Article

A Comparative Study on the RFS Program of Korea with the US and UK

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Abstract: In 2016, the global environmental impact of greenhouse gas (GHG) emissions was 49.3 gigatons in CO_2equivalent. Worldwide, the transportation sector is responsible for 14% of GHG. Electric vehicles powered by less-polluting energy sources are one way to reduce the environmental impact of the transportation sector, but immediate transportation demands cannot be met by existing electric vehicle technology. Use of less polluting biofuel in place of petroleum-based gasoline or diesel fuel to power the existing transportation fleet is a widely accepted transitional solution, including in the Republic of Korea. The purpose of this project is to investigate approaches to biofuels in the US and the UK to evaluate Korea's current energy policies related to use of biofuels and to make recommendations for strengthening Korea's energy policy. This project addresses only policies for use of biodiesel rather than ethanol (widely used in the US) because ethanol is not used in Korea. This research shows that Korea calculates GHG using the principle that biofuel is carbon neutral, but energy policies in the US and the UK treat biofuel as not entirely carbon neutral. Korea should examine how to calculate GHG from biodiesel according to the standard set by the UK. In detail, the project's findings relate to environmental sustainability.

Keywords: RFS (Renewable Fuel Standards); renewable energy; biodiesel; CO_2; GHG; sustainability; carbon neutral

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1. Introduction

1.1. Research objective

The purpose of this paper is to identify shortcomings of Korea's biodiesel program, including its Renewable Fuel Standard (RFS), and to propose modifications to the program to improve the environmental sustainability of biodiesel in Korea. The seventh largest greenhouse gas (GHG) emitting country, Korea is implementing a biodiesel program to improve the sustainability of its energy supply by increasing biodiesel use in the transportation sector [1]. However, while Korea calculates GHG emissions using the principle that biofuel is carbon neutral, energy policies in the US and the UK treat biofuel as not entirely carbon neutral. These countries include GHG emissions of specific biofuel sources and production processes in calculating total GHG emissions for biofuel from various sources.

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Recently, the EU publicly announced that it would ban the import of palm oil, one of the biggest sources of GHG emissions among biofuel feedstocks, for use in biofuel as part of the EU's plan to increase biofuel use while keeping environmental sustainability in view [2]. This is the hottest issue in the biofuel market because it is not simply the ban of a feedstock in the EU but is regarded as a trade war between the EU and Indonesia. This is also a thought-provoking global trend, which may have important implications for energy policy in Korea. The issue of biofuel carbon neutrality was raised at the establishment of the RFS program in 2013 and has been acknowledged by the Korean government and related agencies, but the RFS program has not been modified to address this issue.

The purpose of this project, therefore, is to investigate approaches to use of biofuel in the US and the UK, to evaluate Korea's current energy policies related to biofuel in comparison to the policies of the US and UK, and to make recommendations for strengthening Korea's energy policy. This project addresses only policies for use of biodiesel rather than ethanol (widely used in the US) because ethanol is not used in Korea.

1.2. Biofuel in the World Energy Supply

Together, biofuel, ethanol, and biodiesel provides approximately 3% of world road transport fuel as of 2018. Figure 1 shows the share of the worldwide energy provide by traditional, modern, and non-biomass sources in 2015, when about 2.6% of biofuel was provided to the world transportation sector, including aviation [3].

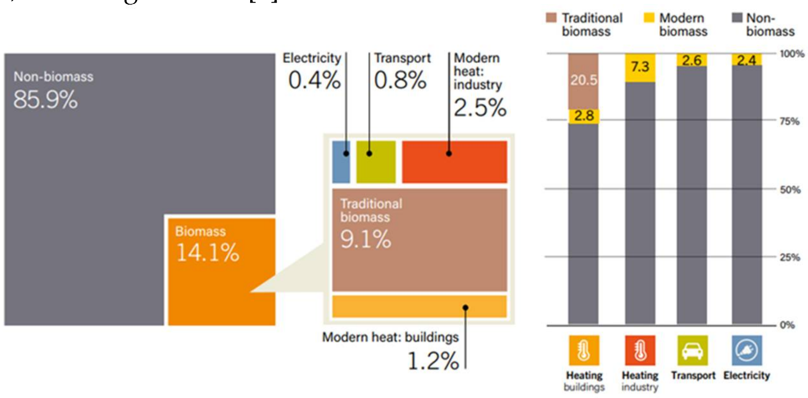

Figure 1. Shares of biomass in total final energy consumption and in final energy consumption, by end-use sector, 2015 [3].

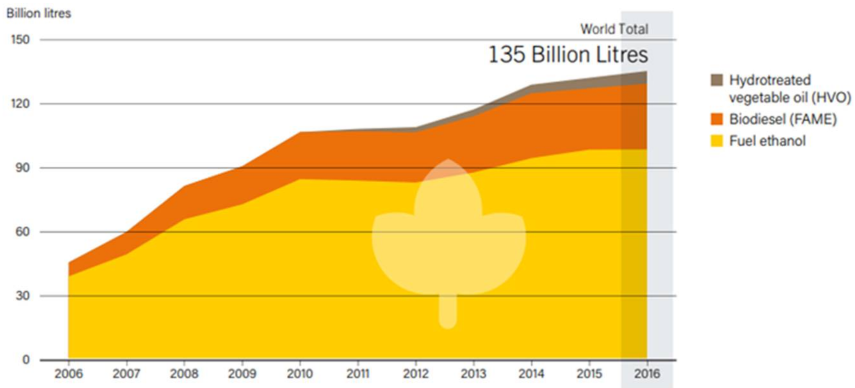

Figure 2. Global trends in ethanol, biodiesel (FAME, Fatty acid methyl ester) and HVO (Hydrotreated vegetable oil) Production, 2006-2016 [3].

In 2016, the US and Brazil were the largest biofuels producers and accounted for 70% of all biofuels between them, followed by Germany, Argentina, China, and Indonesia. As shown in Figure 2, an estimated 72% of biofuel production was ethanol, 23% biodiesel, and 4% was hydrotreated vegetable oil (HVO).

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According to the International Energy Agency (IEA)'s 450 Scenario[1], related to global warming, biofuel will provide about 17% of world transport demand for fuel, including in the aviation sector, through the development and deployment of advanced biofuels coming from waste, algae, and cellulosic feedstocks, which will be available from 2020. As shown in Figure 3, the 450 Scenario targets biofuel as the backbone of energy supply for electric vehicles by 2040, replacing crude oil and displacing the need for refined petroleum products, namely gasoline, diesel, and kerosene [4]. Before electric vehicles displace internal combustion engine vehicles, biodiesel will serve as a bridge between these vehicles for the time being.

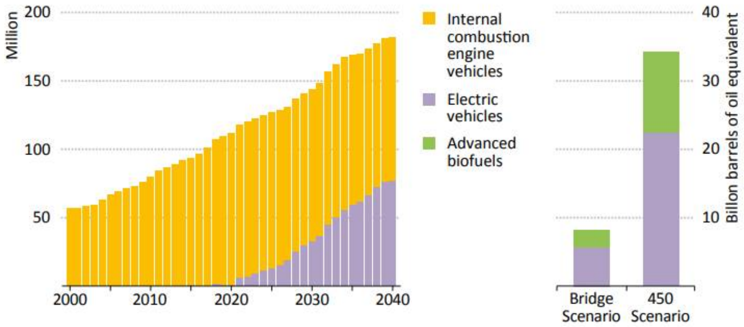

Figure 3. Global light-duty vehicle[2] sales by type in the 450 Scenario (left) and global cumulative oil savings resulting from use of electric vehicles and advanced biofuels, 2015-2040.

1.2.1. Biofuel in the US

As shown in Figure 4, a dramatic expansion of biofuels over time in the US can be broken down into three causes. The government firstly has subsidized bioethanol from corn to promote energy independence since the 1973 oil embargo. The next inducement is related to reduced oil imports after September 11, 2011. The last is the renewable fuel standard (RFS) program, passed by Congress in 2007, which imposed obligations on the part of oil refineries and importers to blend biofuel with conventional fuels [5]. Since 2007, the US has been the largest ethanol-producing country in the world, accounting for 15,800 million gallons in 2017 [6].

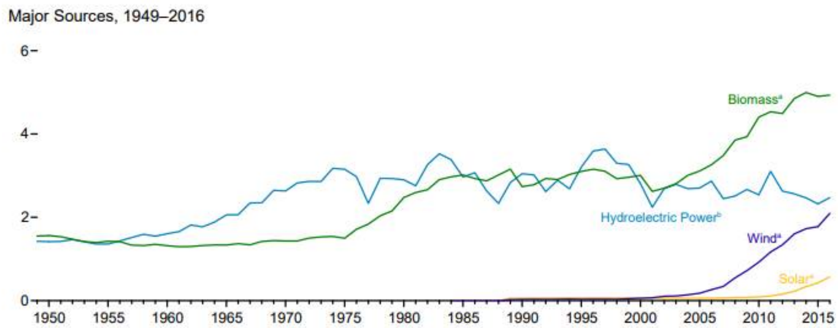

Figure 4. Renewable consumption, quadrillion Btu [7].

However, after the US aggressively expanded the production of biofuel in the 2000s, they, as well as the EU, were thrown into chaos by a new theory suggested by Princeton University and Nature Conservancy in 2008, that in spite of biofuel's many advantages, use of croplands for biofuels increases GHG when emissions from land use change (LUC) are factored into the equation [8, 9].

1. The 450 Scenario sets out an energy pathway consistent with the goal of limiting the global increase in temperature to 2°C by limiting concentration of greenhouse gases (GHGs) in the atmosphere to around 450 parts per million of CO_2eq.

2. Light-duty vehicles include passenger and commercial vehicles; internal combustion engine vehicles include hybrid, natural gas, and flex-fuel vehicles; electric vehicles include pure-electric and plug-in hybrids

 doi:10.20944/preprints201810.0400.v1

An increase in the consumption of biofuel feedstocks leads to the inevitable result of expanding new cropland in one of two ways: directly, when new cropland is created for the production of biofuel feedstocks, resulting in direct land use change, or DLUC, and indirectly, when existing cropland is used for biofuel feedstock production, forcing food, feed, and materials to be produced on new cropland elsewhere. This expansion is called indirect land use change, or ILUC. The study argued that scientists had ignored LUC emission and said that diverting land from its existing uses led to the sacrifice of carbon storage and sequestration [9]. The two largest biologically active stores of terrestrial carbon are soils and plant biomass, which have 2.7 times more carbon than the atmosphere [8]. These reports argued that biofuels from waste products, municipal waste, crop waste, and fall grass harvests from reserved lands could reduce GHG emissions more than biofuels from specially grown feedstocks [9].

1.2.2. Biofuel in the EU and UK

Before discussing the state of biofuel in the UK, it is necessary to discuss the EU's policies because most of the UK's renewable energy policy is connected with EU Renewable Energy Directive (RED). However, after Brexit, the UK seems to be shifting to a stance away from the EU. For example, the UK did not announce its exact stance on EU's ban of importing palm oil [10,11,12].

In addition to the impact of LUC on GHG emissions, the possibility also exists that diverting agricultural land to the production of feedstocks for biofuel will interfere with the production of food crops for human consumption. These concerns about ILUC and DLUC in the production of biofuel represent a significant dilemma for the EU as it seeks to increase the proportion of biofuel in the transportation fuel market. The EU RED (2009/28/EC) specifically ordered the European Commission to develop a methodology for accounting for the effect ILUC. However, ILUC is connected with other factors in agricultural markets at local levels as well as global ones, so it cannot be practically observed or measured [13].

As a result of these concerns about the sustainability of palm oil, in January 2018, the European Parliament proposed a ban on the use of vegetable oils like palm oil to produce biodiesel after 2020, which would represent a significant new direction in the EU's use of biofuels [10]. In 2016 and 2017, the EU was one of the largest palm oil importers in the world, importing about seven million tons. Consequently, this ban will also affect the economies of the EU's primary suppliers of palm oil, Indonesia and Malaysia, because these countries' economies depend on palm oil export, accounting for approximately 10% of Indonesia's total exports [14]. Moreover, 40% of palm oil producers in Indonesia are small business producers, so it is not easy for them to meet the criteria of sustainability demanded by the EU, and it is unclear whether any producer could do so [15]. According to the World Wildlife Fund (WWF) an area of rainforest the size of 300 football fields is destroyed every hour to make way for the growing of palm oil crops, a degree of LUC that is likely to have environmental consequences on a global scale [16]. However, as mentioned earlier, the UK still put off the answer on this critical issue.

1.2.3. Biofuel in Korea

Last January, the Korean government announced that the blending ratio of the RFS would be increased from 2.5% biofuel (B2.5) to 3% biofuel (B3) from 2018 [17]. In response, some of the nation's media said that increasing the blend ratio would go against the global trends, especially the EU's decision, and pointed out a lack of sustainability of biodiesel in Korea [18]. In addition, it was argued that this policy would increase the cost of fuel [19, 20].

Korea was the first nation in Asia to introduce a standard for renewable fuel [21]. However, Korea's RFS does not have a long-term master plan and has a relatively lower blend ratio than other counties. For example, the blend ratio for biodiesel in Korea has just become B3, while in Thailand, the current mandatory blend ratio is B7. Also, unlike the US and the UK, Korea does not have sustainability and carbon-saving criteria [22].

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2. Data and Methods

This research paper covers environmental sustainability. Here, sustainability criteria, according to Renewable Energy Directive (RED), is to ensure that the use of biofuels is done in a way that guarantees real carbon savings and protects biodiversity [23].

To consider the sustainability of biofuel usage, the lifecycle-criteria of programs, Renewable Fuel Standard (RFS) of the US and Renewable Transport Fuel Obligation (RTFO) of the UK, was examined to determine an implication for the related program of Korea. In addition, software which shows the total greenhouse gas (GHG) emissions from biofuel cultivation to biofuel pump, as calculated by the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model suite (2014 version) developed by the Argonne National Laboratory. GREET 2017, and the UK & Ireland carbon calculation were used to calculate how much GHG would be emitted into the air by biofuel in Korea as well.

3. Results

Using biofuel leads to environmental and ethical disputes on the production of biodiesel, called the sustainability issue. In the US, UK, and EU, using biodiesel has been regarded as not perfectly carbon neutral. For example, DeCicco evaluated cumulative carbon uptake on US farmlands and CO_2 emission from burning biofuel from 2005-2013. During this period, DeCicco found that CO_2 uptake by plants was only 37% of CO_2 emitted from biofuels, a result that is far from carbon-neutral [5]. In regard to this, the carbon savings and sustainability criteria from the US and UK will be studied and considered to apply to the Korea RFS program.

3.1. Sustainability of Biodiesel in the US

The US government is trying to expand the nation's renewable fuel sector by reducing both GHG and reliance on imported oil. State and Alternative Fuel Provider Fleet Program of the Department of Energy and the RFS of the Environmental Protection Agency (EPA) are the main programs to reduce GHG; both require covered fleets to use alternative fuels, including biofuels [24]. However, these programs do not only require fleets to use biofuels, but mandates to the use of biofuels that meet their sustainability criteria. In 2010, the EPA established new fuel pathways to qualify for RFS, which is a specific combination of three components: feedstock, production process, and fuel type. Assessment of lifecycle GHG emissions is necessary to determine which fuel pathways can qualify [25]. The EPA's lifecycle GHG analyses include evaluation of all of the process energy and materials used in the production process (i.e., emissions from the storage and handling of the feedstock and fuels, DLUC, and ILUC) as in Figure 5.

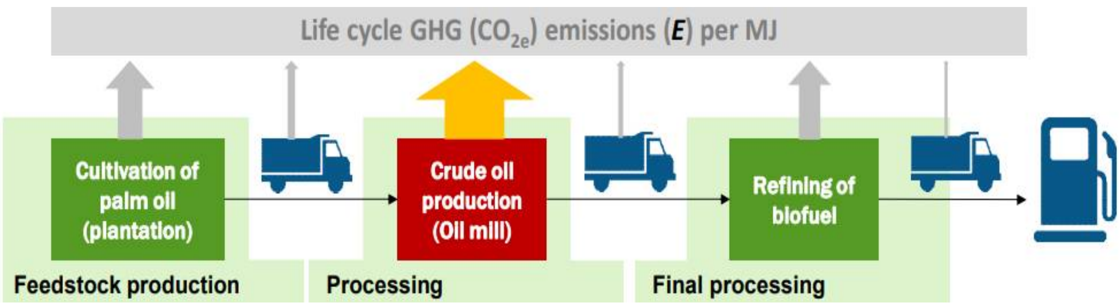

Figure 5. Palm oil-based biofuel's life cycle GHG [26].

To qualify for RFS, fuels must reduce GHG emissions compared to a 2005 petroleum baseline. As shown in Figure 6, the EPA has approved fuel pathways under the RFS program for renewable, advanced, biodiesel, and cellulosic fuels. As Figure 6 shows, advanced and biodiesel fuels must achieve a GHG reduction of 50% compared to petroleum use in order to qualify.

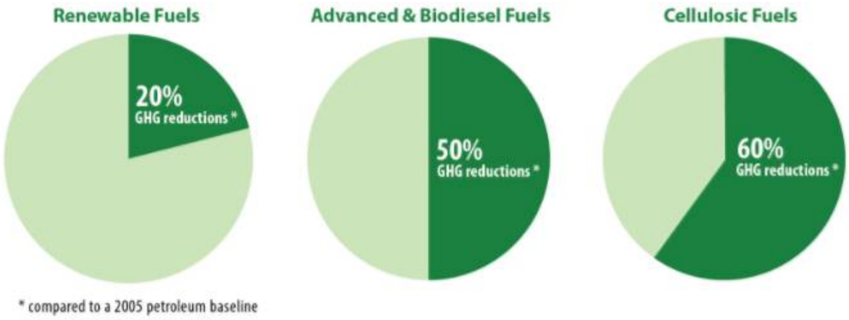

Figure 6. Lifecycle GHG emissions [27].

Table 1. Lifecycle analysis GHG results for select pathways (kg CO_2eq/mmBtu).

Feedstock	Production process	Ag. impact	Land use change	Feedstock transport	Fuel production	Fuel dist. & use	Net emissions	% reduction
Algal oil	Transesterification (Open pond, mid)	0.0	0.0	0.0	31.5	1.5	33.0	66%
	Transesterification (PBR, mid)	0.0	0.0	0.0	26.3	1.5	27.8	71%
Canola oil	Transesterification	8.2	33.9	1.6	2.9	1.5	48.1	50%
Cellulose from corn stover	Fischer-Tropsch process	11.6	-11.2	1.2	5.4	2.0	9.0	91%
Palm oil	Transesterification	4.8	46.1	1.3	25.1	3.4	80.7	17%
	Hydrotreating	4.8	46.8	2.0	30.9	2.2	86.7	11%
Soy bean oil	Transesterification	-8.8	33.6	2.7	13.2	1.5	42.2	57%
Switch-grass	Fischer-Tropsch process	6.5	13.1	1.6	5.4	2.0	28.6	71%
Yellow grease	Transesterification	0.0	0.0	2.7	9.6	1.5	13.8	86%
Petroleum	Refining	0.0	0.0	0.0	18.0	79.0	97.0	0%

Table 1 shows the lifecycle analysis of GHG resulting from various feedstocks [28]. The EPA's analysis found that biodiesel and renewable diesel produced from palm oil have estimated lifecycle GHG emission reductions of 17% and 11%, respectively, compared to the baseline petroleum diesel fuel they replace. These biofuels, therefore, fail to meet minimum GHG emissions reduction threshold of 50% set by the Energy Independence and Security Act (EISA) for renewable fuel made in facilities constructed after December 19, 2007 [29, 30].

Analysis by the EPA highlights a number of key factors which contribute to the lifecycle emissions estimates for biofuels based on palm oil. For example, a process of palm oil production causes wastewater effluent that creates methane (CH_4), a GHG with a high global warming potential. Expanding the expected palm plantations onto land having carbon-rich peat soils is another important factor, as destruction of carbon-rich soils causes greater emissions of GHGs to the atmosphere [29].

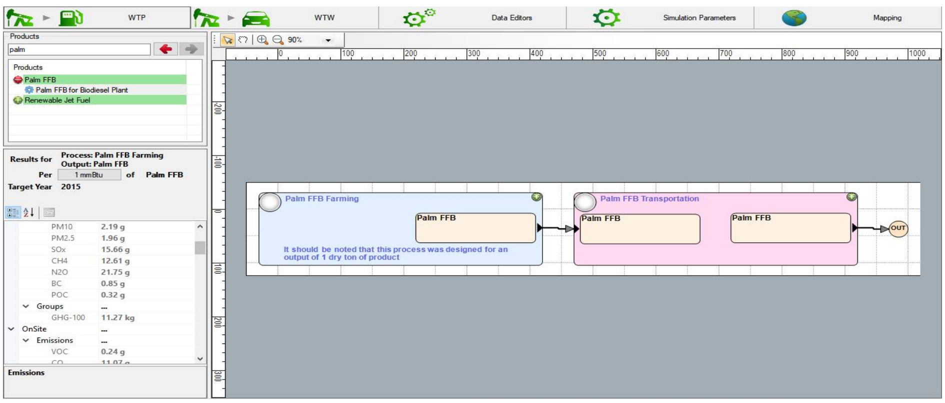

Figure 7. Palm fresh fruit bunches (FFB) lifecycle from GREET 2017.

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Figure 7, above, shows the lifecycle GHG of palm oil-based biodiesel as calculated using GREET 2017. Palm oil-based biodiesel's GHG emission reduction from the GREET Excel version shown in Table 2 below is approximately 24.2 kg CO_2eq/mmBtu (= 10,723 + 13,468, the last ones of Table 2), in which LUC was not included. If the LUC 46.1 kg CO_2eq/mmBtu from Table 1 applies, the total GHG will be about 70.3 kg CO_2eq/mmBtu. This also cannot meet the minimum GHG emissions reduction threshold of 50%. GREET does not include LUC due to controversy in how to calculate it.

Table 2. Palm oil-based biodiesel emissions (g CO_2eq/mmBtu).

Emissions	Feedstock	Fuel
Loss factor		1.000
Unit	per mmBtu	per mmBtu
Total energy	73,005	243,951
Fossil fuels	72,341	184,803
Coal	1,802	10,100
Natural gas	43,444	127,123
Petroleum	27,095	47,579
Water consumption	3.575	4.651
VOC	5.904	5.430
CO	12.704	11.621
NOx	0.000	68.841
PM10	2.004	5.230
PM2.5	1.754	4.664
SOx	14.471	39.803
BC	0.705	0.802
OC	0.302	1.757
CH_4	12.373	29.676
N_2O	19.659	0.170
CO_2	5,104	12,498
CO_2 (w/ C in VOC & CO)	5,143	12,533
GHGs	10,723	13,468

According to the Argonne National Laboratory, the value 24.2 kg CO_2eq/mmBtu, palm oil-based biodiesel's GHG emission, is the result of the assumption that CH_4 coming from palm oil mill effluent is captured. However, some of the CH_4 was not collected and instead discharged into the environment from production sites in Southeast Asian countries due to the cost of capturing it. Therefore, 24.2 kg CO_2eq/mmBtu is the minimum value, and the palm oil-based biodiesel's GHG emission would increase more when considered CH_4 uncaptured and LUC.

3.2. Sustainability of Biodiesel in the UK

As mentioned earlier, the EU, including the UK, faces the dilemma of how to expand biofuel to their markets due to the issue of sustainability of feedstock using raw materials obtained from land with high biodiversity value. As a result of this issue, the EU keeps tightening the rules for use of biofuel, including the recent ban of palm oil. Lately, private companies in the UK moved in advance to ban palm oil. Iceland Foods, a major grocery store chain of the UK, even announced it would stop using palm oil in its own food products, while the UK still avoids officially announcing its opinion on whether the UK would support the EU over the Indonesian palm oil trade dispute [10, 11]. However, regardless of despite this uncertainty, since 2015, none of the biodiesel based on palm oil has been consumed [32].

Although the UK has not yet supported the EU's ban of palm oil imports, the Renewables Obligation (RO) and the RTFO, which are related to providing biofuel and helping the UK meet its target that 15% of energy will come from renewable sources by 2020, are connected with the

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Renewable Energy Directive (RED), establishing an overall policy for the production and promotion of energy from renewable sources in the EU. Under the RED, operators using bioliquids in the EU, as well as the UK, must meet specified carbon intensity (CI) sustainability criteria to be eligible for support under national schemes [33, 34].

As shown in Table 3, according to the RO sustainability criteria, from January 1, 2018, onwards, the percentage saving required against the fossil fuel comparator will be determined by whether the bioliquid was produced in an installation that started bioliquid production before January 1, 2017. If so, the saving required against the fossil fuel comparator will be 50%. If not, then the saving required will be 60% [33].

Table 3. GHG thresholds for bioliquids [36].

	Before Jan. 1, 2017	Jan. 1 ~ Dec. 31, 2017	On or after Jan. 1, 2018	
			For bioliquids produced in an installation that started producing bioliquid before Jan. 1, 2017	For bioliquids not produced in an installation that started producing bioliquid before Jan. 1, 2017
GHG emission threshold	35%	50%	50%	60%

As the RED's Directive 2009/28/EC for biofuels describes, the fossil fuel comparator should be the latest available actual average emissions from the fossil part of petrol and diesel consumed in the community as reported under Directive 98/70/EC. If no such data is available, the value used should be 83.8 g CO_2eq/MJ [34]. The RTFO guidance also provides the same fossil fuel comparator value.

Table 4. Bioliquid default carbon intensities and disaggregated default values [33].

Bioliquid production pathway	Default CI [gCO_2eq/MJ]	Disaggregated default values [gCO_2eq/MJ]			GHG saving [%]
		Cultivation	Processing	Transport & distribution	
Palm oil biodiesel (process not specified)	68	14	49	5	19
Rape seed biodiesel	52	29	22	1	38
Soybean biodiesel	58	19	26	13	31
Waste vegetable or animal biodiesel	14	0	13	1	83

The RTFO guidance, as shown in Table 4, provides each biodiesel's default CI. Palm oil biodiesel's CI is 72 kgCO_2eq/mmBtu (68 gCO_2eq/MJ), and this has approximately the similar value as the EPA's (81 kgCO_2eq/mmBtu). In the UK as in the US, palm oil-based biodiesel's GHG savings of 19% also cannot meet the 50% threshold.

Besides CI, the RTFO administrator, the Secretary of State for Transport, requires the program obligators, biofuel suppliers, to submit verified data regarding the sustainability of the biofuel they supply. In detail, most of the requirements and criteria of the sustainability, comprised of the Nomenclature of Territorial Units for Statistics (NUTS2), biodiversity, carbon stock and peatlands, and cross compliance, are connected with the EU's RED.

First, obligators of the RTFO should demonstrate that feedstocks were sourced from a region where typical GHG emissions associated with their cultivation can be expected to be equal to or lower than the RED GHG default values (Appendix A). Regions are defined at the NUTS2 for the French nomenclature d'unités territoriales statistiques, level [35].

Second, to meet biodiversity criteria, as per land requirements of the RED, biofuels may not be made from raw material coming from land with a high biodiversity value at any point during or since

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January 2008 [35]. Here, high biodiversity value means primary forest and other wooded land, namely forest and other wooded land of native species, where there is no clearly visible indication of human activity, and the ecological processes are not significantly disturbed (Appendix B). The EU also adopted a regulation on the definition of highly biodiverse grasslands, namely grassland that would remain grassland in the absence of human intervention, on December 8, 2014, which applies from October 1, 2015.

Third, biofuels may not be made from raw materials obtained from land with high carbon stock or land that was undrained peatland, like wetlands and forests, in January 2008, unless strict criteria are met (Appendix B).

Last, biofuel feedstocks grown in the European community must be cultivated according to the European Commission's "Cross Compliance" requirements and the minimum requirements for good agricultural and environmental condition (Appendix C).

The RTFO program aggressively tries to introduce biofuel as being less controversial and as providing benefits to obligators using feedstock-like waste and residues. Under the RED, of biodiesel feed materials, wastes, residues, non-food cellulosic material, and ligno-cellulosic material are double counted towards suppliers' obligations. This means that one liter of biofuel produced from wastes/residues will receive two Renewable Transport Fuel Certificates (RTFC).

Table 5 below explains carbon and sustainability reporting data that fuel suppliers should report to the RTFO administrator. This reporting is crucial to explain compliance with the RED sustainability criteria and to gain RFTCs. As mentioned above, the requirements are GHG savings, NUTS2, biodiversity, and carbon stock.

Table 5. Illustrative carbon and sustainability reporting data [35].

General Infor.				Country of origin infor.		Land use	CI	Indirective RED compliance			
Con. No.	Fuel type	Biofuel feedstock	Production process	Country of origin	NUTS2 compliance	Land use on Jan. 1, 2008	Carbon intensity	GHG	Biodiversity	C-stock	RED compliance
1	Bioethanol	Wheat	Unk.	UK	Y	Cropland-protected	70	N	Y	Y	N
2	Bioethanol	Wheat	Natural gas CHP	Croatia	HRO4	Cropland-protected	44	N	Y	Y	N
3	Bioethanol	Bio-gasses	-	Brazil	N/A	-	35	Y	N	N	N
4	Biodiesel	Oilseed rape	-	UK	Y	Cropland-non-protected	52	N	Y	Y	N
5	Biodiesel	UCO	-	Waste/non-ag.residue	N/A	Waste/non-ag.residue	14	Y	Y	Y	Y
6	Biogas	Dry manure	-	Waste/non-ag.residue	N/A	Waste/non-ag.residue	15	Y	Y	Y	Y

For example, the feedstock in consignment 04 above was cultivated in a compliant NUTS2 region, and had no land-use change, and the cropland-nonprotected was reported. The carbon default of 52 gCO_2eq/MJ can be reported. However, it does not meet the GHG saving threshold of 50% introduced from 1 January 2017. It, therefore, does not meet the GHG saving. The oilseed rate met the Red Tractor and ISCC schemes, which both demonstrate compliance with the carbon stock and biodiversity criteria. Overall, the biofuel scores an 'N' for RED compliance, as there is no compliance with the GHG criteria.

In Table 4, palm oil biodiesel's (process not specified) GHG savings cannot meet the threshold, 50%. Yet if companies producing biodiesel from palm oil apply a way to capture CH_4 (the last one of Table 6), they can meet the threshold. The CI of biodiesel (Methyl ester) from palm is 37 gCO_2eq/MJ, a 56% carbon savings, which can meet the threshold, 50%.

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Table 6. Process default values [36].

Fuel	Feedstock	Process characteristic	CI (gCO_2eq/MJ)	Carbon saving (%)
Bioethanol, ETBE, TAME	Corn (produced within the EU)	Natural gas a process fuel in CHP plant	43	49
	Wheat	Lignite as process fuel in CHP plant	70	16
		Natural gas as process fuel in conventional boiler	55	34
		Natural gas as process fuel in CHP plant	44	47
		Straw as process fuel in CHP plant	26	69
Biodiesel (Methyl ester)	Palm	Methane capture at oil mill	37	56
Biodiesel (HVO)	Palm	Methane capture at oil mill	29	65

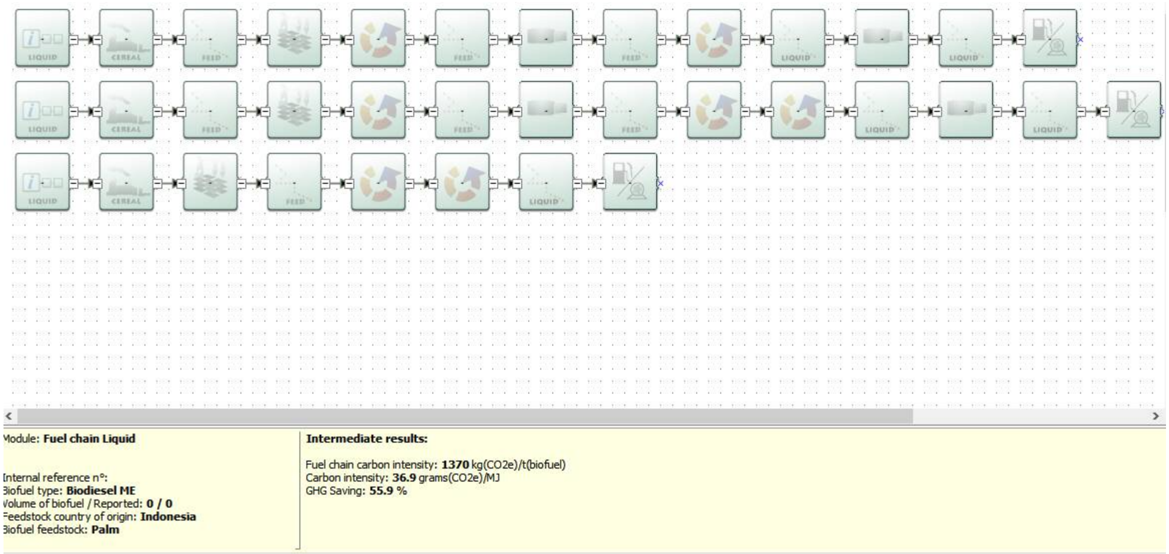

Figure 8. Illustrative carbon and sustainability reporting data.

Figure 8 shows the UK & Ireland carbon calculator, which is used by fuel suppliers to reduce the potential for errors during calculating CI, used by the Department of Transportation. This software shows the biodiesel's (Methyl ester) fuel lifecycle and CI and shows the carbon intensity is 36.9 gCO_2eq/MJ, almost exactly the same as from Table 6.

To expand the qualified yearly biofuel volume, the UK mandates obligators to supply biofuel and requires that they also meet the specific sustainability criteria. In April 2018, the RTFO announced it would increase the biofuel volume target to 9.75% in 2020 and 12.4% in 2032 from the current 4.75%. An initial cap of 4% crop-based biofuel is set for 2018. The cap will be reduced annually from 2021 to reach 3% in 2026 and 2% in 2032 [37].

3.3. Sustainability of Biodiesel in Korea

The RFS program of Korea does not have specified carbon savings and sustainability criteria for biofuels, unlike the US and UK, who have, individually, their own criteria, like fuel pathway and sustainability. In other words, if a supplier in Korea provides 1000 liters of biodiesel to a pump, GHGs corresponding to that volume will be reduced regardless where the biodiesel came from and how much GHGs will be emitted during the fuel's lifecycle. This aspect of the RFS program in Korea

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therefore does not follow the international standard of considering the overall sustainability of the biodiesel lifecycle.

Table 7. Law material proportion of biodiesel in Korea, 10^3 ton [38].

Feedstock		2006	2008	2010	2012	2014	2015
Domestic	UCO	16	57	78	121	144.3	147.1
	Tallow	-	-	-	-	14.9	27.4
	Others	0.4	0.1	-	-	5.3	4.5
	Subtotal	16.4	57.1	78	121	164.5	179.0
Imported	Soybean	46	69	80	19	3.5	2.8
	Palm fatty acid distillate(PFAD)	-	30	102	136	154.8	169.6
	Palm oil	-	34	69	62	21.4	28.3
	UCO	-	0.1	25	38	34.8	34.5
	Tallow (Beef)	-	-	-	-	-	-
	Others	-	16	4	9	5.2	7.1
	Subtotal	46	149.1	280	264	219.7	242.3
Total		62.4	149.1	280	385	384.2	421.3
Localization rate		26.3	27.7	21.8	31.4	42.8	42.5

Table 7 above shows the provided biodiesel by feedstock and year from 2006 to 2015 [38]. Domestic used cooking oil (UCO) and imported Palm fatty acid distillate (PFAD) have been the main feedstocks since 2010.

Of Korea's total domestic biodiesel in 2015, 35% was UCO, which represents an increasing percentage of Korea's biodiesel. According to the RTFO part two C&S, the CI of biodiesel from used cooking oil (UCO) is 14 gCO_2eq/MJ, an 83% carbon saving, which is one of the lowest CIs of the biodiesels. The Korean government plans to increase the role of UCO in Korea's biodiesel portfolio.

Of the total biodiesel used domestically in Korea, palm oil and PFAD accounted for approximately 47% in 2015. Although the percentage of the palm oil and PFAD has been reduced since 2010, these two materials will be the main sources used in the RFS program for the time being. As explained above, palm oil and PFAD derived from Indonesia and Malaysia are high lifecycle GHG emitters. As a result, the EPA stated that palm oil biodiesel did not meet minimum GHG reductions, and the EU also will phase out palm oil from its biofuel program by 2020. Considering this, the biodiesel portfolio of Korea, which mainly uses palm oil and coproducts, presents concerns related to the lifecycle GHG emissions of biodiesel.

What is somewhat fortunate is that the percentage of palm oil, which has been a serious issue in EU, is only about 7% of the total biodiesel in Korea. However, PFAD also has issues in some of the northern European countries Norway and Sweden. They proposed to limit PFAD by reclassifying palm oil feedstocks as coproducts rather than residues, which can be considered to emit relatively lower GHGs. The reason for this reclassification is that they are concerned about the too low GHG savings currently calculated for PFAD-derived HVO biodiesel, 29gCO_2eq/MJ. PFAD, according to the Argonne National Laboratory, is the hottest energy source and is still a controversial issue because there is a great discrepancy between the CIs depending on if PFAD is classified as a residue or coproduct.

Table 8 below shows the result of GHG emissions from biodiesel use in 2015, when the CI criteria of the UK was applied. The domestic GHGs by biodiesel in Korea are zero due to the absence of CI criteria for biodiesel. However, as a result of calculating the GHG emissions with the RTFO's CI criteria, the total GHG emissions were 342.1 10^3tCO_2eq, which accounts for about 4% of the domestic transportation GHG emissions in 2015 [39]. Here, the CI unit (gCO_2eq/MJ) coming from the RTFO was changed to a new one (tCO_2eq/t) (biofuel) due to the provided domestic biodiesels being given by the ton unit.

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Table 8. GHG emissions of biodiesel usage in Korea.

	2015		CI (gCO_2eq/MJ)[3]	CI $(tCO_2eq/t(biofuel)$[4]	GHG emissions $(10^3\ tCO_2eq)$
	10^3ton	Percent			
UCO	181.6	43%	14	471	85.5
PFAD	169.6	40%	29	1,280	217.1
Palm oil	28.8	7%	37	1,370	39.5
Others	41.5	10%	-	-	-
Total	421.5	100%			342.1

4. Discussion

As mentioned earlier, the US and UK have their own criteria for sustainability of using biodiesel due to its not being perfectly carbon neutral. Unfortunately, the Korean RFS program doesn't have any sustainability criteria or requirements for carbon savings. At the beginning of the program, the government tried to establish that, but the RFS is still operating without it.

Of the two countries' sustainability criteria, if the UK's would be applied to the Korean program, biodiesel used in Korea in 2015 would emit 342.1 10^3tCO_2eq GHG, which would account for about 4% of the domestic transportation GHG emissions in 2015. PFAD, accounting for 40%, also has a significant issue regarding sustainability in the EU, although this feedstock is not categorized as a coproduct but residue so that its GHG is relatively lower than palm oil. However, some countries tried to recategorize this feedstock to reduce usage in their countries. When considering these issues, the Korean government should consider introducing the UK and US sustainability criteria to reduce the use of biodiesel base on crops and to regard biofuel as not perfectly carbon-neutral.

5. Conclusions

Last April 2018, the EU tightened the rule of using biofuel by banning palm oil. The EU, which is the birthplace of climate change, has reviewed the biofuel's carbon neutrality since the 2000s, and they put their theory into practice recently. However, Korea, which emitted 585 million tCO_2 in 2015, seventh in total emissions by country rank, does not have the carbon saving and sustainability criteria. When applying the UK's carbon savings, Korea in 2015 would emit 4% of the domestic transportation GHG emissions by using biodiesel. Also, the government does not consider the feedstock's lifecycle GHG. Therefore, the introduction of the RFS program including new criteria should be considered urgent.

Author Contributions: The authors have contributed to the article accordingly; conceptualization, J.-Y.S. and K.-Y.K.; methodology, J.-Y.S., K.-Y.K., and J.Z; software, J.-Y.S. and K.-Y.K.; investigation, J.-Y.S., G.-W.K., and J.Z; writing-original draft preparation, J.-Y.S; writing-review and editing, J.-Y.S., G.-W.K., K.-Y.K., and J.Z; supervision, J.-Y.S., K.-Y.K.

Funding: This work was supported by the Dongguk University Research Fund of 2018 (S-2018-G0001-00066).

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

3. RTFO guidance part two carbon & sustainability
4. UK & Ireland carbon calculation

 doi:10.20944/preprints201810.0400.v1

Appendix A

Directive 2009/28/EC of the European Parliament and of the council of 23 April 2009[5]
Annex V

Rules for calculating the greenhouse gas impact of biofuels, bioliquids and their fossil fuel comparators
D. Disaggregated default values for biofuels and bioliquids
Total for cultivation, processing, transport and distribution

Biofuel and bioliquid production pathway	Typical greenhouse gas emissions (gCO_2eq/MJ)	Default greenhouse gas emissions (gCO_2eq/MJ)
Sugar beet ethanol	33	40
Wheat ethanol (process fuel not specified)	57	70
Wheat ethanol (lignite as process fuel in CHP plant)	57	70
Wheat ethanol (natural gas as process fuel in conventional boiler)	46	55
Wheat ethanol (natural gas as process fuel in CHP plant)	39	44
Wheat ethanol (straw as process fuel in CHP plant)	26	26
Corn (maize) ethanol, Community produced (natural gas as process fuel in CHP plant)	37	43
Sugar cane ethanol	24	24
The part from renewable sources of ETBE	Equal to that of the ethanol production pathway used	
The part from renewable sources of TAEE	Equal to that of the ethanol production pathway used	
Rape seed biodiesel	46	52
Sunflower biodiesel	35	41
Soybean biodiesel	50	58
Palm oil biodiesel (process not specified)	54	68
Palm oil biodiesel (process with methane capture at oil mill)	32	37
Waste vegetable or animal oil biodiesel	10	14
Hydrotreated vegetable oil from rape seed	41	44
Hydrotreated vegetable oil from sunflower	29	32
Hydrotreated vegetable oil from palm oil (process not specified)	50	62
Hydrotreated vegetable oil from palm oil (process with methane capture at oil mill)	27	29
Pure vegetable oil from rape seed	35	36
Biogas from municipal organic waste as compressed natural gas	17	26
Biogas from wet manure as CNG	13	16
Biogas from dry manure as CNG	12	15

5. http://eur-lex.europa.eu/legal-content/E13N/TXT/PDF/?uri=CELEX:32009L0028&from=EN

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Appendix B

Directive 2009/28/EC of the European Parliament and of the council of 23 April 2009[6]

Article 17

Sustainability criteria for biofuels and bioliquids

1. Irrespective of whether the raw materials were cultivated inside or outside the territory of the Community, energy from biofuels and bioliquids shall be taken into account for the purposes referred to in points (a), (b) and (c) only if they fulfil the sustainability criteria set out in paragraphs 2 to 6:

(a) Measuring compliance with the requirements of this Directive concerning national targets;

(b) Measuring compliance with renewable energy obligations;

(c) Eligibility for financial support for the consumption of biofuels and bioliquids.

However, biofuels and bioliquids produced from waste and residues, other than agricultural, aquaculture, fisheries and forestry residues, need only fulfil the sustainability criteria set out in paragraph 2 in order to be taken into account for the purposes referred to in points (a), (b) and (c).

2. The greenhouse gas emission saving from the use of biofuels and bioliquids taken into account for the purposes referred to in points (a), (b) and (c) of paragraph 1 shall be at least 35 %. With effect from January 1, 2017, the greenhouse gas emission saving from the use of biofuels and bioliquids taken into account for the purposes referred to in points (a), (b) and (c) of paragraph 1 shall be at least 50 %. From January 1, 2018 that greenhouse gas emission saving shall be at least 60 % for biofuels and bioliquids produced in installations in which production started on or after January 1, 2017. The greenhouse gas emission saving from the use of biofuels and bioliquids shall be calculated in accordance with Article 19 (1). In the case of biofuels and bioliquids produced by installations that were in operation on January 23, 2008, the first subparagraph shall apply from April 1, 2013.

3. Biofuels and bioliquids taken into account for the purposes referred to in points (a), (b) and (c) of paragraph 1 shall not be made from raw material obtained from land with high biodiversity value, namely land that had one of the following statuses in or after January 2008, whether or not the land continues to have that status:

(a) Primary forest and other wooded land, namely forest and other wooded land of native species, where there is no clearly visible indication of human activity and the ecological processes are not significantly disturbed;

(b) Areas designated:

(i) By law or by the relevant competent authority for nature protection purposes; or

(ii) For the protection of rare, threatened or endangered ecosystems or species recognized by international agreements or included in lists drawn up by intergovernmental organizations or the International Union for the Conservation of Nature, subject to their recognition in accordance with the second subparagraph of Article 18(4);

unless evidence is provided that the production of that raw material did not interfere with those nature protection purposes;

(c) Highly biodiverse grassland that is:

(i) Natural, namely grassland that would remain grassland in the absence of human intervention and which maintains the natural species composition and ecological characteristics and processes; or

(ii) Non-natural, namely grassland that would cease to be grassland in the absence of human intervention and which is species-rich and not degraded, unless evidence is provided that the harvesting of the raw material is necessary to preserve its grassland status.

The Commission shall establish the criteria and geographic ranges to determine which grassland shall be covered by point (c) of the first subparagraph. Those measures, designed to amend nonessential elements of this Directive, by supplementing it shall be adopted in accordance with the regulatory procedure with scrutiny referred to in Article 25(4).

6. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN

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4. Biofuels and bioliquids taken into account for the purposes referred to in points (a), (b) and (c) of paragraph 1 shall not be made from raw material obtained from land with high carbon stock, namely land that had one of the following statuses in January 2008 and no longer has that status:

(a) Wetlands, namely land that is covered with or saturated by water permanently or for a significant part of the year;

(b) Continuously forested areas, namely land spanning more than one hectare with trees higher than five meters and a canopy cover of more than 30%, or trees able to reach those thresholds in situ;

(c) Land spanning more than one hectare with trees higher than five meters and a canopy cover of between 10% and 30%, or trees able to reach those thresholds in situ, unless evidence is provided that the carbon stock of the area before and after conversion is such that, when the methodology laid down in part C of Annex V is applied, the conditions laid down in paragraph 2 of this Article would be fulfilled.

The provisions of this paragraph shall not apply if, at the time the raw material was obtained, the land had the same status as it had in January 2008.

 doi:10.20944/preprints201810.0400.v1

Appendix C

Council Regulation (EC) No 73/2009 of 19 January 2009[7]
Annex III

Good agricultural and environmental condition referred to in Article 6

Issue	Compulsory standards	Optional standards
Soil erosion: Protect soil through appropriate measures	— Minimum soil cover — Minimum land management reflecting site-specific conditions	— Retain terraces
Soil organic matter: Maintain soil organic matter levels through appropriate practices	— Arable stubble management	— Standards for crop rotations
Soil structure: Maintain soil structure through appropriate measures		— Appropriate machinery use
Minimum level of maintenance: Ensure a minimum level of maintenance and avoid the deterioration of habitats	— Retention of landscape features, including, where appropriate, hedges, ponds, ditches trees in line, in group	— Minimum livestock stocking rates or/and appropriate regimes — Establishment and/or retention of habitats
	Avoiding the encroachment of unwanted veg — Protection of permanent pasture	— Prohibition of the grubbing up of olive trees — Maintenance of olive groves and vines in good vegetative condition
Protection and management of water: Protect water against pollution and run-off, and manage the use of water	— Establishment of buffer strips along water courses (1) — Where use of water for irrigation is subject to authorization, compliance with authorization procedures	

(1) Note: The GAEC buffer strips must respect, both within and outside vulnerable zones designated pursuant to Article 3(2) of Directive 91/676/EEC, at least the requirements relating to the conditions for land application of fertilizer near water courses, referred to in point A.4 of Annex II to Directive 91/676/EEC to be applied in accordance with the action programs of Member States established under Article 5(4) of Directive 91/676/EEC.

7. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009R0073&from=en

References

1. Union of Concerned Scientists. Each country's share of CO2 emission. Available online: https://www.ucsusa.org/global-warming/science-and-impacts/science/each-countrys-share-of-co2.html#.WurW3ogvzIU (accessed on 1 October 2018).
2. Chow, E.; Thukral, N. Malaysia to respond with 'might and tact' if EU proceeds with palm oil curbs. JakartaGlobe [Online] 7 March 2018. Available online: https://jakartaglobe.id/international/malaysia-respond-might-tact-eu-proceeds-palm-oil-curbs-minister/ (accessed on 1 October 2018).
3. *Renewables 2017 Global Status Report*; REN21 Secretariat: Paris, France, **2017**; pp. 45–51; ISBN 978-3-9818107-6-9.
4. *Energy and Climate Change: World Energy Outlook Special Report*; OECD/IEA: Paris, France, 2015. Available online: https://www.iea.org/publications/freepublications/publication/ WEO2015SpecialReportonEnergyandClimateChange.pdf (accessed on 1 October 2018).
5. DeCicco, J. Biofuels turn out to be a climate mistake – here's why. *The Conversation* [Online] 5 October **2016**; Available online: https://theconversation.com/biofuels-turn-out-to-be-a-climate-mistake-heres-why-64463 (accessed on 1 October 2018).
6. 2017 global fuel ethanol production by country [Chart] in *2018 Ethanol Industry Outlook*, Renewable Fuels Association (RFA): Washington, D.C, **2018**; p13. Available online: http://www.ethanolresponse.com/wp-content/uploads/2018/02/2018-RFA-Ethanol-Industry-Outlook.pdf (accessed on 1 October 2018).
7. Renewable energy consumption [Figure 10.1] in *Monthly Energy Review* September 2018. U.S. Energy Information Administration, Government Printing Office: Washington D. C., **2018**. Available online: https://www.eia.gov/totalenergy/data/monthly/pdf/sec10_2.pdf (accessed on 1 October 2018).
8. Fargione, J.; Hill, J.; Tilman, D.; Polasky, S.; Hawthorne, P. Land clearing and the biofuel carbon debt. *Science* **2008**, *319*, pp. 1235-1238. DOI: 10.1126/science.1152747
9. Searchinger, T.; Heimlich, R.; Houghton, R. A.; Dong, F.; Elobeid, A.; Fabiosa, J.; Tokgoz, S.; Hayes, D.; Yu T. Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. *Science*. **2008**, *319*, pp. 1238-1240. DOI: 10.1126/science.1151861
10. Neslen, A. UK defies EU over Indonesian palm oil trade. *The Guardian* [Online]. 9 March **2018**. Available online: https://www.theguardian.com/environment/2018/mar/09/uk-defies-eu-over-indonesian-palm-oil-trade-leaked-papers-show (accessed on 2 October 2018).
11. Richards, A. Iceland supermarket vows to ban palm oil in own-brand products. *Evening Standard* [Online] 10 April **2018**. Available online: https://www.standard.co.uk/news/uk/iceland-supermarket-vows-to-ban-palm-oil-in-ownbrand-products-a3810141.html (accessed on 2 October 2018).
12. Fredriksson, G.; Roth, A.; Tagliapietra, S.; Zachmann, G. *The Impact of Brexit on the EU Energy System*; IP/A/ITRE: Brussels, Belgium, **2017**; ISBN: 978-92-846-2255-9. Available online: http://www.europarl.europa.eu/ RegData/etudes/STUD/2017/614181/IPOL_STU(2017)614181_EN.pdf (accessed on 2 October 2018).
13. Valin, H.; Peters, D.; Van den Berg, M.; Frank S.; Havlik, P.; Forsell, N.; Hamelinck, C. *The Land Use Change Impact of Biofuels Consumed in the EU: Quantification of Area and Greenhouse Gas Impacts*; Ecofys: Utrecht, Netherlands, **2015**. Available online: https://ec.europa.eu/energy/sites/ener/files/documents/Final% 20Report_GLOBIOM_publication.pdf (accessed on 1 October 2018).
14. Observatory of Economic Complexity (OEC). Indonesia. Available online: https://atlas.media.mit.edu/en/profile/country/idn/ (accessed on 2 October 2018).
15. National Public Radio. Palm oil plantations are blamed for many evils. But change is coming. 21 April **2015**. Available online: https://www.npr.org/sections/goatsandsoda/2015/04/21/396815303/palm-oil-plantations-are-blamed-for-many-evils-but-change-is-coming (accessed on 2 October 2018).
16. Kim, G. J.; Lee, T. A. Palm oil: Issues of climate change and human right violations. *HuffPost* [Online] 6 April **2015**. Available online: https://www.huffingtonpost.com/grace-jisun-kim/palm-oil-issues-of-climat_b_7007354.html (accessed on 2 October 2018).
17. Yoon, B. H. The new government stresses renewable energy and will increase blend rate of biodiesel. EBN [Online] 27 July **2017**. Available online: http://www.ebn.co.kr/news/view/902953 (accessed on 2 October 2018).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 18 October 2018 doi:10.20944/preprints201810.0400.v1

18. Kim, B. H. Palm plantation indiscriminate felling... Emits three times more greenhouse gas emissions than diesel. *Korea Economy* [Online] 19 March **2018.** Available online: http://news.hankyung.com/article/2018031895191 (accessed on 2 October 2018).
19. Shim, N. Y. Let's reduce carbon. The diesel price will grow again next year. *Asia Economy* [Online] 21 October **2017**. Available online: http://www.asiae.co.kr/news/view.htm?idxno=2017102022481273270 (accessed on 2 October 2018).
20. Biodiesel rate will be increased in diesel. So, what about the price of oil. Yeonhap News [Online] 4 March **2015**. Available online: http://www.yonhapnews.co.kr/bulletin/2015/03/03/0200000000AKR20150303187100003.HTML (accessed on 2 October 2018).
21. Kang, K. J. $46 million additional burden is expected to refineries in Korea by RFS. JOINS [Online] 9 August **2015**. Available online: http://news.joins.com/article/18415013 (accessed on 2 October 2018).
22. An, Y. I. Can biofuel work to reduce GHGs? SBS News [Online] 25 February **2015**. Available online: https://news.sbs.co.kr/news/endPage.do?news_id=N1002850508 (accessed on 2 October 2018).
23. Sustainability of Bioenergy; Commission Staff Working Document: Impact Assessment; European Commission.: Brussels, Belgium, **2016**. Available online: https://ec.europa.eu/energy/sites/ener/files/documents/1_en_impact_ assessment_part4_v4_418.pdf (accessed on 2 October 2018).
24. Renewable Fuel Standard Program [Website]. U. S. Environmental Protection Agency (EPA), Last updated 19 September **2018**. Available online: https://www.epa.gov/renewable-fuel-standard-program (accessed on 2 October 2018).
25. Fuel pathways under renewable fuel standard. EPA, Last updated 6 June **2017**. Available online: https://www.epa.gov/renewable-fuel-standard-program/fuel-pathways-under-renewable-fuel-standard (accessed on 2 October 2018).
26. Enström, A. GHG Reduction with Solid Separation in POME Ponds: Introducing New Emission Factors for Alternative CH4 Reduction Techniques. Available online: https://www.iscc-system.org/wp-content/uploads/2017/08/2.-Reducing-the-Impact-of-Methane-Emissions-2.pdf (accessed on 2 October 2018).
27. Overview for renewable fuel standard. EPA, Last updated 7 June **2017**. Available online: https://www.epa.gov/renewable-fuel-standard-program/overview-renewable-fuel-standard#pathways (accessed on 2 October 2018).
28. Lifecycle greenhouse gas emissions for select pathways [Table]. EPA, **2016**. Available online: https://www.epa.gov/sites/production/files/2016-07/documents/select-ghg-results-table-v1.pdf (accessed on 2 October 2018).
29. EPA issues notice of data availability concerning renewable fuels produced from palm oil under the RFS program. EPA, Office of Transportation and Air Quality, **2011**. Available online: https://www.epa.gov/sites/ production/ files/2015-08/documents/420f11046.pdf (accessed on 2 October 2018).
30. Kotrba, R. US biodiesel production, imports remain strong amid uncertainty. *Biodiesel Magazine* [Online] 22 August **2017**. Available online: http://www.biodieselmagazine.com/articles/2516126/us-biodiesel-production-imports-remain-strong-amid-uncertainty (accessed on 2 October 2018).
31. Elgowainy, A.; Han, J.; Ward, J.; Joseck, F.; Gohlke, D.; Lindauer, A.; Ramsden, T.; Biddy, M.; Alexander, M.; Barnhart, S.; Sutherland, I.; Verduzco, L.; Wallington, T. J. Cradle-to-grave lifecycle analysis of US light-duty vehicle-fuel pathways: A greenhouse gas emissions and economic assessment of current (2015) and future (2025-2030) technologies; Argonne National Laboratory, Energy Systems Division: Chicago, USA, **2016**. Available online: https://greet.es.anl.gov/publication-c2g-2016-report (accessed on 2 October 2018).
32. Renewable Energy Association (REA) News. UK palm oil-based biodiesel consumption is zero to date in 2015/16. 31 May **2016**. Available online: https://www.r-e-a.net/news/uk-palm-oil-based-biodiesel-consumption-is-zero-to-date-in-2015-16 (accessed on 2 October 2018).
33. Renewables Obligation: Sustainability Criteria; Ofgem, Fuelling and Sustainability Team, Renewable Electricity: London, UK, **2016**. Available online: https://www.ofgem.gov.uk/system/files/docs/2016/03/ofgem_ro_ sustainability_criteria_guidance_march_16.pdf (accessed on 2 October 2018).

 doi:10.20944/preprints201810.0400.v1

34. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 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. Official Journal of the European Union, **2009**. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN (accessed on 2 October 2018).
35. Renewable Transport Fuel Obligation Guidance Part Two: Carbon and Sustainability Year 11: 15/4/18 to 31/12/18. Moving Britain Ahead; Department for Transport: London, UK, **2018**. Available online https://assets.publishing. service.gov.uk/government/uploads/system/uploads/attachment_data/file/694300/rtfo-guidance-part-2-carbon-and-sustainability-year-11.pdf (accessed on 2 October 2018).
36. Dark, M. Vehicle Licensing Statistics: Annual 2016. Department for Transport, **2017**. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/608374/vehicle-licensing-statistics-2016.pdf (accessed on 2 October 2018).
37. New UK biofuel targets take effects April 15. Revista RPAnews [Online] 17 April **2018**. Available online: Renewable Transport Fuel Obligation guidance part two carbon & sustainability online: http://revistarpanews. com.br/noticias/64-internacional/5748-new-uk-biofuel-targets-take-effect-april-15 (accessed on 2 October 2018).
38. Hong, W. A. Study on the Improvement of the Cold Properties of Biodiesel and Biodiesel-Blended. Master's Thesis, Seoul National University of Science and Technology, Seoul, Korea, **2017**. Available online: http://www.riss.kr/link?id=T14733130 (accessed on 2 October 2018).
39. National Greenhouse Gas Inventory Report of Korea; Greenhouse Gas Inventory and Research Center: Seoul, Korea, **2017**. Available online: http://www.gir.go.kr/home/board/read.do;jsessionid=Dl2BTno8jLQAFQTQLXOvEWZEB633Q2RJVbXS9E23Oc72O0xCM8JxzCNaDhjgVUEp.og_was_servlet_engine1?pagerOffset=0&maxPageItems=10&maxIndexPages=10&searchKey=&searchValue=&menuId=36&boardId=41&boardMasterId=2&boardCategoryId= (accessed on 2 October 2018).