sustainability

MDPI

Article

Fisheries: A Missing Link in Greenhouse Gas Emission Policies in South Korea

Kyumin Kim [1], Do-Hoon Kim [2,*] and Yeonghye Kim [3]

[1] Department of Agricultural and Resource Economics, University of California, Davis, CA 95616, USA; iamkim@ucdavis.edu
[2] Department of Marine & Fisheries Business and Economics, Pukyong National University, Busan 48513, Korea
[3] Coastal Water Fisheries Resources Research Division, National Institute of Fisheries Science, Busan 46083, Korea; fishmail@korea.kr
* Correspondence: delaware310@pknu.ac.kr; Tel.: +82-51-629-5954

Abstract: Recent studies demonstrate that fisheries are massive contributors to global greenhouse gas (GHG) emissions. The average Korean fishing vessel is old, fuel-inefficient, and creates a large volume of emissions. Yet, there is little research on how to address the GHG emissions in Korean fisheries. This study estimated the change in GHG emissions and emission costs at different levels of fishing operations using a steady-state bioeconomic model based on the case of the Anchovy Tow Net Fishery (ATNF) and the Large Purse Seine Fishery (LPSF). We conclude that reducing the fishing efforts of the ATNF and LPSF by 37% and 8% respectively would not only eliminate negative externalities on the anchovy and mackerel stock respectively, but also mitigate emissions and emission costs in the fishing industry. To limit emissions, we propose that the Korean government reduce fishing efforts through a vessel-buyback program and set an annual catch limit. Alternatively, the government should provide loans for modernizing old fishing vessels or a subsidy for installing emission abatement equipment to reduce the excessive emissions from Korean fisheries.

Keywords: global warming; carbon footprint; food mileage; carbon neutral; marine policy

Citation: Kim, K.; Kim, D.-H.; Kim, Y. Fisheries: A Missing Link in Greenhouse Gas Emission Policies in South Korea. *Sustainability* **2021**, *13*, 5858. https://doi.org/10.3390/su13115858

Academic Editor: Tim Gray

Received: 12 April 2021
Accepted: 20 May 2021
Published: 23 May 2021

1. Introduction

A significant amount of scientific evidence indicates that human activity—specifically, the burning of fossil fuels and deforestation for urbanization and agricultural cultivation—has resulted in increased atmospheric CO_2 concentrations. The accumulation of CO_2 and other heat-trapping gases has accelerated climate change, resulting in various adverse effects on ecosystems and socio-economic activities [1,2].

In 1997, the Kyoto Protocol set specific goals for the most developed countries to moderate their greenhouse gas (GHG) emissions to mitigate climate change [1]. In 2015, 195 UN member nations ratified the Paris Agreement to limit these countries' GHG emissions. Around 200 countries, whose emissions account for 87% of annual global emissions, have been complying with this agreement through local and national policies [3].

Preliminary studies by Parker et al. [4] estimated that GHG emissions of global fisheries increased by 28% from 1990 to 2011. Their work determined that 179 million tons of CO_2 eq. emissions resulted from 40 billion liters of fossil fuel consumption by fisheries. This encouraged further research by Greer et al. [5], who demonstrated that marine fisheries released approximately 168 million tons of CO_2 eq. in 2016 alone, accounting for 4.7 times higher CO_2 emissions than in the 1950s. Another study by Madin and Macreadie concerning the substantial carbon emission levels in seafood production sectors [6] indicates that GHG emissions have become more significant due to the increased distance of fishing trips, required because of movements in fish habitats due to climate change.

In 2016, South Korea announced a detailed plan for reducing emissions by 37% of its estimated 2030 business-as-usual level (851 million tons) by the same year [7]. In the agriculture, fisheries, and forestry sectors, the Korean government has set a goal of abating 1.54 million tons (or 15.5%) of business-as-usual GHG emissions by 2030. Most of the fishing boats in the coastal and offshore fisheries are old and fuel-inefficient (The total number of fishing vessels decreased from 75,031 in 2012 to 65,907 in 2018. In contrast, the ratio of old fishing vessels (aged over 15 years) increased from 35.4% in 2012 to 46.6% in 2018 [8,9]. Regarding fuel consumption, the commercial fishing vessels rely on tax-free oil provided by the government for their fishing production. The total fuel consumption of fishing vessels increased from 968,000 Kilo Liter (KL) in 2012 to 1,042,000 KL (diesel 911,000 KL, heavy fuel oil 16,000 KL, gasoline 103,000 KL, lubricant 8000 KL, and LPG 4000 KL) [9,10]. Although there has been a decrease in the total number of fishing vessels, the evident aging trend in fishing vessels and the increased fuel consumption represent a significant fuel inefficiency.) [8,11]. It is estimated that from 2011 to 2013, about 1.45 million tons of CO_2 eq. GHGs were released by offshore fisheries annually [8,11]. This estimate used the Tier 1 method suggested by the Intergovernmental Panel on Climate Change [12]; however, the results are not reliable in terms of accuracy [13]. Despite the need to reduce current emission levels, there is scant research that addresses the GHG emissions of Korean fisheries. The quantitative analyses to measure the exact emission levels in Korean fisheries are at a nascent stage [14].

Although the fisheries industry is not currently included in the Korean Emission Trading Scheme (ETS), it may be required to participate at some point if there is a strong commitment (or pressure) to abide by global norms to reduce emissions. Therefore, it is necessary to place greater focus on the issue of GHG emissions in Korean fisheries. This study discusses the emission levels of South Korean fisheries and proposes suggestions for mitigating these emissions by examining the cases of the Anchovy Tow Net Fishery (ATNF) and the Large Purse Seine Fishery (LPSF). Another substantial contributor to CO_2 emission is the Offshore Jigging Fishery, which involves catching squid at night with conventional metal halide lamps, but fuel consumption in this industry can be significantly reduced by the use of low-energy light-emitting diode (LED) lamps [15,16].

The anchovies harvested off the southern and western coast of the Korean peninsula account for a large share of Korea's total fisheries production. In 2018, the anchovy catch was 188,000 tons of a single species, accounting for 18.6% of the total fisheries production. This was the second-largest catch of a single species after mackerel [9].

We chose the ATNF to understand the GHG emissions of Korean fisheries for the following reasons. Firstly, the ATNF accounts for a significant proportion of annual fisheries production in South Korea. It harvests approximately 90% of the anchovy production from the southern coast of South Korea. Secondly, the fishery operates in only one region: off the southern coast of South Korea. Thirdly, according to the internal report of the National Institute of Fisheries Sciences (NIFS) [10], the ATNF contributed 152,108 tons CO_2 eq. of emissions in 2015, ranking fifth out of 25 Korean fisheries in emission levels (Table 1). Lastly, unlike other Korean fisheries that catch multiple species, the ATNF harvests only one, anchovy, making it easier to use bioeconomic models and estimate the emission costs of their fishing operations.

Furthermore, we analyzed the emissions and emission costs of the LPSF to provide additional information about emission problems in Korean fisheries. The LPSF annually generates considerable carbon emissions as well, ranking second (Table 1). Akin to the ATNF, the LPSF also catches a large quantity of a single species, mackerel, which accounts for around 80–90% of its total annual catch. Research on emissions and emission costs of the LPSF has been attempted before [11]. Nevertheless, we re-estimated the LPSF's emissions, not only using up-to-date data but also considering another explanatory variable (i.e., horsepower) for fishing efforts.

Table 1. GHG emission estimate (in MT CO_2 eq.) in the Korean offshore fisheries (2009–2015).

Fishery	2009	2010	2011	2012	2013	2014	2015
Offshore Jigging	221,175	223,756	199,844	206,680	222,175	210,922	249,063
Large Purse Seine	239,876	222,328	224,998	226,142	229,785	229,089	232,883
Pair Trawl	158,625	161,294	154,967	143,372	161,712	158,718	176,901
Offshore Trap	124,873	125,136	124,076	129,318	137,557	144,895	158,559
Anchovy Tow Net	131,686	149,992	143,519	138,560	149,202	137,061	152,108
Offshore Longline	119,276	118,017	114,368	107,159	107,684	110,159	114,548
Large Trawl	127,459	126,519	102,837	85,593	93,282	84,744	115,471

Adapted from National Institute of Fisheries Science (2018) [10].

By analyzing these two fisheries, we estimated the changes in GHG emissions at different levels of fishing operations using a steady-state bioeconomic model. Assuming an ETS is introduced in the Korean fisheries industry, we also estimated the change in emission costs for different fishing efforts. Our results have implications for several important policy questions: How can we reduce GHG emissions in fisheries? To what extent can we reduce emissions and emission costs by reducing fishing effort? How do these actions affect fishing rent? In conclusion, we suggest policy measures to reduce emissions and emission costs for the ATNF and LPSF. In doing so, we expect not only to provide insights on emission issues in the Korean fisheries but also to establish a basis for future studies to address GHG emission issues on a more extensive scale across various fisheries.

2. Materials and Methods

2.1. Bioeconomic Model: Surplus Production Model

Here, we employ a bioeconomic model using the surplus production model proposed by Schaefer [17,18]. Schaefer's model can be depicted as Equation (1),

$$F(X_t) = rX_t\left(1 - \frac{X_t}{K}\right) \tag{1}$$

where $F(X_t)$ is the growth function of stock, X_t is stock biomass in period t, r is the intrinsic rate of growth, and K is the carrying capacity of the stock. Here, we assume that the catch is proportional to fishing effort and stock size. Suppose the short-run harvest of fish stock is a linear function of stock size and fishing effort. This function can then be written as follows:

$$Y_t = qX_tE_t \tag{2}$$

where q is the catchability coefficient and E is fishing effort (i.e., total horsepower in fisheries). To achieve a sustainable harvest, the growth of the stock should be equal to the short-run yield (steady state).

$$\frac{dX}{dt} = F(X_t) - qX_tE_t = 0 \tag{3}$$

At a given fishing effort E_t in period t, Equation (3) can be solved for X_t to derive the fish population size at equilibrium. The derived Equation (4) shows that fish stock at equilibrium is dependent on fishing effort:

$$X_t = K - \left(\frac{qK}{r}\right)E_t \tag{4}$$

By substituting Equation (4) into the right side of Equation (3), the sustainable yield at long-run equilibrium can be defined as the function of fishing effort E, carrying capacity K, and intrinsic growth rate r, as shown below.

$$Y_t = qK_tE_t - \frac{q^2K}{r}E_t{}^2 \tag{5}$$

In Equation (5), by substituting $a = qK$ and $b = \frac{q^2K}{r}$, the above equation can be rearranged as a function of fishing effort E_t, as shown below [11,19]. In this study, the parameters a and b in Equation (6) are estimated using ordinary least squares.

$$Y_t = Y(E_t) = aE_t - bE_t^2 \tag{6}$$

To derive the fishing effort that maximizes yield, Equation (6) can be differentiated considering fishing effort. It is then possible to derive the maximum sustainable yield (MSY), Y_{MSY}, and the fishing effort (E_{MSY}) at the MSY. These can be written as follows:

$$E_{MSY} = \frac{a}{2b} \quad Y_{MSY} = \frac{a^2}{4b} \tag{7}$$

2.2. Derivation of Maximum Economic Yield (MEY)

MEY is the output level at which economic rent is maximized. Unlike MSY, which only utilizes biological information, MEY incorporates economic parameters such as price and fishing cost in the model [19,20].

By omitting the subscript t for convenience, the total revenue from the yield can be written as a function of production price p and sustainable yield Y.

$$R = p * Y = p\left(aE - bE^2\right) \tag{8}$$

Regarding fishing cost, the cost function (TC) is assumed to be a linear equation of unit fishing cost c and fishing effort E in Equation (9) [19].

$$TC = c * E \tag{9}$$

Finally, by subtracting total cost from total revenue, fishing rent π by yield is set as follows:

$$\pi = TR - TC \tag{10}$$

By differentiating Equation (10) with respect to fishing effort, it is possible to derive fishing effort at MSY and MEY.

$$MR = \frac{dTR}{dE} = \frac{d\left(p\left(aE - bE^2\right)\right)}{dE}, \quad MC = \frac{dTC}{dE} = \frac{d(cE)}{dE}, \quad MR = MC \tag{11}$$

Finally, it is also possible to calculate yield and fishing effort under Open Access (OA), for which there are no fishing regulations [11,19].

$$TR = pY = p\left(aE - bE^2\right), \quad TC = cE, \quad TR = TC \tag{12}$$

2.3. Data Sources

We used annual fisheries data for this study. The annual time-series data related to total anchovy and mackerel catch, total revenue of anchovy and mackerel production, and fishing effort E (i.e., the total horsepower (HP) of the ATNF and LPSF fishing vessels) were gathered from statistics released by the Ministry of Oceans and Fisheries of Korea [15] and the Korean Department of Statistics [21]. Due to limitations in data access, only the data from 2002 to 2018 were available.

Regarding the fishing cost of the ATNF and LPSF, annual cost data were taken from reports released by the National Federation of Fisheries Cooperatives (NFFC) from 2016 to 2018 [22–24]. The data of the ATNF and LPSF GHG emissions were collected from the NIFS [10]. As the latest estimates for emissions were not available, we used the average GHG emission estimates from 2013 to 2015 for both fisheries. By dividing the average emissions by the average total tonnage of the vessels during the same period, a parameter for unit GHG emissions per fishing effort was calculated. Lastly, the emission permit price per ton was taken from the annual statistics for 2018 released by the Korean Exchange [25] (Table 2).

Table 2. Data sources and descriptions.

Data	Description	Source
Anchovy production	Total annual catch of ATNF and LPSF (2002–2018)	Ministry of Oceans and Fisheries of Korea (Fisheries Info. Portal)
Anchovy production revenue	Total annual production revenue (2016–2018)	Ministry of Oceans and Fisheries of Korea (Fisheries Info. Portal)
Fishing effort	Total annual horsepower (HP) of fishing vessels of ATNF and LPSF (2002–2018)	Department of Statistics of Korea (KOSIS)
Emissions by ATNF and LPSF	Emission estimated by NIFS (2013–2015)	National Institute of Fisheries Science
Fishing cost of ATNF and LPSF	Total annual fishing costs of ATNF (2016–2018)	National Federation of Fisheries Cooperatives
Emission permit price	Emission permit price in the Korean ETS (2018)	Korean Exchange (KRX)

Note: Although the emission data are not recent due to limited data availability, the emissions per tonnage for the last ten years are stable. We pre-checked the trend of fishing efforts and emissions, which generally showed consistent and stable values over time.

3. Results

3.1. Parameter Estimation

Using the annual production and fishing effort data, we estimated the parameters in Equation (6). Parameters a and b for the ATNF were both statistically significant at 1% and 10%, respectively.

As stated earlier, the parameters for unit cost of fishing and unit price of fish, c and p, are predetermined values. We derived unit fishing cost c by dividing the total fishing cost of the ATNF by total fishing effort and averaged the three years' unit costs. Similarly, we calculated unit anchovy price p by dividing total fishing revenue by total anchovy production from 2016 to 2018 and averaged the values over three years. We conducted the same procedure for the LPSF and derived the two parameters, unit price and unit cost. In the estimation of the two parameters, both coefficients were statistically significant at 1% and 10%, respectively (Table 3).

Table 3. Estimation of parameters for analysis in ATNF and LPSF.

Parameter	Coefficient (ATNF)	Coefficient (LPSF)
a	1.8627 (3.026)	1.0962 (3.96)
b	-6.345×10^{-6} (-1.99)	-2.449×10^{-6} (-1.90)
c	369.36	269.07
p	1880.04	1395.80

Note: The numbers in parentheses are t-statistics.

3.2. Yield and Fishing Effort at MEY, MSY, and OA

Based on the parameters from the bioeconomic model, the yield and fishing effort at MEY, MSY, and OA were estimated. In Table 4, the highest rent for the ATNF is at MEY, 62% higher than the current rent. At MSY, fishing rent is estimated to be KRW 202 billion, which is around 59% higher than the current rent. However, fishing rent is eliminated at OA.

Table 4. Estimate of anchovy yield and fishing efforts at E_{MEY}, E_{MSY}, and E_{OA}.

	E_0 (2018)	E_{MEY}	E_{MSY}	E_{OA}
Y (MT)	108,563	135,198	136,719	51,594
E (HP)	209,119	131,308	146,789	262,616
Rent (π) (KRW 1000)	126,862,470	205,679,125	202,820,004	0
Effort ratio (E/E_0)	1	0.62	0.70	1.25
Rent ratio (π/π_0)	1	1.62	1.59	0

Note: 1000 Korean won (KRW 1000) is approximately USD 1.0~1.2.

Fishing effort was found to be the highest at OA, which is 25% higher than the current fishing effort. The fishing efforts at MEY and MSY are 131,308 horsepower and 146,789 horsepower, respectively. These two fishing efforts are respectively 37% and 29% lower than the current effort. These estimates show that reducing fishing effort up to MEY (by 38%) could increase fishing rent by 62% over the current rent (Table 4).

In the estimation for the LPSF, the highest rent is at MEY. The rent at MEY is higher than the current rent level (approximately 17%). Regarding the rent level at MSY and OA, the rent is expected to increase by 11% at MSY and completely dissipate at OA (Table 5).

Table 5. Estimate of mackerel yield and fishing efforts at E_{MEY}, E_{MSY}, and E_{OA}.

	E_0 (2018)	E_{MEY}	E_{MSY}	E_{OA}
Y (MT)	120,067	118,894	122,687	71,122
E (HP)	199,828	184,472	223,832	368,944
Rent (π) (KRW 1000)	99,246,103	116,316,367	111,020,999	0
Effort ratio (E/E_0)	1	0.99	1.02	1.68
Rent ratio (π/π_0)	1	1.17	1.11	0

3.3. Emission Level and Emission Costs at MEY, MSY, and OA

According to the NIFS [10], the average annual total emissions of the ATNF and LPSF from 2013 to 2015 were 146,124 and 230,586 tons, respectively. Dividing total emissions by total fishing efforts and averaging the values for three years, we calculated the unit emission per fishing effort for the ATNF and LPSF as 0.75 and 1.15 tons, respectively. The annual average emission price (KRW 1000/MT CO_2 eq.) was KRW 25.11 on the Korean ETS (KAU 18) during 2018 (Tables 6 and 7).

Table 6. ATNF emissions from 2013 and 2015.

Year	Total Emission (MT CO_2 eq.)	Total Fishing Effort (HP)	Emission per Fishing Effort (MT CO_2 eq./HP)
2013	149,202	193,064	0.77
2014	137,061	199,822	0.69
2015	152,108	199,822	0.78
Average	146,124	195,755	**0.75**
Permit Price per MT CO_2 eq. (KRW 1000/MT CO_2 eq.)			
25.11			

Table 7. LPSF emissions from 2013 and 2015.

Year	Total Emission (MT CO_2 eq.)	Total Fishing Effort (HP)	Emission per Fishing Effort (MT CO_2 eq./HP)
2013	229,785	198,771	1.16
2014	229,089	197,688	1.16
2015	232,883	203,783	1.14
Average	230,586	200,081	**1.15**
Permit Price per MT CO_2 eq. (KRW 1000/MT CO_2 eq.)			
25.11			

Using the predetermined parameters related to emissions in Tables 6 and 7, emission levels and costs were computed to show the change in emissions and cost at MEY, MSY, and OA. The expected total emissions were calculated by multiplying total fishing efforts with unit emissions per fishing effort.

In Table 8, the emission level of the ATNF at OA is estimated to be 196,962 MT, which is the highest among the effort reference data points. The emissions at MEY and MSY are 98,481 and 110,092 tons, respectively. As expected, the emissions at MEY are the lowest among all the reference data points.

Table 8. Estimates for emissions and emission costs of the ATNF at MEY, MSY, and OA.

	E_0 (2018)	E_{MEY}	E_{MSY}	E_{OA}
Emissions (MT CO_2 eq.)	156,839	98,481	110,092	196,962
Emission cost (KRW 1000)	3,938,234	2,472,858	2,764,404	4,945,716
Emission savings (MT CO_2 eq.)	-	58,358	46,748	−40,123
Emission cost savings (KRW 1000)	-	1,465,376	1,173,830	−1,007,482

By multiplying the total emissions by the unit emission price in the Korean ETS, the total emission costs were computed. At the current fishing level, emission costs are approximately KRW 3.9 billion. At MEY and MSY, emission costs are estimated to be KRW 2.4 and 2.7 billion, respectively. In contrast, if there were no fishing regulations, emission costs could increase by KRW 4.9 billion (Table 8).

We also computed the emission savings and emission costs when reducing fishing effort up to MEY and MSY. Compared with the current emissions and emission costs, there could be a reduction of 58,358 tons of emissions at MEY. It is also possible to reduce emission costs by KRW 1.46 billion annually at MEY. At MSY, the emissions could be reduced by around 46,748 tons. Emission costs could also be reduced by KRW 1.17 billion. However, at OA, both the emissions and costs are estimated to increase by approximately 40,123 tons and KRW 1.0 billion respectively (Table 8).

Emission levels of the LPSF at OA are estimated to be 424,286 MT. The emissions at MEY and MSY are 212,143 and 257,407 MT, respectively. If the LPSF were to decrease fishing efforts up to MEY, the emissions would be expected to decrease by 17,659 MT. However, at MSY, emissions would increase by 27,605 tons. At the current fishing levels, emission costs are approximately KRW 5.8 billion, while at MEY and MSY emission costs are estimated to be KRW 5.3 and 6.4 billion respectively. Furthermore, if there were no fishing regulations, emission costs could increase by KRW 10.6 billion (Table 9).

Table 9. Estimates for emissions and emission costs of LPSF at MEY, MSY, and OA.

	E_0 (2018)	E_{MEY}	E_{MSY}	E_{OA}
Emissions ($MT\ CO_2$ eq.)	229,802	212,143	257,407	424,286
Emission cost (KRW 1000)	5,770,333	5,326,906	6,463,485	10,653,811
Emission savings ($MT\ CO_2$ eq.)	-	17,659	−27,605	−194,483
Emission cost savings (KRW 1000)	-	443,428	−693,152	−4,883,478

4. Discussion

We find that the ATNF currently uses excessive fishing efforts compared with what would be required at MEY. This demonstrates that current fishing efforts not only overexploit the anchovy stock but also create higher than optimal GHG emissions (MEY). Further, we show that by reducing fishing effort by 37%, 58,131 tons of emissions and KRW 1.46 billion in emission costs could be saved. Simultaneously, such efforts would create a 62% rent increase over the current rent. Furthermore, reducing fishing efforts up to MEY may not only increase the fishing rents but also decrease the external emission costs, as shown by the analysis of the LPSF. Therefore, the ATNF and LPSF should reduce their fishing efforts as soon as possible.

A focused and intensive vessel buyback program should be considered to help regulate fishing effort. A reduction in fishing effort would not only eliminate negative externalities to fish stocks but also help mitigate the externality resulting from emissions. Furthermore, the absence of a total annual quota in anchovy production leads to excessive fishing effort, which in turn leads to higher emission levels. Anchovies have a relatively high natural mortality rate and a high intrinsic growth rate [26–28]. Due to its large fluctuations in annual catch, anchovy has been excluded from the list of species managed using a total annual quota in South Korea. Setting an annual catch limit and introducing an individual transferable quota could reduce unnecessary fishing effort in the long run [29]. In turn, that would lead to a decline in emissions.

Unfortunately, a buyback program requires massive government funding. Moreover, annual catch limits and individual transferable quota systems have resulted in severe political conflicts and controversies among South Korean fishers in the past [30]. Therefore, other policies for addressing the emission levels from fisheries should also be considered.

As previously mentioned, a significant proportion of fishing vessels in Korean fisheries are old and fuel-inefficient. Fishing is also inherently fraught with a high degree of uncertainty; fish production is never guaranteed because of its dependence on natural conditions. Thus, fishers actively refrain from replacing their fuel-inefficient engines with fuel-efficient ones. Therefore, providing government loans or subsidizing fuel-efficient technology is essential for limiting emissions, although the increased fuel efficiency could potentially lead to increased fishing operations. Fortunately, this problem could be solved if the government were to simultaneously set a catch limit.

Another alternative would be to subsidize emission abatement equipment for old vessels. As stated earlier, Korean fishers are risk-averse about capital investment in their fishing operations. If fishers are not enthusiastic about modernizing their fishing vessels, subsidizing emission abatement equipment for old vessels may also be a feasible solution.

Author Contributions: Conceptualization, K.K. and D.-H.K.; methodology, K.K., Y.K., and D.-H.K.; software, K.K.; validation, K.K. and D.-H.K.; formal analysis, K.K.; investigation, D.-H.K. and Y.K.; resources, K.K. and D.-H.K.; data curation, K.K. and D.-H.K.; writing—original draft preparation, K.K. and D.-H.K.; writing—review and editing, Y.K. and D.-H.K.; visualization, K.K.; supervision, Y.K. and D.-H.K.; project administration, K.K. and D.-H.K.; funding acquisition, Y.K. and D.-H.K. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by a grant from the National Institute of Fisheries Science (R2021028).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The study did not report any data.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Keohane, M.N.O.; Olmstead, D.S.M. *Markets and the Environment*, 2nd ed.; Island Press: Washington, DC, USA, 2016.
2. Carleton, T.A.; Hsiang, S.M. Social and economic impacts of climate. *Science* **2016**, *353*, aad9837. [CrossRef] [PubMed]
3. Bush, M.J. *Climate Change and Renewable Energy: How to End the Climate Crisis*, 1st ed.; Palgrave Macmillan: New York, NY, USA, 2019.
4. Parker, R.W.R.; Blanchard, J.L.; Gardner, C.; Green, B.S.; Hartmann, K.; Tyedmers, P.H.; Watson, R.A. Fuel use and greenhouse gas emissions of world fisheries. *Nat. Clim. Chang.* **2018**, *8*, 333–337. [CrossRef]
5. Greer, K.; Zeller, D.; Woroniak, J.; Coulter, A.; Winchester, M.; Palomares, M.L.D.; Pauly, D. Global trends in carbon dioxide (CO_2) emissions from fuel combustion in marine fisheries from 1950 to 2016. *Mar. Policy* **2019**, *107*, 103382. [CrossRef]
6. Madin, E.M.P.; Macreadie, P.I. Incorporating carbon footprints into seafood sustainability certification and eco-labels. *Mar. Policy* **2015**, *57*, 178–181. [CrossRef]
7. Jin, S.H.; Bai, L.; Kim, J.Y.; Jeong, S.J.; Kim, K.S. Analysis of GHG emission reduction in South Korea using a CO_2 transportation network optimization model. *Energies* **2017**, *10*, 1027. [CrossRef]
8. Park, J.A.; Gardner, C.; Chang, M.I.; Kim, D.H.; Jang, Y.S. Fuel use and greenhouse gas emissions from offshore fisheries of the Republic of Korea. *PLoS ONE* **2015**, *10*, e0133778. [CrossRef] [PubMed]
9. Fisheries Information Portal. Domestic Fisheries Production and Fisheries Revenue Statistics. Available online: https://www.fips.go.kr/p/Main/Accessed (accessed on 24 April 2020).
10. Error! Hyperlink reference not valid. *National Institute of Fisheries Science (NIFS). Annual Report of the Korean Coastal and Offshore Fisheries of Inventions of Emission Reduction Equipment Program*; NIFS: Busan, Korea, 2018; p. 296.
11. Choi, J.D. A study on the optimal emission of CO_2 due to climate change: An application for large purse seine. *Ocean Polar Res.* **2017**, *39*, 195–203. [CrossRef]
12. IPCC. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*; Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K., Eds.; Institute for Global Environmental Strategies: Hayama, Japan, 2006; Volume 5.
13. Hwang, I.C.; Jin, S.H. An analysis of uncertainties in energy category: Estimation by using Tier 1 method. *Environ. Resour. Econ. Rev.* **2014**, *23*, 249–280. [CrossRef]
14. Bae, J.; Yang, Y.; Kim, H.; Hwang, B.; Lee, C.; Park, S.; Lee, J. A quantitative analysis of greenhouse gas emission from the major offshore fisheries. *J. Korean Soc. Fish. Technol.* **2019**, *55*, 50–61. [CrossRef]

15. Matsushita, Y.; Azuno, T.; Yamashita, Y. Fuel reduction in coastal squid jigging boats equipped with various combinations of conventional metal halide lamps and low-energy LED panels. *Fish. Res.* **2012**, *125*, 14–19. [CrossRef]
16. Nguyen, K.Q.; Winger, P.D. Artificial light in commercial industrialized fishing applications: A review. *Rev. Fish. Sci. Aquacult.* **2019**, *27*, 106–126. [CrossRef]
17. Schaefer, M.B. Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. *Inter Am. Trop. Tuna Comm. Bull.* **1954**, *1*, 23–56.
18. Schaefer, M.B. Some considerations of population dynamics and economics in relation to the management of the commercial marine fisheries. *J. Fish. Res. Bd. Can.* **1957**, *14*, 669–681. [CrossRef]
19. Anderson, L.G.; Seijo, J.C. *Bioeconomics of Fisheries Management*, 1st ed.; John Wiley & Sons: Hoboken, NJ, USA, 2010.
20. Dichmont, C.M.; Pascoe, S.; Kompas, T.; Punt, A.E.; Deng, R. On implementing maximum economic yield in commercial fisheries. *Proc. Natl. Acad. Sci. USA* **2010**, *107*, 16–21. [CrossRef] [PubMed]
21. Korea Statistics Information (KOSIS). Annual Fishing Capacity Statistics in the Coastal and Offshore Fisheries. Available online: http://kosis.kr/index/index.do (accessed on 24 April 2020).
22. National Federation of Fisheries Cooperatives (NFFC). *Costs and Earnings in Fisheries*; NFFC: Seoul, Korea, 2016; p. 211.
23. National Federation of Fisheries Cooperatives (NFFC). *Costs and Earnings in Fisheries*; NFFC: Seoul, Korea, 2017; p. 211.
24. National Federation of Fisheries Cooperatives (NFFC). *Costs and Earnings in Fisheries*; NFFC: Seoul, Korea, 2018; p. 206.
25. Korean Exchange. Emission Trade Market Statistics. Available online: http://www.krx.co.kr (accessed on 24 April 2020).
26. Yatsu, A. Review of population dynamics and management of small pelagic fishes around the Japanese Archipelago. *Fish Sci.* **2019**, *85*, 611–639. [CrossRef]
27. Pyo, H. A comparative analysis of surplus production models and a maximum entropy model for estimating the anchovy's stock in Korea. *J. Fish. Mar. Sci. Educ.* **2006**, *18*, 19–30.
28. Wan, R.; Bian, X. Size variability and natural mortality dynamics of anchovy eggs under high fishing pressure. *Mar. Ecol. Prog. Ser.* **2012**, *465*, 243–251. [CrossRef]
29. Brinson, A.A.; Thunberg, E.M. *Research Report: The Economic Performance of U.S. Catch Share Programs*; National Oceanic and Atmospheric Administration: Washington, DC, USA, 2013; p. 179.
30. Ministry of Oceans and Fisheries (MOF). *Research Report on the Introduction of Individual Transferable Quota (ITQ) as a Tool to Manage Fisheries Resources*; Ministry of Oceans and Fisheries (MOF): Seoul, Korea, 2012; p. 540.