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# A Survey on Energy Consumption in Fisheries, and Measures to Reduce CO<sub>2</sub> Emissions

Atsumi Furuya<sup>1</sup>, Masahito Fukami<sup>1</sup>, Harald Ellingsen<sup>2</sup>, Seiichi Kagaya<sup>1</sup>

This study estimates energy (fuel) consumption in squid, fixed net and gill net fishing, which are typical coastal fisheries in Japan, as well as in kelp aquaculture that uses large amounts of fuel, in order to compare with fishing industries in other countries. It also analyzes the characteristics of Japanese fisheries and fuel oil consumption, and presents fuel reduction measures.

In addition, the study estimates the amounts of carbon dioxide emissions from energy (fuel oil and electricity) use and leakage of refrigerant HCFCs and HFCs, and the amounts absorbed by the ocean and forests in fishing communities, and discusses carbon dioxide emission reduction measures taken throughout the communities.

**Keywords:** *Fisheries, Energy Consumption, Fishing communities, CO<sub>2</sub>balance, HCFCs and HFCs, Measures of CO<sub>2</sub>Emissions Reduction*

## 1. Introduction

When considering measures against global warming, the role of the ocean as a CO<sub>2</sub> sink is very significant. It is said that the land areas (forests) and oceans absorb almost half of man-made CO<sub>2</sub> emissions (7.1 billion tons throughout the world). However, the carbon balance in shallow seas, where organisms that are involved in ocean CO<sub>2</sub> sinks and sources, is almost unknown.

Fishing is a major source of energy-derived CO<sub>2</sub> emission among Japan's production activities, and the CO<sub>2</sub> emission strength (CO<sub>2</sub> emission per ¥1 million of production volume) of marine fisheries in 2005 was the third highest (Center for Global Environmental Research, National Institute for Environmental Studies) of all industries (largely classified into 37 categories).

### 1.1 Fossil fuel consumption in Japanese fisheries

In Japan, production by operating fishing vessels is the main fishery activity, and distribution of fishing communities is extremely uneven. This means that long-distance transportation is necessary between production and consumption areas. Trucks are the main means of such transportation.

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Hasegawa[1] estimated the total fuel oil consumption and carbon dioxide emission of Japan's vessel-based fishing industry. The results estimated that the annual fuel oil use by powered fishing vessels was 3.22 million kiloliters and the annual CO<sub>2</sub> emission was 8.37 million tons (both calculated for Bunker A).

While 0.8% of Japan's total CO<sub>2</sub> emission (1.1 billion tons in 2008) is derived from the fishing industry, the GDP of fisheries in the same year accounted only for 0.15% of the national total.

## 1.2 CO<sub>2</sub> emission strength (CO<sub>2</sub> emission per ¥1 million of production volume)

The Center for Global Environmental Research, National Institute for Environmental Studies, published Embodied Energy and Emission Intensity Data for Japan (3EID), which estimated energy consumption and CO<sub>2</sub> emission by industry, based on input-output tables (2005) published by the Ministry of Internal Affairs and Communications. Table 1 ranks unit direct-CO<sub>2</sub> emissions (t-CO<sub>2</sub>/¥1 million) from 37 integrated industrial categories in descending order. Marine fisheries ranks third and aquaculture ranks eighth and ninth, indicating that the environmental burdens of fisheries are large.

Table1 Unit direct-CO<sub>2</sub> emission by industry (t-CO<sub>2</sub>/¥1 million)

Rank	Category	Unit direct-CO <sub>2</sub> emission(t-CO <sub>2</sub> /¥1 million)
1	Electricity, gas, heat supply	23.11
2	Ceramic, stone and clay production	9.13
3	Marine fisheries	7.51
4	Iron and steel	6.82
5	Transportation	3.88
6	Water, waste disposal	3.44
7	Petroleum and coal production	2.44
8	Inland water fisheries and culture	1.89
9	Marine culture	1.67
10	Chemical production	1.61
:	:	:
35	Real estate	0.03
36	Finance and insurance	0.02
37	Office supplies	0

Center for Global Environmental Research, National Institute for Environmental Studies[2]

## 1.3 Acceleration of the establishment of low-carbon society in Japan

The Japanese government has set a medium-term goal to reduce greenhouse gas emissions by 25% by 2020, compared with 1990 levels. To reinforce environmental and energy technologies and accelerate green innovation in order to achieve the goal, the Basic Bill on Global Warming Countermeasures, centering on the three main measures –

cap-and-trade-type domestic emission trading, introduction of global warming tax and the feed-in tariff system for renewable energy – was approved by the Cabinet in June 2010 and submitted to the Diet. However, the bill still remains under deliberation.

The course of action and measures to achieve reductions of 25% by 2020 and 80% by 2050 is indicated in the Mid- and Long-Term Roadmap to Low-carbon Japan. To achieve the mid- and long-term goals, it is considered necessary to focus on the practice of low-carbon lifestyles (eco-style) through promotion of eco-investment and Challenge 25, as well as on a variety of investment benefits to establish low-carbon society, including the creation of markets and employments, regional revitalization and ensuring energy security.

#### **1.4 What the fishing industry should promote toward the establishment of a low-carbon society**

Since the fishing industry depends on natural environments, fishing communities become sustainable through coexistence with these natural environments. People who reduce the burden on nature and take action toward a low-carbon society are those living together with nature in fishing communities, and their actions and appeals can inspire people living in urban areas.

However, the current status of fisheries is far from low carbon. For example, vessel-based fishing consumes fossil fuels in large amounts, as mentioned before, and almost no measures are taken to reduce CO<sub>2</sub> emissions from such fuel consumption. Marine processing facilities also employ large freezer-refrigerator and air conditioning systems, ice machines and water coolers that use HCFCs and HFCs as refrigerants, in addition to large amounts of energy. Since the distributed products are mainly fresh, they are transported to areas of consumption in large trucks every day. Resources are decreasing due to environmental deterioration and excessive fishing. Therefore, the fishing industry must take a variety of measures, such as energy saving, effective use of resources, use of renewable energy, environmental conservation, maintenance of natural carbon dioxide absorption functions, awareness-raising among people engaged in fisheries, and reduction of fishing and distribution mileages, as well as the establishment of systems for promoting such measures, in order to reduce CO<sub>2</sub> emissions from fossil fuels and refrigerants, and to preserve biodiversity.

#### **1.5 Goals and content of this paper**

The goals of this paper are as listed below.  
For a fishing community as a model area:

- 1) to analyze the characteristics of fuel oil consumption and present fuel reduction measures by estimating energy consumption and CO<sub>2</sub> emissions of fisheries and comparing them with those of the same types of fishing industries in other countries,
- 2) to identify the CO<sub>2</sub> balance by estimating CO<sub>2</sub> emissions from energy (fuel oil and electricity) use and leakage of refrigerant HCFCs and HFCs and the amounts absorbed by forests and oceans, and
- 3) to present a CO<sub>2</sub> emission reduction plan for the entire region.

## 2. Method of estimating CO<sub>2</sub> emissions in a fishing community

In this study, CO<sub>2</sub> emissions from fishing, other industries and general households were estimated using the Minamikayabe area in Hakodate (Fig. 1) as a model.

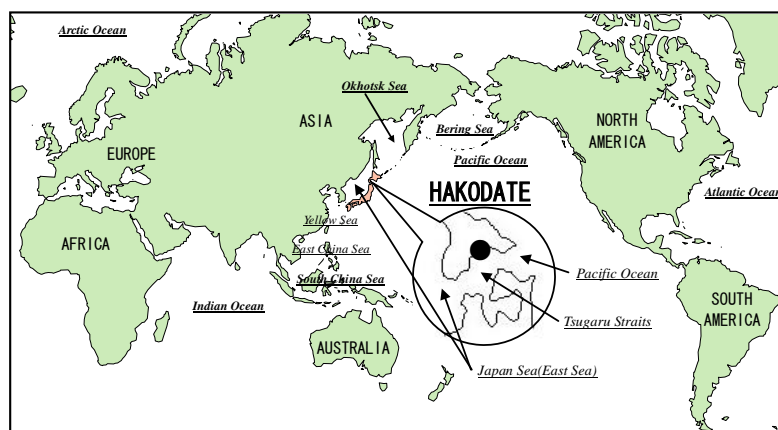


Fig. 1 Hakodate City as seen on a world map

### 2.1 Energy-derived CO<sub>2</sub> emissions

Figures 2 and 3 show the methods for estimating CO<sub>2</sub> emissions from fishing and marine processing and those from other industrial sectors, respectively.

Energy consumption in the fishing industry was surveyed, and basic data on CO<sub>2</sub> emissions was collected (2006). The survey was conducted for four fishery sectors (squid, fixed net, gill net and kelp) and marine processing as shown in Table 2. The energy consumption of the targets in each sector was estimated for three items – fuel/lighting expenses, waste and haulage/transportation. The annual energy consumption by activities of the targets was estimated using the survey sheet shown in Table 3.

The Ministry of the Environment's List of Emission Coefficients (2010) was used to derive CO<sub>2</sub> emissions from the annual energy consumption found in the survey. These coefficients indicate the CO<sub>2</sub> emission (t-CO<sub>2</sub>) deriving from one unit of electricity, city gas, gasoline and other types of energy. CO<sub>2</sub> emissions can be estimated by multiplying the energy consumption and waste discharge by this coefficient.

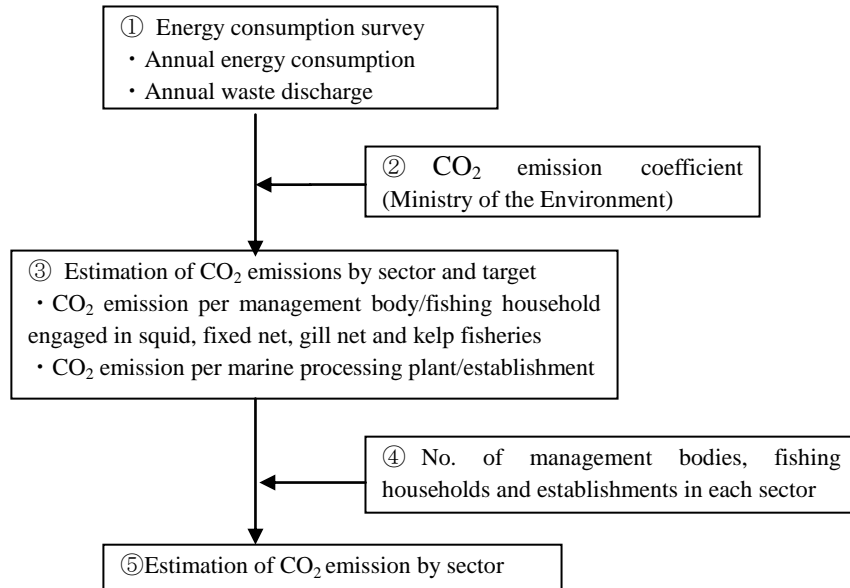


Fig. 2 Method of estimating CO<sub>2</sub> emissions from fishing and marine processing

With regard to CO<sub>2</sub> emissions from other industrial sectors, CO<sub>2</sub> emission intensity for each sector was determined using the production for each industrial sector and CO<sub>2</sub> emission presented in the input-output table of the Minamikayabe area (1998). By multiplying the CO<sub>2</sub> emission intensity for each industry by the production for each industrial sector in the Minamikayabe area in 2010, CO<sub>2</sub> emissions for each industry in 2010 were estimated.

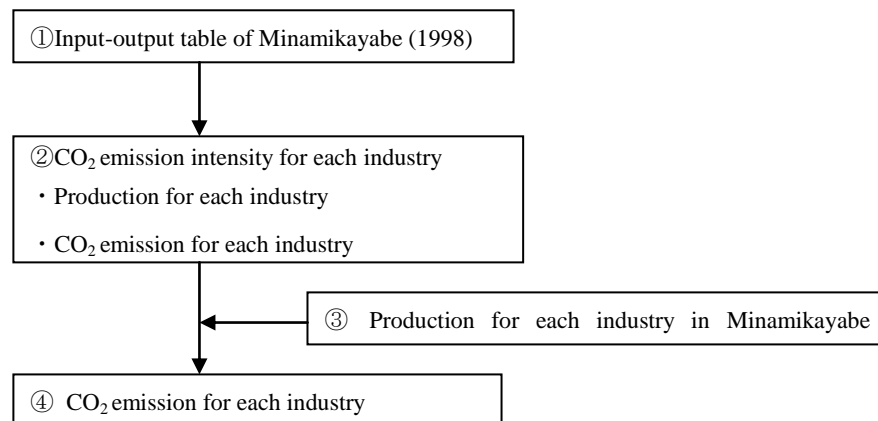


Fig. 3 Method of estimating CO<sub>2</sub> emissions from other industries

For general households, the national annual CO<sub>2</sub> emission per household (2008) – which was 5.04t-CO<sub>2</sub>/household – was multiplied by the number of households (2,208) in the Minamikayabe area (2010).

(1) Fisheries subject to the estimation of energy consumption, and number of targets

Table 2 shows the fishing and marine processing sectors subject to estimation of energy

consumption, and the number of targets. There were ten squid-fishing households, although they were also engaged in other types of fishing, and one of them was selected as a target. Of the 28 management bodies engaging in fixed net fishing, three (two large and one small) were surveyed. Two households engaging in gill net fishing were selected from a total of 118. Of the 396 kelp-fishing households, three with different production scales were surveyed. Of the seven marine processing plants, two with different production scales were surveyed. In-person interviews were conducted with all targets.

Table 2 Fishing and marine processing sectors subject to the estimation of energy consumption, and number of targets

Sectors	Number of targets	Number of management bodies, fishing households and plants
Squid-fishing	1	10
Fix net fishing	3	28
Gill net fishing	2	118
Kelp-fishing	3	396
Marine processing	2	7

## (2)Details of the energy consumption survey

Table 3 shows the energy consumption survey chart. Fuel and lighting expenses, annual consumption of coal, fuel oil, electricity and running water were surveyed, and the annual amounts and disposal methods for each type of waste were surveyed. The annual work-related driving distances were survey under haulage/transportation.

Table 3 Energy consumption survey chart

Fuel/lighting expenses	Item	Unit	Annual consumption
	Coal	t	
	Gasoline	L	
	Kerosene	L	
	Diesel	L	
	Bunker	L	
	Electricity	kwh	
	Running water	m <sup>3</sup>	
	Others		
Waste	Type	Unit	Annual amounts waste and disposal methods
Haulage/transportation	Vehicle	Unit	Annual driving distances
	Track	km	
	Bus	km	
	Automobile	km	
	他	km	

## (3) CO<sub>2</sub> emission coefficients

Table 4 shows the CO<sub>2</sub> emission coefficients in 2010 according to the Ministry of the Environment.

Table 4 List of CO<sub>2</sub> emission coefficients[3]

Item		Unit	Emission coefficient	Basis for calculation
Emission from fuel use	Coal	t-CO <sub>2</sub> /t	2.33	MOE’s list of emission coefficients
	Gasoline	t-CO <sub>2</sub> /l	2.32	
	Kerosene	t-CO <sub>2</sub> /l	2.49	
	Diesel	t-CO <sub>2</sub> /l	2.58	
	Bunker A	t-CO <sub>2</sub> /l	2.71	
	Bunker B	t-CO <sub>2</sub> /l	3.00	
	LP gas	t-CO <sub>2</sub> /kg	3.00	
	City gas	t-CO <sub>2</sub> /m <sup>3</sup>	2.23	
Emissions from energy supplied by others	Electricity	t-CO <sub>2</sub> /kwh	0.000588	MOE’s list of emission coefficients
	Heat	t-CO <sub>2</sub> /GJ	0.060	
Emissions from waste disposal	Nonburnable garbage	No emission		MOE’s list of emission coefficients
	Residue	No emission		
	Waste oil	t-CO <sub>2</sub> /t	2.92	
	Waste plastic	t-CO <sub>2</sub> /t	2.55	

## 2.2 CO<sub>2</sub> emissions from refrigerant HCFCs and HFCs

HCFCs and HFCs used as refrigerants for freezer/refrigerator and air conditioning systems are highly likely to have serious effects on global warming when they are released into the atmosphere. Measures against refrigerants used in automobiles, electrical appliances and industrial freezers and refrigerators have focused on their disposal, by requiring collection of disposed items. However, a recent study revealed that discharges during use (due to accidents, breakages, repairs, leakages, etc.) were also significant, and new measures for HCFCs and HFCs are urgently required for the establishment of a low-carbon society.

In fishing areas, HCFCs and HFCs are used as refrigerants for refrigerators/freezers, ice machines and water coolers owned by fisheries cooperatives, as well as for refrigerators/freezers and the condensing and chilling units of freezing chambers owned by marine processing plants. HCFCs and HFCs are also used in domestic refrigerators, automobile air conditioners and vending machines, and the amount leaked during use is thought to be considerable.

This study estimated the amounts of refrigerant HCFCs and HFCs leaked from fishery-related establishments (fishing cooperatives and marine processing plants) and the amounts from domestic refrigerators and automobile air conditioners in the Minamikayabe area (Figs. 4 and 5), and converted them into amounts of CO<sub>2</sub> to estimate emissions derived from refrigerant HCFCs and HFCs.



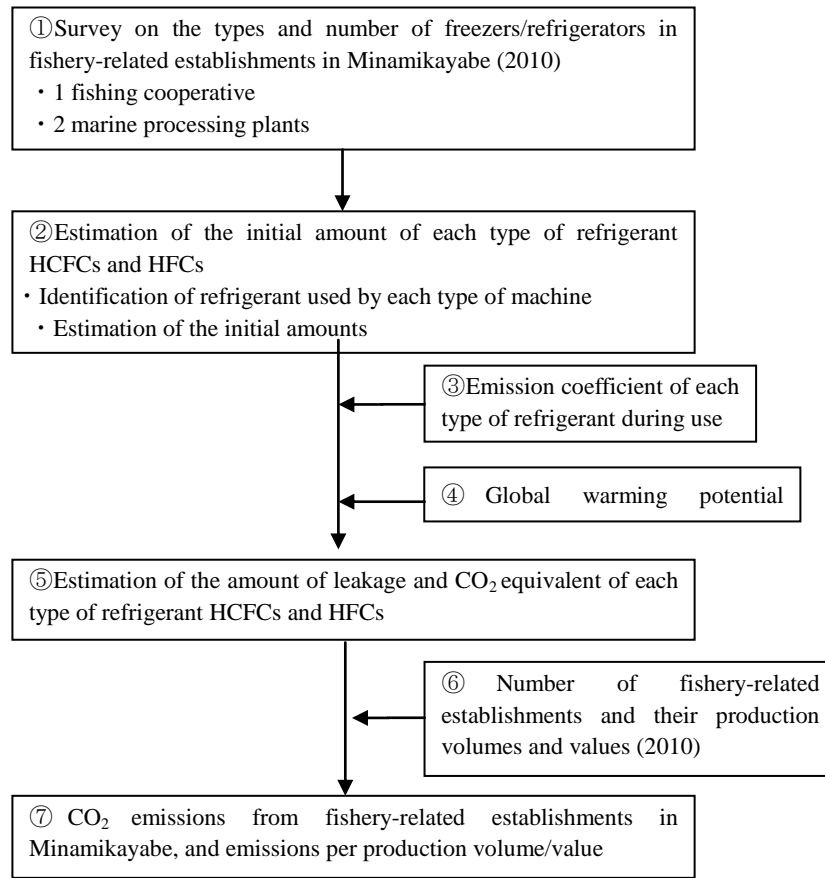


Fig. 4 Estimation of the amount of HCFCs and HFCs leaked from fishery-related establishments, and their CO<sub>2</sub> equivalents

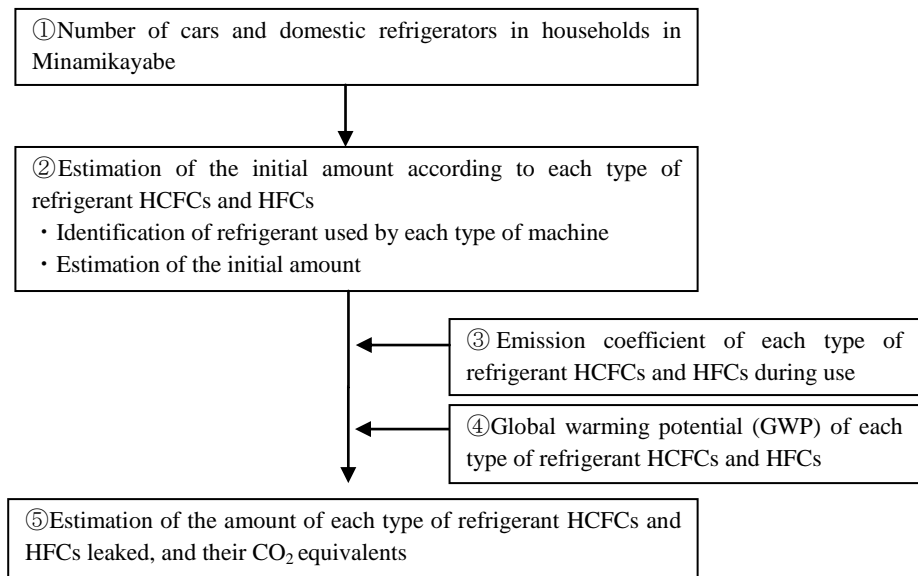


Fig. 5 Estimation of the amounts of HCFCs and HFCs leaked from cars and domestic refrigerators, and their CO<sub>2</sub> equivalents

### (1) Targets of the survey on refrigerant HCFCs and HFCs

A survey on the ownership of freezers/refrigerators containing HCFCs and HFCs was conducted for the targets listed in Table 5.

Since there was only one fishing cooperative in the area, it was possible to survey all units. Since it was difficult to survey all seven marine processing plants, ownership at two establishments was surveyed, and the amount of refrigerant HCFCs and HFCs leaking from processing plants in the entire area was estimated by estimating the emission per establishment and multiplying it by the number of establishments in the area. The amounts from freezers/refrigerators in automobile air conditioners and domestic refrigerators were estimated from the numbers of automobiles and households, respectively.

Table 5 Targets of the survey on refrigerant HCFCs and HFCs

Target of the survey	Number of targets	Number of cooperatives and plants
Fishing cooperative	1	1
Marine processing	2	7
Automobiles	Entire automobile of region	-
Domestic refrigerators	Entire household of region	-

### (2) Details of the survey on refrigerant HCFCs and HFCs

Table 6 shows the survey chart of freezer/refrigerator systems containing refrigerant HCFCs and HFCs. The types of refrigerants and initial amounts were found from the models of freezers/refrigerators, ice machines, water coolers, air conditioners, showcases, refrigerated trucks and freezing chambers. However, estimation regarding older models and showcases was made using the types and amounts of refrigerants for different models presented by the Ministry of Economy, Trade and Industry [4].

Table 6 Survey chart of freezer/refrigerator systems containing HCFCs and HFCs

		Manufacturing company	Type	Refrigerant	Number
Fishing cooperative	Freezers/refrigerator				
	Ice machines				
	Water coolers				
	Air conditioners				
	Showcases				
Marine processing	Freezers/refrigerator				
	Freezing chambers				
	Showcases				
		Refrigerant	Numbe		
	Refrigerated trucks				

## 3. Definition of CO<sub>2</sub> sinks in coastal areas

Fishing communities are located in coastal areas, and forests and sea areas play

important roles as CO<sub>2</sub> sinks. Forests absorb CO<sub>2</sub> over a long period of time, and CO<sub>2</sub> is constantly exchanged between the ocean and the atmosphere. While seaweed absorbs CO<sub>2</sub> by photosynthesis during its growth, it naturally falls into decay when it stops growing. It is known from past study results[5] that part of such decayed seaweed drifts away and becomes fixed to the seabed. Sinks include natural and cultured kelp and man-made seaweed beds.

It is also known from research results[6] that, in continental shelf and other shallow water areas, seawater contains carbon that becomes heavier as it cools by heat release in winter, and this absorbs CO<sub>2</sub> as it sinks deep down, moving under the offshore oceanic water by means of equal-density mixing and carrying it to an intermediate layer deeper than the continental shelf (continental shelf pump).

In addition, the amounts reduced by man-made CO<sub>2</sub> emission reduction methods in coastal areas, such as energy saving, cyclical use of resources and use of renewable energy, were also estimated.

From the above, the amounts absorbed by the following four coastal area sinks were estimated in this study. The estimation methods are as described below.

#### (1) Forest carbon sinks

The carbon stocks of man-made forests (by type and age of trees) in the Minamikayabe area were calculated. The fixation period of 50-year-old trees was investigated, and the carbon stocks found were converted into CO<sub>2</sub> emissions to estimate the amount of CO<sub>2</sub> absorption.

#### (2) Seaweed carbon sinks

The amounts absorbed by natural and cultured kelp and drifting seaweed in man-made seaweed beds off the coast of the Minamikayabe area were estimated. To estimate the amounts of CO<sub>2</sub> absorbed by drifting seaweed, the seaweed bed area was determined and the existing amount of kelp and its carbon stock were calculated for natural kelp; the carbon stock was calculated from excess kelp cut off in the cultured kelp cultivation area, and the existing amount of kelp and its carbon stock were calculated for artificially developed seaweed beds.

#### (3) Amount absorbed by the continental shelf pump function

By assuming the continental shelf pump function off the coast of Minamikayabe, the carbon stock in the intermediate layer was found and converted into the amount of CO<sub>2</sub>. The amounts absorbed in (2) were deducted from this.

#### (4) Amount absorbed by man-made methods

Five CO<sub>2</sub> emission reduction measures feasible in Minamikayabe were presented, and the amounts of CO<sub>2</sub> reduced by them were calculated.

Table 7 Measures to reduce CO<sub>2</sub> emission by man-made methods in the Minamikayabe area

CO <sub>2</sub> emission reduction measure	Details
Improvement in efficiency of kelp drying	Improvement in heat efficiency in drying areas
Energy saving in squid fishery	Use of energy-saving lights for squid-fishing boats
Energy saving at fish farms	Introduction of a heat exchange system for heating/cooling of seawater
Introduction of new energy to fishing cooperative facilities	Installation of solar panels on the roof of the fishing cooperative building
Utilization of marine biomass	Methane fermentation of kelp roots to use as an energy source

## 4. Study results

### 4.1 Energy-derived CO<sub>2</sub> emissions

#### (1) CO<sub>2</sub> emissions by industrial sectors

Table 8 shows CO<sub>2</sub> emissions of each type of industry in the Minamikayabe area (2010). The total CO<sub>2</sub> emission from all industries in 2010 was estimated to be 41,011 t-CO<sub>2</sub>. The CO<sub>2</sub> emissions from the fishing industry were large since large amounts of fuel are consumed during operations. The emission from kelp fishery was the largest since large amounts of fuel oil is used for drying. Power consumption by processing plants was also large as they use multiple large-scale freezers/refrigerators.

Table 8 Estimated values of CO<sub>2</sub> emissions of each industry

	Input-output table of Minamikayabe (1998)			Emission in 2010		Estimation method *2
	Production value	CO <sub>2</sub> emission	Emission intensity	Production value *1	CO <sub>2</sub> emission	
	Million yen	t-CO <sub>2</sub>	t-CO <sub>2</sub> /million yen	Million yen	t-CO <sub>2</sub>	
Agriculture/forestry	357	900	2.519	357	899	b
Cultured kelp	3,843	21,347	5.555	5,052	21,945	a
Natural kelp						
Fixed net	3,068	2,413	0.786	2,540	1,118	a
Gill net	1,292	3,415	2.644	1,024	3,384	
Longline	0	0	-	0	0	b
Squid fishery	219	3,053	13.930	204	2,842	a
Other fisheries	681	3,541	5.196	874	4,541	
Kelp processing	5,670	2,358	0.416	5,492	2,303	a
Squid processing						
Food processing						
Manufacturing	119	380	3.189	139	443	b
Machine products	219	423	1.932	255	493	b
Education/research	1,414	139	0.098	3,606	354	b
Medical/social	2,360	234	0.099	3,408	338	b
Service	16,053	619	0.039	17,666	681	b
Restaurant	330	18	4.596	363	1,669	b
Accommodation		1,499				b
Total	35,625	40,338	-	40,980	41,011	-

\*1. Production values are for 2009.

\*2. a. Estimated from energy consumption

b. Estimated from the emission intensity of Minamikayabe in 1998

#### (2) Estimated domestic CO<sub>2</sub> emission

The emission was estimated to be 11,128 t by multiplying the average nationwide CO<sub>2</sub> emission per household by the number of households in Minamikayabe.

$$\text{Domestic CO}_2 \text{ emission (2010)} = 5.04 \text{ t-CO}_2/\text{household} \times 2,208 \text{ households} = 11,128 \text{ t-CO}_2/\text{year}$$

#### **4.2 CO<sub>2</sub> emissions from refrigerant HCFCs and HFCs**

Table 9 shows the conditions of appliances owned by the fishing cooperative and marine processing plants, and the types and amounts of refrigerant HCFCs and HFCs, emission coefficients, amounts of leakage, as well as GWP and CO<sub>2</sub> equivalent of refrigerant HCFCs and HFCs. Table 10 lists domestic refrigerant HCFCs and HFCs.

Many large freezers/refrigerators are used at marine processing plants. The fishing cooperative uses several large-scale ice machines. Water coolers are the chilling units used for fish preserves and nursery production.

Table 11 shows CO<sub>2</sub> emissions from refrigerant HCFCs and HFCs in Minamiyayabe (2010). The emissions from freezers/refrigerators and passenger cars are significant. The total emission of the entire area was 1,109 tons.

#### **4.3 CO<sub>2</sub> emissions in the Minamikayabe area**

Table 12 shows the estimated values of CO<sub>2</sub> emissions from energy and refrigerants in the Minamikayabe area in 2010. The CO<sub>2</sub> emissions from energy and refrigerant HCFCs and HFCs were estimated to be 52,139 and 1,109 tons, respectively, and 53,247 tons in total. The emission from refrigerant HCFCs and HFCs accounted for 2% of the total.

#### **4.4 Estimation of the amounts of CO<sub>2</sub> absorbed in coastal areas**

A past study by Furuya et al.[7] estimated the amounts of CO<sub>2</sub> absorbed in the coastal part of the Minamikayabe area, as shown in Table 13. The annual amount of absorption was 68,857 tons, of which 80% was absorbed by forests and the continental shelf pump function. It is possible to increase the absorption through forestation, forest preservation, seaweed bed development, revitalization of the continental shelf pump function and other measures.

### **5. Discussion**

#### **5.1 Comparison of CO<sub>2</sub> emissions by fishing industries of different countries and those in the Minamikayabe area**

##### **(1) Comparison of emissions from fishing industries**

Table 14 shows fuel consumption per 1 kg catch of major fisheries in the Minamikayabe and Rausu areas. The fuel consumption in the Rausu area estimated in a past study[15] was

added to the consumption in the Minamikayabe area estimated in this paper. Table 15 is an excerpt from Table 5 of a study by Erwin M. Shau et al., showing the fuel consumption by round haul net, trawl, longline, gill net and trap fisheries in Norway, Iceland, Denmark and Sweden, which were used as the targets of comparison.

Table 9 Conditions of appliances owned by the fishing cooperative and marine processing plants, and CO<sub>2</sub> emissions from refrigerant HCFCs and HFCs

	Office		Number	Refrigerant	Initial amounts of refrigerant(kg)※1	Emission coefficients (%)※2	Amount of refrigerant leaked(kg/year)※3	GWP	CO <sub>2</sub> Equivalents (t-CO <sub>2</sub> /year)
Freezers/refrigerators	Fishing cooperative	Condensing units	6	R22	237	13	30.81	1810	56
		Freezers/refrigerators units	2	R22	4	17	0.68	1810	1
		Condensing units	1	R404A	13	13	1.69	3260	6
		Refrigerators	1	R134a	1	2	0.02	1300	0.03
		Total						63	
	Marine processing plant A	Freezers/refrigerators units	3	R22	112	17	19.04	1810	34
		Condensing units	3	R404A	36	13	14.04	3260	46
		Screw freezers	1	R22	32	12	3.84	1810	7
	Marine processing plant B	Screw freezers	7	R22	240	12	28.8	1810	52
		Freezers/refrigerators units	1	R22	40	17	6.8	1810	12
	Total								152
Ice machines	Fishing cooperative	Condensing units	4	R404A	231	13	30.03	3260	98
		Condensing units	4	R22	121.4	13	15.782	1810	29
		Freezers	1	R134a	1	2	0.02	1300	0
		Total						126	
	Marine processing plant Condensing unit		1	R404A	24	13	3.12	3260	10
Water coolers	Fishing cooperative	Chilling units	6	R22	138.4	6	8.304	1810	15
		Chilling units	4	R407C	109	6	6.54	1526	10
		Condensing units	2	R22	60	13	7.8	1810	14
	Total							39	
Air conditioners			3	R401A	5	3.5	0.525	3280	1.7
Showcases	Fishing cooperative	Freezers	12	R404A	2	2	0.48	3260	1.6
		Refrigerators	13	R404A	0.5	2	0.13	3260	0.4
	Marine processing plant B	Freezers	6	R404A	2	2	0.24	3260	0.8

\*1. Amount of refrigerant: the initial amount of HCFCs and HFCs indicated on the appliance. If there is no indication, the amount is estimated from the type of and amount of refrigerant for the model presented by the Ministry of Economy, Trade

and Industry[4].

\*2. Emission coefficients are according to the Ministry of the Environment's Subcommittee on Fluorocarbons Reduction Measures.

\*3. Amount of refrigerant during use  $\times$  emission coefficient

Table 10 Types of domestic refrigerant HCFCs and HFCs, amounts of leakage and CO<sub>2</sub> equivalents

			Refrigerant	Initial amounts of refrigerant (kg) $\times$ 1	Emission coefficients (%)	Amount of refrigerant leaked(kg/year) $\times$ 2	GWP	CO <sub>2</sub> Equivalents (t-CO <sub>2</sub> /year)
Automobiles	Air conditioners	Numbers						
		4,416	R134a	1	5.2	229.63	1300	298.5
Domestic	Refrigerators	Households						
		2,208	R134a	0.13	2	5.74	1300	7.5

Table 11 Summary of CO<sub>2</sub> emissions (2010) from refrigerant HCFCs and HFCs in Minamikayabe

	Freezer s/refrigerators	Ice machines	Water coolers	Show cases	Air conditioners	Total	per office	Number of offices	Total regional CO <sub>2</sub> (t-CO <sub>2</sub> /year)
Fishing cooperative	63.0	126.0	39.0	2.0	1.7	231.7	231.7	1	231.7
Marine processing plants	152.0	10.0	0.0	0.8	0.0	162.8	81.4	7	569.8
Domestic	7.5	-	-	-	-	-	-	-	7.5
Automobiles	299	-	-	-	-	-	-	-	299.0
合計	521.5	136.0	39.0	2.8	1.7	394.5	313.1	8.0	1108.0

According to Table 14, kelp fishery consumes the largest amount of fuel in the above two areas. This is because the drying process in the production of kelp products requires large amounts of fuel. Consumption is the largest in the Rausu area due to the long drying times. The next highest consumption was of squid fishing in Minamikayabe, which uses strong lighting powered by generators that consume large amounts of fuel. The consumption was equivalent to that of trawling in Table 15. The fuel consumption of gill/fixed net fishing, in which fish are caught with nets set up along the coast, is very small compared with other methods, although fuel oil is used when traveling to and from fishing grounds and pulling nets. It is also equivalent to that of purse seine fishery in Table 15. Gill net and longline fishing methods consume fuel oil when pulling nets, and the amounts consumed are equivalent to those of the same types of fishing in Norway and Denmark.

With regard to Table 15, Erwin M. Schau et al. mentioned several characteristics.

The table shows the fuel use coefficients for most of the different fishing gears used by the Norwegian fleet. Purse seine and pelagic trawl are clearly the most fuel-efficient fishing gears. The large difference between the resulting fuel consumption for bottom trawling and double trawling (one boat pulling two nets) can partly be explained by the species of fish these trawlers are catching. Double trawling is used almost only for deep-sea shrimp, requiring trawlers with a small mesh size that lead to higher resistance and higher fuel consumption.

The figures for Swedish and Danish fisheries clearly indicate higher levels of fuel coefficients, which may be due to the different fishing gears used and less dense stocks in the Baltic and the North Sea.

Table 12 CO<sub>2</sub> emissions in the Minamikayabe area (2010) Unit: t-CO<sub>2</sub>/year

	CO <sub>2</sub> emissions from energy	CO <sub>2</sub> emissions from refrigerant HCFCs and HFCs	Total CO <sub>2</sub> emissions
Agriculture/forestry	899		899
Cultured kelp	21,945		21,945
Natural kelp			0
Fixed net	1,118		1,118
Gill net	3,384		3,384
Longline	0		0
Squid fishery	2,842		2,842
Other fisheries	4,541		4,541
Kelp processing	2,303	570	2,873
Squid processing			
Food processing			
Manufacturing	443		443
Machine products	493		493
Education/research	354		354
Medical/social	338		338
Services	681	231	913
Restaurant	1,669		1,669
Accommodation			0
Domestic	11,128	307	11,435
Total	52,139	1,108	53,247

Table 13 Estimated amounts of CO<sub>2</sub> absorbed in the coastal area[7]

Sink	Amount of CO <sub>2</sub> absorbed (t-CO <sub>2</sub> /year)
Forests	20,402
Natural kelp	10,253
Cultured kelp	1,269
Man-made seaweed	16
Continental shelf	35,287
Man-made sinks	1,630
Total	68,857



Table 14 Fuel consumption of major types of fishing in the Minamikayabe and Rausu areas

Area	Type of fishing	CO <sub>2</sub> emission (t-CO <sub>2</sub> ) *1	Emission coefficient (Bunker A, kg- CO <sub>2</sub> /L) *2	Fuel consumption (L) *3	Production volume (t) *4	Fuel consumption per production volume *5 (kg-fuel/Kg-fish)
Minamikayabe	Kelp	21,945	2.71	8,097,786	2964	2.35
	Fixed net	1,118	2.71	412,546	23104	0.02
	Gill net	3,384	2.71	1,248,708	10558	0.10
	Squid	2,842	2.71	1,048,708	841	1.07
Rausu	Gill	22,277	2.71	8,220,295	20112	0.35
	Fixed net	3,115	2.71	1,149,446	29987	0.03
	Kelp	5,393	2.71	1,990,037	417	4.10

\*1. The CO<sub>2</sub> emission (t-CO<sub>2</sub>) is based on the estimated CO<sub>2</sub> emission in Minamikayabe (2010).

\*2. The specific gravity of Bunker A is 0.86 and the emission coefficients are for 2010.

\*3. Fuel consumption = CO<sub>2</sub> emission/emission coefficient

\*4. The production volume of each type of fishing is for 2009.

\*5. Fuel consumption per production volume = fuel consumption/production volume

\*6. Data from the Rausu area is an excerpt from the reference [15].

## (2) Emission reduction measures in Norway and the possibility of introducing them to the Minamikayabe area

Erwin M. Schau et al. also stated the following regarding CO<sub>2</sub> emissions from Norwegian fisheries:

Trawlers involved in on-board processing consume more fuel than those without on-board processing facilities, and the processing cost from the catch to processing is lower if it is done off board. This is because electricity is mainly supplied by hydropower generation in Norway, and is cheaper than fuel oil used on board.

Large vessels also make ice on board using diesel engine power, and fuel for this is included in the consumption. Since small vessels use ice made on land, the energy for it is land-based. In other words, fuel consumption by vessels depends not only on navigation and operation, but also on where (on board or on land) energy is consumed for processing, ice making, feed production and other processes.

In the 1970s and '80s, there were cases of using sails and low-speed rotating propellers for energy saving. It is still considered possible to save energy by 10 to 20% by modifying vessel forms, thrust systems and propellers. Conversion to liquefied natural gas is also effective. Non-technical measures, such as raising awareness among consumers and fishery operators, are also important.

Introduction of the above-mentioned Norwegian fishing industry's CO<sub>2</sub> reduction measures to Minamikayabe was considered.

Fish distribution in Japan is basically for fresh products and, except for freezing on large

vessels, on-board processing is very rare. Since ice is supplied from ice machines on land, fuel is consumed mainly for navigation and operation. Fish that are caught are taken to the market, where buyers bid for them. Since landing extremely fresh fish as soon as possible after catching is an important factor in determining prices, it is unacceptable to reduce the navigation speed. While it is possible to replace power sources with natural gas engines or hydrogen batteries when buying new boats, it takes time to introduce such alternative power sources due to the high initial cost and long renewal cycle of boats. Sailboats that are still used in some areas of Japan are not used for fishing in Minamikayabe. However, small power-boats use electric outboard engines.

Since the Japanese and Norwegian fishing industries have different bidding, production and on-land processing systems, it is difficult to introduce measures taken in Norway without modifications.

Table 15 Comparison of fuel use coefficients in various international fisheries[8]

	Fuel use coefficients (kg fuel/kg fish)	Analysis includes energy inputs to	Source
Purse seine for capeline (Iceland)	0.02	Fuel	[9]
Purse seine for small pelagic (North Atlantic)	0.04	Fuel	[10]
Purse seine (Norway)	0.09	Fuel	[8]
Trawling for small pelagic (North Atlantic)	0.08	Fuel	[10]
Trawling for pelagic (Norway)	0.09	Fuel	[8]
Trawling for groundfish (North Atlantic)	0.44	Fuel	[10]
Trawling for groundfish (Baltic Sea)	1.5	Fuel	[11]
Trawling for groundfish (Denmark)	1.4	Fuel	[12]
Trawling for codfish (Denmark)	0.4	Fuel	[13]
Bottom trawling for flatfish (Denmark)	0.84	Fuel	[13]
Trawling for groundfish (Iceland)	0.65	Fuel	[14]
Trawling for groundfish (Norway)	0.28	Fuel	[8]
Trawling for shrimp (North Atlantic)	0.76	Fuel	[10]
Trawling for shrimp (Norway)	1.04	Fuel	[8]
Trawling for Norwegian lobster (North Atlantic)	0.85	Fuel	[10]
Longlining for groundfish (North Atlantic)	0.41	Fuel	[10]
Longlining for groundfish (Norway)	0.31	Fuel	[8]
Gillnetting for codfish (Denmark)	0.21	Fuel	[13]
Gillnetting for groundfish (North Atlantic)	0.53	Fuel	[10]
Gillnetting for groundfish (Norway)	0.19	Fuel	[8]
Trapping crabs (North Atlantic)	0.28	Fuel	[10]
Trapping (Norway)	0.13	Fuel	[8]

## 5.2 CO<sub>2</sub> balance in the Minamikayabe area

The amount of absorption was 68,857 t-CO<sub>2</sub>/year and was larger than the emission,

which was 53,247 t-CO<sub>2</sub>/year. However, there are still many uncertain points concerning the continental shelf pump function that accounts for more than 50% of the absorption. In fact, because it is a function in the sea area, the only increase in absorption that can be expected from it may be the amount increased by taking certain measures to improve the function.

The emission from kelp fishery accounted for 40% and that from all types of fisheries was 64% of the total emission. The emissions from households and refrigerant HCFCs and HFCs were 21 and 2%, respectively.

## **6. Conclusion**

The above results indicated that the fishing industry must take various measures to reduce CO<sub>2</sub> emissions from fossil fuels and refrigerant HCFCs and HFCs, and preserve biodiversity, and it is necessary to establish systems to promote such measures. Measures to reduce CO<sub>2</sub> emissions from fishing include the following:

### **(1) Energy saving**

#### **1) Fishing ports**

- Improvement in efficiency of berthing, landing and cargo handling work through improvements in fishing ports
- Energy saving at onshore workplaces (e.g. kelp drying sites)
- Increasing cooperatives within the fishing industry

#### **2) Fishing vessels and facilities**

- Conversion to fuel-efficient, electric outboard engines and spread of the use of sailboats
- Onshore supply of electricity for fishing vessels
- Introduction of LED lamps and fishing lights

#### **3) Related facilities**

- Improvement in heat efficiency of water coolers, air conditioners, ice machines and other appliances owned by the fishing cooperatives, and conversion to energy-saving or HCFCs and HFCs-free appliances

### **(2) Introduction of renewable energy**

4) Utilization of wind, thermal difference, ocean current, wave force, tidal current, geothermal heat, snow and ice energy and other energy sources for heating, power generation and fuel

### **(3) Computerization**

#### **5) Facilities to improve distribution efficiency**

- Introduction of electronic bidding and auctions that are rare in Japan
- High-speed communication facilities

### **(4) Marine product distribution and a reduction in the carbon footprint of the fishing industry**

#### **6) Local consumption of marine products**

- 7) Promotion of local value added processing
- 8) Reduction in the carbon footprint of the fishing industry
  - Conversion to aquaculture
  - Establishment of on-land fish preserving and farming facilities (catching a larger number of fish at once)
  - Development of fishing grounds near fishing ports
- (5) Utilization of marine biomass resources
  - 9) Utilization of marine biomass resources for heat, power and fuel
  - 10) Extraction of functional ingredients
- (6) Utilization of recycled materials
  - 11) Use of scallop shells, etc. for land improvement, construction and other materials
- (7) Improvement in carbon fixation/absorption functions of sea areas
  - 12) Improvement and effective use of the continental shelf pump function
    - Improvement in the pump function by controlling river flow rates
    - Maximum utilization in the active season (winter) of the continental shelf pump
  - 13) Development of seaweed beds as sinks

While these measures are effective in reducing regional CO<sub>2</sub> emissions, there are problems concerning the cost of establishing facilities when introducing measures, and the methods of creating incentives among fishing operators and other parties concerned. Possible systems to support such measures include participation in measures against global warming by making use of the market mechanism. For example, the carbon offset scheme led by the Ministry of the Environment was launched in 2008 as a system for domestic companies and organizations that wish to reduce greenhouse gases, to purchase the amounts reduced/absorbed by other entities or in other places as credits for emission that are difficult to reduce by their own efforts. Since coastal areas are treasure troves of CO<sub>2</sub> sinks and have much potential for reduction, incentives can be created from the economic efficiency achieved by selling surplus reductions as credits. It may also be possible to introduce a domestic CDM in which companies in urban areas invest into CO<sub>2</sub> reduction in coastal areas.

While writing this paper, the Great East Japan Earthquake occurred, followed by a nuclear accident. The limited power supply conditions in the Tokyo metropolitan area increased awareness of the necessity of reconsidering excessive energy demand and promoting energy saving. However, in the fishing industry it is not easy to promote conversion of production and distribution structures and renewal of production base facilities, equipment and fishing vessels. Therefore, it is certainly necessary to take measures to support awareness arising among parties involved and their independent efforts.

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