M Road transport fuels

This appendix provides information on the use and characteristics of transport fuels used to support the Commission's analysis of biofuel policies and fuel taxes. It provides a brief overview of road transport fuel consumption and greenhouse gas emissions by study country. It also explains the Commission's use of life-cycle assessment for greenhouse gas emissions from transport fuels and details the specific estimates used in the analysis.

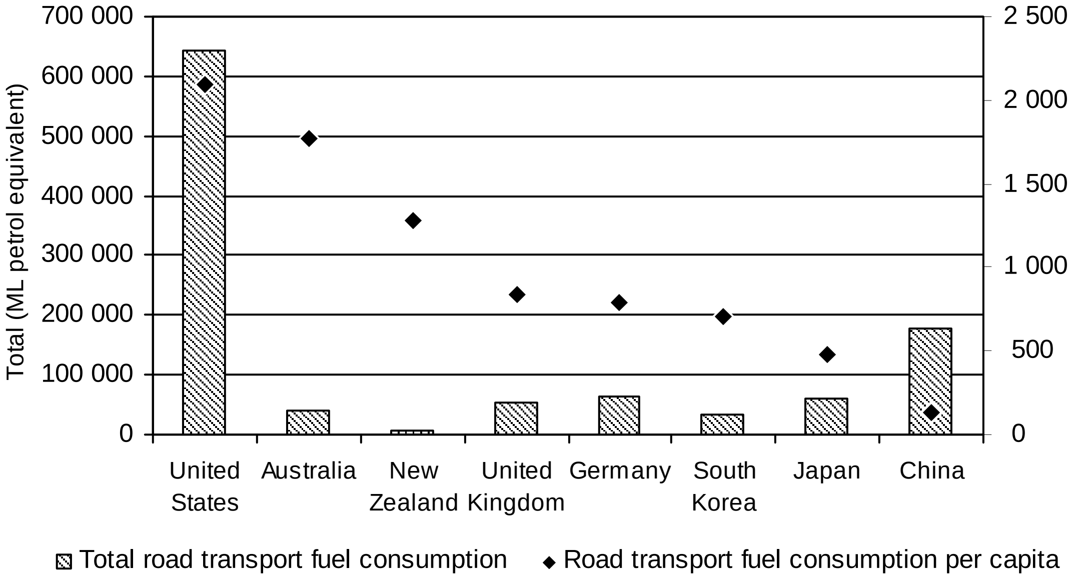
M.1 Transport fuel use

An understanding of the volume and composition of road transport fuel consumption in each of the study countries provides useful context for the analysis of fuel taxes and biofuel policies. Figure M.1 below shows total consumption of road transport fuel and fuel consumption per-capita in each of the study countries during the year of analysis. In absolute terms, the United States was by far the largest consumer of road transport fuel, using more fuel than all the other study countries combined.

On a per-capita basis, road transport fuel consumption varied greatly by study country. Again, the United States was the largest consumer, but this time followed closely by Australia and New Zealand. Per-capita fuel consumption was much lower in the European study countries and lower still in the developed Asian study countries. Despite relatively high total fuel consumption, China's per-capita figure was by far the lowest, at just seven per cent of the value for Australia. Differences in per-capita fuel consumption are attributable to variation in a number of factors including income per-capita, the spatial distribution of the population and economic activity, the availability of modal substitutes and the fuel-efficiency of vehicles.

Figure M.1 **Fuel consumption by country**

Total and per-capita, 2009-2010[a]



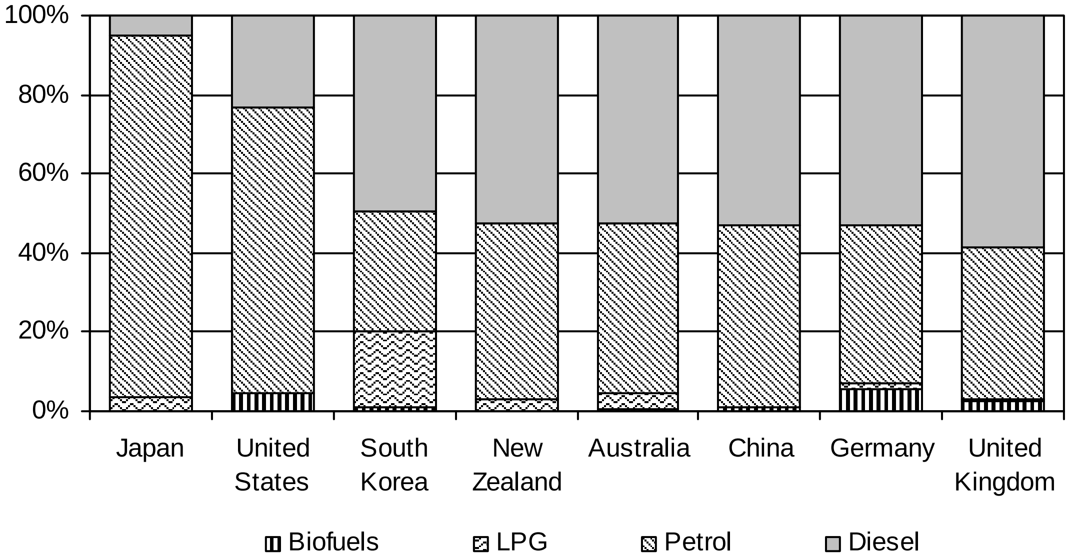
[a] Fuel consumption figures for each country reflect the annual estimate in the year of analysis for biofuel policies (appendix N).

Sources: UN (2011); Appendix N; Productivity Commission estimates.

The composition of road transport fuels consumed in each country is also instructive when considering the impact of transport policies. In the United States and Japan, petrol was the most commonly used fuel, whereas in all other study countries, diesel was the most commonly used fuel during the period of analysis (figure M.2). Consumption of liquefied petroleum gas (LPG) was highest in South Korea both in absolute terms and as a proportion of total fuel consumption. Japan, Australia and New Zealand were also significant consumers of LPG as a proportion of total fuel consumption. Consumption of biofuels (biodiesel, ethanol and vegetable oil) accounted for only a small share of total fuel consumption in each of the study countries.

Figure M.2 **Composition of fuel consumption by country**

2009-2010[a]



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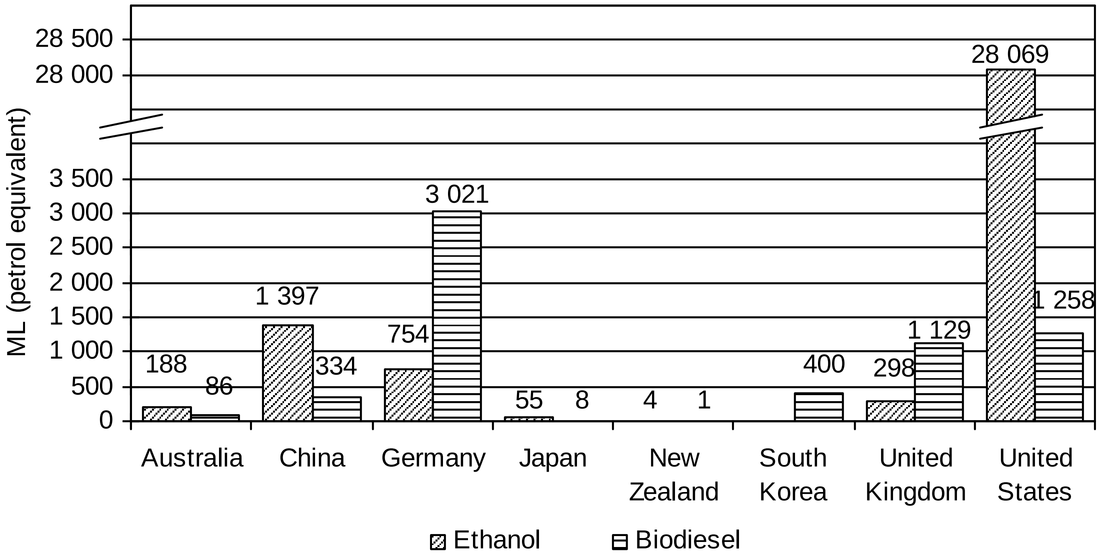
[a] Fuel consumption figures for each country reflect the annual estimate in the year of analysis for biofuel policies (appendix N).

Sources: Appendix N; Productivity Commission estimates.

Given that biofuel policies are a focus of this study, a closer look at consumption of biofuels by country is warranted. Figure M.3 shows total consumption of ethanol and biodiesel in each of the study countries during the year of analysis. Reflecting high levels of government support, the United States was by far the largest consumer of biofuel. US ethanol consumption was equal to more than ten times total consumption in all other study countries combined. Other major ethanol consumers included China and Germany. Germany was also the largest consumer of biodiesel among study countries, with the United States and the United Kingdom also significant consumers.

Figure M.3 **Biofuel consumption by country**[a]
2009-2010[b]



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[a] The biodiesel figure for Germany includes pure vegetable oil used as a road transport fuel. [b] Fuel consumption figures for each country reflect the annual estimate in the year of analysis for biofuel policies (appendix N).

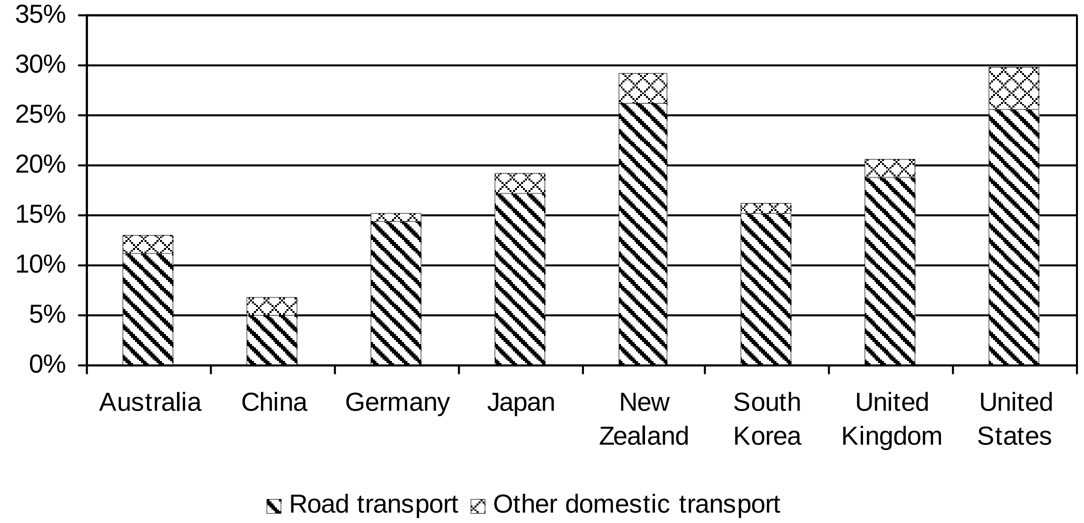
Sources: Appendix N; Productivity Commission estimates.

M.2 Emissions from transport fuel

Road transport fuels are a major source of greenhouse gas emissions. Figure M.4 shows the proportion of greenhouse gas emissions attributable to road transport in each of the study countries during 2008. For every country except China, road transport emissions represented at least 10 per cent of total greenhouse gas emissions and in some countries greater than 20 per cent. Furthermore, while China's road transport emissions were only about five per cent of total emissions, they were growing strongly. Between 1990 and 2008, road transport emissions increased by more than 400 per cent in China (IEA 2010a).

Figure M.4 **Road transport greenhouse gas emissions as a percentage of total national emissions**[a,b]

2008 (or most recent year available)



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[a] 'Other domestic transport' includes emissions from fuel used for domestic civil aviation, railways, domestic water-borne navigation, pipeline transport, fishing, off-road transport and other non-specified domestic transport emissions. It excludes emissions from fuel sold for use in any aircraft or marine vessel engaged in international transport. [b] As China and South Korea do not have official reporting obligations under the Kyoto Protocol, national emissions are 2007 estimates (WRI 2010) and exclude emissions from land-use change and forestry. Road transport and other domestic transport emissions for China and South Korea are 2008 estimates from IEA (2010a).

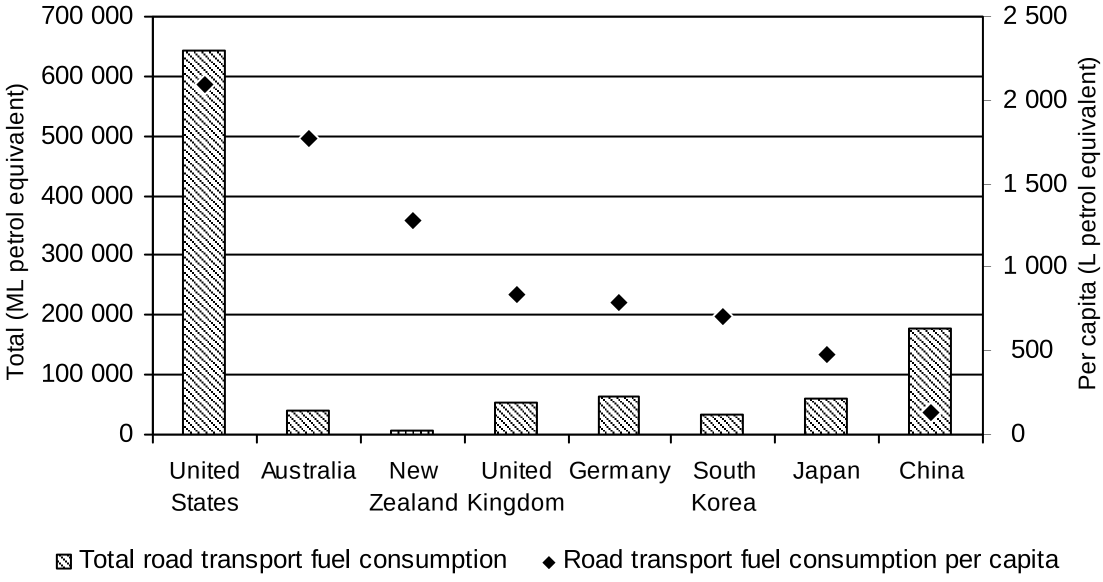
Sources: WRI (2010); IEA (2010a); UNFCCC (2011a).

To provide context for the above numbers, figure M.5 shows greenhouse gas emissions from road transport in absolute and per-capita terms. Reflecting high levels of fuel consumption, road transport emissions from the United States were the largest on either basis. While China's emissions were the next largest in absolute terms, its per-capita emissions were considerably lower than in any other study countries.

Figure M.5 also illustrates significant variation in per-capita emissions between the other study countries. Road transport emissions per-capita were between 50 and 100 per cent higher in Australia and New Zealand than in Korea, Germany, Japan and the United Kingdom. These differences are mostly attributable to variation in fuel consumption per-capita, but the composition of transport fuels also plays a role as the emissions intensity of some fuels is greater than others.

Figure M.5 **Greenhouse gas emissions from road transport**

2008, total and per-capita



Sources: IEA (2010a); UN (2011).

M.3 Using life-cycle emissions estimates

The emissions intensity of different fuel types was a crucial input to the Commission's estimates of abatement from fuel taxes and biofuel policies. In order to provide an adequate picture of abatement, the Commission has used 'life-cycle' assessments (LCA) of greenhouse gas emissions. This section explains the purpose of LCA and why it was used for transport sector policies. It also discusses the potential for differences in LCA estimates and provides details of the LCA estimates used by the Commission.

What is life-cycle assessment?

LCA is a technique used to assess the environmental impacts of a product or activity. It involves compiling an inventory of relevant energy and material inputs and environmental releases and evaluating their potential environmental impact. A life-cycle assessment of the greenhouse gas emissions associated with a product involves assessing all of the emissions attributable to the product beginning with the production or extraction of raw materials and ending with the product's disposal. Life-cycle assessment of greenhouse gas emissions from transport fuel is often described as 'well to wheels' analysis because it takes into account both 'upstream' emissions (that is, ‘well to tank’) and ‘downstream’ emissions (that is, ‘tank to wheels’).

Upstream emissions refer to all those emissions taking place during the production of the fuel up until delivery to the end user. For example, major sources of upstream emissions from diesel include fugitive emissions during oil exploration, emissions from flaring during oil production, emissions from electricity usage during the production of oil and its refinement into diesel, and all emissions from the transport of diesel and its precedents. Downstream emissions refer to the emissions from fuel combustion by the end user.

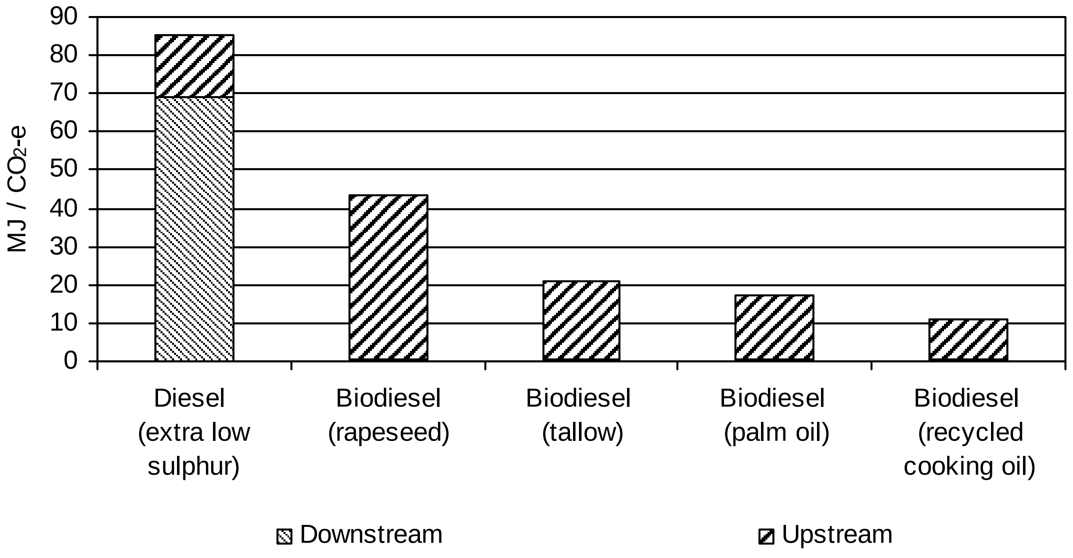
Why use life-cycle assessments?

Life-cycle assessment of greenhouse gas emissions from transport fuels is important to adequately account for the abatement achieved by road transport policies. This is particularly true where policies impact consumption of biofuels relative to conventional fuels because the emissions profiles of the two fuel types differ significantly.

Both conventional fuels and biofuels emit carbon dioxide through fuel combustion. However, conventional fuels use crude oil as a feedstock whereas biofuels use plant and animal products. The carbon content of crude oil is stored underground for millions of years prior to its extraction. By contrast, the carbon content of plants and animals comes from the sequestration of carbon dioxide from the atmosphere during their lifetime (Beer, Grant and Campbell 2007). The emissions from these processes are accounted for differently. Current international greenhouse gas accounting rules include carbon dioxide emissions from the combustion of conventional fuels but assign a value of zero to the carbon dioxide emissions from the combustion of biofuels (Australian Government 2008).

While the downstream emissions of biofuels are therefore much lower than conventional fuels, the upstream emissions of biofuels are often much higher because the production and conversion of biofuel feedstocks can be quite emissions intensive. To illustrate this point, figure M.6 contrasts the upstream and downstream emissions of diesel with biodiesel produced from various feedstocks in Australia. Downstream emissions constitute more than 80 per cent of life-cycle diesel emissions, but less than five per cent of life-cycle biodiesel emissions. Thus, if only downstream emissions were considered, abatement estimates would be biased in favour of biofuels.

Figure M.6 **Comparing upstream and downstream emissions**
Diesel and biodiesels by feedstock, Australia



Source: Beer, Grant and Campbell (2007).

Life-cycle assessment of greenhouse gas emissions has not been used in analysis of policies in the electricity sector. The Commission’s abatement estimates for the electricity sector are instead based on downstream emissions only (that is, emissions from the combustion of fuels to generate electricity). Upstream emissions in the electricity sector were not taken into account due to limited data availability and uncertainty about the scope of these emissions. The exclusion of upstream emissions from the analysis of the electricity sector is unlikely to have a significant effect on the ranking of generation technologies because downstream emissions from most conventional forms of electricity generation are significantly larger than the upstream emissions of even the most emissions-intensive renewable energy technologies (Weisser 2007). It is important to note, however, that because transport emissions were assessed on a different basis to electricity emissions, estimates for abatement and implicit abatement subsidies for policies in the transport sector and the electricity sector are not strictly comparable.

Life-cycle assessment of greenhouse gas emissions in the transport sector also has important implications for the interpretation of results. Most estimates of road transport sector greenhouse gas emissions, including those provided in the previous section, only include downstream emissions. Figures on total road transport emissions indicate the scale of abatement achieved in different study countries, but such comparisons are only illustrative as the abatement estimates also include reductions in emissions associated with other sectors.

Further to this, transport fuels and fuel feedstocks are often imported by study countries. Because LCA of emissions takes into account emissions attributable to the production as well as the consumption of these fuels, abatement estimates may take into account the effect of a policy on emissions occurring beyond a country's borders. Given that emissions occurring in all countries contribute equally to climate change, inclusion of these emissions was appropriate but also noteworthy.

Choosing life-cycle assessments

There is a significant body of literature on the emissions intensity of transport fuels. However, the estimates for any given fuel type vary significantly by study and the volume of available literature varies greatly from country to country.

The Commission's approach to choosing estimates of life-cycle emissions from fuels has been to source government publications wherever possible. Estimates for Australia, Germany, Japan, New Zealand, the United Kingdom and the United States relied on the use of life-cycle emissions estimates published by government departments, associated government agencies or government-employed consultants.

Where estimates from official government sources were unavailable or not sufficiently detailed, refereed academic literature was also used. Country-specific studies were an important supplementary source of estimates for China. In the case of South Korea, where neither government estimates nor country-specific estimates from academic literature were available, the Commission used a combination of emissions estimates for Japan and default estimates from the Renewable Fuel Agency's (RFA) (UK) Carbon Calculator (box M.1). In all cases where sources other than government estimates were used or where government estimates were lacking in sufficient detail to ensure accurate results, the Commission conducted sensitivity analysis to show the effect of using other estimates of life-cycle emissions intensities.

Explaining differences in LCA estimates

Estimates of life-cycle emissions for transport fuels consumed in study countries vary significantly even when comparing the same type of fuel. There are a large number of variables relating to the production and consumption of any given fuel that can affect the final estimate of greenhouse gas emissions intensity. As the results in the following section illustrate, the potential for differences between countries and feedstocks is greatest for biofuels because the steps in the life-cycle process vary greatly.

Box M.1 Using the RFA’s Carbon Calculator for South Korean estimates

The Carbon Calculator is a software program developed by the United Kingdom’s Renewable Fuel Agency. The program assists UK fossil fuel and biofuel suppliers to prepare reports on the volume and emissions intensity of biofuels sold to meet reporting requirements under the United Kingdom’s Renewable Transport Fuels Obligation.

The Carbon Calculator uses default values to provide estimates of the emissions intensity of different fuel life cycles. Fuel suppliers can alter default values in the Carbon Calculator and improve the accuracy of an estimate by including information specific to the batch of biofuel being reported. However, the Carbon Calculator is designed so that fuel suppliers can still meet reporting requirements where little is known about the origin, feedstock or means of manufacture of the biofuel being supplied. Default values are conservative in assuming relatively high emissions intensities so that suppliers are encouraged to provide additional information (RFA (UK) 2010c). Default emissions intensity values are available not just for biofuel produced in the United Kingdom but also for biofuel imported from a number of other countries using various feedstocks.

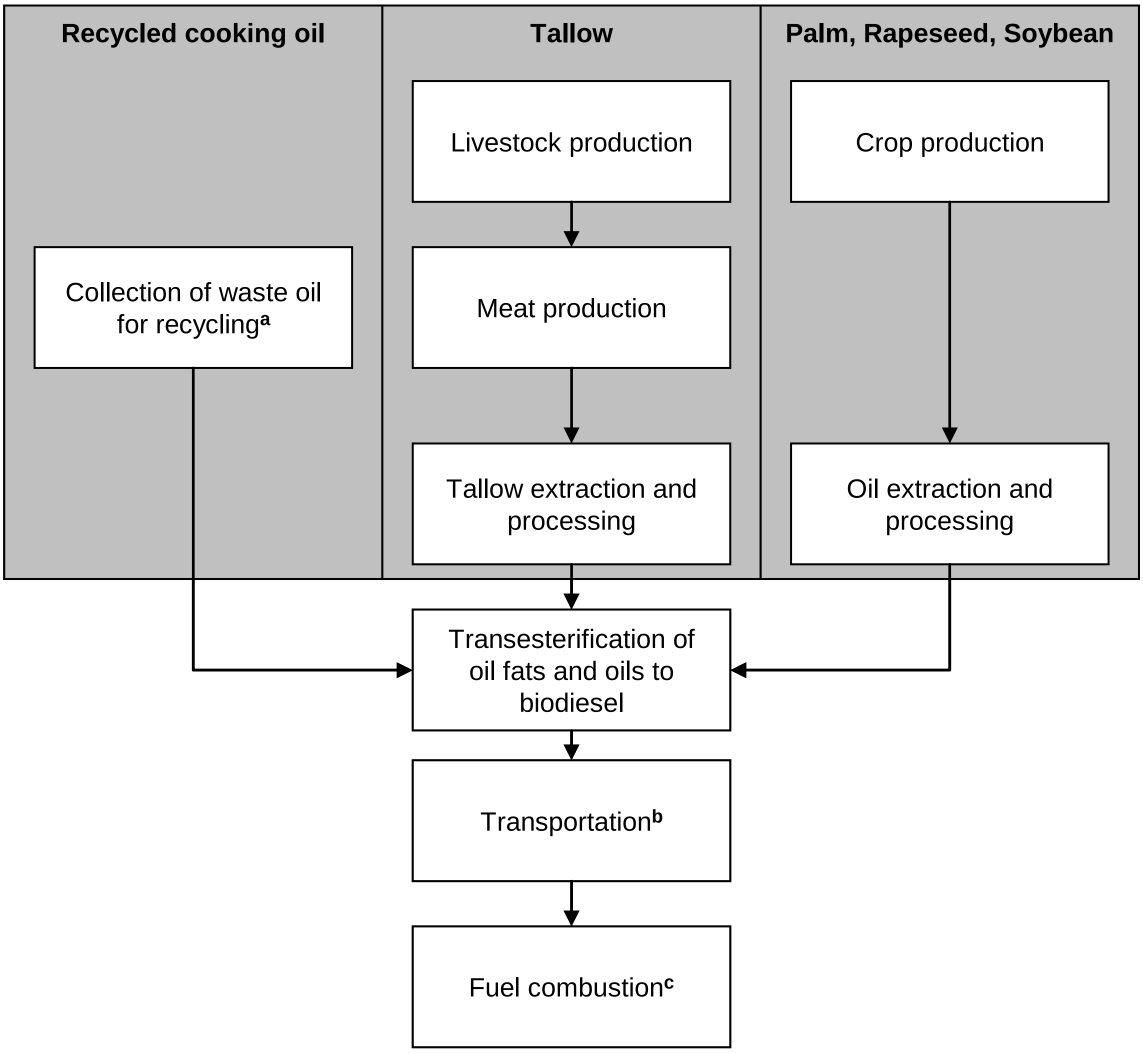
In the absence of estimates from government sources or refereed academic literature, the Commission used the Carbon Calculator to estimate the life-cycle emissions intensity of South Korean biodiesel produced with palm oil imported from Indonesia and Malaysia and soybean oil imported from Argentina and Brazil. Because the Carbon Calculator is designed to provide estimates for biodiesel imported and consumed in the United Kingdom, the Commission altered the default values in the Carbon Calculator to reflect differences between South Korea and the United Kingdom. In particular, the default estimates were adjusted to reflect differences in shipping distances, the emissions intensity of electricity generation and the emissions intensity of road transport. In all other respects, the default values were used.

Source: RFA (UK) (2010c).

Figure M.7 provides a stylised example of the components of a product life cycle for various types of biodiesel. In each step in the life cycle, greenhouse gas emissions are generated. The emissions intensity of any given step in the process is determined by several interacting variables.

The most emissions intensive step in the process tends to be the first step — the production or collection of the raw material. For biodiesel produced from plants such as rapeseed, this means cultivation of the feedstock crop. The emissions intensity of crop production depends on a variety of factors including previous land use, the type of crop grown and its yield, and the type and rate of fertiliser and pesticide applied.

Figure M.7 **Biodiesel life cycle by feedstock**



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[a] The general approach to estimating life-cycle emissions for biofuels produced from waste feedstocks (such as cooking oil) is to not include emissions associated with the production of the waste product. Consequently, the first step in the life-cycle process of biodiesel produced from recycled cooking oil is the collection of waste oil. [b] Transportation is pictured here as occurring only between the biodiesel production facility and the fuel pump but transportation and associated emissions actually take place between each step in the process. [c] Due to sequestration by feedstocks, carbon dioxide emissions due to biodiesel combustion are usually assigned a value of zero.

Source: Productivity Commission based on Beer et al. (2005).

Depending on the feedstock used, later steps in the process may involve extraction and processing of raw materials into suitable feedstocks before conversion into biodiesel via a chemical process known as ‘transesterification’. Both the processing of raw materials and the conversion of feedstocks into biodiesel involve further greenhouse gas emissions that vary according to factors such as the process yield, the energy intensity of the extraction and conversion processes and the emissions intensity of energy used. Additional greenhouse gas emissions occur during the transport of raw materials, feedstocks and final products, and these emissions are affected by the distance travelled and the emissions intensity of the transport mode used.

Due to the wide variety of variables at play, it is possible that biodiesel produced in two different plants (or two different countries) using the same feedstock can have significantly different overall emissions intensities. Although biodiesel has been used as the example, similar differences in variables affect the emissions from each step in the life cycle of all types of biofuel, and to a lesser extent, conventional fuels. Differences in these variables account for most of the variation in emissions intensity estimates between countries within and across each fuel type.

However, even in cases where all of the key variables affecting the emissions intensity of a fuel are the same there is still the potential for estimates to somewhat diverge due to methodological differences in accounting for emissions. While methodological differences are limited due to the adoption of international standards for life-cycle assessment (ISO 2006), some differences are inevitable given the wide variety of sources used for estimates in different countries. Two key methodological differences with the potential to affect results relate to the inclusion or exclusion of emissions due to direct land-use change and the treatment of emissions where biofuels are produced from coproducts or byproducts.

The inclusion of direct land-use change can have significant impacts on emissions intensity estimates, particularly for biofuels (box M.2). Assessing emissions due to land-use change is complex and information intensive. Consequently, estimates reported by government agencies tend not to take into account changes in land use. The United Kingdom is the exception — the strict reporting guidelines under the Renewable Transport Fuels Obligation require that direct land-use change be taken into account if previous land use is known. However, in UK fiscal year 2009, previous land use was reported by UK biofuel suppliers as either unknown or cropland for all ethanol and biodiesel not based on byproducts. Consequently, inclusion of land-use change emissions for the United Kingdom is not likely to have significantly biased abatement estimates.

The second key methodological difference relates to the treatment of emissions associated with biofuels produced from coproducts and byproducts. Biofuel feedstocks produced as coproducts or byproducts include tallow, rapeseed oil, sugar cane and wheat starch. Methodological differences occur for these feedstocks because when more than one product is produced from the same process, the emissions resulting from that process need to somehow be shared between the products.

Box M.2 **Fuel emissions and direct land-use change**

Direct land-use change refers to a change in management practices on a certain type of land cover (Garnaut 2008). An example of direct land-use change is the clearing of forest so that land can be used for agricultural crops to produce ethanol. Changes in land use can have significant immediate impacts on greenhouse gas emissions by removing carbon dioxide sequestered in vegetation and soil. Whether or not land-use changes are taken into account can therefore significantly affect estimates of the emissions intensity of a given fuel.

A case in point is land-use change due to biodiesel produced using palm oil. Beer, Grant and Campbell (2007) estimate the emissions intensity of biodiesel-produced palm oil under three scenarios:

1. An existing plantation of palm oil in Malaysia (that is, no land-use change).
2. A new plantation of palm oil on cleared rainforest in Malaysia.
3. A new plantation of palm oil on cleared peat swamp forest in Indonesia.

In each scenario, emissions from land-use change are shared over fifty years of production from the palm oil plantation. Under the first scenario where there is no land-use change, the emissions intensity of biodiesel produced from palm oil is 79 per cent lower than that of regular diesel. However, under the second scenario the emissions intensity of biodiesel produced with palm oil is almost ten times higher than diesel and, under the third scenario, more than 20 times higher after taking into account emissions from land-use change.

In most cases, emissions from direct land-use change are unlikely to be this significant as a large share of biofuel is produced on existing cropland. Nonetheless, it is important to recognise the potential impact of land-use change on emissions estimates.

Sources: Beer, Grant and Campbell (2007); Garnaut (2008).

Some studies allocate emissions based on the estimated economic value of each product. Others use a process known as ‘system boundary expansion’ to take into account potential flow-on effects of using the feedstock to produce biofuel rather than its traditional use. For example, if tallow was traditionally used to produce soap and is now diverted to make biodiesel, the emissions associated with producing vegetable oil as an alternative input to soap production would also need to be taken into account (Beer et al. 2005). While, ‘system boundary expansion’ is the preferred approach under international standards (ISO 2006), it is also more information intensive. Consequently, studies in different countries have adopted different approaches and estimates used by the Commission are therefore based on a mix of approaches.

M.4 Fuel properties and life-cycle emissions intensities

The following tables show the energy content, density and emissions intensity of fuels that have been used for each of the study countries. The emissions intensity of each fuel is reported per megajoule (MJ) and 'litres of petrol equivalent' (converted using the energy content values reported for each country). In addition, several other conversion rates were used for units of energy and volume (table M.1).

Table M.1 **General conversion rates**

Conversion	*Value*
Litres per US gallon	3.7854
US gallons per barrel	42
MJ per million British thermal units	1 055
MJ per million calories	4.1868
MJ per kWh	3.6

For China and South Korea, low, central and high estimates are provided for the emissions intensity of some fuels. These estimates are used for the sensitivity analysis in appendix N. In the case of China these figures reflect variation in reported estimates. In the case of South Korea, the Commission has calculated high and low estimates that are, respectively, 10 per cent above and below the central figure to reflect uncertainty around the accuracy of the central estimate. Where not otherwise stated in the tables, feedstocks are domestically produced.

Table M.2 **Fuel properties and emissions intensities**[a]

Australia

Fuel type	*Feedstock*	*Energy content*	*Density*	*Life-cycle emissions intensity*[b]	*Life-cycle emissions intensity*
		MJ/L	kg/L	g CO_2-e/MJ	g CO_2-e/L petrol equivalent
Petrol	Petroleum	34.2	0.74	88.4	3 023
Diesel	Petroleum	38.6	0.85	85.5	2 924
LPG	Petroleum	25.7	0.53	76.4	2 613
Ethanol		23.4	0.79	..	..
	Molasses	..	..	55.7	1 904
	Sorghum	..	..	61.9	2 115
	Wheat starch	..	..	55.7	1 904
Biodiesel		32.8[c]	0.89[d]	..	..
	Rapeseed oil	..	..	43.3	1 481
	Recycled cooking oil	..	..	10.9	373
	Soybean oil	..	..	32.6	1 115
	Tallow	..	..	20.9	715

a All energy content and density figures are from ABARES (2011) except for biodiesel. The energy density of biodiesel is assumed to be the same as the United States. The energy content of biodiesel was estimated by the Commission assuming 36 800 MJ/t (IEA 2010e). **b** Emissions intensities for extra low sulphur diesel and biodiesel produced from all feedstocks except soybean oil are from Beer, Grant and Campbell (2007). Emissions intensities for petrol, biodiesel produced from soybean oil, and ethanol produced from all feedstocks are from CSIRO, ABARE and BTRE (2003). The emissions intensity for LPG (Autogas) is from Beer et al. (2005). **..** Not applicable

Sources: Beer et al. (2005); Beer, Grant and Campbell (2007); CSIRO, ABARE and BTRE (2003); IEA (2010e).

Table M.3 **Fuel properties and emissions intensities**[a]

China

Fuel type	*Feedstock*	*Energy content*	*Density*	*Life-cycle emissions intensity*[b]	*Life-cycle emissions intensity*
		MJ/L	kg/L	g CO_2-e/MJ	g CO_2-e/L petrol equivalent
Petrol	Petroleum	33.2	0.74	89.0	2 951
Diesel	Petroleum	37.7	0.87	89.0	2 951
LPG	Petroleum	25.6	0.54	77.0	2 553
Ethanol		21.2	0.79	..	..
High	Cassava	..	..	75.0	2 486
Central	Cassava	..	..	75.0	2 486
Low	Cassava	..	..	71.0	2 360
High	Maize	..	..	131.0	4 343
Central	Maize	..	..	94.0	3 116
Low	Maize	..	..	71.0	2 360
High	Wheat	..	..	108.0	3 580
Central	Wheat	..	..	108.0	3 580
Low	Wheat	..	..	71.0	2 360
Biodiesel		33.4	0.89	..	..
	Recycled cooking oil	..	..	75.0	2 486

[a] All energy content and density figures are from Yan and Crookes (2009) except for energy densities for biodiesel and ethanol. The energy densities of biodiesel and ethanol are assumed to be the same as the United States. [b] Central estimates of emissions intensity are from Yan and Crookes (2009), low estimates are from Yan et al. (2009) and high estimates are Productivity Commission estimates. **..** Not applicable

Sources: Yan and Crookes (2009); Yan et al. (2009); Productivity Commission estimates.

Table M.4 **Fuel properties and emissions intensities**[a]

Germany

Fuel type	*Feedstock*[a]	*Energy content*[b]	*Density*	*Life-cycle emissions intensity*[c]	*Life-cycle emissions intensity*
		MJ/L	kg/L	g CO_2-e/MJ	g CO_2-e/L petrol equivalent
Petrol	Petroleum	32.2	0.75	86.0	2 769
Diesel	Petroleum	35.9	0.83	87.5	2 818
LPG	Petroleum	25.3	0.55	73.7	2 373
Ethanol		21.1	0.79[c]	..	..
	Wheat	..	..	50.0	1 610
	Sugar beet	..	..	24.0	773
	Sugar cane (imported from Brazil)	..	..	33.0	1 063
	Organic waste	..	..	10.0	322
Biodiesel		32.7	0.89[c]	..	..
	Palm oil (imported from Malaysia)	..	..	32.0	1 030
	Rapeseed oil	..	..	46.0	1 481
	Recycled cooking oil	..	..	10.0	322
	Soybean oil(imported from the Americas)	..	..	50.0	1 610
Vegetable oil	Rapeseed oil	34.6	..	35.0	1 127

[a] Rapeseed oil and all ethanol feedstocks except for sugar cane and organic waste are sourced both domestically and from elsewhere in Europe. [b] Energy content and density figures for petrol, diesel and LPG are from JEC-EUCAR-CONCAWE (2008a). Energy content figures for ethanol, biodiesel and vegetable oil are from ARR (Germany) (2010). Energy density figures for ethanol and biodiesel are assumed to be the same as for the United States. [c] Emissions intensities for petrol, diesel and LPG are from JEC-EUCAR-CONCAWE (2008a; 2008b). Emissions intensities of biofuels are from FMENCNS (Germany) (2010). **..** Not applicable

Sources: ARR (Germany) (2010); FMENCNS (Germany) (2010); JEC-EUCAR-CONCAWE (2008a; 2008b).

Table M.5 **Fuel properties and emissions intensities**[a]

Japan

Fuel type	*Feedstock*	*Energy content*	*Density*	*Life-cycle emissions intensity*	*Life-cycle emissions intensity*
		MJ/L	kg/L	g CO_2-e/MJ	g CO_2-e/L petrol equivalent
Petrol	Petroleum	32.2	0.75	85.3	2 747
Diesel	Petroleum	35.5	0.83	79.8	2 570
LPG	Petroleum	25.4	0.55	72.6	2 338
Ethanol		21.2	0.79	..	..
	Rice (paddy field with water management)	..	..	91.6	2 950
	Rice (paddy field without water management)	..	..	57.3	1 845
	Sugar beet	..	..	39.3	1 265
	Sugar cane (imported from Brazil)	..	..	32.7	1 053
	Waste wood	..	..	8.2	264
	Wheat	..	..	44.2	1 423

[a] Biodiesel is not included because no biodiesel policies were assessed for Japan. Energy content, energy density and emissions intensity of petroleum-derived fuels are from MIRI (2004). Emissions intensities of ethanol are from METI (Japan) (2010b). The energy density of ethanol is assumed to be the same as the United States. The Commission estimated the energy content of ethanol assuming 26 800 MJ/t (IEA 2010e). **..** Not applicable

Sources: IEA (2010e); METI (Japan) (2010b); MIRI (2004); Productivity Commission estimates.

Table M.6 **Fuel properties and emissions intensities**[a]

New Zealand

Fuel type	*Feedstock*	*Energy content*	*Density*	*Life-cycle emissions intensity*[b]	*Life-cycle emissions intensity*
		MJ/L	kg/L	g CO_2-e/MJ	g CO_2-e/L petrol equivalent
Petrol	Petroleum	32.7	0.75	88.4	2 892
Diesel	Petroleum	35.9	0.84	85.5	2 798
LPG	Petroleum	24.4	0.53	76.4	2 500
Ethanol		23.5	0.79	..	..
	Whey	..	..	61.6	2 016
	Sugar cane (imported from Brazil)	..	..	20.3	664
Biodiesel		32.8	0.89	..	..
	Rapeseed oil	..	..	59.8	1 957
	Recycled cooking oil	..	..	22.5	736
	Tallow	..	..	21.8	713

[a] Energy and density factors for petrol and diesel are for Automotive Gas Oil and LPG 60/40 net calorific values (MED (NZ) 2010b). The energy and density figures for petrol have been converted to a weighted average of premium and regular unleaded using consumption data from MED (NZ) (2011d). Energy density figures for ethanol and biodiesel are assumed to be the same as the United States. The Commission estimated the energy content of ethanol and biodiesel assuming 26 800 MJ/t for ethanol and 36 800 MJ/t for biodiesel (IEA 2010e). [b] Emissions intensity figures for petroleum-derived fuels are derived from Barber (2009), for whey ethanol from URS (2009b), for sugar cane from Barber et al. (2008), for all biodiesel feedstocks from URS (2009b) and for petrol, diesel and LPG from MED (NZ) (2011d). **..** Not applicable

Sources: Barber (2009); Barber et al. (2008); IEA (2010e); MED (NZ) (2010b; 2011d); URS (2009a; 2009b); Productivity Commission estimates.

Table M.7 **Fuel properties and emissions intensities**[a]

South Korea

Fuel type	*Feedstock*	*Energy content*[b]	*Density*	*Life-cycle emissions intensity*[c]	*Life-cycle emissions intensity*
		MJ/L	kg/L	g CO_2-e/MJ	g CO_2-e/L petrol equivalent
Petrol	Petroleum	33.5	0.75	85.3	2 858
Diesel	Petroleum	37.9	0.83	79.8[d]	2 673
LPG	Petroleum	27.5	0.55	72.6	2 432
Biodiesel		34.0[e]	0.89[f]	..	..
High	Palm oil (imported from Indonesia or Malaysia)	..	..	75.5	2 528
Central	Palm oil (imported from Indonesia or Malaysia)	..	..	69.4	2 325
Low	Palm oil (imported from Indonesia or Malaysia)	..	..	61.7	2 068
High	Soybean oil (imported from Brazil or Argentina)	..	..	76.3	2 557
Central	Soybean oil (imported from Brazil or Argentina)	..	..	68.6	2 298
Low	Soybean oil (imported from Brazil or Argentina)	..	..	62.5	2 092
	Recycled cooking oil	..	..	11.2	375

[a] Fuel densities and emissions intensity estimates for petroleum-derived fuels were not available for South Korea, and hence the same values as Japan have been used. [b] Energy content values for petroleum-derived fuels are from KEEI (2010a). A value for LPG was not published and hence the values for butane and propane have been used, assuming a ratio of 60:40. [c] Central estimates for imported feedstocks were generated by the Commission using the RFA (UK) (2010a) Carbon Calculator. High and low estimates for imported feedstocks are Productivity Commission estimates assuming ten per cent above and below Carbon Calculator figures; the figure for recycled cooking oil is from Singhabhandhu et al. (2006); and the figure for diesel is from MIRI (2004). [d] Note that the low estimate for the analysis of biofuels policies assumes that the emissions intensity of diesel is approximately equal to the average diesel emissions intensity of other study countries (86.6 g CO_2-e/MJ). [e] Productivity Commission estimate assuming 38 210 MJ/t for biodiesel (IEA 2010e). [f] Assumed to be the same as the United States. **..** Not applicable

Sources: KEEI (2010a); IEA (2010e); MIRI (2004); RFA (UK) (2010a); Singhabhandhu et al. (2006); Productivity Commission estimates.

Table M.8 Fuel properties and emissions intensities

United Kingdom

Fuel type	*Feedstock*	*Energy content*	*Density*[a]	*Life-cycle emissions intensity*	*Life-cycle emissions intensity*
		MJ/L	kg/L	g CO_2-e/MJ	g CO_2-e/L petrol equivalent
Petrol	Petroleum	32.8	0.73	83.3	2 732
Diesel	Petroleum	35.9	0.84	88.5	2 903
LPG	Petroleum	25.4	0.55[b]	66.0	2 165
Ethanol		21.3	0.79	..	..
	Barley	..	..	106.0	3 477
	Cassava	..	..	115.0	3 772
	Maize	..	..	49.0	1 605
	Molasses	..	..	56.0	1 851
	Sugar beet	..	..	22.0	708
	Sugar cane	..	..	24.0	803
	Triticale	..	..	66.0	2 167
	Wheat	..	..	64.0	2 108
	Unknown[c]	..	..	115.0	3 772
Biodiesel		35.7	0.89	..	..
	Maize	..	..	18.0	590
	Rapeseed oil	..	..	60.0	1 956
	Palm oil	..	..	46.0	1 518
	Soybean oil	..	..	50.0	1 650
	Sunflower oil	..	..	67.0	2 207
	Tallow	..	..	16.0	511
	Recycled cooking oil	..	..	13.0	427
	Unknown[c]	..	..	93.0	3 043

[a] The Commission assumed the energy density figures for ethanol and biodiesel to be the same as the United States. [b] Density data are not published for LPG in DECC (UK) (2010a) and hence the values for butane and propane have been used, assuming a ratio of 60:40. [c] Where the feedstock is unknown, the RFA assumes emissions intensity equivalent to the highest intensity of any feedstock estimated. **..** Not applicable

Sources: DECC (UK) (2010a); DEFRA (UK) (2010); RFA (UK) (2010b); Productivity Commission estimates.

Table M.9 **Fuel properties and emissions intensities**

United States

Fuel type	*Feedstock*	*Energy content*[a]	*Density*	*Life-cycle emissions intensity*[b]	*Life-cycle emissions intensity*
		MJ/L	kg/L	g CO_2-e/MJ	g CO_2-e/L petrol equivalent
Petrol	Petroleum	34.0	0.75	85.3	2 904
Diesel	Petroleum	38.3	0.85	87.8	2 988
LPG	Petroleum	23.9	0.51	83.6	2 846
Ethanol		23.5	0.79	..	..
	'Cellulosic'[c]	..	..	5.1	174
	Maize	..	..	62.2	2 116
	Sugar cane	..	..	22.8	775
Biodiesel		35.7	0.89	..	..
	Soybean oil	..	..	19.7	669

a Energy content values are from EIA (US) (2010a). **b** The value for cellulosic ethanol is from ANL (US) (2010); all other values are from ANL (US) (2011). **c** 'Cellulosic' ethanol refers to ethanol produced from cellulose, hemicellulose or lignin (that is, not from plant starches or sugars). **..** Not applicable

Sources: ANL (US) (2010; 2011); EIA (US) (2010a).

Summary of life-cycle emissions estimates

Tables M.10 to M.12 provide cross-country comparisons of the emissions intensity estimates for petroleum-derived fuels, ethanol and biodiesel. While estimates of the emissions intensity of petroleum-derived fuels are relatively similar across study countries, estimates for ethanol and biodiesel vary significantly.

Estimates for the United Kingdom include ethanol feedstocks with the highest emissions intensity (such as barley imported from Spain and cassava imported from Cambodia), although these feedstocks account for only a small share of total ethanol consumption. High estimates for the emissions intensity of both ethanol and biodiesel feedstocks in China reflect high fertilisation rates during the planting of feedstocks and China's relatively high energy consumption in industrial processes (Ou et al. 2009).

Estimates for biodiesel consumed in South Korea produced from palm oil and soybean oil are also relatively high. As discussed above, these estimates are based on default estimates from the RFA's Carbon Calculator which are deliberately high.

Table M.10 **Summary of LCA estimates for petroleum-derived fuels**

Emissions intensity by fuel type (g CO_2-e/MJ)

	Australia	*China*	*Germany*	*Japan*	*New Zealand*	*South Korea*	*United Kingdom*	*United States*
Petrol	88.4	89.0	86.0	85.3	88.4	85.3	83.3	85.3
Diesel	85.5	89.0	87.5	79.8	85.5	79.8	88.5	87.8
LPG	76.4	77.0	73.7	72.6	76.4	72.6	66.0	83.6

Source: Tables M.2 to M.9.

Table M.11 Summary of LCA estimates for ethanol

Emissions intensity by feedstock (g CO_2-e/MJ), central estimates

	Australia	*China*	*Germany*	*Japan*	*New Zealand*	*United Kingdom*	*United States*
Cellulosic	..	..	..	..	..	..	5.1
Barley	..	..	..	..	..	106.0	..
Cassava	..	75.0	..	..	..	115.0	..
Maize	..	94.0	..	..	..	49.0	62.2
Grain	..	..	50.0	..	..	..	..
Molasses	55.7	..	..	..	..	56.0	..
Organic waste	..	..	10.0	..	..	..	..
Rice (paddy field with water management)	..	..	..	91.6	..	..	..
Rice (paddy field without water management)	..	..	..	57.3	..	..	..
Sorghum	61.9	..	..	..	..	..	..
Sugar beet	..	..	24.0	39.3	..	22.0	..
Sugar cane	..	..	33.0	32.7	20.3	24.0	22.8
Triticale	..	..	..	..	..	66.0	..
Waste wood	..	..	..	8.2	..	..	..
Wheat	..	108.0	..	44.2	..	64.0	..
Wheat starch	55.7	..	..	..	..	..	..
Whey	..	..	..	..	61.6	..	..
Unknown	..	..	..	..	..	115.0[a]	..

[a] In the United Kingdom, where the feedstock is unknown the emissions intensity is assumed to be equal to that of the most emissions-intensive estimate for any feedstock or importing country. **..** Not applicable

Source: Tables M.2 to M.9.

Table M.12 Summary of LCA estimates for biodiesel

Emissions intensity by feedstock (g CO_2-e/MJ), central estimates

	Australia	*China*	*Germany*	*New Zealand*	*South Korea*	*United Kingdom*	*United States*
Maize	..	..	..	..	..	18.0	..
Palm oil	..	..	32.0	..	69.4	46.0	..
Rapeseed oil	43.3	..	46.0	59.8	..	60.0	..
Recycled cooking oil	10.9	75.0	10.0	22.5	11.2	13.0	..
Soybean oil	32.6	..	50.0	..	68.6	50.0	19.7
Sunflower oil	..	..	..	..	..	67.0	..
Tallow	20.9	..	..	21.8	..	16.0	..
Unknown[a]	..	..	..	..	..	93.0	..

[a] In the United Kingdom, where the feedstock is unknown the emissions intensity is assumed to be equal to that of the most emissions-intensive estimate for any feedstock or importing country. **..** Not applicable

Source: Tables M.2 to M.9.