Chapter 15
National Strategy Options for Japan

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15.1 Introduction

The introduction and diffusion of biofuel industry have been promoted in many developed countries including Japan, which has established concrete mandates with numerical targets for both bioethanol and biodiesel. Table 15.1 shows changes to the biofuel introduction targets in Japan. In response to government requests to achieve the GHG emission reduction goals of the Kyoto protocol, the Petroleum Association of Japan has agreed to blend 840,000 kl/year of bio-ETBE (ethyl tertiary-butyl ether), equivalent to 210,000 kl of crude oil, into gasoline starting in fiscal year (FY) 2010. This blended bio-ETBE gasoline has been sold as "biogasoline," and the number of service stations selling it has increased from 50 in 2007 to 3210 in 2012. On the other hand, Japan's Ministry of the Environment (MOE) has been promoting a strategy to accelerate the use of biomass energy by supplying E3 gasoline, a blend of gasoline with 3% bioethanol. Demonstration projects for E3 have been conducted in Osaka, Tokyo, and Okinawa, but the amount of E3 gasoline sold in 2010 remained approximately 28,000 kl.

A number of studies have evaluated how achieving these mandates can contribute to reductions in GHG emissions and how the expansion of biofuel production can affect food security. However, there are few studies focusing on the interlinkages between different impacts, including trade-offs and synergies among different types of impacts. This chapter quantitatively assesses various environmental impacts by expanding biofuel production and ethanol usage and analyzes the interlinkages among different impacts under several options for introducing biofuel in Japan. We use three indicators for this analysis, life-cycle carbon footprint (LCCO$_2$), water footprint (WF), and ecological footprint (EF), by considering feedstock types,

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Table 15.1 Changes to biofuel introduction targets in Japan

April 2005	The plan for achieving the Kyoto protocol target (approved by the Cabinet on April, 28 2005) identified 3080,000 kl crude oil equivalent of biomass thermal energy use including 500,000 kl crude oil equivalent of liquid biofuel for transportation, which is equivalent to approximately 0.6% of the total liquid fuel for transportation (86,000,000 kl)
March 2006	New biomass Nippon strategy has also set the target of introducing 500,000 kl crude oil equivalent of liquid biofuel for transportation
May 2006	New national energy strategy has set the target to reduce petroleum dependency of transportation sector from 98% in 2000 to 80% by 2030
November 2006	Prime Minister Shinzo Abe directed the development of a road map to expand the domestic biofuel production up to 6000,000 kl, which is equivalent to 10 % of the annual domestic gasoline consumption
November 2010	A new law on nonfossil energy use and effective use of fossil energy resources by energy suppliers was enacted, and its public notice (No. 242)[a] indicated the following targets with respect to bioethanol usage
	Bioethanol usage targets from FY 2011 to FY 2017:
	FY 2011: 210,000 kl crude oil equivalent
	FY 2012: 210,000 kl
	FY 2013: 260,000 kl
	FY 2014: 320,000 kl
	FY 2015: 380,000 kl
	FY 2016: 440,000 kl
	FY 2017: 500,000 kl

[a] Ministry of Economy, Trade, and Industry (2010)

changes in land use, imports, and environmental conditions as well as domestic supply capacity and national mandates. Based on the analysis, we end the discussion with policy implications of moving toward sustainable biofuel.

15.2 Methods and Materials

Available future scenarios were reviewed for transportation usage of bioethanol and biodiesel. The national targets for bioethanol (Table 15.2) were set on the basis of Public Notice No. 242 issued by the Ministry of Economy, Trade, and Industry (METI) in 2010. The biodiesel targets in Table 15.2 followed the targets set by the MOE in 2006, but we modified them by shifting 5 years ahead from the original targets (i.e., interpreting the 2030 MOE target as the 2035 target for this analysis) because the actual diffusion of biodiesel has been delayed.

For analyzing each scenario, five options were prepared by considering the type of biomass, producer country, associated land use changes, competition with respect to food production, supply pattern, and transportation (Figs. 15.1 and 15.2).

We used three assessment indicators: carbon footprint (CF), WF, and EF. CFs and WFs for biofuel derived from different crops were collected extensively and

Table 15.2 Biofuel diffusion scenario for this study (Crude oil equivalent)

		2015	2025	2035
Assumption of fuel demand for transportation		Current demand (86,000,000 kl) gasoline (53,400,000 kl) diesel (32,600,000 kl)	80 % of the current demand gasoline (42,720,000 kl) diesel (26,080,000 kl)	50% of current demand gasoline (26,700,000 kl) diesel (16,300,000 kl)
Bioethanol	Assumption of bioethanol usage	Based on the target set by the Ministry of Economy, Trade, and Industry in 2010, the amount of bioethanol usage is assumed to increase from 210,000 kl crude oil eq. in 2011 by 60,000 kl crude oil eq. per year by promoting E3- and ETBT-added gasoline	The amount of bioethanol usage is assumed to continuously increase by 60,000 kl crude oil eq. every year from 210,000 kl crude oil eq. in 2011 by promoting E3-, E10-, and ETBT-added gasoline. (380,000 kl + 60,000 kl/year × 10 years = 980,000 kl)	The amount of bioethanol usage is assumed to continuously increase by 60,000 kl eq. crude oil every year from 210,000 kl crude oil eq. in 2011 by promoting E10- and ETBT-added gasoline. (980,000 kl + 60,000 kl/year × 10 years = 1,580,000 kl)
	Amount of bioethanol usage[a, b]	656,000 kl (380,000 kl)	1,692,000 kl (980,000 kl)	2,850,000 kl (1,580,000 kl)
	Domestic production	50,000 kl (30,000 kl)	950,000 kl (550,000 kl)	Ensure 2,850,000 kl not only by domestic bioethanol but also by imports from Brazil and Asian countries
	Import	606,000 kl (350,000 kl)	742,000 kl (430,000 kl)	

(continued)

Table 15.2 (continued)

		2015	2025	2035
Biodiesel	Assumption of biodiesel	High concentration of mixed biodiesel such as BDF 100 % and B20 will be promoted, whereas low-concentration mixed BDF such as B5 will be introduced extensively	Approximately one-third of the total demand for light diesel oil will be supplied by BDF, eco-diesel, and BTL (biomass–liquid). Domestic vegetable oil will be used to produce BDF and eco-diesel. Domestic wastes and forest biomass will be used for producing BTL	The total demand for light diesel oil will be supplied by BDF, eco-diesel, and BTL. Fulfill the demand by maximizing the utilization of domestic biomass resources and imports from Asian countries
	Amount of biodiesel[b]	11,000–16,000 kl (10,000–15,000 kl)	1,000,000 kl (900,000 kl)	2,000,000 kl (1,800,000 kl)
	Domestic production	11,000–16,000 kl (10,000–15,000 kl)	1,000,000 kl (900,000 kl) including the import from Asian countries, etc.	2,000,000 kl (1,800,000 kl) including import from Asian countries, etc.
	Import	Depending on the expansion of domestic production capacity		

[a] Ministry of Economy, Trade, and Industry (2010)

[b] Global Environmental Bureau, Ministry of Environment (2006): Report by the Promotion Council for Eco-Fuel Utilization, http://www.hkd.meti.go.jp/hokne/sui2nd_result/data1_7.pdf

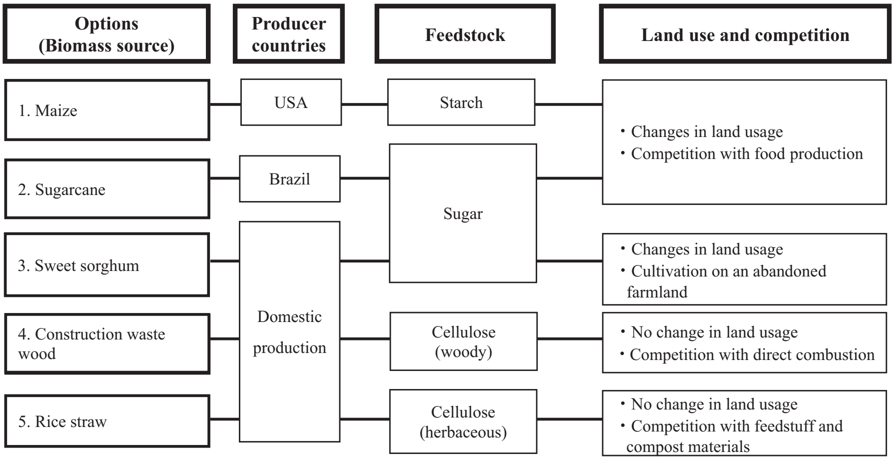


Fig. 15.1 Supply options for bioethanol in Japan

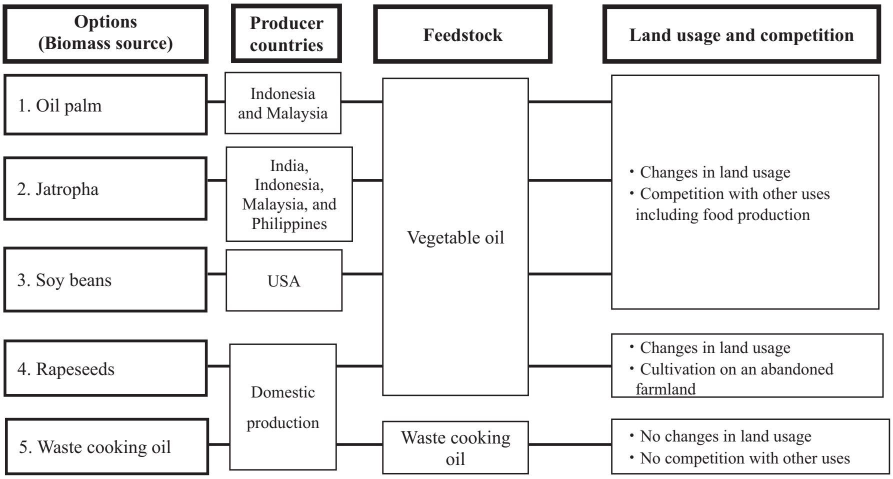


Fig. 15.2 Supply options for biodiesel in Japan

reviewed to identify differences among biomass sources. The maximum supply capacities of domestic options such as rice straw ethanol and waste cooking oil were calculated on the basis of domestic production and consumption of each biomass source (Table 15.3). Due to the variation in CF and WF values within the same biomass source, we used both upper-end and lower-end values as best case and worst case while calculating EF. Table 15.4 summarizes the domestic biofuel ratio (%) of each case and the target year. Unless Japan cannot expand the maximum supply capacity of the domestic options (Table 15.3), the domestic biofuel ratio will decrease owing to the increase in imported biofuel, which is necessary to fill the gap between domestic production and the targets, as described in Table 15.2.

Table 15.3 Maximum supply capacity of domestic options

	Biomass source	Maximum supply capacity (kL)	Assumption of calculation and source
Bioethanol	Sweet sorghum (case 3)	851,796	The size of abandoned farmland in Japan is 396,000 ha in 2010 (Ministry of Agriculture, Forestry, and Fishery), and the ethanol production yield from sorghum is 2151 L/ha (Williams et al. 2007)
	Construction waste (case 4)	769,600	The amount of available construction waste is 2.96 million t (Ministry of Land, Infrastructure, Transport, and Tourism), the ethanol production yield from construction waste is 0.208 L/kg (Taneda 2006), and the specific weight of bioethanol is 0.8 kg/L
	Rice straw (case 5)	1,600,080	The amount of available rice straw is 6.78 million t (METI 2007); the ethanol production yield from rice straw is 0.236 L/kg (National Institute of Advanced Industrial Science and Technology 2010)
Biodiesel	Rapeseed (case 4)	283,000–343,000	The BDF supply potentials from rapeseed and waste cooking oil were calculated by METI (2007)
	Waste cooking oil (case 5)	500,000	

Table 15.4 Domestic biofuel ratio (%) by case and target year

	Case	2015	2025	2035	Note
Bioethanol	Case 1: maze	0	0	0	Depends entirely on imports
	Case 2: sugarcane	0	0	0	
	Case 3: sweet sorghum	100	50	30	Assume the imported sugarcane ethanol to fill the gap between domestic production and targets
	Case 4: construction waste	100	46	27	
	Case 5: rice straw	100	95	56	
	Case 6: combination of domestically produced bioethanol	100	100	100	Depends entirely on domestically produced bioethanol
Biodiesel	Case 1: palm oil	0	0	0	Depend entirely on imports
	Case 2: *Jatropha*	0	0	0	
	Case 3: soybean	0	0	0	
	Case 4: rapeseed	100	28–34	14–17	Assume the imported palm oil biodiesel to fill the gap between domestic production and targets
	Case 5: waste cooking oil	100	50	25	
	Case 6: combination of domestically produced biodiesel	100	78–84	39–42	

15.2.1 Carbon Footprint

CF or $LCCO_2$ is one of the most popular indicators used in many LCA studies. CF can be defined as the total GHG emission due to biomass cultivation, extraction, transportation, the process of conversion to biofuel, and shipping of the biofuel. Today, CF is applied to the product labeling scheme in many countries.

15.2.2 Water Footprint

Water is needed for several processes in biofuel production. WF can be defined as the total annual volume of fresh water used to produce goods and services for consumption. WF consists of three components: the green WF, blue WF, and gray WF (Worldwatch Institute 2007). The green WF refers to rainwater that evaporates during production, mainly during crop growth. The blue WF is the surface- and groundwater used for irrigation that evaporates during crop growth. The gray WF is the amount of water needed to dilute pollutants discharged into the natural water system to the extent that the quality of the ambient water remains above agreed-upon water quality standards.

15.2.3 Ecological Footprint

EF is a tool to measure human demand by comparing with Earth's ecological capacity to regenerate. It indicates the amount of biologically productive land and sea area needed to regenerate the resources consumed by a human population and to absorb its wastes (Rees 1992; Wackernagel 1994). Conceived in 1990 by Mathis Wackernagel and William Rees at the University of British Columbia, EF has been widely used by scientists, businesses, governments, agencies, individuals, and institutions to monitor ecological resource use and assess our pressure on Earth's system. The following equation was used to calculate EF in this study. Wackernagel and Rees (1995) selected 6.6 mt as their average value for the total CO_2 sequestered by the world's forests. Therefore, we also used the value of 6.6 Mg/ha for CO_2 sequestration. This value would be 3.2 Mg/ha (Greenhouse Gas Inventory Office of Japan 2010) by assuming the offset CO_2 emissions from the forests in Japan:

$EF(ha) = EF_{cf} + EF_{harvest} + EF_{water}$where

EF_{cf} = Forest cover (ha) needed to assimilate CO_2 emissions from the biofuel supply (i.e., CF)

$EF_{harvest}$ = Farmland cover (ha) needed to harvest crops or vegetables for biofuel

EF_{water} = Water catchment area (ha) needed to collect the total water volume required to grow biofuel crops and vegetables (the blue *WF* and the green *WF*)

15.3 Results

15.3.1 CF, WF, and EF per Unit Amount

15.3.1.1 Carbon Footprint

Table 15.5 and Fig. 15.3 summarize the net life-cycle GHG emissions from biofuels derived from different biomass sources. Within the same type of biofuel such as corn ethanol, different studies report different values depending on the researcher, production system, and accounting boundary. Until 2005, most of the studies on corn ethanol showed a corn ethanol CF slightly larger than that of gasoline, but studies after 2006 have demonstrated a 20 % or even greater GHG reduction by

Table 15.5 Life-cycle GHG emissions excluding those due to changes in land usage

		Year	Net GHG emissions (g-CO2/MJ)	Notes	Source
Reference	Gasoline		94.0		[a]
	Gasoline		92.0	[b]	
	Gasoline (Japan)		81.7	[c, d]	
	Diesel		82.3	[e]	
Corn ethanol	Marland and Turhollow	1991			[f]
	Lorenz and Morris	1995			[f]
	Wang	2001	71.0		[a]
	Graboski	2002	99.0		[a]
	Shapouri et al.	2002			[f]
	Patzek	2004	121.0		[a]
	Shapouri et al.	2004	61.0		[a]
	Pimentel et al.	2005	116.0		[a]
	de Oliveira et al.	2005	98.0		[a]
	Kim and Dale	2005			[f]
	Farrell et al.	2006	87.0		[a]
	Hill et al.	2006	84.9		[e]
	Fargione et al.	2008	78.3		[g]
	Serchinger et al.	2008	74.0		[b]
	Toyota Motor Corporation and Mizuho Information and Research Institute	2008	81.4	Maximum case	[h]
			54.0	Minimum case	[h]
	EU directive 2009/28/EC	2009	43.0	Community produced (natural gas as process fuel in CHP plant)	[i]

(continued)

Table 15.5 (continued)

		Year	Net GHG emissions (g-CO2/MJ)	Notes	Source
Sugarcane ethanol	Fargione et al.	2008	17.9		g
	Toyota Motor Corporation and Mizuho Information and Research Institute	2008	14.8	Maximum case	h
			14.5	Minimum case	h
	EU directive 2009/28/EC	2009	24.0		i
	Ministry of Economy, Trade, and Industry, Japan	2010	32.7	Including shipping from Brazil to Japan (13.9 g-CO2eq/MJ)	c, d
Sugar beet ethanol	EU directive 2009/28/EC	2009	40.0		i
Sweet sorghum ethanol	Xunmin et al.	2009	36.3	China	j
Wheat ethanol	EU directive 2009/28/EC	2009	70.0	Process fuel not specified	i
			44.0	Natural gas process fuel in CHP plant	i
			26.0	Straw gas process fuel in CHP plant	i
Soybean biodiesel	Hill et al.	2006	49.0		e
	EU directive 2009/28/EC	2009	58.0		i
	Xunmin et al.	2009	41.9	China	j
Palm biodiesel	Fargione et al.	2008	37.0		g
	Toyota Motor Corporation and Mizuho Information and Research Institute	2008	13.4		h
	Yee et al.	2009	31.7		k
	EU directive 2009/28/EC	2009	68.0	Process not specified	i
			37.0	Process with methane capture at oil mill	i
Rapeseed biodiesel	EU directive 2009/28/EC	2009	52.0		i
Jatropha biodiesel	Prueksakorn and Gheewala	2005	16.5		l
	Tobin and Fulford	2006	56.7		m
	Xunmin et al.	2009	34.6	China	j

(continued)

Table 15.5 (continued)

		Year	Net GHG emissions (g-CO2/MJ)	Notes	Source
Cellulosic bioethanol	Farrell et al.	2006	11.0		[a]
	Serchinger et al.	2008	27.0	Switch grass	[b]
	Toyota Motor Corporation and Mizuho Information and Research Institute	2008	50.3	USA (cellulosic) maximum case	[h]
			25.2	USA (cellulosic) minimum case	[h]
			20.3	Forest thinning's (Japan) maximum case	[h]
			7.9	Forest thinning's (Japan) minimum case	[h]
	EU directive 2009/28/EC	2009	13.0	Wheat straw ethanol	[i]
			22.0	Waste wood ethanol	[i]
			25.0	Farmed wood ethanol	[i]

[a] Farrell et al. (2006)
[b] Searchinger et al. (2008)
[c] Agency for Natural Resources and Energy, Ministry of Economy, Trade, and Industry (2010)
[d] Ministry of Economy, Trade, and Industry (2010)
[e] Hill et al. (2006)
[f] Hammerschlag (2006)
[g] Fargione et al.(2008)
[h] Toyota Motor Corporation and Mizuho Information and Research Institute (2008)
[i] Directive 2009/28/EC of the European Parliament and of the Council of April 23, 2009, on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC
[j] Xunmin et al. (2009)
[k] Kian et al. (2009)
[l] Tobin and Fulford (2005)
[m] Prueksakorn and Gheewala (2006)

gasoline. Sugarcane ethanol has a smaller CF than that of corn ethanol, which is equivalent to one-fifth of the gasoline GHG emission. This relative advantage of sugarcane is because the bagasse—a by-product of the sugarcane plant—can be used as an energy source in ethanol refinery. METI's Public Notice No.242 (2010) specifies that CF from bioethanol should be less than 50 % of that from gasoline (81.7 g-CO_2eq/MJ).

CF from soybean biodiesel is reported to be approximately half that of conventional diesel. CF from palm oil biodiesel is even smaller than that of soybean biodiesel if we ignore the methane emissions from the conversion of peatland to oil palm plantations, a common occurrence in Indonesia and Malaysia.

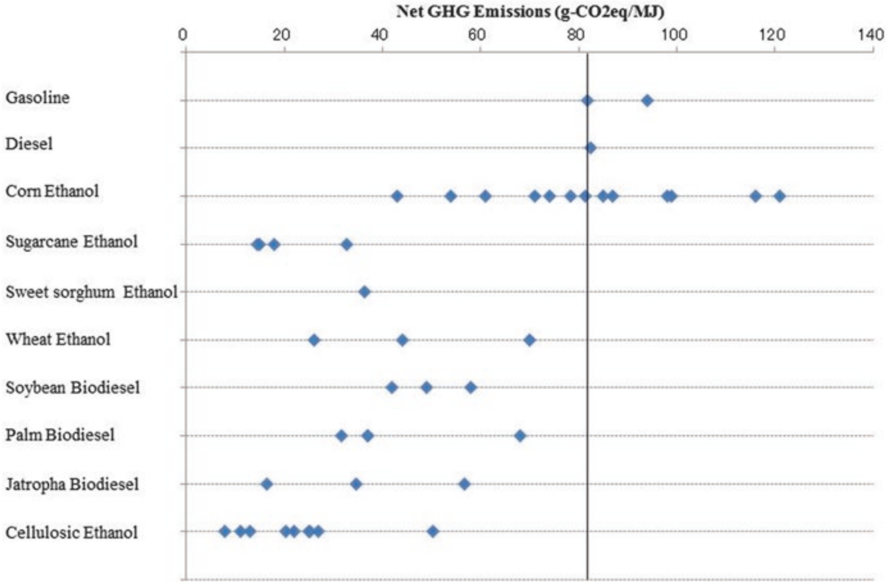


Fig. 15.3 Life-cycle GHG emissions (carbon footprint) of various biofuels

15.3.1.2 Water Footprint

Table 15.5 summarize WF per unit amount of fuel. Gerbens–Leenes et al. (2009a) report that WF of biodiesel is generally greater than that of bioethanol while using global averages. The global average WF of biodiesel crops ranges from 394 to 574 m^3/GJ biodiesel. *Jatropha* is famous for being tolerant to wasteland, but its requirement for water is greater than many other energy crops, which implies that water availability may be one of the constraints for *Jatropha* biodiesel supply.

The global average WF of bioethanol crops ranges from 59 to 419 m^3/GJ. WFs of sugar beet, potato, and sugarcane are 59, 103, and 108 m^3/GJ, respectively, whereas sorghum (419 m^3/GJ) has the largest WF of all ethanol crops (Table 15.6).

These results suggest that switching to biomass energy may result in an increased demand for fresh water, which eventually will intensify the competition between water usage for food production and energy (Bazilian et al. 2011).

15.3.1.3 Ecological Footprint per Unit Amount of Biofuel

EFs per unit of biofuel are compared according to cases in Fig.15.4. Producing bioethanol from sorghum and maize results in a larger EF than production from other biomass sources. Using construction waste wood is the best option for minimizing EF (Fig. 15.4a). Biodiesel from *Jatropha* and soybean yields an EF two to

Table 15.6 Water footprints for ten crops providing ethanol and five crops providing biodiesel (m^3/GJ)

Crop	Total WF	Blue WF	Green WF	Note		Source
Ethanol	m^3/GJ ethanol					
	Sugar beet	59	35	24	Total weighted global average	a
	Potato	103	46	56		a
	Sugar cane	108	58	49		a
	Maize	110	43	67		a
	Cassava	125	18	107		a
	Barley	159	89	70		a
	Rye	171	79	92		a
	Paddy rice	191	70	121		a
	Wheat	211	123	89		a
	Sorghum	419	182	238		a
Biodiesel	m^3/GJ biodiesel					
	Palm oil and kernel	247			Brazil	b
	Sunflower	377			Average of the Netherlands, the USA, Brazil, and Zimbabwe	b
	Soybean	394	217	177	Total weighted global average	a
	Rapeseed	409	245	165		a
	Jatropha	574	335	239		a

[a] Gerbens–Leenes et al. (2009a)
[b] Gerbens–Leenes et al. (2009b)

three times greater than other cases, and converting waste cooking oil to BDF is the best among all cases (Fig. 15.4b). Palm oil shows the smallest EF among three cases of imported biodiesel from other countries.

15.3.2 Scenario Analysis

Considering the targets for 2015, 2025, and 2035, different cases to achieve the targets (Figs. 15.1 and 15.2), the maximum supply capacity of each domestic biomass source (Table 15.3), and the domestic biofuel ratio (Table 15.4), we calculated CF, WF, and EF from 2015 to 2023 (Figs. 15.5, 15.6, 15.7, and 15.8). In addition to the five cases for each biofuel described in Figs. 15.1 and 15.2, we prepared a sixth case that maximizes the domestic biomass sources by combining sorghum, construction waste wood, and rice straw for bioethanol and by combining rapeseed and waste cooking oil for biodiesel (Table 15.4).

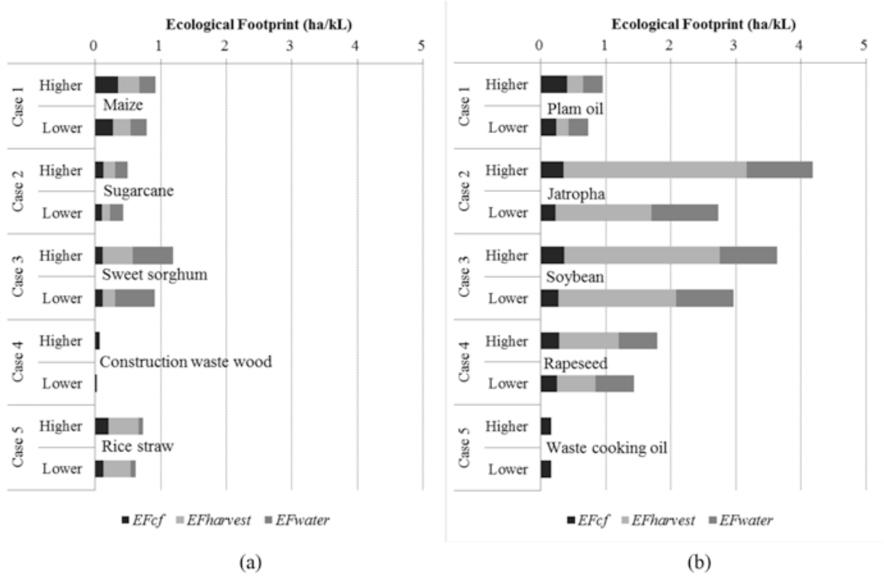


Fig. 15.4 Ecological footprint per unit of biofuel for five cases each of (**a**) bioethanol and (**b**) biodiesel

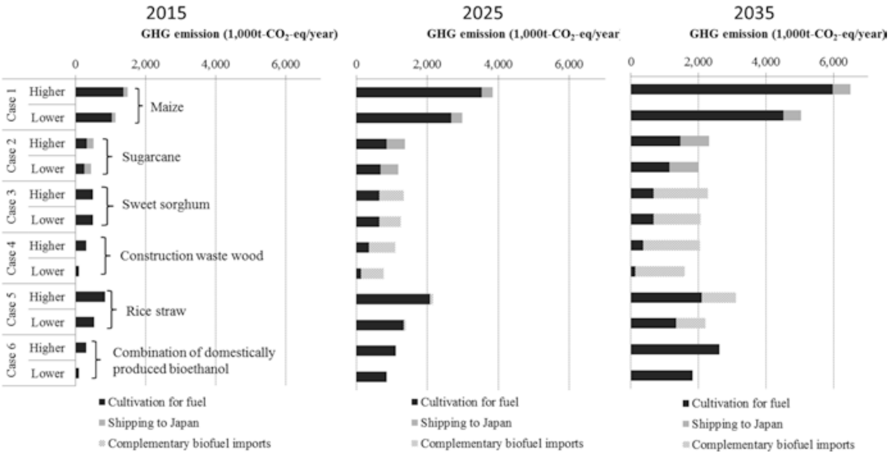


Fig. 15.5 Carbon footprints of six bioethanol supply cases from 2015 to 2035

In terms of GHG emissions (CF), imported maize bioethanol shows the worst performance of the six cases, whereas bioethanol from sweet sorghum and construction waste wood shows better performances (Fig. 15.5). Bioethanol from rice straw emits more GHGs than other domestic cases (cases 3, 4, and 6). The difference between sugarcane ethanol imported from Brazil (case 2) and ethanol from

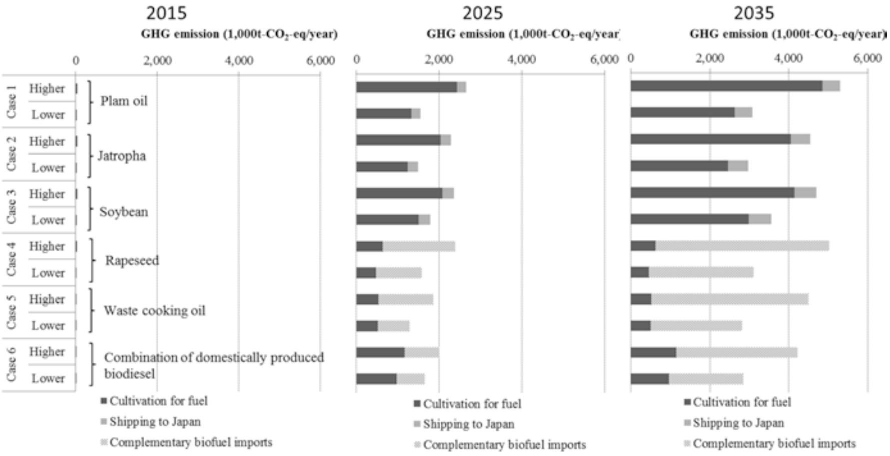
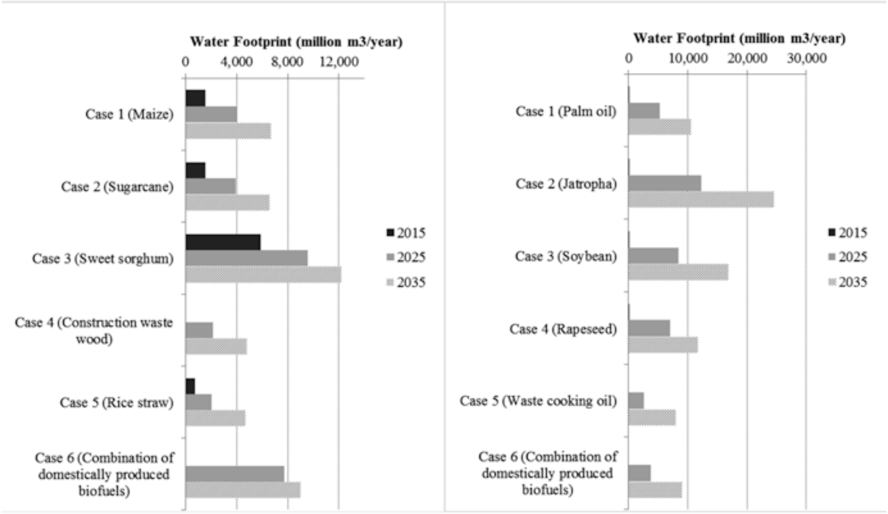


Fig. 15.6 Carbon footprints of six biodiesel supply cases from 2015 to 2035



(a) (b)

Fig. 15.7 Water footprints of six supply cases from 2015 to 2035. (**a**) Bioethanol (**b**) Biodiesel

domestic construction waste wood (case 4) is reduced in 2035 because imports of complementary bioethanol are increased to achieve the target.

GHG emissions from the domestic biodiesel cases (cases 4–6) tend to be lower than the importing cases, but the differences are not as significant as those in the bioethanol cases (Fig. 15.6). The combination of all domestic BDFs (case 6) gives the best result of all the cases.

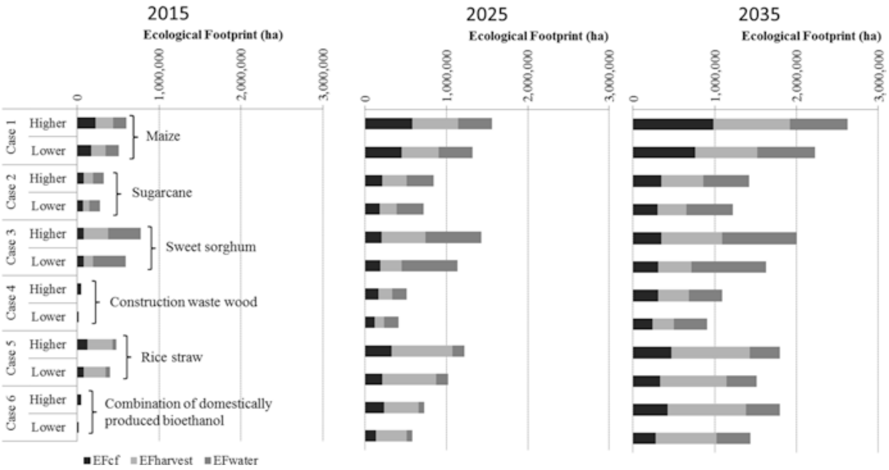


Fig. 15.8 Ecological footprints of six bioethanol supply cases from 2015 to 2035

Among the bioethanol WFs from the six cases, sweet sorghum (case 3) shows the largest WF (Fig. 15.7a). Therefore, case 6, which maximizes domestic biodiesel, indicates a larger WF than that of construction waste wood (case 4) and rice straw (case 5). *Jatropha* (case 2) requires the maximum amount of water out of any of the other cases investigated in this study (Fig. 15.7b). Palm oil (case 1) and domestic rapeseed (case 4) show similar WF performances. Waste cooking oil (case 5) is the best option in terms of WF, even considering the complementary import of biodiesel (palm oil) to fill the gap between the maximum supply capacity of waste cooking oil and the national target.

Figure 15.8 summarizes EFs of all bioethanol cases from 2015 to 2035. Construction waste wood shows the smallest EF out of all the cases, whereas maize ethanol is calculated to have the largest EF. In 2035, maximizing the domestic sources (case 6) would not be the best option because the performance of bioethanol is almost similar to that of sugarcane (case 2) and rice straw (case 5), which suggests that care should be taken while selecting combinations of available options to minimize EF in longer term.

Jatropha has the largest EF of all the cases, with soybean coming in the second place (Fig. 15.9) because of the large land area required to harvest it ($EF_{harvest}$) and the catchment area required for water (EF_{water}). EF of waste cooking oil (case 5) was the smallest of all the cases, but the EFs of palm oil (case 1), rapeseed (case 4), and the combination of domestically produced biodiesel (case 6) were all less than 2 million ha. The results demonstrate that importing biodiesel produced from *Jatropha* and soybean does not make sense in terms of EF because their EFs are three to four times larger than those of other cases.

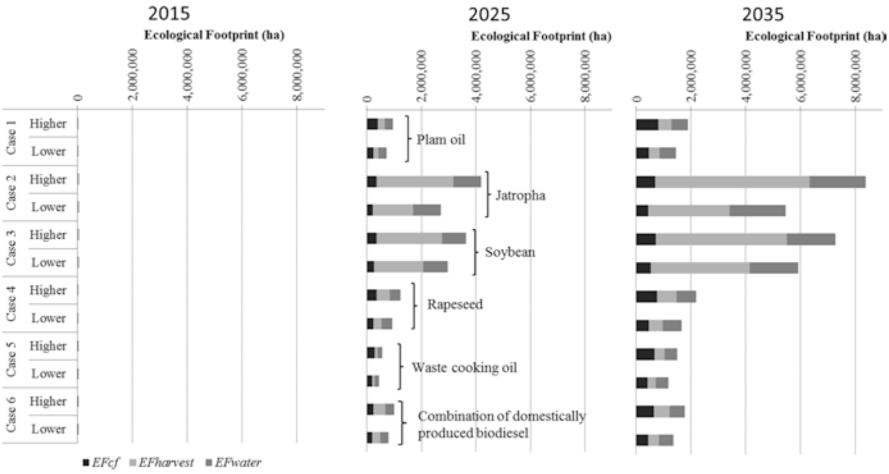
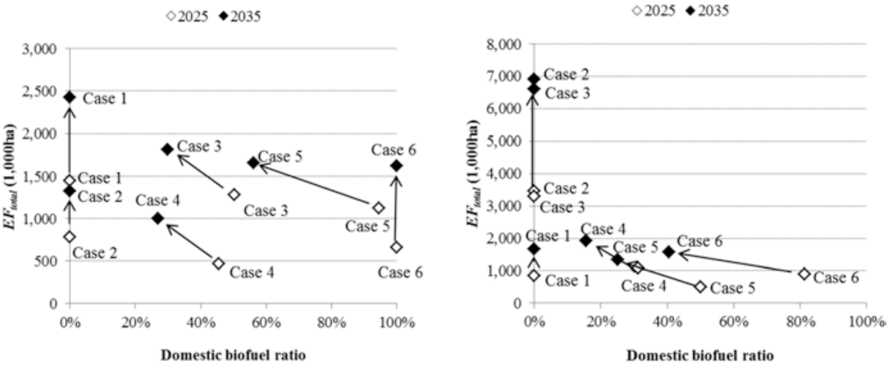


Fig. 15.9 Ecological footprints of six biodiesel supply cases from 2015 to 2035



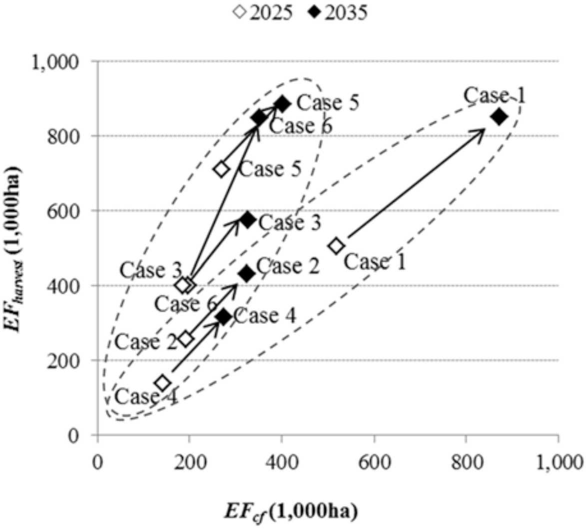
(a) (b)

Fig. 15.10 $\mathrm{EF}_{\mathrm{total}}$ and domestic biofuel ratio by case. (**a**) Bioethanol (**b**) Biodiesel

15.4 Discussion and Conclusion

An integrated sustainability assessment model of biofuel that uses several biomass sources was developed in this chapter. Figure 15.10 summarizes the results of the scenario analysis, which uses six different cases to achieve Japan's national target for bioethanol and biodiesel. This figure suggests that Japan needs to import more than 40 % of its bioethanol to achieve the national target in 2035, except in case 6 (maximizing domestically produced bioethanol) (Fig. 15.10a). Similarly, Japan needs to import at least 59 % of its total biodiesel to achieve the 2035 target

Fig. 15.11 Relationships between EF_{cf} and $EF_{harvest}$ in six bioethanol cases



(Fig. 15.10b). In general, a dependency on the imported biofuel or a self-sufficiency in biofuel production has an influence on the level of EF_{total}.

This assessment model can provide not only the overall ecological footprint for each case but also a detailed breakdown of EF_{cf}, $EF_{harvest}$, and EF_{water}. This allows us to identify relationships across these indicators. For example, Fig. 15.11 indicates the linkage between EF_{cf} and $EF_{harvest}$ in six bioethanol cases, which suggests that EF_{cf} in general increases $EF_{harvest}$, but we can find different paths (regression lines) with steeper slopes, such as case 6, and those with moderate slopes, such as cases 1, 2, and 4. This means that the same reduction in GHG emission results in different levels of $EF_{harvest}$ depending on the case chosen by the government. It is highly recommended that the government applies multi-criteria sustainability assessment as demonstrated by this chapter in addition to conventional cost-benefit analysis prior to making a policy decision to expand biofuel production and import.

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