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Estimating CO_2 Efficiency of Bio-ethanol Production

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Abstract

This paper estimates the CO_2 efficiency of bio-ethanol production using IO analysis for a case study in Hokkaido, Japan. Previous studies have measured CO_2 emission from bio-ethanol production mainly by lifecycle assessment, but this approach cannot measure economic impact. Furthermore, initiating a bio-ethanol industry leads to structural changes throughout the regional economy; this in turn, causes changes in the CO_2 emission of each sector. In Hokkaido, plans call for production of bio-ethanol from substandard wheat, sugar beets and rice. According to our calculation, up to 350,000kl of 3% bio-ethanol blended gasoline (E3) can be produced from substandard wheat annually in Hokkaido. We modify the conventional IO table of Hokkaido to incorporate the bio-ethanol sector and then estimate CO_2 emission by sector. Next, by assuming that production of 10,000kl of E3 replaces the equivalent domestic gasoline demand, we measure the repercussions of CO_2 emission as well as the economic impact (direct, indirect, and induced). Finally, we estimate the CO_2 efficiencies of both E3 and gasoline,

As a result, the economic impact of E3 is much larger than that of gasoline. On the contrary, E3 production causes less CO_2 emission than gasoline, and the CO_2 efficiency of E3 is 80% higher than that of gasoline. From these results, we conclude that bio-ethanol production brings a larger economic impact with a smaller increase in CO_2 emission, thus contributing to the CO_2 efficiency of a specific region.

Keywords: Bio-ethanol production, E3, Repercussions of CO_2 emission, CO_2 efficiency

1. Introduction

In recent years, people have paid more and more attention to bio-ethanol as a useful tool of global warming mitigation. Promotion of bio-ethanol has various effects on the environment, energy security, and economy etc., and many researchers have analyzed its effects. Studies, such as Shapouri et al. (1995), Pimentel and Patzek (2005), Kim and Dale (2006), and Masuda (2008) have measured CO_2 emission from bio-ethanol production and energy balance mainly by lifecycle assessment (LCA). On the other hand, Evans (1997), Hu (2007), and Urbanchuk (2007) have estimated the economic impact of bio-ethanol. Evans (1997) illustrates bio-ethanol industry in the U.S. boosts farm income by $4.5 billion, employment by 192,000, and tax income by $0.45 billion, in 1997. Urbanchuk (2007) applied IO analysis and showed that operation of bio-ethanol plants added $23.1 billion of GDP and 163,000 job opportunities. However, these studies focus only on the economic aspects of bio-ethanol. To understand the impact with ease, we need comprehensive evaluation of bio-ethanol considering both the environmental and the economic side. Furthermore, initiating a bio-ethanol industry leads to structural changes throughout the regional economy; this in turn, causes changes in the CO_2 emission of each sector. So, initiation of bio-ethanol production causes change of CO_2 exhausted in a region.

This study estimates the CO_2 efficiency of bio-ethanol production, defined by the ratio of the economic impact to CO_2 emission, using IO analysis for a case study in Hokkaido, Japan. First of all, we explain the plans of bio-ethanol production in Hokkaido. Then, we modify the conventional IO table of Hokkaido to incorporate the bio-ethanol sector and then estimate CO_2 emission by sector with reference to previous sector-based studies that estimated CO_2 intensity. Next, by assuming that additional demand of 10,000kl of 3% bio-ethanol blended gasoline (E3) and the equivalent domestic gasoline, we measure the repercussions of CO_2 emission as well as the economic impact (direct, indirect, and induced). Finally, we estimate the CO_2 efficiencies of both E3 and gasoline.

2. Analysis

2.1 Bio-ethanol production in Hokkaido

In Hokkaido, Hokkaido Bio-ethanol Co. Ltd. is now constructing a bio-ethanol plant in Tokachi region, Hokkaido, to be launched in 2009. The plans call for 15,000kl of bio-ethanol production, and substandard wheat is one of the main raw materials available in this region. According to our calculation, up to 10,490kl of bio-ethanol equalling 349,668kl of E3 can be produced annually from substandard wheat. At present, wheat farmers sell substandard wheat to dairy farmers as cattle feed, and its price is about 1/10 of high-quality wheat. Bio-ethanol producers focus on substandard wheat as raw material of bio-ethanol because of its cheaper price and its convenience of collection, transportation, and preservation. As agriculture is one of the main industries in Hokkaido, and major types of agriculture are arable crops—rice cropping and dairy farming—it is convenient for bio-ethanol producers here to collect raw material, such as wheat and sugar beet.

2.2 Modification of IO Table

In this study, we apply the 105-sector Hokkaido IO table of the year 2003, which is the latest available IO table. As the IO table doesn't contain a bio-ethanol sector, we need to add a bio-ethanol sector in the table to analyze the impacts of bio-ethanol production. Therefore, we incorporate a bio-ethanol sector in the table, referring to the methodologies applied in Kunimitsu and Ueda (2006).

First, we assume that the product of bio-ethanol sector is E3, and E3 substitutes for generic gasoline, which is one of the products in the petroleum refinery sector. As we mentioned above, if production of bio-ethanol is launched in the Tokachi region, 10,490kl of bio-ethanol, which equals to 349,668kl of E3, is produced from substandard wheat annually (Table 1). This E3 volume is about 14% of gasoline consumption in Hokkaido and accounts to 35.6 billion yen in 2003(1). In the conventional IO table, production of petroleum refinery sector is 624.0 billion yen. As the bio-ethanol sector substitutes a part of generic gasoline production, the production of petroleum refinery

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1 The difference of contained heat value between E3 and gasoline is taken into account in the calculation. Although economic value includes taxes imposed on gasoline, ethanol is untaxed. Therefore, tax levied on E3 is 3% lower than that on generic gasoline.

sector amounts to 588.4 billion yen (calculated by deducting 35.6 from 624.0). This means that 5.7% of the production in petroleum refinery sector is substituted by bio-ethanol sector. Therefore, we separate the bio-ethanol sector from previous petroleum refinery sector using the share of 5.7%.

In terms of the supply side, as there are differences of input structure between the bio-ethanol sector and the petroleum refinery sector, we need to compile an input structure of the bio-ethanol sector. The largest difference is that the bio-ethanol sector purchases material not from crude oil sector, but from the crop cultivation sector. From our previous study of LCA (Masuda (2008)), we estimate the input of bio-ethanol sector as shown in Table 2.

In regards to the demand side, we assume that the bio-ethanol produced in Tokachi is consumed in Hokkaido and there is no export to other areas in Japan. This assumption is quite rational because the volume of bio-ethanol produced is much smaller than that of consumed in Hokkaido and there is no room for export.

As the result of the modification, domestic production in Hokkaido accounts for 33,498 billion yen, which increased by 0.4 billion yen from the conventional IO table. This is because of the result of adjusting input and output.

2.3 Estimation of increase in CO_2 (CO_2 impact)

Initiating a bio-ethanol industry leads to structural changes throughout the regional economy; this in turn, causes changes in the CO_2 emission of each sector. So, initiation of bio-ethanol production causes change of CO_2 exhausted in a region. To measure the amount of induced CO_2 emission by bio-ethanol production, we refer to previous sector-based studies that estimated CO_2 intensity; Nansai et al. (2002). In that study, they define CO_2 intensity as the following equation: with intensity vector e, vector of direct impact per unit production d, input coefficient matrix A, and diagonal matrix of import M.

$$e = d\{I - (I - M)A\}^{-1} \tag{1}$$

This equation means that CO_2 intensity e includes primary induced CO_2 impact, therefore, we can calculate the primary CO_2 impact of bio-ethanol production ΔE_1 as follows:

$$\Delta E_1 = e_{bioethanol} \cdot \Delta F_{1bioethanol} \tag{2}$$

where, the CO_2 intensity of bio-ethanol sector $e_{bioethanol}$ and the primary increase in final demand in bio-ethanol sector $\Delta F_{1bioethanol}$. The secondary CO_2 impact is defined by the impact caused by the secondary induced economic impact. We can formulate the impact by the following equation: where secondary CO_2 impact ΔE_2, CO_2 intensity in sector i e_i, and secondary increase in final demand in sector i ΔF_{2i} ;

$$\Delta E_2 = \sum_{i=1}^{n} \left(e_i \cdot \Delta F_{2i} \right) \tag{3}$$

In this study, as we calculate CO_2 impact up to secondary effect, we can calculate total inpact ΔE by summing up ΔE_1 and ΔE_2:

$$\begin{aligned} \Delta E &= \Delta E_1 + \Delta E_2 \\ &= e_{bioethanol} \cdot \Delta F_{1bioethanoll} + \sum_{i=1}^{n} \left(e_i \cdot \Delta F_{2i} \right) \end{aligned} \tag{4}$$

2.3 Scenarios

In this study, we assume that 10,000kl of additional demand of transportation fuel arises in Hokkaido. To meet the additional demand, there are two options for its supply: (1) 10,000kl of E3; and (2) 10,000kl of generic gasoline (2). We measure the repercussions of CO_2 emission, as well as the economic impact (direct, indirect, and induced). Finally, we estimate the CO_2 efficiencies of both E3 and gasoline. We define the CO_2 efficiency by the ratio of the economic impact to CO_2 impact, shown as the following equation, where ΔX is ecomonic impact (primary, and secondary) measured by monetary term:

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(2) As there is a difference between heat content of E3and generic gasoline, strictly speaking, 10,000kl of E3 equals to not 10,000kl but 9,904kl of generic gasoline from a viewpoint of heat content. Of course, we consider the difference in the analysis but, in the paper, we say “10,000kl of generic gasoline” and “10,000kl of E3” for easy understanding.

$$Eff_{CO2} = {}^{\Delta X}\!\big/_{\Delta E} \tag{5}$$

The unit of the efficiency is million yen/t-CO_2.

3. Results

Results of the estimation are shown in Figure 1. Due to increase in E3 demand, indirect and induced economic impact, which is brought by sales of 10,000kl of E3, account to 0.29 billion yen, and by adding to the direct economic impact, total economic impact accounts to 1.31 billion yen; and the multiplier, which is defined by ration of economic impact to the additional increase in final demand, is 1.29. On the other hand, when the demand of gasoline increased, indirect impact is 0.17 billion yen and total economic impact accounts to 1.20 billion yen, and the multiplier is 1.16, which is smaller than that of E3. From these results, we can recognize that, from an economic point of view, E3 brings larger economic impact than generic gasoline.

Table 3 illustrates the economic impact by sector. Of course, the sector that has the largest impact is the bio-ethanol for E3 and the petroleum refinery for gasoline, respectively. Although gasoline gives no impact to the crop cultivation sector, E3 brings a production increase of 9 million yen to the sector. As we mentioned, the main industry in Hokkaido is agriculture, so additional demand of E3 impacts the main industry in Hokkaido. In terms of CO_2 impact by sector, in the case of E3, CO_2 emission from the energy sector (electricity, gas, and water supply) is lower than that of gasoline (21t-CO_2 and 36t-CO_2, respectively). Despite E3 causing economic impact on the crop cultivation sector, increase in CO_2 in the sector is nearly zero. This is because CO_2 intensity in the sector is low.

In terms of CO_2 impact, increase in E3 demand brings an increase in $CO_{2,}$ by 2,296t (Figure 1). However, increase in gasoline demand causes an additional 3801t of CO_2. These results show that in spite of larger economic impact, E3 can keep the increase in CO_2 smaller than gasoline. This is because E3 induces larger economic impact on the sectors whose CO_2 intensity is smaller. Finally, we estimate CO_2 efficiency of both E3 and gasoline: 0.571 million yen/t-CO_2 for E3 and 0.316 million yen/t-CO_2 for gasoline

(Figure 1). CO_2 efficiency of E3 is 1.8 times that of gasoline. These results also show the advantages of E3 compared to generic gasoline.

From these results, we conclude that from the regional perspective, bio-ethanol production in Hokkaido brings a larger economic impact with a smaller increase in CO_2 emission, thus contributing to the CO_2 efficiency of a specific region.

4. Conclusion

This paper measures economic and CO_2 impact of bio-ethanol production using IO analysis for a case study in Hokkaido, Japan, and then estimates the CO_2 efficiency. In spite of larger economic impact, E3 can keep the increase in CO_2 smaller than that of gasoline, and the CO_2 efficiency of E3 is 1.8 times larger than that of gasoline. Therefore, bio-ethanol production brings a larger economic impact with a smaller increase in CO_2 emission, thus contributing to the CO_2 efficiency of a specific region. These results also show the advantage of bio-ethanol compared to gasoline.

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Tables:

Table 1

	Volume (kl)	Heat value (TOE)	Economic value (billion yen)
Ethanol	10,490	5,906	----
Gasoline for E3	339,178	280,364	----
E3	349,668	286,270	35.6
Gasoline substituted by E3	346,323	286,720	35.8

Note:
(1)1 TOE (Ton Oil Equivalent) equals 10,000,000Kcal.

Volume of bio-ethanol production from substandard wheat

Table 2

(million yen)

	Bio-ethanol
Crop cultivation	508
Livestock	0
Forestry	0
Fisheries	0
Coal mining	2
Crude oil and natural gas	0
Other mining	0
Dairy products	0
Seafoods	0
Other foods	71
Textile	1
Timber and wooden furniture	1
Pulp, paper, and wooden products	0
Publishing and printing	8
Chemical products	83
Bio-ethanol	0
Petroleum refinery products	12,469
Coal products	0
Leather and rubber products	0
Ceramic, stone and clay products	2
Pig iron and crude steel	0
Steel	0
Non-ferrous metal products	0
Metal products	55
Machinery	0
Musical instruments	78
Civil engineering and construction	41
Electric power, gas, steam and hot water supply	77
Commerce	285
Financial service, insurance, and real estate	531
Transportation, telecommunication, and broadcasting	778
Public administration	0
Public service	239
Business services	222
Office supplies	1
Activities not elsewhere classified	13
Total of intermediate sectors	15,465
Consumption expenditure outside households (row)	97
Compensation of employees	591
Operating surplus	499
Depreciation of fixed capital	1,112
Depreciation of fixed capital	0
Indirect taxes	18,248
(less) Current subsidies	-415
Total of gross value added sectors	20,132
Domestic production (gross inputs)	35,597

Note:
1. Although some sectors are aggregated in the table, we made actual analysis with a 106-sector IO tabl

Input structure of the bio-ethanol sector

Table 3

Sector	Economic Impact: ΔX (million yen)		Increase in CO_2 : ΔE ($t\text{-}CO_2$)	
	E3	Gasoline	E3	Gasoline
Crop cultivation	9	0	0	0
Livestock	1	0	1	0
Forestry	0	0	0	0
Fisheries	0	0	0	0
Mining	2	18	0	0
Bio-ethanol	1,031	0	2,210	0
Petroleum refinery products	144	1,053	9	3,716
Other manufacturing products	8	6	6	5
Construction	3	3	1	1
Electricity, gas, and water supply	7	16	21	36
Commerce	11	10	2	2
Financial, insurance and real estate	32	31	4	4
Transport, telecom., and broadcasting	34	31	35	31
Public administration	0	0	0	0
Public services	9	9	1	1
Business services	19	21	5	5
Office supplies	0	0	0	0
Activities not elsewhere classified	1	2	0	0
Total	1,311	1,200	2,296	3,801

Economic impact and increase in CO_2 by sector

Figures:

Figure 1

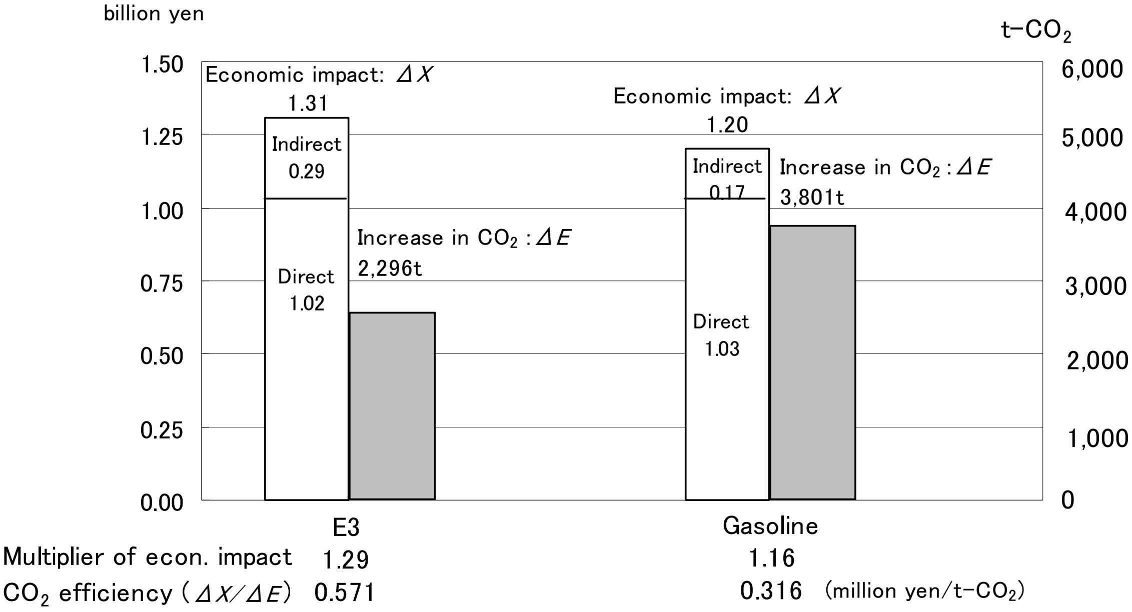

Figure 1: Economic impact and increase in CO_2