheries if they are being used to monitor the eco-system impacts and adjust the fish catch according to the more accurate stoke level predictions. In addition, improving the availability of oceanographic information may cause changes to the industry and traditional practices. For example, sharing the local ocean conditions which are trade secrets of the local fishermen may have considerable impact to the existing industry norms. Hence achieving a good governance of the usage of the created information is very important for the long term sustainability. As the local government officials mentioned, it is important to make use of this proposal for the regional level industrial development by extending its potentials to create indirect benefits. Few industrial development opportunities are, developing the supply chain industries such as ocean monitoring equipment suppliers and maintenance businesses, ocean condition forecasting agencies etc. Further, improving the stakeholder knowledge by sharing project related information as well as possible further improvements of the stakeholder collaboration opportunities will add synergies to the local economy. In addition, improving the long term strategy and policies that facilitates the primary industries to collaborate with emerging industries is also being identified as an improvement opportunity.

4.3 Limitations of the research and possible future improvements

This research is based on ocean renewable energy sector which is still in the development or testing stage. Hence there are very few commercial level deployments even in the global level. The OCP project considered in this research is the first of its kind in Japan. Hence there are no previous data which can be referred. Even the technical and financial data of the on-going OCP project is also very limited and subjected to change according to the final deployment configurations. External stakeholders such as fisheries also have a very limited knowledge about the context. Even though precautionary actions were taken to minimize the stakeholders' knowledge limitations, (such as improving the stakeholder knowledge about project by giving knowledge sharing sessions prior to the main basic interviews or focus group discussions) there were a considerable level of uncertainty when getting the stakeholder perspectives.

Indirect relationship between the oceanographic information and the potential industrial and academic benefits is also a considerable limitation in this research. Valuation of the basic knowledge about ocean conditions was difficult and not consistent even among the local fishermen. Even though indirect methods (such as referring to the current cost of information and willingness to pay for new information etc.) was used, there still a significant level of uncertainty involved.

Sensitivity analysis of the economic benefit estimation was done on the financial values obtained from the statistics. Hence the sensitivity analysis was based on number of assumptions since the data on more directly related parameters were not available in this research.

Very limited number of stakeholder interactions were possible in this research since each interview or focus group discussion consumed a lot of time and effort due to the stakeholders' unfamiliarity of the topic. This research discussed about the proposed information sharing scheme in a holistic approach. This holistic approach was necessary and important to capture social, economic and technical considerations related to the research context, further discussions on each of the subjects are still necessary and should be done iteratively once the new data is available.

Another limitation is the possibility to generalize the research outcomes to the similar type of ocean renewable energy projects and to the other case studies. Although the theoretical framework and the methodologies can be directly applicable in other cases, the results may not be the same due to the reasons such as technical limitations of the ocean renewable energy project considered, the differences of existing sea use patterns with respect to the Wakayama case study area as well as the existing socio-economic and political conditions of the case study areas.

Lack of policy guidelines to test the feasibility of the practical implementation of the proposed system can also be highlighted as a limitation of this research. Due to the time and resource limitations, only the information demand and supply was considered with a very rough financial estimations. Even though this research outcomes can be used to test the technical and economic feasibility of the proposed information sharing scheme, practical implementation depends on the existing legal and policy conditions as well as the financing sources which should be analyzed further. Finally, the authors' lack of experience on the local level community factors such as local politics, national and international level influences, socio-cultural norms etc. may also have an influence on the accuracy of the final outcomes.

To minimize the above mentioned limitations, following suggestions can be considered in the future research.

Expanding the stakeholder group considered (such as including shipping and tourism industries) as well as including other potential deployment areas (such as Kagoshima area) when evaluating the proposal will improve the reliability and the holistic nature of the research outcomes.

Stakeholders' incremental benefits should be estimated based on variables that are directly related with the benefits of the oceanographic information described qualitatively. For example fish catch improvement is the direct outcome of the efficient fishing ground selection. Hence potential improvement of the landing quantity should be used as the basic indicator instead of fishery income. Similarly reductions in distances the fishery vessels travel in searching for the fishing grounds is the direct indicator of the fuel consumption. Reduced exposure to the high risk situations can be leading to a lower insurance costs etc. Hence using the indicators which has a direct relationship with improved oceanographic information can improve the results of the financial estimates by removing the effect other factors such as market prices.

Improving the technical feasibility analysis and the costing estimates with reference to the detailed project design specifications is important in the future research to improve the accuracy of the estimates.

Integration with the proposed system with the other strategies to improve the multi-stakeholder collaboration strategies such as co-location, integrated marine spatial planning etc. and analyzing the related policy impacts should be done when analyzing the implementation of the proposed system.

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APPENDIXES

Appendix I: Stakeholders' oceanographic information requirement survey

Q1. What oceanographic information is required for your operational and planning activities? Please fill the following table in the order of parameter preference. (Index for the parameters and its qualities are in the second sheet table 1&2) (あなたの操業や計画には、海の状態に関するどのような情報が必要ですか。下記の項目のそれぞれについて、その重要性を選択して下さい。)

Q2. What kind of information sources or sensors do you use currently for your operational activities? At what cost?　E.g. GPS systems (もし自分たちで情報を収集している場合、そうするために全体でいくら投資しましたか。例)GPS、航路ナビなど)

Q3. What is the cost of getting the above data if you can get it from the market? (現在、企業や研究機関から毎日の活動に情報を得ていますか？もしそうである場合、いくら支払っていますか。)

Q4. What is the most that you would be prepared to pay for getting the specified oceanographic information as a data set / downloadable package?　(将来、もしすべての項目の情報が手に入るとしたら最大いくらなら支払ってもよいと思いますか。)

Stakeholders Oceanographic information requirement survey

	1	2	3		4		5		6		7		8		9		10		11		12
	Parameter Category (Table 2) 情報群（表 2）	Parameter (Table 2) (情報)（表 2）	Coverage（モニターされる範囲）	Grade（順位）	Product Type 情報の種類	Grade（順位）	Accuracy (正確性)	Grade（順位）	Temporal resolution（モニターされる頻度）(毎)	Grade（順位）	Spatial resolution（モニターされる地点の間隔）	Grade（順位）	Vertical resolution（モニターされる水深の間隔（毎））	Grade（順位）	Forecast period（観測期間）（対象とする期間）	Grade（順位）	Latency （待機時間）（情報が得られるまでの期間）	Grade（順位）	Delivery medium（配信媒体）	Grade（順位）	Other Comments（その他注釈）
1																					
2																					
3																					
4																					
5																					
6																					
7																					

<u>Grading Instructions</u>

Blank（空白）- Not Useful （まったく役に立たない）

1- Might have some occasional use. （時々使用するかもしれない）

2- Might be useful, but it falls short of what we need
（役に立つかもしれないが、本当とする必要な情報ではない）

3 - Useful product. （役に立つ情報である）

4 - Good product which would be very useful.（とても役に立ちそうである）

5 - Ideal product which would meet the highest requirements
（必要な情報であり、得られたら理想的である）

Source: Made by the author based on Fischer & Flemming (1999)

Table 1 – List of Parameters　　(表 1 - 情報)

(1) Surface level information ("海面に関する情報)	(2) Surface Topography information (海面の形状)	(3) Upper Ocean Information (海中)	(4) Sea Ice Information (海氷)
1.1 Sea Surface Temperature (海面の温度)	2.1 Hourly Mean Sea Level (海面の高さ（毎時間))	3.1 XBT_ Depth wiseTemp Distr (海中温度の分布)	4.1 Extent, Boundary, Leads % (海氷が占める面積%)
1.2 Sea Surface wind (海面の風力)	2.2 Marine geoid (海域ジオイド)	3.2 XCTD sections (XCTD_ Depth wise CTD Distr)	4.2 Concentration/Density (密度)
1.3 Wind velocity (風速)	2.3 Monthly mean sea level (海面の高さ（毎月))	3.3 Upper ocean heat content (上層海洋熱容量)	4.3 Surface Ice state (表面海氷の状態)
1.4 Wind Direction (風向き)	2.4 Sea level anomaly (海面高度アノマリ)	3.4 Upper ocean salinity (塩度)	4.4 Surface Ice Roughness (氷の硬さ)
1.5 Heat Flux (熱流速 熱流束)	2.5 Oceanic Tides (海面の潮流)	3.5 Upper ocean fresh water % (淡水が占める割合)	4.5 Ice Thickness (氷の厚さ)
1.6 Moisture Flux (湿流)	2.6 Geostrophic currents (地衡流)	3.6 Upper ocean heat transport (熱輸送)	4.6 Ice surface temperature (氷の表面の温度)
1.7 Precipitation (降水量)	2.7 Meteorological forcing (気象関連の力)	3.7 Fresh water transport (淡水輸送)	4.7 Air, Sea & Ice temp (気温、海中の氷の温度)
1.8 Sea surface Salinity (海面の塩度)		3.8 Salt transport (塩分輸送)	4.8 Ice motion (氷の動き)
1.9 Wave spectrum (波浪スペクトル)		3.9 Salt flux (塩分フラックス)	4.9 Albedo, Reflection coefficient (反射能)
1.10 Wave direction spectrum (波浪方向スペクトル)		3.10 Buoyancy Flux (浮力フラックス)	4.10 Snow on ice (氷上の降雪量)
1.11 Wave Heights (波の高さ)		3.11 Upper Ocean Current Speed (海流流速)	4.11 Water on ice (氷上の水量)
1.12 Wave Period　(波周期)		3.12 Ocean Currents　(海流)	
1.13 波のうねり (Wave Swell)		3.13 Upwelling velocity (上昇流の流速)	
1.14 Sea surface CO_2 (海面の二酸化炭素量)		3.14 Downwelling Velocity (下降流の流速)	
1.15 Sea surface GHGs (海面の温室効果ガス量)		3.15 Eddies, Jets & Fronts (渦流，ジェット，フロント)	

Table 1 – List of Parameters (Continued)

(5) Ice shelves Information (棚氷)	**(6) Icebergs Information (氷山)**	**(7) Deep Ocean Information (深海)**	**(8) Seabed information (海底の状態)**
5.1 Surface area (表面積)	6.1 Numbers (数)	7.1 CTD sections (電気伝導度、温度、水深)	8.1 Bathymetry (海底地形)
5.2 Topography (地形)	6.2 Distribution (分布)	7.2 Ocean Salinity (深海塩度)	8.2 Surface outcrops (地面の露出の割合)
5.3 Hardness (硬さ)	6.3 Trajectories (軌道)	7.3 Carbon Storage (炭素量)	8.3 Surface sediments (表層体積物)
5.4 Surface condition (表面の状態)	6.4 Area, Volume (面積・体積)	7.4 Ocean tracers (海洋トレーサー)	8.4 Gridded bathymetry (グリッド化的な海底地形)
5.5 Bottom Topography (底面の形状)		7.5 Deep Ocean Currents (深海海流)	8.5 Gravity (重力)
5.6 Snow line (凍結線)			8.6 Magnetics (磁気)
5.7 Albedo, Reflection coefficient (反射能)			8.7 Heat flow (熱流)
5.8 Surface Temperature (表面温度)			
5.9 surface Ice velocity (移動する速度)			
5.10 Sub-shelf ocean circulation (サブ大陸棚海洋循環)			

Table 1 – List of Parameters (Continued)

(9) Coastal & Shelf information (海岸/大陸棚)	**(10) Bio-Chemical Information (生物化学的情報)**	**(11) Optics (光学)**	**(12) Acoustics (音響学)**
9.1 Coastline map (海岸線地図)	10.1 Chlorophyll (葉緑素)	11.1 Incident light spectrum (入射光スペクトル)	12.1 Sound velocity profiles (音速プロファイル)
9.2 Hinterland topography (ヒンターランド地形)	10.2 Nitrate (硝酸塩)	11.2 Depth of photic zone (透光層の水深)	12.2 Sound ray paths (音線経路)
9.3 Coastal bathymetry (海岸線地形)	10.3 Phosphate (リン酸塩)	11.3 Transmissivity (透過率)	12.3 Acoustic scattering (音波の散乱)
9.4 Shelf bathymetry (大陸棚地形)	10.4 Oxygen (酸素)	11.4 Phosphorescence (リン光)	12.4 Reverberation characteristics (残響特性)

9.5 Tidal constants (潮汐調和常数)	10.5 Silicate (ケイ酸塩)	11.5 Secchi disk depth (透明度)	12.5 Ambient noise spectrum (背景雑音スペクトル)
9.6 Tidal ellipses (潮流楕円)	10.6 Iron (鉄)	11.6 Bioluminescence (生物発光)	12.6 Anthropogenic noise (人為的ノイズ)
9.7 Stratification (層化)	10.7 Biological pigment (生物色素)		12.7 Acoustic tomography (音響トモグラフィー)
9.8 River runoff (河川流出)	10.8 Pathogens (病原体)		
9.9 Land non-river runoff (非河川流出)	10.9 Suspended Sediments (浮遊堆積物)		
9.10 Sediment transport (土砂流送)	10.10 Artificial radionuclides (人工放射性核種)		
9.11 Wetlands characteristics (湿地情報)	10.11 Petroleum hydrocarbons (石油性炭素水素)		
	10.12 Pesticides & Herbicides (害虫駆除剤/ 除草剤)		
	10.13 Trace metals (微量金属)		
	10.14 Pharmaceutical wastes (薬物廃棄物)		
	10.15 Phytoplankton (植物プランクトン)		
	10.16 Zooplankton (動物プランクトン)		
	10.17 CO_2 amount (二酸化炭素量)		
	10.18 Tritium (トリチウム)		
	10.19 Marine toxins (海中の毒素)		

Source: Made by the author based on Fischer & Flemming (1999)

Table 2 – Data Quality levels (表 2- 情報の質)

Coverage (モニターされる範囲)	Product Type (情報の種類)	Accuracy (正確性)	Temporal resolution (モニターされる頻度)(毎)
1.1 Ocean basin (海底盆地)	1.2 Raw data (そのままの情報)	1.1 0.01%	1.1 1 hr (1 時間)
1.2 Coastal seas (沿岸部)	1.3 Processed (処理済みの情報)	1.2 0.1%	1.2 6 hr (6 時間)
1.3 Estuarine (河口部)	1.4 Forecast (予報)	1.3 1%	1.3 1 day (1 日)
	1.5 Nowcast (リアルタイムの情報)	1.4 10%	1.4 10 days (10 日)
	1.6 Statistics (統計)	1.5 20%	1.5 1 month (1 ヵ月)
		1.6 30%	1.6 3 months (3 ヵ月)
			1.7 1 yr (1 年)
			1.8 3 yr (1 年)

Table 2 – Data Quality levels (Continued)

Spatial resolution 空間分解能 (モニターされる地点の間隔)	Vertical resolution モニターされる水深の間隔(毎)	Forecast period 観測期間 (対象とする期間)	Latency 待機時間 (情報が得られるまでの期間)	Delivery medium 配信媒体
1.1 Less than 0.5 km (0.5 km 以下)	1.1 1 m	1.1 10 days (10 日)	1.1 Realtime (リアルタイムの情報)	1.1 Internet (インターネット)
1.2 0.5 km	1.1 10 m	1.2 30 days (30 日)	1.2 6 hour (6 時間)	1.2 Hardcopy (紙媒体)
1.3 1 km	1.2 50 m	1.3 3 months (3 ヵ月)	1.3 12 hours (12 時間)	1.3 FAX (ファックス)
1.4 10 km	1.3 100 m	1.4 1 year (1 年)	1.4 1 day (1 日)	1.4 Email (電子メール)
1.5 100 km	1.4 500 m	1.5 10 years (10 年)	1.5 5 days (5 日)	1.5 EDE
1.6 500 km	1.5 1000 m		1.6 10 days (10 日)	1.6 *other (その他)
1.7 1000 km			1.7 1 month (1 か月)	

Source: Made by the author based on Fischer & Flemming (1999)

* Please specify the others

Appendix II: DS-AHP Questionnaire

Relative importance of the selected two criteria (選択された二つの基準の相対的重要性)
1 - Equal Importance (同様に重要である)
3 - Moderate importance of one over another (適度に重要である)
5 - Essential or strong importance (必要であり、とても重要である)
7 - Very strong importance (非常に重要である)
9 - Extreme importance (極めて重要である)
2,4,6,8 - Intermediate values between the two adjacent judgements (隣接する二つの判決の間の中間値)

Q1. Please select the relative importance of the criteria given in each row according to the legend shown above. (上記の指標に沿って、下記の項目の選択肢を埋めて下さい。)

First Criteria 選択肢(1)	If the first criteria is more important 選択肢(1)の方が重要である場合、どれくらい重要か点数をつけてください								Equal Importance (同様に重要である)	If the second criteria is more important 選択肢(2)の方が重要である場合、どれくらい重要か点数をつけてください								Second Criteria 選択肢(2)
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
C1. Monetary costs and benefits 費用対効果 (金額で測る)																		C2. Improvements of the prevailing data sets 海の観測法の改善
C1. Monetary costs and benefits 費用対効果 (金額で測る)																		C3. Stakeholder engagement 利害関係者の参加・産業提携の影響
C2. Improvements of the prevailing data sets 海の観測法の改善																		C3. Stakeholder engagement 利害関係者の参加・産業提携の影響

Source: Made by the author

Q2. With respect to the 'Cost-Benefit Ratio (Which can be evaluated in monetary terms)', what is the favorability of each alternatives (alternative groups)?
費用対効果　（金額で測る）に関して、次の項目についてあなたにとっての重要さを選んでください（関係があるを思う選択肢に限り）。

Alternative / Alternative group	Favorability Level				
	2	3	4	5	6
S1 - No information sharing (情報共有システムなし)					
S2 - Sharing all the information required by the stakeholders (利害関係者の情報要求を満足できる情報共有システム（の開発）)					
S3 - Sharing information which can be obtained by the standard CMS (発電所を持続的に維持できる情報共有システム（の開発）)					
S1.S2 - No information sharing / sharing all the information required by the stakeholders (情報共有システムなし /　利害関係者の情報要求を満足できる情報共有システム（の開発）)					
S1.S3 - No information sharing / sharing information which can be obtained by the standard CMS (情報共有システムなし /　発電所を持続的に維持できる情報共有システム（の開発）)					
S2.S3 - Sharing all the information required by the stakeholders / sharing information which can be obtained by the standard CMS (利害関係者の情報要求を満足できる情報共有システム（の開発）/　発電所を持続的に維持できる情報共有システム（の開発）)					

Source: Made by the author

Q3. With respect to the 'Improvements of the prevailing data sets', what is the favorability of each alternatives (alternative groups)?
海の観測法の改善 に関して、次の項目についてあなたにとっての重要さを選んでください（関係があるを思う選択肢に限り）。

Alternative / Alternative group	Favorability Level				
	2	3	4	5	6
S1 - No information sharing (情報共有システムなし)					
S2 - Sharing all the information required by the stakeholders (利害関係者の情報要求を満足できる情報共有システム（の開発）)					
S3 - Sharing information which can be obtained by the standard CMS (発電所を持続的に維持できる情報共有システム（の開発）)					
S1.S2 - No information sharing / sharing all the information required by the stakeholders (情報共有システムなし / 利害関係者の情報要求を満足できる情報共有システム（の開発）)					
S1.S3 - No information sharing / sharing information which can be obtained by the standard CMS (情報共有システムなし / 発電所を持続的に維持できる情報共有システム（の開発）)					
S2.S3 - Sharing all the information required by the stakeholders / sharing information which can be obtained by the standard CMS (利害関係者の情報要求を満足できる情報共有システム（の開発）/ 発電所を持続的に維持できる情報共有システム（の開発）)					

Source: Made by the author

Q4. With respect to the 'Stakeholder engagement', what is the favorability of each alternatives (alternative groups)?
利害関係者の参加・産業提携の影響 に関して、次の項目についてあなたにとっての重要さを選んでください（関係があるを思う選択肢に限り）。

Alternative / Alternative group	Favorability Level				
	2	3	4	5	6
S1 - No information sharing (情報共有システムなし)					
S2 - Sharing all the information required by the stakeholders (利害関係者の情報要求を満足できる情報共有システム（の開発）)					
S3 - Sharing information which can be obtained by the standard CMS (発電所を持続的に維持できる情報共有システム（の開発）)					
S1.S2 - No information sharing / sharing all the information required by the stakeholders (情報共有システムなし / 利害関係者の情報要求を満足できる情報共有システム（の開発）)					
S1.S3 - No information sharing / sharing information which can be obtained by the standard CMS (情報共有システムなし / 発電所を持続的に維持できる情報共有システム（の開発）)					
S2.S3 - Sharing all the information required by the stakeholders / sharing information which can be obtained by the standard CMS (利害関係者の情報要求を満足できる情報共有システム（の開発）/ 発電所を持続的に維持できる情報共有システム（の開発）)					

Source: Made by the author

Appendix III: DS-AHP Software

General description

This software tool has been developed using C# programing language on .net 4.5 framework using the Microsoft visual studio 2010™ software development tool. This software has five basic modules i.e. user management, DS-AHP problem set up, criteria evaluation, scenario evaluation and results display. All the user inputs are being saved to a local database (SQL Server Compact 3.5) and calculations are performed on demand and results are passed to the subsequent calculations or the final results display module. According to the latest version, only two decision hierarchy levels can be handled (criteria level and scenario level) and only one decision maker's inputs are being considered at a time (Group decision calculation has not been developed yet). Currently this tool can be considered as single user PC application. However, basic design can facilitate the future development up to a web based application where multiple decision makers can participate in the group decision making scenario online.

Installation guide

Prerequisites: dot net framework 4 or above
SQL server compact edition

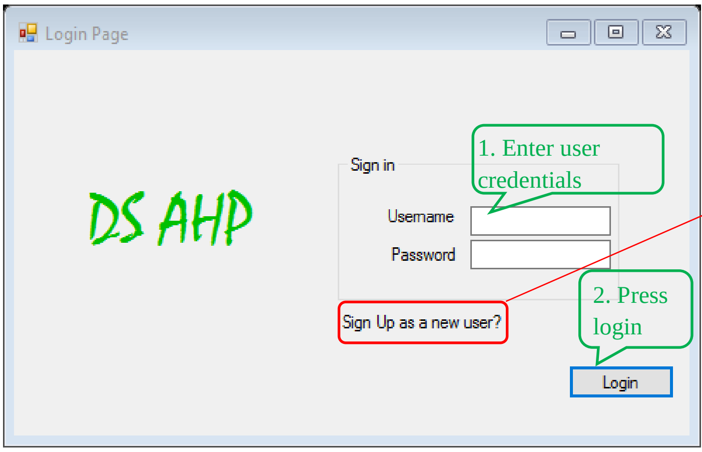
A test version of this software can be downloaded from
https://drive.google.com/a/edu.k.u-tokyo.ac.jp/file/d/0BwMj6PFEZfBOSVF0R0NRNk54Q28/view?usp=sharing

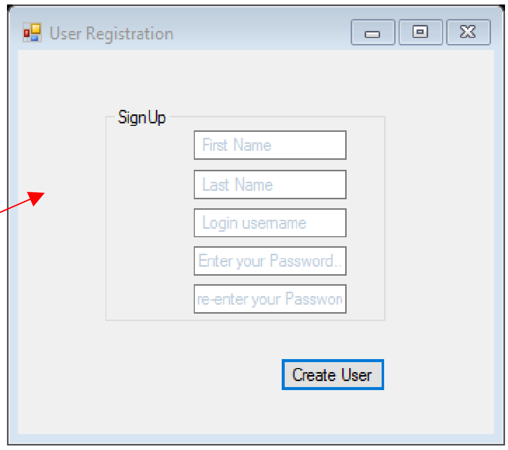
Basic steps of using this software can be described as follows.

Work flow

Step 1: User registration and authentication

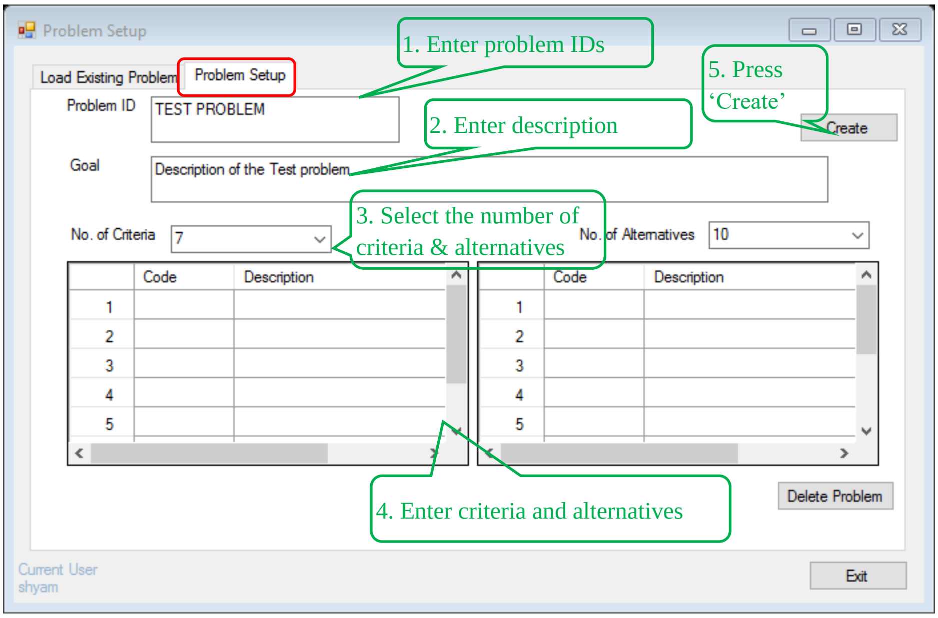
All the user inputs are being saved with the UserID (decision maker ID). Hence user login is required at the beginning. New users can sign up by clicking on ‘sign up as new user?’ label.



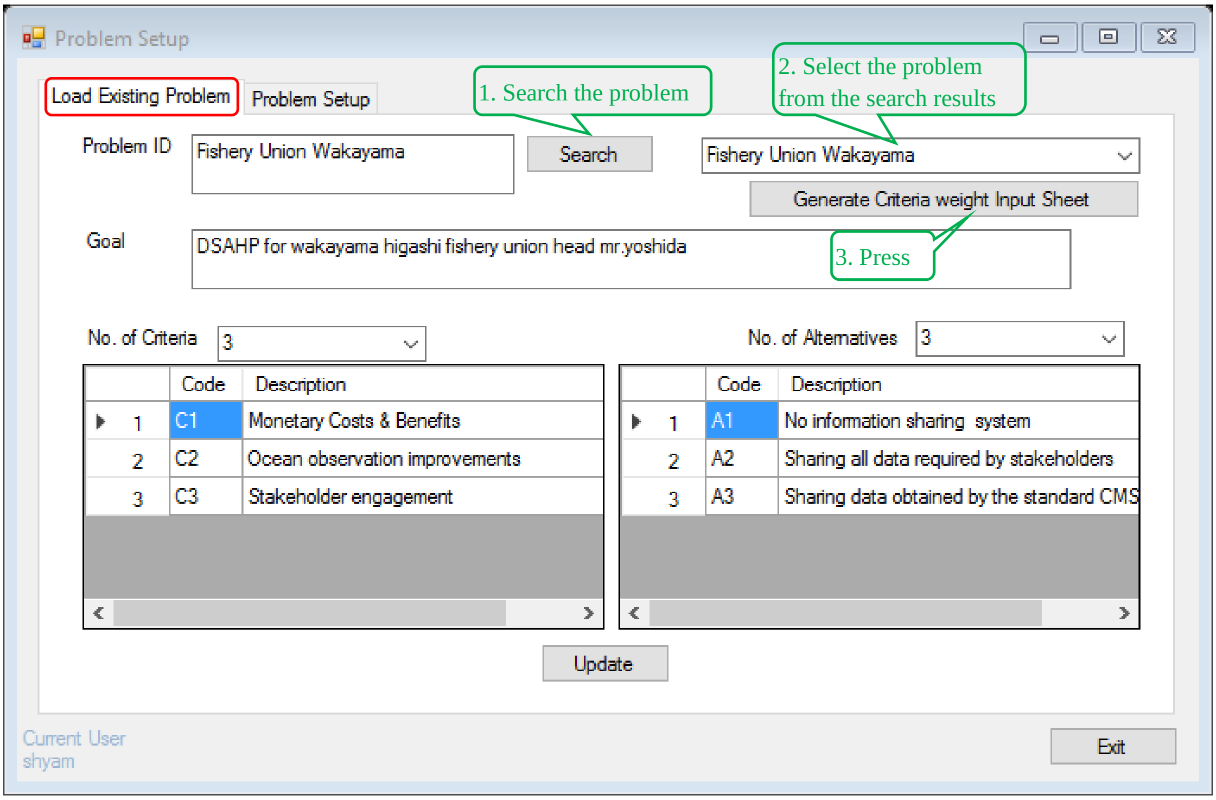


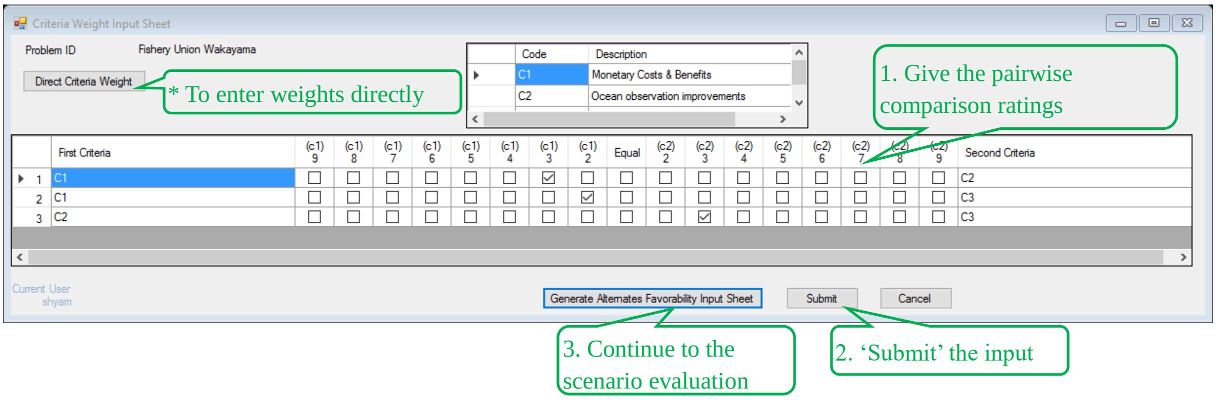
Step 2: Setting up the decision criteria and scenarios (two level decision hierarchy)

After login to the system, users can create the decision hierarchy by the second tab of the subsequent window.

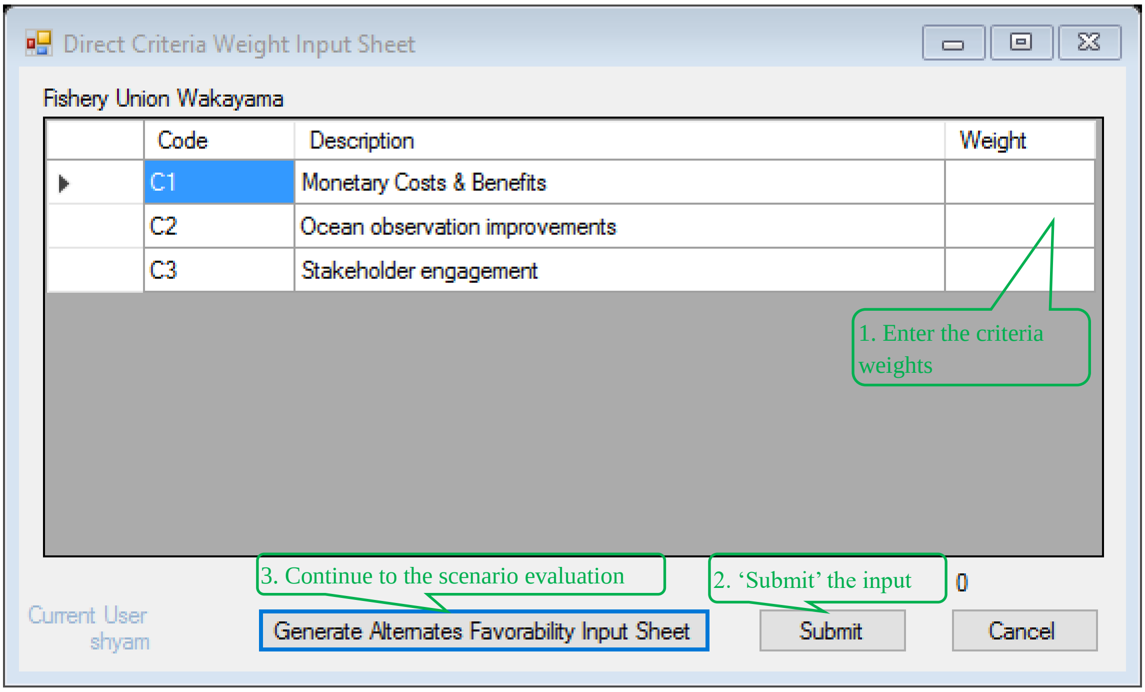


Step 3: Selecting the problem and giving the criteria evaluation

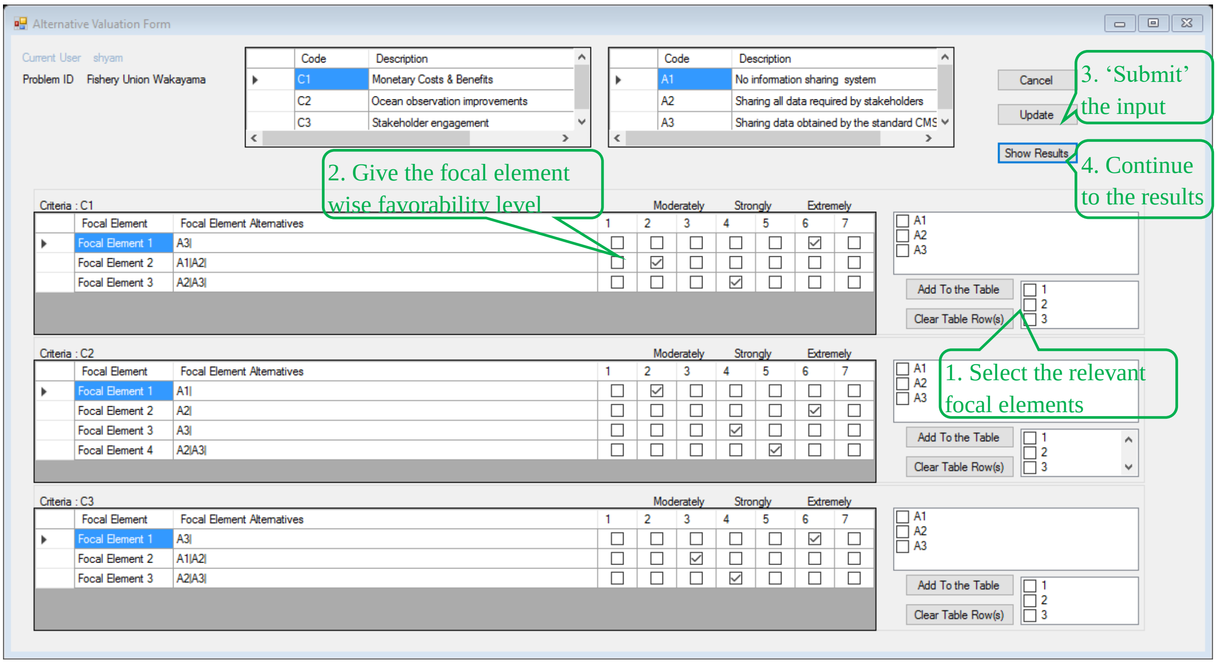




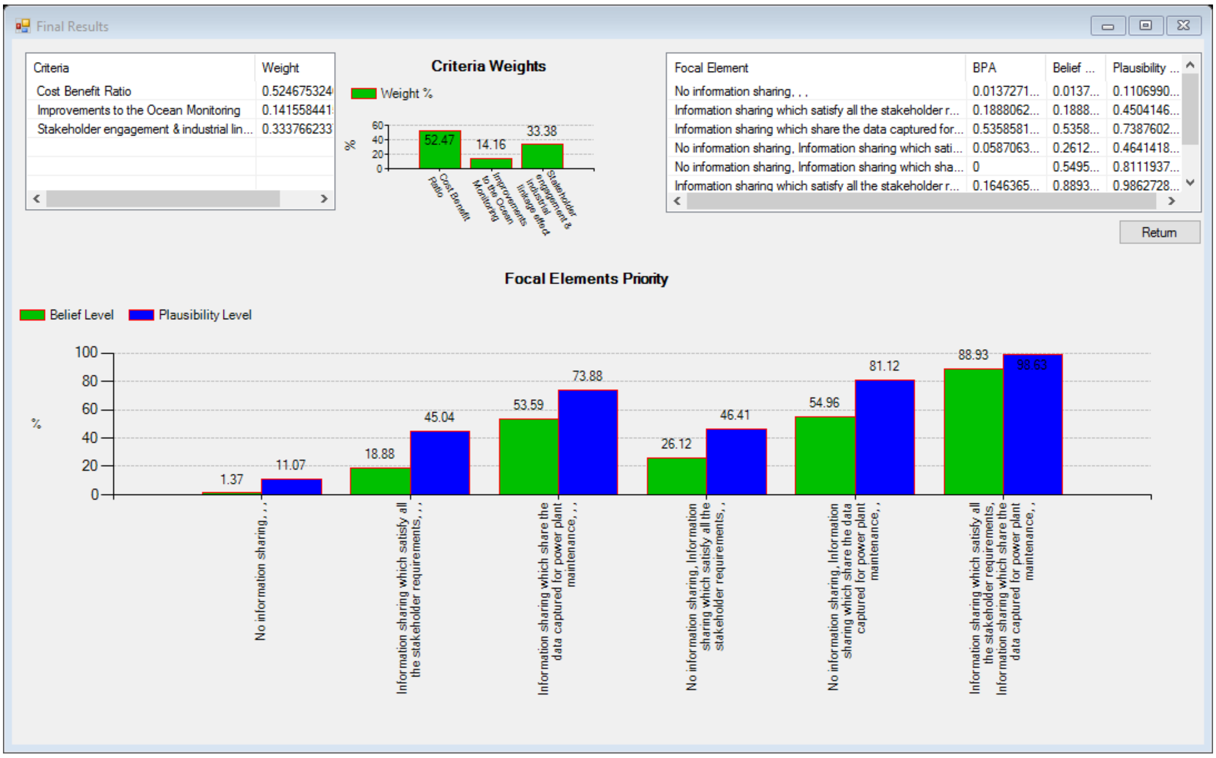
* Proceed to the direct criteria weights option if the decision maker can give direct criteria weights without doing the pairwise comparison.



Step 4: Selecting the scenarios which can be evaluated for each criteria and giving a criteria wise preference level for the selected scenario or group of scenarios (Focal elements)



Step 5: Results display



Appendix IV: Summary of DS-AHP Calculations

	Fishermen			Fishery Union			Researchers			Developer			All Stakeholders- Equal Weight*			All Stakeholders- Weight based on group size*		
Criteria	Weight			Weight			Weight			Weight			Weight			Weight		
C1 (Fishermen*)	0.472			0.5247			0.4443			0.3844			0.25			0.2857		
C2 (Fishery Union*)	0.0837			0.1416			0.472			0.0689			0.25			0.1429		
C3 (Researchers*)	0.4443			0.3337			0.0837			0.5467			0.25			0.3571		
(Developer*)													0.25			0.2143		
Scenario(s)	Final BPA	Belief	Plaus--ibility	Final BPA	Belief	Plaus--ibility	Final BPA	Belief	Plaus--ibility	Final BPA	Belief	Plaus--ibility	Final BPA	Belief	Plaus--ibility	Final BPA	Belief	Plaus--ibility
S1	0.0973	0.0973	0.2181	0.0137	0.0137	0.1107	0.0274	0.0273	0.0744	0.1097	0.1097	0.1770	0.0012	0.0012	0.0013	0.0068	0.0068	0.0108
S2	0.2408	0.2408	0.3829	0.1888	0.1888	0.4504	0.3082	0.3082	0.5609	0.2663	0.2663	0.5950	0.2235	0.2235	0.2312	0.2555	0.2555	0.2842
S3	0.4653	0.4653	0.6352	0.5359	0.5359	0.7387	0.4117	0.4117	0.6592	0.2890	0.2890	0.6240	0.7675	0.7675	0.7752	0.7061	0.7061	0.7345
S1,S2	0.0265	0.3647	0.5346	0.0587	0.2613	0.4641	0.0052	0.3408	0.5883	0	0.3760	0.7110	0.0001	0.2247	0.2324	0.0011	0.2634	0.2918
S1,S3	0.0543	0.6170	0.7591	0	0.5496	0.8112	0	0.4391	0.6918	0.0063	0.4050	0.7337	0.0000	0.7687	0.7764	0.0009	0.7137	0.7424
S2,S3	0.0756	0.7818	0.9026	0.1646	0.8893	0.9862	0.2056	0.9256	0.9726	0.2677	0.8230	0.8903	0.0076	0.9986	0.9987	0.0255	0.9871	0.9911
S1,S2,S3	0.0398	1	1	0.0383	1	1	0.0418	1	1	0.0610	1	1	0.0000	0.9999	0.9999	0.0021	0.9979	0.9979

Source: Made by the author

Appendix V: Sensitivity analysis results - fishery benefits of oceanographic information

*Net Improvement		Depreciation ,Repair & Other cost reductions							
Income increase	**Fuel cost reduction**	**0.0%**	**1.0%**	**2.5%**	**5.0%**	**7.5%**	**10.0%**	**12.5%**	**15.0%**
0.0%	0.0%	0.0000	0.0204	0.0510	0.1020	0.1530	0.2040	0.2550	0.3060
	1.0%	0.0078	0.0282	0.0588	0.1098	0.1608	0.2118	0.2628	0.3138
	2.5%	0.0195	0.0399	0.0705	0.1215	0.1725	0.2235	0.2745	0.3255
	5.0%	0.0390	0.0594	0.0900	0.1410	0.1920	0.2430	0.2940	0.3450
	7.5%	0.0585	0.0789	0.1095	0.1605	0.2115	0.2625	0.3135	0.3645
	10.0%	0.0780	0.0984	0.1290	0.1800	0.2310	0.2820	0.3330	0.3840
	12.5%	0.0975	0.1179	0.1485	0.1995	0.2505	0.3015	0.3525	0.4035
	15.0%	0.1170	0.1374	0.1680	0.2190	0.2700	0.3210	0.3720	0.4230
1.0%	0.0%	0.0628	0.0832	0.1138	0.1648	0.2158	0.2668	0.3178	0.3688
	1.0%	0.0706	0.0910	0.1216	0.1726	0.2236	0.2746	0.3256	0.3766
	2.5%	0.0823	0.1027	0.1333	0.1843	0.2353	0.2863	0.3373	0.3883
	5.0%	0.1018	0.1222	0.1528	0.2038	0.2548	0.3058	0.3568	0.4078
	7.5%	0.1213	0.1417	0.1723	0.2233	0.2743	0.3253	0.3763	0.4273
	10.0%	0.1408	0.1612	0.1918	0.2428	0.2938	0.3448	0.3958	0.4468
	12.5%	0.1603	0.1807	0.2113	0.2623	0.3133	0.3643	0.4153	0.4663
	15.0%	0.1798	0.2002	0.2308	0.2818	0.3328	0.3838	0.4348	0.4858
2.5%	0.0%	0.1570	0.1774	0.2080	0.2590	0.3100	0.3610	0.4120	0.4630
	1.0%	0.1648	0.1852	0.2158	0.2668	0.3178	0.3688	0.4198	0.4708
	2.5%	0.1765	0.1969	0.2275	0.2785	0.3295	0.3805	0.4315	0.4825
	5.0%	0.1960	0.2164	0.2470	0.2980	0.3490	0.4000	0.4510	0.5020
	7.5%	0.2155	0.2359	0.2665	0.3175	0.3685	0.4195	0.4705	0.5215
	10.0%	0.2350	0.2554	0.2860	0.3370	0.3880	0.4390	0.4900	0.5410
	12.5%	0.2545	0.2749	0.3055	0.3565	0.4075	0.4585	0.5095	0.5605
	15.0%	0.2740	0.2944	0.3250	0.3760	0.4270	0.4780	0.5290	0.5800
5.0%	0.0%	0.3140	0.3344	0.3650	0.4160	0.4670	0.5180	0.5690	0.6200
	1.0%	0.3218	0.3422	0.3728	0.4238	0.4748	0.5258	0.5768	0.6278
	2.5%	0.3335	0.3539	0.3845	0.4355	0.4865	0.5375	0.5885	0.6395
	5.0%	0.3530	0.3734	0.4040	0.4550	0.5060	0.5570	0.6080	0.6590
	7.5%	0.3725	0.3929	0.4235	0.4745	0.5255	0.5765	0.6275	0.6785
	10.0%	0.3920	0.4124	0.4430	0.4940	0.5450	0.5960	0.6470	0.6980
	12.5%	0.4115	0.4319	0.4625	0.5135	0.5645	0.6155	0.6665	0.7175
	15.0%	0.4310	0.4514	0.4820	0.5330	0.5840	0.6350	0.6860	0.7370

7.5%	0.0%	0.4710	0.4914	0.5220	0.5730	0.6240	0.6750	0.7260	0.7770
	1.0%	0.4788	0.4992	0.5298	0.5808	0.6318	0.6828	0.7338	0.7848
	2.5%	0.4905	0.5109	0.5415	0.5925	0.6435	0.6945	0.7455	0.7965
	5.0%	0.5100	0.5304	0.5610	0.6120	0.6630	0.7140	0.7650	0.8160
	7.5%	0.5295	0.5499	0.5805	0.6315	0.6825	0.7335	0.7845	0.8355
	10.0%	0.5490	0.5694	0.6000	0.6510	0.7020	0.7530	0.8040	0.8550
	12.5%	0.5685	0.5889	0.6195	0.6705	0.7215	0.7725	0.8235	0.8745
	15.0%	0.5880	0.6084	0.6390	0.6900	0.7410	0.7920	0.8430	0.8940
10.0%	0.0%	0.6280	0.6484	0.6790	0.7300	0.7810	0.8320	0.8830	0.9340
	1.0%	0.6358	0.6562	0.6868	0.7378	0.7888	0.8398	0.8908	0.9418
	2.5%	0.6475	0.6679	0.6985	0.7495	0.8005	0.8515	0.9025	0.9535
	5.0%	0.6670	0.6874	0.7180	0.7690	0.8200	0.8710	0.9220	0.9730
	7.5%	0.6865	0.7069	0.7375	0.7885	0.8395	0.8905	0.9415	0.9925
	10.0%	0.7060	0.7264	0.7570	0.8080	0.8590	0.9100	0.9610	1.0120
	12.5%	0.7255	0.7459	0.7765	0.8275	0.8785	0.9295	0.9805	1.0315
	15.0%	0.7450	0.7654	0.7960	0.8470	0.8980	0.9490	1.0000	1.0510
12.5%	0.0%	0.7850	0.8054	0.8360	0.8870	0.9380	0.9890	1.0400	1.0910
	1.0%	0.7928	0.8132	0.8438	0.8948	0.9458	0.9968	1.0478	1.0988
	2.5%	0.8045	0.8249	0.8555	0.9065	0.9575	1.0085	1.0595	1.1105
	5.0%	0.8240	0.8444	0.8750	0.9260	0.9770	1.0280	1.0790	1.1300
	7.5%	0.8435	0.8639	0.8945	0.9455	0.9965	1.0475	1.0985	1.1495
	10.0%	0.8630	0.8834	0.9140	0.9650	1.0160	1.0670	1.1180	1.1690
	12.5%	0.8825	0.9029	0.9335	0.9845	1.0355	1.0865	1.1375	1.1885
	15.0%	0.9020	0.9224	0.9530	1.0040	1.0550	1.1060	1.1570	1.2080
15.0%	0.0%	0.9420	0.9624	0.9930	1.0440	1.0950	1.1460	1.1970	1.2480
	1.0%	0.9498	0.9702	1.0008	1.0518	1.1028	1.1538	1.2048	1.2558
	2.5%	0.9615	0.9819	1.0125	1.0635	1.1145	1.1655	1.2165	1.2675
	5.0%	0.9810	1.0014	1.0320	1.0830	1.1340	1.1850	1.2360	1.2870
	7.5%	1.0005	1.0209	1.0515	1.1025	1.1535	1.2045	1.2555	1.3065
	10.0%	1.0200	1.0404	1.0710	1.1220	1.1730	1.2240	1.2750	1.3260
	12.5%	1.0395	1.0599	1.0905	1.1415	1.1925	1.2435	1.2945	1.3455
	15.0%	1.0590	1.0794	1.1100	1.1610	1.2120	1.2630	1.3140	1.3650

0 Net benefit level 1 million yen

*Net benefits are in Yen millions

Source: Made by the author

*Net Improvement		Depreciation ,Repair & Other cost reductions							
Income increase	**Fuel cost reduction**	**0.0%**	**1.0%**	**2.5%**	**5.0%**	**7.5%**	**10.0%**	**12.5%**	**15.0%**
0.0%	0.0%	0.0000	0.0204	0.0510	0.1020	0.1530	0.2040	0.2550	0.3060
	1.0%	0.0078	0.0282	0.0588	0.1098	0.1608	0.2118	0.2628	0.3138
	2.5%	0.0195	0.0399	0.0705	0.1215	0.1725	0.2235	0.2745	0.3255
	5.0%	0.0390	0.0594	0.0900	0.1410	0.1920	0.2430	0.2940	0.3450
	7.5%	0.0585	0.0789	0.1095	0.1605	0.2115	0.2625	0.3135	0.3645
	10.0%	0.0780	0.0984	0.1290	0.1800	0.2310	0.2820	0.3330	0.3840
	12.5%	0.0975	0.1179	0.1485	0.1995	0.2505	0.3015	0.3525	0.4035
	15.0%	0.1170	0.1374	0.1680	0.2190	0.2700	0.3210	0.3720	0.4230
1.0%	0.0%	0.0628	0.0832	0.1138	0.1648	0.2158	0.2668	0.3178	0.3688
	1.0%	0.0706	0.0910	0.1216	0.1726	0.2236	0.2746	0.3256	0.3766
	2.5%	0.0823	0.1027	0.1333	0.1843	0.2353	0.2863	0.3373	0.3883
	5.0%	0.1018	0.1222	0.1528	0.2038	0.2548	0.3058	0.3568	0.4078
	7.5%	0.1213	0.1417	0.1723	0.2233	0.2743	0.3253	0.3763	0.4273
	10.0%	0.1408	0.1612	0.1918	0.2428	0.2938	0.3448	0.3958	0.4468
	12.5%	0.1603	0.1807	0.2113	0.2623	0.3133	0.3643	0.4153	0.4663
	15.0%	0.1798	0.2002	0.2308	0.2818	0.3328	0.3838	0.4348	0.4858
2.5%	0.0%	0.1570	0.1774	0.2080	0.2590	0.3100	0.3610	0.4120	0.4630
	1.0%	0.1648	0.1852	0.2158	0.2668	0.3178	0.3688	0.4198	0.4708
	2.5%	0.1765	0.1969	0.2275	0.2785	0.3295	0.3805	0.4315	0.4825
	5.0%	0.1960	0.2164	0.2470	0.2980	0.3490	0.4000	0.4510	0.5020
	7.5%	0.2155	0.2359	0.2665	0.3175	0.3685	0.4195	0.4705	0.5215
	10.0%	0.2350	0.2554	0.2860	0.3370	0.3880	0.4390	0.4900	0.5410
	12.5%	0.2545	0.2749	0.3055	0.3565	0.4075	0.4585	0.5095	0.5605
	15.0%	0.2740	0.2944	0.3250	0.3760	0.4270	0.4780	0.5290	0.5800
5.0%	0.0%	0.3140	0.3344	0.3650	0.4160	0.4670	0.5180	0.5690	0.6200
	1.0%	0.3218	0.3422	0.3728	0.4238	0.4748	0.5258	0.5768	0.6278
	2.5%	0.3335	0.3539	0.3845	0.4355	0.4865	0.5375	0.5885	0.6395
	5.0%	0.3530	0.3734	0.4040	0.4550	0.5060	0.5570	0.6080	0.6590
	7.5%	0.3725	0.3929	0.4235	0.4745	0.5255	0.5765	0.6275	0.6785
	10.0%	0.3920	0.4124	0.4430	0.4940	0.5450	0.5960	0.6470	0.6980
	12.5%	0.4115	0.4319	0.4625	0.5135	0.5645	0.6155	0.6665	0.7175
	15.0%	0.4310	0.4514	0.4820	0.5330	0.5840	0.6350	0.6860	0.7370
7.5%	0.0%	0.4710	0.4914	0.5220	0.5730	0.6240	0.6750	0.7260	0.7770
	1.0%	0.4788	0.4992	0.5298	0.5808	0.6318	0.6828	0.7338	0.7848

	2.5%	0.4905	0.5109	0.5415	0.5925	0.6435	0.6945	0.7455	0.7965
	5.0%	0.5100	0.5304	0.5610	0.6120	0.6630	0.7140	0.7650	0.8160
	7.5%	0.5295	0.5499	0.5805	0.6315	0.6825	0.7335	0.7845	0.8355
	10.0%	0.5490	0.5694	0.6000	0.6510	0.7020	0.7530	0.8040	0.8550
	12.5%	0.5685	0.5889	0.6195	0.6705	0.7215	0.7725	0.8235	0.8745
	15.0%	0.5880	0.6084	0.6390	0.6900	0.7410	0.7920	0.8430	0.8940
10.0%	0.0%	0.6280	0.6484	0.6790	0.7300	0.7810	0.8320	0.8830	0.9340
	1.0%	0.6358	0.6562	0.6868	0.7378	0.7888	0.8398	0.8908	0.9418
	2.5%	0.6475	0.6679	0.6985	0.7495	0.8005	0.8515	0.9025	0.9535
	5.0%	0.6670	0.6874	0.7180	0.7690	0.8200	0.8710	0.9220	0.9730
	7.5%	0.6865	0.7069	0.7375	0.7885	0.8395	0.8905	0.9415	0.9925
	10.0%	0.7060	0.7264	0.7570	0.8080	0.8590	0.9100	0.9610	1.0120
	12.5%	0.7255	0.7459	0.7765	0.8275	0.8785	0.9295	0.9805	1.0315
	15.0%	0.7450	0.7654	0.7960	0.8470	0.8980	0.9490	1.0000	1.0510
12.5%	0.0%	0.7850	0.8054	0.8360	0.8870	0.9380	0.9890	1.0400	1.0910
	1.0%	0.7928	0.8132	0.8438	0.8948	0.9458	0.9968	1.0478	1.0988
	2.5%	0.8045	0.8249	0.8555	0.9065	0.9575	1.0085	1.0595	1.1105
	5.0%	0.8240	0.8444	0.8750	0.9260	0.9770	1.0280	1.0790	1.1300
	7.5%	0.8435	0.8639	0.8945	0.9455	0.9965	1.0475	1.0985	1.1495
	10.0%	0.8630	0.8834	0.9140	0.9650	1.0160	1.0670	1.1180	1.1690
	12.5%	0.8825	0.9029	0.9335	0.9845	1.0355	1.0865	1.1375	1.1885
	15.0%	0.9020	0.9224	0.9530	1.0040	1.0550	1.1060	1.1570	1.2080
15.0%	0.0%	0.9420	0.9624	0.9930	1.0440	1.0950	1.1460	1.1970	1.2480
	1.0%	0.9498	0.9702	1.0008	1.0518	1.1028	1.1538	1.2048	1.2558
	2.5%	0.9615	0.9819	1.0125	1.0635	1.1145	1.1655	1.2165	1.2675
	5.0%	0.9810	1.0014	1.0320	1.0830	1.1340	1.1850	1.2360	1.2870
	7.5%	1.0005	1.0209	1.0515	1.1025	1.1535	1.2045	1.2555	1.3065
	10.0%	1.0200	1.0404	1.0710	1.1220	1.1730	1.2240	1.2750	1.3260
	12.5%	1.0395	1.0599	1.0905	1.1415	1.1925	1.2435	1.2945	1.3455
	15.0%	1.0590	1.0794	1.1100	1.1610	1.2120	1.2630	1.3140	1.3650

Cell color legend

Net benefit Less than 0.4 million yen

Net benefit between 0.4-0.6 million yen

Net benefit between 0.6-1.0 million yen

Net benefit more than 1.0 million yen

*Net benefits are in Yen millions

Source: Made by the author

*Net Improvement		Depreciation, Repair & Other cost reductions								
Income improvement	Fuel Cost reduction	0.0%	0.5%	1.0%	2.5%	5.0%	7.5%	10.0%	12.5%	15.0%
0.0%	0.0%	0	0.0102	0.0204	0.051	0.102	0.153	0.204	0.255	0.306
	0.5%	0.0039	0.0141	0.0243	0.0549	0.1059	0.1569	0.2079	0.2589	0.3099
	1.0%	0.0078	0.018	0.0282	0.0588	0.1098	0.1608	0.2118	0.2628	0.3138
	2.5%	0.0195	0.0297	0.0399	0.0705	0.1215	0.1725	0.2235	0.2745	0.3255
	5.0%	0.039	0.0492	0.0594	0.09	0.141	0.192	0.243	0.294	0.345
	7.5%	0.0585	0.0687	0.0789	0.1095	0.1605	0.2115	0.2625	0.3135	0.3645
	10.0%	0.078	0.0882	0.0984	0.129	0.18	0.231	0.282	0.333	0.384
	12.5%	0.0975	0.1077	0.1179	0.1485	0.1995	0.2505	0.3015	0.3525	0.4035
	15.0%	0.117	0.1272	0.1374	0.168	0.219	0.27	0.321	0.372	0.423
0.5%	0.0%	0.0314	0.0416	0.0518	0.0824	0.1334	0.1844	0.2354	0.2864	0.3374
	0.5%	0.0353	0.0455	0.0557	0.0863	0.1373	0.1883	0.2393	0.2903	0.3413
	1.0%	0.0392	0.0494	0.0596	0.0902	0.1412	0.1922	0.2432	0.2942	0.3452
	2.5%	0.0509	0.0611	0.0713	0.1019	0.1529	0.2039	0.2549	0.3059	0.3569
	5.0%	0.0704	0.0806	0.0908	0.1214	0.1724	0.2234	0.2744	0.3254	0.3764
	7.5%	0.0899	0.1001	0.1103	0.1409	0.1919	0.2429	0.2939	0.3449	0.3959
	10.0%	0.1094	0.1196	0.1298	0.1604	0.2114	0.2624	0.3134	0.3644	0.4154
	12.5%	0.1289	0.1391	0.1493	0.1799	0.2309	0.2819	0.3329	0.3839	0.4349
	15.0%	0.1484	0.1586	0.1688	0.1994	0.2504	0.3014	0.3524	0.4034	0.4544
1.0%	0.0%	0.0628	0.073	0.0832	0.1138	0.1648	0.2158	0.2668	0.3178	0.3688
	0.5%	0.0667	0.0769	0.0871	0.1177	0.1687	0.2197	0.2707	0.3217	0.3727
	1.0%	0.0706	0.0808	0.091	0.1216	0.1726	0.2236	0.2746	0.3256	0.3766
	2.5%	0.0823	0.0925	0.1027	0.1333	0.1843	0.2353	0.2863	0.3373	0.3883
	5.0%	0.1018	0.112	0.1222	0.1528	0.2038	0.2548	0.3058	0.3568	0.4078
	7.5%	0.1213	0.1315	0.1417	0.1723	0.2233	0.2743	0.3253	0.3763	0.4273
	10.0%	0.1408	0.151	0.1612	0.1918	0.2428	0.2938	0.3448	0.3958	0.4468
	12.5%	0.1603	0.1705	0.1807	0.2113	0.2623	0.3133	0.3643	0.4153	0.4663
	15.0%	0.1798	0.19	0.2002	0.2308	0.2818	0.3328	0.3838	0.4348	0.4858
5%	0.0%	0.157	0.1672	0.1774	0.208	0.259	0.31	0.361	0.412	0.463
	0.5%	0.1609	0.1711	0.1813	0.2119	0.2629	0.3139	0.3649	0.4159	0.4669
	1.0%	0.1648	0.175	0.1852	0.2158	0.2668	0.3178	0.3688	0.4198	0.4708
	2.5%	0.1765	0.1867	0.1969	0.2275	0.2785	0.3295	0.3805	0.4315	0.4825
	5.0%	0.196	0.2062	0.2164	0.247	0.298	0.349	0.4	0.451	0.502
	7.5%	0.2155	0.2257	0.2359	0.2665	0.3175	0.3685	0.4195	0.4705	0.5215

	10.0%	0.235	0.2452	0.2554	0.286	0.337	0.388	0.439	0.49	0.541
	12.5%	0.2545	0.2647	0.2749	0.3055	0.3565	0.4075	0.4585	0.5095	0.5605
	15.0%	0.274	0.2842	0.2944	0.325	0.376	0.427	0.478	0.529	0.58
5.0%	0.0%	0.314	0.3242	0.3344	0.365	0.416	0.467	0.518	0.569	0.62
	0.5%	0.3179	0.3281	0.3383	0.3689	0.4199	0.4709	0.5219	0.5729	0.6239
	1.0%	0.3218	0.332	0.3422	0.3728	0.4238	0.4748	0.5258	0.5768	0.6278
	2.5%	0.3335	0.3437	0.3539	0.3845	0.4355	0.4865	0.5375	0.5885	0.6395
	5.0%	0.353	0.3632	0.3734	0.404	0.455	0.506	0.557	0.608	0.659
	7.5%	0.3725	0.3827	0.3929	0.4235	0.4745	0.5255	0.5765	0.6275	0.6785
	10.0%	0.392	0.4022	0.4124	0.443	0.494	0.545	0.596	0.647	0.698
	12.5%	0.4115	0.4217	0.4319	0.4625	0.5135	0.5645	0.6155	0.6665	0.7175
	15.0%	0.431	0.4412	0.4514	0.482	0.533	0.584	0.635	0.686	0.737
7.5%	0.0%	0.471	0.4812	0.4914	0.522	0.573	0.624	0.675	0.726	0.777
	0.5%	0.4749	0.4851	0.4953	0.5259	0.5769	0.6279	0.6789	0.7299	0.7809
	1.0%	0.4788	0.489	0.4992	0.5298	0.5808	0.6318	0.6828	0.7338	0.7848
	2.5%	0.4905	0.5007	0.5109	0.5415	0.5925	0.6435	0.6945	0.7455	0.7965
	5.0%	0.51	0.5202	0.5304	0.561	0.612	0.663	0.714	0.765	0.816
	7.5%	0.5295	0.5397	0.5499	0.5805	0.6315	0.6825	0.7335	0.7845	0.8355
	10.0%	0.549	0.5592	0.5694	0.6	0.651	0.702	0.753	0.804	0.855
	12.5%	0.5685	0.5787	0.5889	0.6195	0.6705	0.7215	0.7725	0.8235	0.8745
	15.0%	0.588	0.5982	0.6084	0.639	0.69	0.741	0.792	0.843	0.894
10.0%	0.0%	0.628	0.6382	0.6484	0.679	0.73	0.781	0.832	0.883	0.934
	0.5%	0.6319	0.6421	0.6523	0.6829	0.7339	0.7849	0.8359	0.8869	0.9379
	1.0%	0.6358	0.646	0.6562	0.6868	0.7378	0.7888	0.8398	0.8908	0.9418
	2.5%	0.6475	0.6577	0.6679	0.6985	0.7495	0.8005	0.8515	0.9025	0.9535
	5.0%	0.667	0.6772	0.6874	0.718	0.769	0.82	0.871	0.922	0.973
	7.5%	0.6865	0.6967	0.7069	0.7375	0.7885	0.8395	0.8905	0.9415	0.9925
	10.0%	0.706	0.7162	0.7264	0.757	0.808	0.859	0.91	0.961	1.012
	12.5%	0.7255	0.7357	0.7459	0.7765	0.8275	0.8785	0.9295	0.9805	1.0315
	15.0%	0.745	0.7552	0.7654	0.796	0.847	0.898	0.949	1	1.051
12.5%	0.0%	0.785	0.7952	0.8054	0.836	0.887	0.938	0.989	1.04	1.091
	0.5%	0.7889	0.7991	0.8093	0.8399	0.8909	0.9419	0.9929	1.0439	1.0949
	1.0%	0.7928	0.803	0.8132	0.8438	0.8948	0.9458	0.9968	1.0478	1.0988
	2.5%	0.8045	0.8147	0.8249	0.8555	0.9065	0.9575	1.0085	1.0595	1.1105
	5.0%	0.824	0.8342	0.8444	0.875	0.926	0.977	1.028	1.079	1.13
	7.5%	0.8435	0.8537	0.8639	0.8945	0.9455	0.9965	1.0475	1.0985	1.1495
	10.0%	0.863	0.8732	0.8834	0.914	0.965	1.016	1.067	1.118	1.169

	12.5%	0.8825	0.8927	0.9029	0.9335	0.9845	1.0355	1.0865	1.1375	1.1885
	15.0%	0.902	0.9122	0.9224	0.953	1.004	1.055	1.106	1.157	1.208

Cell color legend

- Net benefit Less than 0.4 million yen
- Net benefit between 0.4-0.6 million yen
- Net benefit between 0.6-1.0 million yen
- Net benefit more than 1.0 million yen

*Net benefits are in Yen millions

Source: Made by the author

*Net Improvement		Depreciation, Repair & Other cost reduction								
Income improvement	Fuel Cost reduction	0.0%	0.5%	1.0%	2.5%	5.0%	7.5%	10.0%	12.5%	15.0%
0.0%	0.0%	0.000	0.010	0.020	0.051	0.102	0.153	0.204	0.255	0.306
	0.5%	0.004	0.014	0.024	0.055	0.106	0.157	0.208	0.259	0.310
	1.0%	0.008	0.018	0.028	0.059	0.110	0.161	0.212	0.263	0.314
	2.5%	0.020	0.030	0.040	0.071	0.122	0.173	0.224	0.275	0.326
	5.0%	0.039	0.049	0.059	0.090	0.141	0.192	0.243	0.294	0.345
	7.5%	0.059	0.069	0.079	0.110	0.161	0.212	0.263	0.314	0.365
	10.0%	0.078	0.088	0.098	0.129	0.180	0.231	0.282	0.333	0.384
	12.5%	0.098	0.108	0.118	0.149	0.200	0.251	0.302	0.353	0.404
	15.0%	0.117	0.127	0.137	0.168	0.219	0.270	0.321	0.372	0.423
0.5%	0.0%	0.031	0.042	0.052	0.082	0.133	0.184	0.235	0.286	0.337
	0.5%	0.035	0.046	0.056	0.086	0.137	0.188	0.239	0.290	0.341
	1.0%	0.039	0.049	0.060	0.090	0.141	0.192	0.243	0.294	0.345
	2.5%	0.051	0.061	0.071	0.102	0.153	0.204	0.255	0.306	0.357
	5.0%	0.070	0.081	0.091	0.121	0.172	0.223	0.274	0.325	0.376
	7.5%	0.090	0.100	0.110	0.141	0.192	0.243	0.294	0.345	0.396
	10.0%	0.109	0.120	0.130	0.160	0.211	0.262	0.313	0.364	0.415
	12.5%	0.129	0.139	0.149	0.180	0.231	0.282	0.333	0.384	0.435
	15.0%	0.148	0.159	0.169	0.199	0.250	0.301	0.352	0.403	0.454
1.0%	0.0%	0.063	0.073	0.083	0.114	0.165	0.216	0.267	0.318	0.369
	0.5%	0.067	0.077	0.087	0.118	0.169	0.220	0.271	0.322	0.373
	1.0%	0.071	0.081	0.091	0.122	0.173	0.224	0.275	0.326	0.377
	2.5%	0.082	0.093	0.103	0.133	0.184	0.235	0.286	0.337	0.388
	5.0%	0.102	0.112	0.122	0.153	0.204	0.255	0.306	0.357	0.408
	7.5%	0.121	0.132	0.142	0.172	0.223	0.274	0.325	0.376	0.427
	10.0%	0.141	0.151	0.161	0.192	0.243	0.294	0.345	0.396	0.447
	12.5%	0.160	0.171	0.181	0.211	0.262	0.313	0.364	0.415	0.466
	15.0%	0.180	0.190	0.200	0.231	0.282	0.333	0.384	0.435	0.486

2.5%	0.0%	0.157	0.167	0.177	0.208	0.259	0.310	0.361	0.412	0.463
	0.5%	0.161	0.171	0.181	0.212	0.263	0.314	0.365	0.416	0.467
	1.0%	0.165	0.175	0.185	0.216	0.267	0.318	0.369	0.420	0.471
	2.5%	0.177	0.187	0.197	0.228	0.279	0.330	0.381	0.432	0.483
	5.0%	0.196	0.206	0.216	0.247	0.298	0.349	0.400	0.451	0.502
	7.5%	0.216	0.226	0.236	0.267	0.318	0.369	0.420	0.471	0.522
	10.0%	0.235	0.245	0.255	0.286	0.337	0.388	0.439	0.490	0.541
	12.5%	0.255	0.265	0.275	0.306	0.357	0.408	0.459	0.510	0.561
	15.0%	0.274	0.284	0.294	0.325	0.376	0.427	0.478	0.529	0.580
5.0%	0.0%	0.314	0.324	0.334	0.365	0.416	0.467	0.518	0.569	0.620
	0.5%	0.318	0.328	0.338	0.369	0.420	0.471	0.522	0.573	0.624
	1.0%	0.322	0.332	0.342	0.373	0.424	0.475	0.526	0.577	0.628
	2.5%	0.334	0.344	0.354	0.385	0.436	0.487	0.538	0.589	0.640
	5.0%	0.353	0.363	0.373	0.404	0.455	0.506	0.557	0.608	0.659
	7.5%	0.373	0.383	0.393	0.424	0.475	0.526	0.577	0.628	0.679
	10.0%	0.392	0.402	0.412	0.443	0.494	0.545	0.596	0.647	0.698
	12.5%	0.412	0.422	0.432	0.463	0.514	0.565	0.616	0.667	0.718
	15.0%	0.431	0.441	0.451	0.482	0.533	0.584	0.635	0.686	0.737
7.5%	0.0%	0.471	0.481	0.491	0.522	0.573	0.624	0.675	0.726	0.777
	0.5%	0.475	0.485	0.495	0.526	0.577	0.628	0.679	0.730	0.781
	1.0%	0.479	0.489	0.499	0.530	0.581	0.632	0.683	0.734	0.785
	2.5%	0.491	0.501	0.511	0.542	0.593	0.644	0.695	0.746	0.797
	5.0%	0.510	0.520	0.530	0.561	0.612	0.663	0.714	0.765	0.816
	7.5%	0.530	0.540	0.550	0.581	0.632	0.683	0.734	0.785	0.836
	10.0%	0.549	0.559	0.569	0.600	0.651	0.702	0.753	0.804	0.855
	12.5%	0.569	0.579	0.589	0.620	0.671	0.722	0.773	0.824	0.875
	15.0%	0.588	0.598	0.608	0.639	0.690	0.741	0.792	0.843	0.894
10.0%	0.0%	0.628	0.638	0.648	0.679	0.730	0.781	0.832	0.883	0.934
	0.5%	0.632	0.642	0.652	0.683	0.734	0.785	0.836	0.887	0.938
	1.0%	0.636	0.646	0.656	0.687	0.738	0.789	0.840	0.891	0.942
	2.5%	0.648	0.658	0.668	0.699	0.750	0.801	0.852	0.903	0.954
	5.0%	0.667	0.677	0.687	0.718	0.769	0.820	0.871	0.922	0.973
	7.5%	0.687	0.697	0.707	0.738	0.789	0.840	0.891	0.942	0.993
	10.0%	0.706	0.716	0.726	0.757	0.808	0.859	0.910	0.961	1.012
	12.5%	0.726	0.736	0.746	0.777	0.828	0.879	0.930	0.981	1.032
	15.0%	0.745	0.755	0.765	0.796	0.847	0.898	0.949	1.000	1.051
12.5%	0.0%	0.785	0.795	0.805	0.836	0.887	0.938	0.989	1.040	1.091

	0.5%	0.789	0.799	0.809	0.840	0.891	0.942	0.993	1.044	1.095
	1.0%	0.793	0.803	0.813	0.844	0.895	0.946	0.997	1.048	1.099
	2.5%	0.805	0.815	0.825	0.856	0.907	0.958	1.009	1.060	1.111
	5.0%	0.824	0.834	0.844	0.875	0.926	0.977	1.028	1.079	1.130
	7.5%	0.844	0.854	0.864	0.895	0.946	0.997	1.048	1.099	1.150
	10.0%	0.863	0.873	0.883	0.914	0.965	1.016	1.067	1.118	1.169
	12.5%	0.883	0.893	0.903	0.934	0.985	1.036	1.087	1.138	1.189
	15.0%	0.902	0.912	0.922	0.953	1.004	1.055	1.106	1.157	1.208

0 Net benefit level 1 million yen

*Net benefits are in Yen millions

Source: Made by the author