DIRECTORATE FOR TRADE AND AGRICULTURE

ECONOMIC ASSESSMENT OF BIOFUEL SUPPORT POLICIES

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FOREWORD

This report has been primarily prepared by Martin von Lampe, Agricultural Policy Analyst in the OECD Trade and Agriculture Directorate, but it also contains sections provided by other units within and outside this Organisation. These in particular include the sections on Trends in Science and Innovation (OECD Directorate for Science, Technology and Innovation) and on Biofuel Performance with Respect to Environmental and Other Criteria (International Energy Agency, in co-operation with the United Nations Environment Programme and the European Environment Agency).

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EXECUTIVE SUMMARY

The production and use of biofuels – mainly ethanol based on cereals and sugar crops, and biodiesel based on vegetable oils such as rapeseed or canola oil – has grown rapidly over the past few years and is expected to further double in the decade to come. The United States and Brazil remain the largest ethanol producers with 48% and 31% of global ethanol output in 2007, respectively, while the European Union accounts for about 60% of global biodiesel production. A large number of other countries' governments have begun, or are considering promoting biofuel production and use.

In most countries, biofuels remain highly dependent on public support policy. This report estimates support to the US, EU and Canadian biofuel supply and use in 2006 at about USD 11 billion per year, projected to rise to USD 25 billion in the medium term (all medium-term projections in this executive summary refer to the annual average for the 2013-17 period). Many different forms of support are provided at various stages of biofuel production and use but the three major categories of support are:

- **Budgetary support measures**, either as tax concessions for biofuel producers (refineries), retailers or users, or as direct support to biomass supply, biofuel production capacities, output, blending, specific infrastructure or equipment for biofuel users. All these measures directly affect the public budget either in the form of forgone tax revenues or of additional outlays.
- **Blending or use mandates** require biofuels to represent a minimum share or quantity in the transport fuel market. While these measures generally are neutral for public budgets, the higher production costs of biofuels result in increased fuel prices for the final consumer.
- **Trade restrictions**, mainly in the form of import tariffs, protect the less cost-efficient domestic biofuel industry from competition from lower-cost foreign suppliers and result in higher domestic biofuel prices. These measures impose a cost burden on domestic biofuel users and limit development prospects for alternative suppliers.

The high level of public support has placed biofuels policy at the centre of a debate about the expected environmental, energy and economic benefits. This report presents new economic analysis, provides policy recommendations and identifies areas where more research is necessary. The report focuses on liquid biofuels for transport derived from agricultural feedstocks or from biomass related to agricultural production.

A range of reasons are behind the public interest in, and public support for, biofuels. Prioritising these policy objectives is difficult and varies by country, over time and across government ministries. With increased concerns about climate change, however, the reduction of greenhouse gas (GHG) emissions and fossil energy savings can safely be counted among the prime reasons to support biofuel production and use.

Ethanol based on sugar cane - the main feedstock used in Brazil - generally reduces GHG emissions by 80% or more over the whole production and use cycle, relative to emissions from fossil fuels. Current support policies in the US, the EU and in Canada target feedstocks that tend to reduce GHG emissions by much less. Biofuels produced from wheat, sugar beet or vegetable oils rarely provide GHG emission savings of more than 30% to 60%, while corn (maize) based ethanol generally allows for savings of less than 30%. Current budgetary support, mandates and trade restrictions (not considering the most recent US and currently discussed EU initiatives) reduce net GHG emissions by less than 1% of total emissions from transport. Fossil fuel use is also reduced by less than 1% for most of these transport sectors and by 2-3% in the EU diesel sector. These relatively modest effects come at a projected cost equivalent to about USD 960 to USD 1700 per tonne of CO_2-eq. saved, or of roughly USD 0.80 to USD 7 per litre of fossil fuel not used.

The sometimes predicted improved economic viability of biofuel production and use associated with higher crude oil prices so far has not materialised in many countries. Most production chains for biofuels have costs per unit of fuel energy significantly above those for the fossil fuels they aim to replace. Despite the rapid and substantial increase in crude oil prices and hence in the costs for gasoline and fossil diesel, the cost disadvantage of biofuels has widened in the past two years as agricultural commodity prices soared and thereby feedstock costs increased.

The medium-term impacts of current biofuel policies on agricultural commodity prices are important, but their role should not be overestimated. The price effects attributable to biofuel policies derive largely from increased demand for cereals and vegetable oils. With biofuel support policies in place in 2007, 12% of global coarse grain production and 14% of global vegetable oil production could be used for biofuels in the medium-term, up from 8% and 9% in 2007, respectively. But future policy developments matter: with full implementation of the recently enacted US Energy Independence and Security Act and the currently proposed new EU Directive for Renewable Energy, close to 20% of global vegetable oil production and more than 13% of world coarse grain output could shift to biofuels production.

Current biofuel support measures are estimated to increase average wheat, maize and vegetable oil prices by about 5%, 7% and 19%, respectively, in the medium term. Prices for sugar and particularly for oilseed meals are actually reduced by these policies – a result of slightly lower production of sugar cane-based ethanol in Brazil and significantly higher biodiesel-related oilseed crush. The new US and proposed EU initiatives could further increase commodity prices by a similar magnitude.

The price impact of second-generation biofuel production would depend on the amount of feedstock biomass that would be produced on current crop land. If the total production area is significantly expanded, the price effects would be reduced but concerns over negative environmental impacts on sensitive areas and high-carbon soils, including GHG emissions, water use and biodiversity losses, would increase.

Linked to the price effects noted above, existing and any additional support for biofuels might have important implications for global land use and are likely to accelerate the expansion of land under crops particularly in Latin America and large parts of Africa. While this might provide additional income opportunities to generally poor rural populations, care would need to be taken to avoid possible environmental damages, including accelerated deforestation, additional release of greenhouse gases, loss of biodiversity and runoff of nutrients and pesticides.

Based on this analysis, a number of **policy recommendations** are offered:

- The multifold objectives behind the public support for biofuels as well as the side effects of biofuel production call for differentiated and suitable policy approaches. Appropriate policy mixes will depend on countries' priorities and conditions. There is no "one size fits all" policy mix that meets all different objectives and minimizes negative effects.

- The primary focus for fossil energy saving needs to be redirected from alternative fuels towards lower energy consumption, particularly with respect to the transport sector. Generally, the costs of reducing GHG emissions by saving energy are much lower than by substituting energy sources. It should also be noted that while the strong increase of GHG emissions in the transport sector is a concern, the costs of emission reductions are often substantially lower in other sectors, e.g. by better insulation of buildings.

- With respect to alternative transport fuels, a clear focus needs to be placed on those biofuels that maximise the reduction of fossil fuel usage and GHG emissions. Minimum reduction criteria should be established, set at ambitious levels and tightened over time to enhance technological progress in this rapidly developing field.

- The type of land used for biofuel production affects the environmental performance of these fuels. Governments should favour the use of areas not currently used for crop production – either degraded or with low nature values – while use of environmentally sensitive land needs to be discouraged. The production of large biofuel quantities will have an important impact on land use that needs to be carefully monitored in order to ensure sustainable supply chains.

- Import tariffs on feedstock or biomass to protect domestic production impose an implicit tax on biofuels production by raising input prices. Tariffs are also applied to biofuel imports, distorting resource allocation and imposing a burden on users. Opening markets for biofuels and related feedstocks would allow for more efficient and lower cost production, and at the same time could improve both environmental outcomes and reduce reliance on fossil fuels.

- Further development and expansion of the biofuels sector will contribute to higher food prices over the medium term and to food insecurity for the most vulnerable population groups in developing countries. Modifying current support policies along the lines outlined above would reduce this unintended impact. In addition, with a more liberal trade environment, increased biofuel production might be a viable option in some developing countries, thereby improving employment and income opportunities.

Some areas for **further research** have also been identified:

- The high productivity of first generation biofuel production from tropical and semi-tropical countries deserves further examination, in particular regarding the potential economic benefits relative to sustainable resource use.

- More generally, interdisciplinary research is needed to better understand the environmental risks related to land use change resulting from biofuels expansion and to capture the interrelationships between economic and environmental effects. Present analysis shows that problems can be significant, but clearly remains at too aggregate a level to provide conclusive answers. The environmental problems of land use changes are not restricted to biofuels produced in sensitive areas. Indirect land use changes (where sensitive areas become converted to produce crops other than for biofuels due to biofuel-induced incentives) can create quite similar negative effects, and require effective monitoring at field level.

- Both the commercial-scale development of advanced and second-generation biofuel technologies and the exploitation of the improvement potential of different first-generation biofuel supply chains need – and indeed get – sustained R&D efforts over time. Biogas and BTL-fuels from organic waste or other biomass and cellulosic ethanol from crop and forest residues are options with potentially very low feedstock costs. Second-generation biofuels from dedicated biomass such as grasses and fast-growing trees may offer higher energy yields.

- Research and development should not focus solely on biofuels. In the long run, innovations in solar energy generation, hydrogen fuel cells and other technologies offer much promise.

INTRODUCTION, OBJECTIVES AND SCOPE OF THE REPORT

Biofuels are in the centre of intensive discussion. Seen by many to help reduce greenhouse gas emissions and fossil fuel use, to foster rural development and to create new markets for agricultural products, others worry about threats to natural habitats, environmental damages due to more intensive agricultural practices and the competition for food commodities and land needed to feed the world.

This report aims to shed light on the discussion about both hopes and concerns by providing information and analysis on a wide range of biofuel-related issues. In particular, it tries to distinguish areas where available information is sufficient to draw policy conclusions from areas where more research is necessary.

In doing so, this report largely limits itself to liquid biofuels for transport derived from agricultural feedstocks or from biomass that is related to agricultural production. Hence, in addition to first-generation biofuels from grains, sugar cane and beet, oilseeds, palm oil and – in some developing countries – roots and tubers, it also looks at second-generation biofuels derived from agricultural residues or from biomass dedicatedly produced, either on agricultural land or by bringing other land into production. It does not look in any detail (other than as an outside factor in the quantitative analysis) into a range of other biofuel chains which are being developed, such as fuels from wastes, used cooking oils, algae, residues from the dairy and meat processing industry, etc. This report also does not deal with other forms of non-food biomass use, such as for generating heat and/or power – other OECD work will look at these developments at a later stage.

The structure of this report is as follows: Chapter 1 provides facts and trends related to biofuels. In particular, an overview of recent developments in the biofuel markets looks at production, use and trade for ethanol and biodiesel and briefly discusses recent price developments in the ethanol market. Public policies are presented in some detail together with the objectives behind them. A subsequent section looks at the scientific and technological aspects of biofuel developments, before the environmental performances of current and next-generation biofuels are discussed.

Chapter 2 presents the methods and results of the quantitative analysis of biofuel policies and developments. In particular, using the OECD/FAO Aglink-Cosimo model, it looks at the impacts current and new biofuel policies have on biofuel production, use and trade as well as on agricultural commodity markets. It also discusses the potential implications second-generation biofuels might have and compares them to those of commodity-based biofuels. A third issue analysed is the impact of higher or lower oil prices. Finally, the chapter looks into environmental effects of current and new policies by using the integrated economic and natural science model SAPIM.

Costs and benefits of biofuel support are compared in Chapter 3. Here, the report looks at several policy objectives individually and reviews the impacts of biofuel support policies and the growth in the biofuel industry on each of them. In doing so, it brings together the results from the quantitative analysis obtained in Chapter 2 and the information presented in Chapter 1. A final Chapter 4 concludes and derives policy recommendations.

CHAPTER 1. FACTS AND TRENDS

Market developments[1]

Biofuels - liquid transport fuels derived from biomass[2] - attract substantial interest in many countries. Growth in biofuel production and demand has been stimulated by high levels of government support in many countries, as well as by recent surges in international oil prices. Processing costs to produce biofuels have declined markedly with increased experience and improved technologies, which together with the higher prices for fossil fuels have helped to improve the competitiveness relative to conventional fuels. Given that feedstock prices have increased as well, however, further reductions in costs will be needed for biofuels in most countries to be able to compete effectively with gasoline and diesel without subsidy. Land availability and food needs will also limit the growth in conventional biofuels production based on sugar, cereals and seed crops. New biofuels technologies being developed today, notably enzymatic hydrolysis and gasification of ligno-cellulosic feedstock, could allow biofuels to play a much bigger role in the long term, with potentially less land-use and environmental impact. Whether they can be viable in all but niche markets without subsidies is less clear.

There are several types of biofuels and many different ways of producing them. Today, almost all biofuels produced around the world are either ethanol or esters - commonly referred to as biodiesel. Ethanol is usually produced from sugar and starchy crops, such as cereals, while biodiesel is produced mainly from oilseed crops, including rapeseed, palm, sunflower seed and soyabeans. Other crops and organic wastes (such as used cooking oils and animal fats and wastes) can also be used. Each fuel has its own unique characteristics, advantages and drawbacks. Ethanol, in an almost water-free form (anhydrous ethanol), is usually blended with gasoline (either pure or in a derivative form, known as ethyl-tertiary-butyl-ether, or ETBE).[3] Biodiesel can be used fairly easily in most existing compression-ignition engines in blends with conventional diesel forms, while modest modifications allow the use of biodiesel in high-level blends or in its pure form. Ethanol in a hydrous form (containing up to 5% water) and some types of biodiesel can be used unblended or in high-proportion blends only with modifications to the vehicle engine. Almost all biofuels are used in cars and trucks, though small quantities are used as railway and aviation fuel.

Global production of biofuels amounted to 62 billion litres or 36 million tonnes of oil equivalent (Mt)[4] in 2007 - equal to about 1.8% of total global transport fuel consumption in energy terms. Brazil and the United States together account for almost three-quarters of global supply (Table 1.1). Brazil, which used to

1 This section is substantially rewritten, updated and extended based on IEA (2006), pp. 386-391.

2 The term biofuels is used in this report to refer exclusively to liquid fuels derived from biomass that can be used for transport purposes. Some studies use the term more broadly to cover all types of fuels derived from biomass used in different sectors.

3 ETBE has lower volatility than ethanol, but there are health concerns about its use as a gasoline blending component.

4 Unless otherwise stated, volume equivalents are not adjusted to take account of differences in energy content, because the latter differ by type of fuel and because other characteristics affect fuel economy in practice.

be the world's largest producer of biofuels, has been overtaken by the United States only recently. In both countries, ethanol accounts for almost all biofuel output, though US biodiesel production has increased substantially in the last few years. US output of ethanol, derived mainly from corn (maize), has surged in recent years as a result of tax incentives, mandates and demand for ethanol as a replacement for methyl-tertiary-butyl-ether (MTBE)[5] and gasoline-blending component. In Brazil, production of ethanol, entirely based on sugar cane, peaked in the 1980s, then declined as international oil prices fell back, but has been increasing rapidly since the beginning of the century. Falling production costs, higher oil prices and the introduction of vehicles that allow switching between ethanol and conventional gasoline have led to this renewed surge in output. Production of biofuels in Europe is growing rapidly owing to strong government incentives. The bulk of EU production is biodiesel, which, in turn, accounts for almost two-thirds of world biodiesel output. Elsewhere, China and India are major producers of ethanol, whereas Malaysia and Indonesia have started substantial biodiesel programmes. The share of biofuels in total transport-fuel demand in 2007 was about 20% in Brazil. While in the US biofuels represented about 3% of transport fuels, the share of biofuels in EU transport-fuel consumption was less than 2% for the region as a whole, though the shares in a few individual Member States such as Germany and Sweden were higher (Figure 1.1). The shares are nonetheless growing rapidly in many countries as new capacity comes on stream.

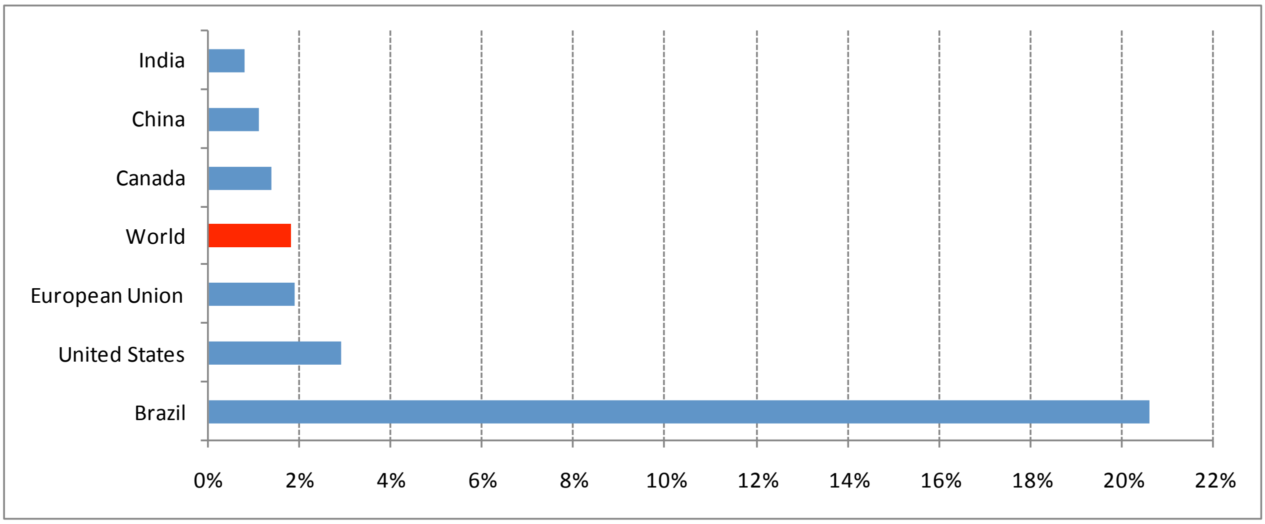
Table 1.1. Biofuels production by country, 2007

	Ethanol		Biodiesel		Total	
	million l	Mtoe	million l	Mtoe	million l	Mtoe
United States	26 500	14.55	1 688	1.25	28,188	15.80
Canada	1 000	0.55	97	0.07	1,097	0.62
European Union	2 253	1.24	6 109	4.52	8,361	5.76
Brazil	19 000	10.44	227	0.17	19,227	10.60
China	1 840	1.01	114	0.08	1,954	1.09
India	400	0.22	45	0.03	445	0.25
Indonesia	0	0.00	409	0.30	409	0.30
Malaysia	0	0.00	330	0.24	330	0.24
Others	1 017	0.56	1 186	0.88	2,203	1.44
World	52 009	28.57	10 204	7.56	62,213	36.12

Source: Based on F.O.Licht (2007) data.

5 Methyl-tertiary-butyl-ether is a chemically produced fuel additive raising the oxygen content of motor gasoline, helping it to burn more completely in the engine and therefore reducing harmful tailpipe emissions. Following water contamination problems, the use of MTBE has been phased out in the US.

Figure 1.1. Share of biofuel production in total road-fuel consumption in energy terms, selected countries



Note: 2007 biofuel quantities relative to 2005 transport fuel use.
Source: Based on EBB (2008), F.O.Licht (2007) and IEA (2007).

Ethanol

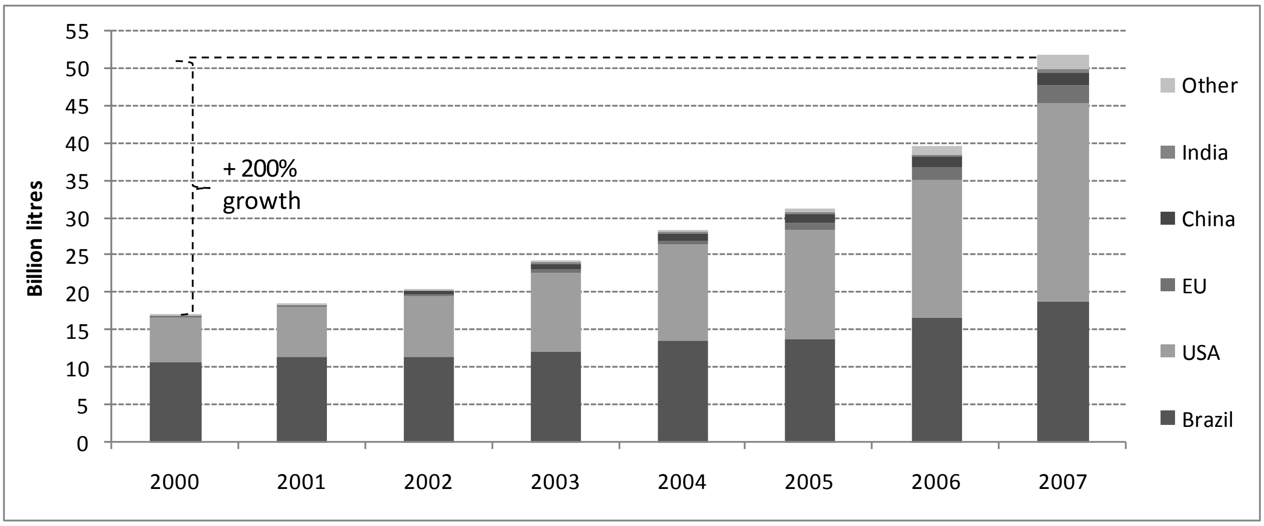
Conventional ethanol production technology involves fermenting sugar obtained directly from sugar cane or beet, or indirectly from the conversion of the starch contained in cereals. The ethanol produced is then distilled and dehydrated to produce a fuel-grade liquid. In OECD countries, most ethanol is produced from starchy crops like corn, wheat and barley, but ethanol can also be made from potatoes and cassava, directly from sugar cane and sugar beet, or from molasses (a sugar by-product). In tropical countries like Brazil, ethanol is derived entirely from sugar cane, while others use the molasses produced as a by-product in the sugar production process. Starchy crops first have to be converted to sugar in a high-temperature enzymatic process. The sugar produced in this process or obtained directly from sugar crops is then fermented into alcohol using yeasts and other microbes. The grain-to-ethanol process yields several by-products, including protein-rich animal feed. By-products reduce the overall cost of ethanol. In addition, and depending on their utilisation, crop residues and process by-products may also improve the greenhouse-gas balance on a live-cycle bases (in particular if crop residues such as straw or bagasse are used to provide heat and power for the ethanol production process).

Efforts to introduce ethanol into the market for road-transport fuels for spark-ignition engines have focused on low-percentage blends, such as ethanol E10, a 10% ethanol and 90% gasoline blend (known as gasohol in Brazil and the United States) or E5 used in some European countries. Such blends, which are already marketed in many countries, generally do not require engine modifications in recent cars and can be supplied in the same way as gasoline through existing retail outlets. Higher-percentage blends, with more than 30% ethanol, or pure ethanol can be used only with some modifications to the vehicle engine. Ethanol has a high octane value, which makes it an attractive gasoline-blending component. It has generally good performance characteristics, though its energy content by volume is only two-thirds that of gasoline. The higher volatility of ethanol can create problems and requires adjusted gasoline formulas, especially in the summer months.

Demand for ethanol as an octane enhancer is rising in several countries, especially the United States, where MTBE – until recently the most commonly used oxygenate - was phased out or discouraged for health and environmental reasons. The fuel economy of a vehicle with an engine modified to run on pure ethanol, measured by kilometres per litre, can approach that of a gasoline-only version of the same vehicle, despite ethanol's lower energy content.[6] In several countries, "flex-fuel" vehicles, which allow consumers to switch freely between high-proportion ethanol blends and gasoline, have been available now for several years in Brazil, and have recently become available in a number of other countries as well. This insulates the consumer from any sudden jump in the price of ethanol relative to gasoline that might result from a supply shortage, or from a drop in gasoline prices. In consequence this technology creates a stronger link between gasoline and ethanol markets.

Ethanol production is rising rapidly in many parts of the world partly in response to higher oil prices, which, all other factors being constant, are making ethanol more competitive. Government incentives and rules on fuel specifications further contributed to biofuel growth. Global production tripled from its 2000 level and reached 52 billion litres (28.6 Mt) in 2007 (Figure 1.2). The United States accounted for much of the increase in output over that period. In most cases, virtually all the ethanol produced is consumed domestically, though trade is growing. Brazil accounts for more than half of global trade in ethanol (see the section on biofuel trade below).

Figure1.2. World fuel ethanol production 2000-2007



Source: Data from F.O.Licht (2007).

Substantial research effort - both private and public - is being put into the production of ethanol from biomass other than starch or sugar crops, such as straw, stover, wood chips or grasses. This second-generation biofuel uses the cellulosic, hemi-cellulosic and lignin parts representing the bulk of the biomass. While this would imply less competition for land used for food and feed production, in particular if crop residues are used, the research has not yet succeeded to generate economically viable production processes. A number of production plants have been installed mostly in North America and Europe, but as these are still at pilot or demonstration phase levels, ethanol output using these new technologies is still negligible.

6 This depends on whether the engine is optimised to run on ethanol. The high octane number of ethanol-rich blends, plus the cooling effect from ethanol's high latent heat of vaporisation, allows a higher compression ratio in engines designed for ethanol-rich blends. This is especially the case for vehicles using direct-injection systems. These characteristics result in increased horsepower and can partially offset the lower energy content of ethanol *vis-à-vis* gasoline.

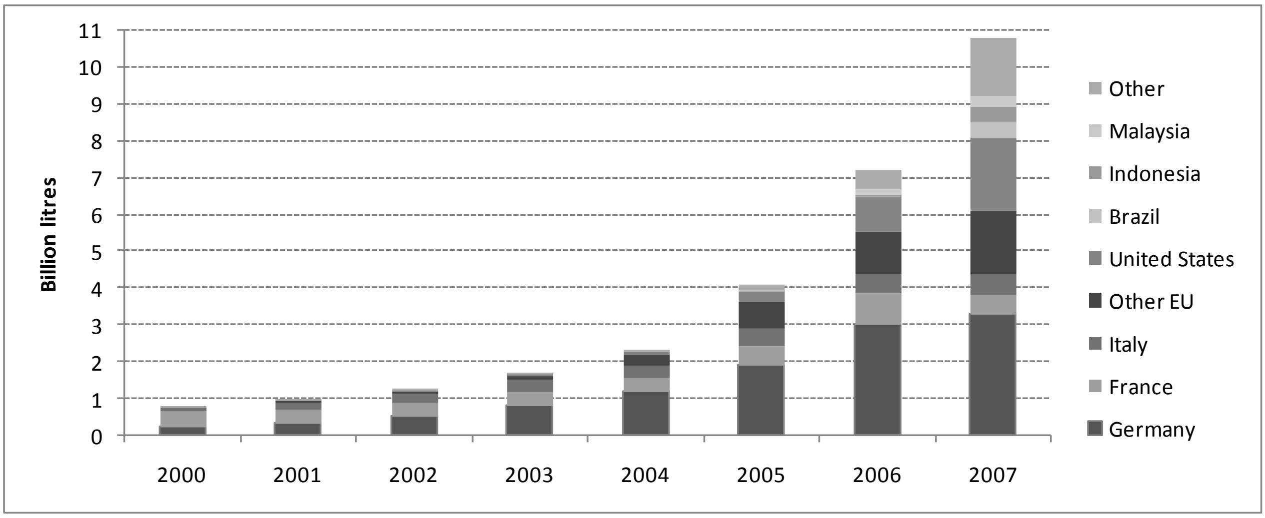
Biodiesel

The most well-established technology for biodiesel production is the transesterification of vegetable oils or animal fats. The process involves filtering the feedstock to remove water and contaminants, and then mixing it with an alcohol (usually methanol) and a catalyst (usually sodium hydroxide or potassium hydroxide). This causes the oil molecules (triglycerides) to break apart and reform into esters (biodiesel) and glycerol, which are then separated from each other and purified. The process also produces glycerine, which is used in many types of cosmetics, medicines and foods.[7]

Total production of biodiesel worldwide remains small compared with that of ethanol, amounting to about 10.2 billion litres (7.6 Mtoe) in 2007. Close to 60% is produced in the European Union. Germany and France are the biggest producers in the EU. US production has increased rapidly in recent years, and in 2007 the United States became the second-largest producer behind Germany. Indonesia and Malaysia have recently started to produce biodiesel for the European market, while biodiesel production in Argentina started in 2007. In total, biodiesel production has risen sharply in recent years, and grew by 43% in 2007 despite slowed growth within the EU (Figure 1.3).

As with ethanol, most biodiesel is blended with conventional fuel, usually in a 5% blend (B5) for use in conventional vehicles. It is also marketed in some countries in blends up to 30% (B30) or in a pure form (B100) that some specially modified diesel vehicles can handle. In Germany, B100 has been available for several years at more than 700 service stations. Biodiesel's zero-sulphur content and its solvent and lubricant properties, which improve engine performance and the life of engine parts, make it an attractive blending component. Biodiesel contains only about 90% as much energy as conventional diesel, but its lubricity and higher cetane number (a measure of the combustion quality of diesel under compression) mean that fuel economy is similar.

Figure 1.3. World biodiesel production 2000-2007



Source: Data derived from EBB (2008), F.O.Licht (2007), EIA (2008) and Agra-Informa (2008). 2007 data are rough estimates only.

7 The co-production of glycerine improves the economics of making biodiesel, but the market value of crude glycerine has fallen in recent years with rising biodiesel production because the commercial demand for non-energy uses is limited: it may increasingly be used as an energy input to the production process itself or as a chemical intermediary product.

In addition to vegetable oils, other feedstock can be used for the production of biodiesel as well. Used vegetable oils collected from restaurants and households could represent a competitive feedstock as they are generally of little alternative use.[8] The cost of collecting these materials can be high but need to be weighed against disposal costs due to environmental considerations.

Significant research is underway to produce diesel-type second-generation biofuels from other sources of biomass via gasification and Fischer-Tropsch synthesis, a technology that was used in several oil-embargoed countries in the 20th century to produce transport fuels from coal. While these technologies allows to use larger proportions of plants than just the oil-bearing seeds to produce fuels - similar to the cellulose-based ethanol production – or even to recycle waste materials, production costs of such biofuels are still much higher than those of conventional biofuels and fossil fuels, and current output of plants using these technologies remains very small compared to first-generation biodiesel.

Trade in biofuels[9]

International trade in ethanol and biodiesel has been small so far. Global trade in fuel ethanol is estimated to have been about 3 billion litres per year over the last two years, up from less than one billion litres in 2000 (F.O.Licht, 2007). International ethanol trade is still dominated by non-fuel ethanol used for beverages, in the chemical industry etc.[10] It is estimated that the share of non-fuel ethanol in international ethanol trade has declined from about 75% at the beginning of the century to between 50% and 60% in recent years – but the distinction in trade statistics is difficult given that fuel and non-fuel ethanol often share the same tariff lines at the level trade is reported.[11] In the following, therefore, total ethanol trade is discussed.

Brazil has been by far the largest exporter of ethanol in recent years. In 2006, its ethanol exports amounted to almost 3.5 billion litres, out of just under 5 billion litres of ethanol traded globally (excl. intra-EU trade) (Figure 1.4). In contrast, the USA imported more than half the ethanol traded. Of the 2.7 billion litres imported by the US, about 1.7 billion litres were imported directly from Brazil, while much of the remainder was imported from countries which are members of the Caribbean Basin Initiative (CBI) and which enjoy preferential access to the US market. These countries in turn import (hydrated) ethanol from Brazil, dehydrate it and re-export to the US.

China, too, has been a net exporter of ethanol over the last several years, though at significantly lower levels than Brazil. Despite some exports to the US as well as to CBI countries, most of the largest destinations for Chinese ethanol are within the Asian region, in particular South Korea and Japan. The European Union represents the second-largest import region, with about half of its 2006 imports

8 With the use as feedstock for biodiesel production, prices for used vegetable oils have been bidden up to become additional sources of revenues for a number of restaurants recently.

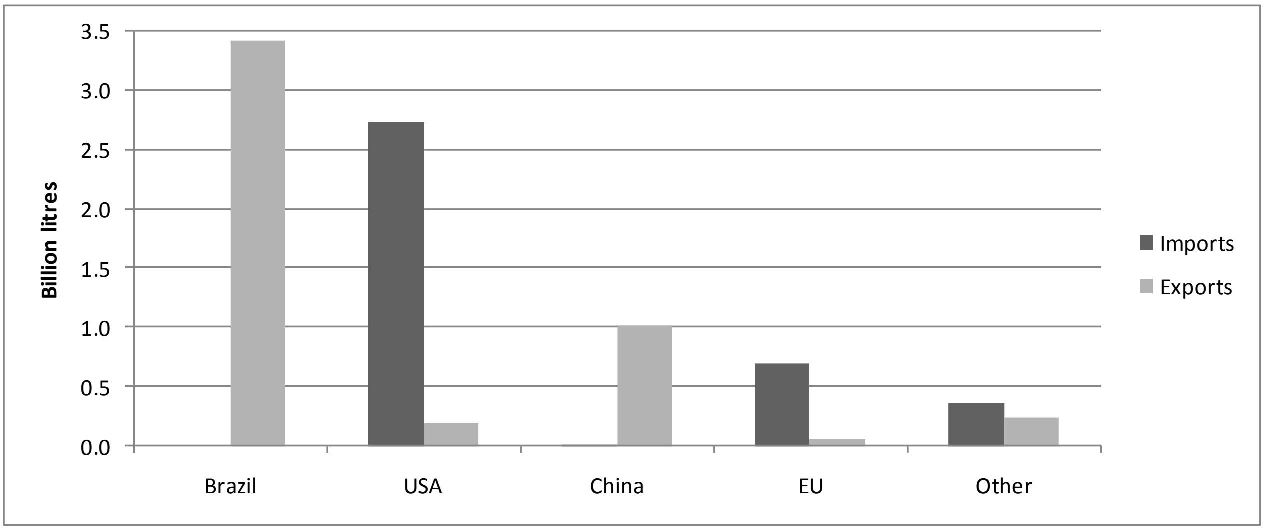
9 Note that in trade statistics, fuel ethanol trade is often not separated from ethanol for other uses. For ethanol, this section therefore discusses total trade only. Globally, an increasing share of today’s and expected ethanol trade is for fuel use, however.

10 LMC International, 2007

11 Ethanol is reported under two codes at the HS-6 level: HS 2207.10 (“Undenatured ethyl alcohol, of actual alcoholic strength of >= 80%”) and HS 2207.20 (“Denatured ethyl alcohol and other spirits of any strength”). Biodiesel is included in the rather wide HS 3824.90 (“Chemical products and preparations of the chemical or allied industries, incl. those consisting of mixtures of natural products, n.e.s.”).

originating in Brazil. With a little less than 5 billion litres, international trade in ethanol represented some 9% of global ethanol production.[12]

Figure 1.4. International trade in ethanol, 2006

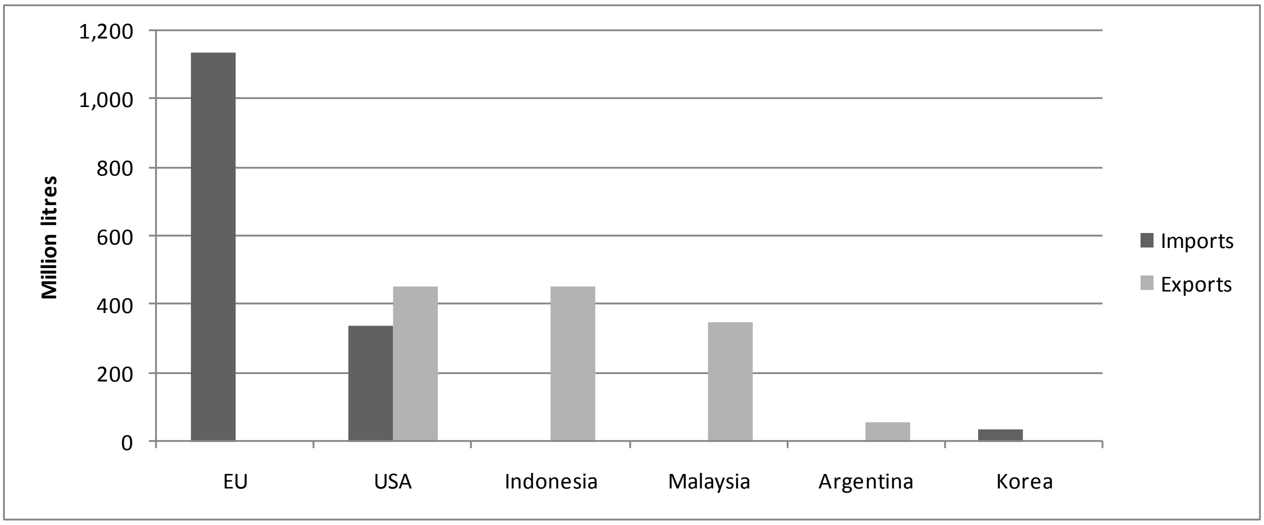


Source: Data compiled from F.O.Licht's (2008).

Biodiesel trade to date is largely about Indonesia and Malaysia as the main exporters, and the European Union as the main importing region (Figure 1.5). Due to specifics in the US biofuel policies (see below), the US also appears as a major biodiesel trader: within the US imported biodiesel is blended with small quantities (less than 1%) of fossil diesel. With this blending, the biodiesel qualifies for the domestic "blenders' tax credit". Subsequently, this high-level blend is re-exported to the EU where it benefits from additional incentives due to excise tax reductions. International biodiesel exports in 2007 amounted to some 1.3 billion litres, about 12% of global production.

12 Note that global ethanol production includes that of non-fuel ethanol which in 2006 was about 16 billion litres (LMC, 2007b).

Figure 1.5. International trade in biodiesel, 2007

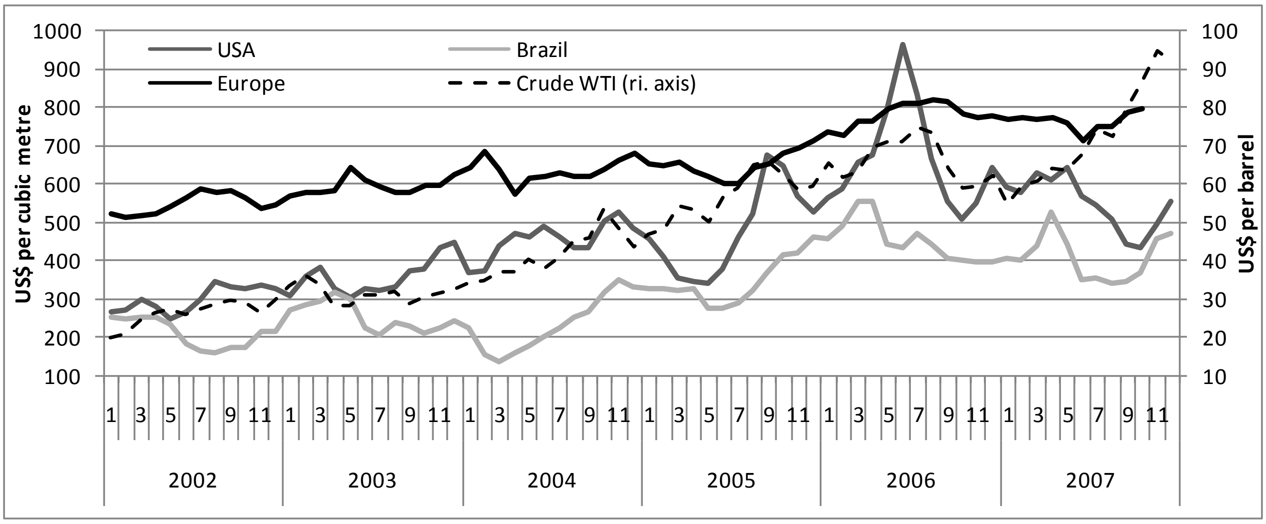


Source: Data compiled from LMC (2007a).

Price and cost developments

Apart from short-term fluctuations, international ethanol prices are more or less linked to the prices of fossil fuels and hence to crude oil (Figure 1.6) – following the increase in crude notations, ethanol prices in Brazil, the US and Europe have risen as well. In the past, Brazil prices for anhydrous ethanol have been fairly close to crude oil prices on a per-litre basis. Due to higher production costs, freight rates and border protection, fuel ethanol prices in the US and in particular Europe have been substantially higher, even though US prices have narrowed their gap to Brazil prices recently. Short-term fluctuations following regional supply and demand conditions (and due to changes in biofuel policies) are, however, important, such as the strong increase in US ethanol prices following the accelerated phase-out of MTBE in mid-2006, and the subsequent drop in prices in 2007 as large additional production capacities came on-stream. In addition, feedstock prices affect these markets - low sugar prices in large parts of 2007 and rising sugar prices from October are reflected in recent developments in Brazilian and hence global ethanol markets.

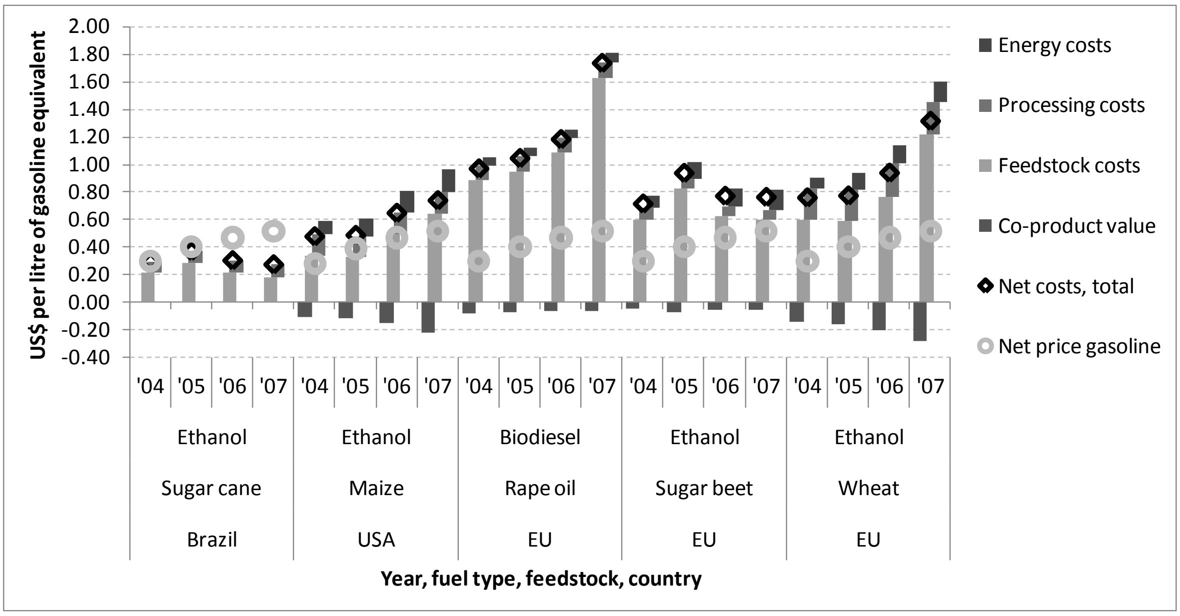
Figure 1.6. Fuel ethanol prices in Brazil, US and Europe



Source: Data compiled from F.O.Licht's (2007), F.O.Licht's (various issues).

Despite higher prices for crude oil and fuels, the economic viability has not improved much in the recent past. Due to higher feedstock prices (world prices for maize, wheat and vegetable oils have increased by 86%, 110% and 91%, respectively between 2004 and 2007), biofuel production costs have increased in most OECD countries, and in many cases the gap between biofuel production costs and the energy value of the final fuel has widened (Figure 1.7). The much lower competitiveness of wheat and vegetable oils as feedstocks for biofuel production when compared to maize, sugar cane and sugar beet has remained unchanged and indeed become more pronounced in 2007.

Figure 1.7. Production costs of major biofuel chains, 2004-2007



Source: Data from Aglink-Cosimo Database, compiled using data from LMC International (2007) and other sources.

Policy developments

Government objectives for bioenergy

In the last ten years, public support for bioenergy has increased in both developed and developing countries. Motivations behind the provision of more support for renewable energy are numerous and complex, ranging from environmental to economic and political considerations. A thorough analysis of all these objectives is a complex task and beyond the scope of the present paper. For many countries, the list of objectives for implementation of biofuel policies includes: security of energy supply; environmental improvement, including mitigation of climate change; creation of new outlets or demand for agricultural products; stimulating regional development and contributing to enhanced economic activity.

An important motivation for some countries' biofuel policies is the desire to improve the security of energy supply, which in a context of strongly rising prices for crude oil is seen to be under threat from several angles. Industrialised countries are highly reliant on fossil fuels for running their economies and particularly on petroleum products. Supplies of fossil fuels are finite, subject to depletion and face a significant risk of exhaustion and rising prices in coming years. Another element contributing to the insecurity of energy supplies is the high, and rising, import dependence of many countries on foreign oil supplies. As economies have expanded so has oil consumption with the result that OECD countries have increased their imports of petroleum products between 1992 and 2006. Beside the objective to improve security of energy supplies, OECD countries have been implementing biofuel policies in response to growing **environmental concerns** associated with the issue of climate change and global warming. The development of renewable biofuels is seen by a number of countries as one way to reduce their greenhouse gas emissions (GHG), as part of established Kyoto commitments arising from the Convention on Climate Change of 1992. Ethanol extracted from agricultural feedstocks such as maize, wheat or sugar and other agricultural biomass generally offers some reductions in greenhouse gas emissions when used as transport fuel. In addition, the improvement of local and regional environmental conditions (such as water and urban air quality) has also been cited in justification of support for biofuel policies.

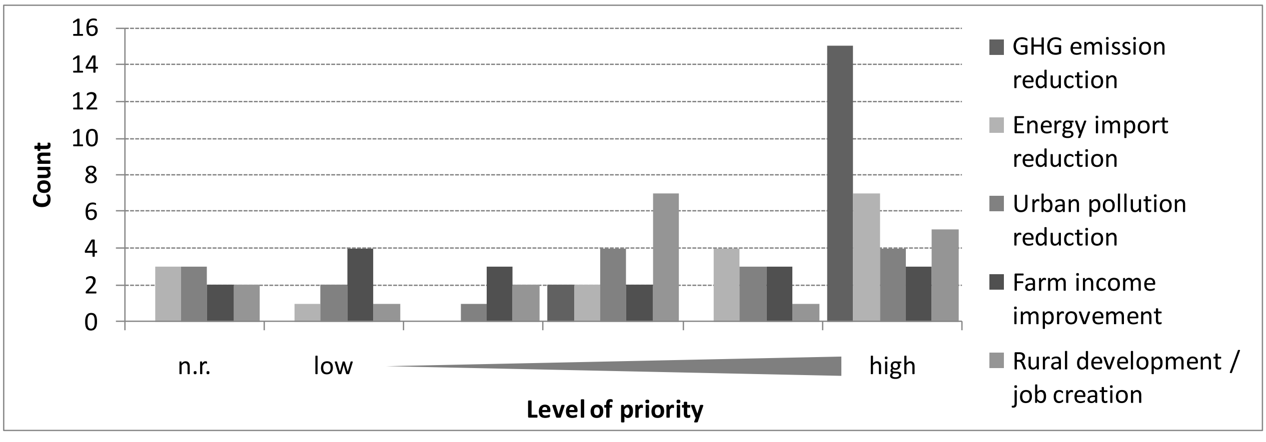
Another factor that has been mentioned in support of policies for renewable fuels, based on agricultural feedstocks, is the **creation of new market outlets** or additional demand for agricultural products. The creation of new uses for agricultural products can be seen as a way to support the farm sector and improve both commodity prices and farm incomes. This effect is of particular interest in times when agricultural support regimes are being reformed and overall support reduced. In some countries, the improvement of farm incomes is seen in the larger context of developing rural areas rather than exclusively as a farm policy objective.

Beyond the agricultural sector itself, an expanding biofuels sector is also expected to stimulate economic activity more generally in the economy and employment in rural regions in particular, which often lag behind urban areas in terms of economic growth and performance. **Regional development** and broader **economic growth** objectives are, thus, also mentioned as objectives in support of the development of renewable biofuel programmes.

Priority objectives in supporting biofuels

As mentioned above, biofuels are supported by governments for a variety of objectives. Prioritising these objectives generally is difficult, as the ranking of objectives to be achieved by public policies not only differ by countries, but also is likely to change in time as well as across Ministries and officials. Notwithstanding these difficulties, a number of OECD countries, the European Commission as well as some non-member economies have provided the OECD Secretariat with what was thought to be of priority to the respective administrations.

Figure 1.8. Indications of priority of various objectives behind biofuel/bioenergy support policies



Note: "n.r." refers to "not relevant"
Source: Data from questionnaires provided to the OECD Secretariat between October 2007 and April 2008

Figure 1.8 summarises the 17 responses received by the OECD Secretariat. Several points can be noted. First, a large number of countries consider several of the objectives given as very important, indicating that the motivation for most governments to support biofuel production and use is a set of objectives of largely equal priority rather than one specific objective.

Second, however, the reduction of greenhouse gases rates among the top priorities for almost all of the countries considered in this analysis. Clearly, increased concerns about the ongoing climate change, fulfilment of the Kyoto Protocol and the efforts to achieve another, further-reaching international agreement to combat the increased CO2-concentration in the earth's atmosphere express themselves in this priority setting.

Third, other priorities for other objectives differ across countries and regions and obviously depend on the countries' specific conditions. For instance the fact that Brazil attaches a rather low priority level to the objective of energy import reduction can be explained by the fact that this country not only disposes over significant reserves of fossil energy, but also produces a large share of its domestic demand from water power. Energy imports therefore only play a minor role in Brazil. The opposite is true for *e.g.* a number of European countries which consequently attach great importance to this objective.

Fourth, a number of countries attach high importance to the objective of rural development and the creation of additional jobs in the rural area. Clearly this objective goes beyond a focus on agriculture alone and includes the conversion industry as well as related economic activities.

Finally, a range of other objectives for supporting bioenergy in general and biofuels in particular were provided in the questionnaire in addition to those suggested by the Secretariat. These include the reduction of the transport sector's energy intensity and diversification of energy supplies within and outside the transport sector, the facilitation of setting up small businesses facing high start-up costs, improvement of the economies' sustainability, the development of a recycling-based society and related strategic developments, and the fostering of technological developments.

National targets for renewable energy

Many countries have followed the practice of setting indicative targets for the share of renewable fuels in their total fuel consumption. These targets refer to the use of renewable energy sources (RES) which for biofuels essentially mean biomass. Table 1.2 provides an overview of national targets in terms of the percentage of total biofuels to be produced from RES by 2010. Rather ambitious targets tend to be set for biofuel production. Some of them are even obligatory, as indicated in Table 1.2.

Table 1.2. Targets for Renewable Energy and Fuels in 2010 for selected countries

COUNTRIES	% of RES in total primary energy	Fuels from RES[1]
EU-25	12%	5.75%
Austria		Mandatory target of 5.75%
Belgium		5.75%
Cyprus [2, 3]	9%	5.75%
Czech Rep	5-6%	5.55%
Denmark	20% in 2011	5.75%
Estonia	13%	5.75%
Finland		Mandatory target of 5.75%
France	10% in 2010	7% (2010), 10% (2015)
Germany	4%	Mandatory target of 5.75%
Greece		5.75%
Hungary		5.75%
Italy		2.5%
Ireland		NA
Latvia	6%	5.75%
Lithuania	12%	5.75%
Luxembourg		5.75%
Malta		NA
Netherlands	10% by 2020	Mandatory target of 5.75%
Poland	7.5% by 2010 14% by 2020	5.75%
Portugal		5.75%
Slovak Rep		5.75%
Slovenia		Mandatory target of 5%
Spain	12.1%	Mandatory target of 5.83% in 2010
Sweden		5.75%
UK		Mandatory target of 5% of transport fuel suppliers' sales by 2010

Other OECD Countries		
Australia		350 million litres
Canada		5% renewable content in gasoline by 2010 2% renewable content in diesel fuel and heating oil by 2012
Iceland		
Japan		50 million litres of biofuels by 2011(domestic production)
Korea		
Mexico		
Norway		No
New Zealand	90% of total electricity	Mandatory target of 3.4% of total transport fuel sales by 2012
Switzerland		
Turkey		
US		36 billion gallons by 2022

1. Fuels from RES in majority produced from biomass.

2. Footnote by Turkey.
The information in this document with reference to « Cyprus » relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Turkey recognizes the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of United Nations, Turkey shall preserve its position concerning the "Cyprus issue".

3. Footnote by all the European Union Member States of the OECD and the European Commission.
The Republic of Cyprus is recognized by all members of the United Nations with the exception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus."

Support measures for biofuels

A number of different policy measures are being examined and/or applied to nurture the development and use of renewable biofuel industries in OECD countries. These measures affect various stages in the production-use chain of biofuel. For example, support measures are provided for agricultural feedstock or biomass production, feedstock or biomass conversion, biofuel distribution and final consumption. Given the lack of economic viability of biofuels generally due to high production costs compared to fossil based alternatives and/the need for modifications of existing logistics covering infrastructure, transport and delivery equipment, renewable fuels are unlikely to prosper in most countries in the absence of public support. This section aims to present the measures currently used in OECD countries and some non OECD economies to support the production, distribution and consumption of biofuels. For reasons of convenience and data availability, most of the national illustrations used as examples in this section tend to focus on European countries.

Measures affecting the production of biomass

In order to reduce the production cost of agricultural crops or biomass as a feedstock for biofuels, one method is to provide a direct subsidy per output of biomass produced to a farmer, a producer of wood etc. The Energy Crop Aid (ECA) introduced by the 2003 reform of the Common Agricultural Policy (CAP) in the European Union is a good example. The 2003 CAP reform established a system of decoupling support payments from current crop production via the introduction of a Single Farm Payment (SFP), that combined a number of existing directs payments received by farmers into a single payment. On the other hand, the reform also introduced an Energy Crop Aid (ECA) as an area payment of EUR 45 per hectare to encourage the production of crops for non food or industrial uses. In addition, set-aside land could be used for the cultivation of crops for non food use, thus providing a second mechanism for encouraging farmers to produce crops for renewable fuels production.

Regardless of the end-use of agricultural products (*i.e.* for energy, food, feed or fibre use), their production has been supported by **general input subsidies** in some OECD countries. While not a direct subsidy for biomass production, such subsidies have, however, an indirect effect on the production cost of agricultural biomass by reducing the price paid by farmers for variable inputs. Among these inputs are fertilizers, feed, seeds, energy, water, electricity, transportation and insurance subsidies, etc.

Measures affecting the conversion of agricultural biomass

Reduction of infrastructure costs

Since the initial investment costs for agricultural feedstock conversion for renewable fuels are generally higher than those for fossil energy, support for biofuels production is often oriented toward a **reduction of infrastructure costs**. To that end, **capital grants** are widely used, which allow the government to finance a percentage of the investment cost faced by a producer for a renewable fuel installation (*i.e.* biofuels plant, combined heat and power generation (CHP) plant based on biomass etc.). Apart from subsidizing conversion costs, capital grants can also be provided at the distribution level such as for fuel pumps. Infrastructure development costs can also be reduced with a **system of guaranteed loans**, underwritten by the State. In the US, for example, the Energy Security Act of 1980 initiated this system of support for ethanol producers. Another option is an **Enhanced Capital Allowances** scheme. This allows a greater proportion of the cost of a renewable energy/biofuel investment to qualify for tax relief against a business's taxable profits for the period during which the investment is made. Finally, governments can reduce infrastructure costs through capital grants allocated by making a selection from tenders of the most efficient firms and allowing them to convert biomass only if they own a **license** granted on logistics, production costs, and distance criteria

Direct reduction of production costs

Support of biomass can also be orientated towards a reduction of production costs through the granting of an amount of money proportional to the quantity of biofuel or energy output. This support can take the form of a **direct subsidy per unit of output** of biofuel produced and given to the upstream producer. The subsidy can also take the form of an **income tax credit** granted to the downstream producer. This type of measure was use to assist small ethanol producers In the US under the Energy Policy Act of 2005.

Guaranteed price for biofuel produced

A further way to support renewable fuels or biofuel production consists of guaranteeing a minimum price that a biofuel distributor, for instance, has to pay to a private, independent and eligible producer of renewable fuel. This guaranteed minimum price of purchase for the biofuel produced (also known in some situations as the "feed-in-tariff"), can be fixed either for a certain multi-annual period, in order to provide certainty for a renewable fuel producer over the medium or long term, or else adjusted periodically (mostly the premium) in order to maintain some flexibility and to account for unforeseen cost reductions of renewable fuel production. In some situations the guaranteed price is augmented by a premium, used to account for the social or environmental benefits of renewable fuels can also be granted. The premium can be multilateral (same premium for all kind of renewable energy) or differentiated depending on the renewable technology used. Another variation is a **green bonus** which can be granted as an incentive to supply "green" or renewable energy to the market. In that case, the producer sells the biofuel on the market for the wholesale price but receives an additional green bonus from the distribution system operator.[13]

Quantitative requirements

Finally, support for agricultural feedstock or biomass conversion can take the form of a quantitative requirement. To that extent, a **quota obligation scheme** can be used that sets the proportion of fuel that must be produced from agricultural feedstocks or biomass. This type of measure, however, has not been widely employed. All of these orientations (reductions of infrastructure and production costs, guaranteed prices and quantitative requirements) are generally combined in one form or another to support biofuel production.

Measures affecting the distribution of biofuels

Reduction of the distribution costs

In order to reduce the cost of distribution, a **fuel excise tax credit** can be granted to biofuel blenders. Under this arrangement, the fuel excise tax is normally paid by the blenders when they supply the fuel on the market but in a second step, they are allowed to claim a tax credit for the biofuel component of the fuel mixture with gasoline, for example. This system has been used in the US. When a blender benefits from an excise tax credit system but does not have sufficient tax liability, an **income tax credit** can be granted. In that case, the amount of the credit will be imputed on the income instead of the fiscal liability. A **direct subsidy** can also be granted to reduce the distribution costs of biofuels. In Sweden for instance, under the Renewable Fuels Act (2005:1248), a State aid has been introduced for measures to promote the distribution of renewable fuels.

Quantitative requirements

To support the distribution of renewable fuels, quantitative requirements on both distributed quantities and distributing infrastructures can also be used. On the distribution side, a **quota obligation scheme** is one procedure which can be implemented to ensure supply. In relation to **distributing infrastructures quotas**, governments can require, for example, that petrol stations sell a certain amount of renewable fuels. In Sweden, for example, from April 2006, petrol stations selling more than 3 000 cubic metres of petrol or diesel per year must sell renewable fuels as ethanol or biogas. In 2009, this requirement will be enlarged to points of sale that provide 1 000 cubic meters of conventional fuels or more annually. Penalties can be applied to ensure compliance with the quota objectives.

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13 Austrian Energy Agency, http://www.energyagency.at/enercee/cz/supplybycarrier.en.htm#res

Support measures for renewable fuels consumption

Reduction of biofuel prices

In order to support the consumption of renewable fuels, one approach is to offer a price reduction for the biofuel, relative to the price of the competing fossil fuels. In this context, a majority of countries currently grant a **fuel excise tax exemption** for renewable fuels such as bioethanol and biodiesel. The exemption can be limited to a certain quantity of biofuels or else be open-ended and unlimited in the quantity of biofuel covered. Some countries grant a **CO2 excise tax exemption** (Norway, Sweden and Denmark) to promote the consumption of biofuels. **VAT exemption** is sometimes also granted. An **income tax credit** on the purchase of renewable infrastructure such as flex-fuel engine technology in cars that run on pure biofuel or blends with fossil based fuels etc., can also be granted. Under this measure, a percentage of the total cost of the renewable fuel infrastructure can be deducted from the income tax of a households or a firm.

Quantitative requirements

Quantitative requirements can be set for renewable fuel infrastructure (cars, renewable equipment etc.) or for the biofuel itself. Quantitative requirements can also be set on the consumption of renewable fuels through a **quota obligation scheme** implemented, for example, through a minimum share target or by a blending percentage under which fuel users may be required to consume a certain amount of renewable fuel with their total fuel purchases. As in the case of distribution support for renewable fuels, a **penalty** can be applied for non-compliance with the set objectives.

Other support measures

Almost all countries have research and development (**R&D) support schemes** in place for renewable fuels. Research on technology improvement and new technologies is currently being pursued through R&D programmes, with a strong emphasis on the commercial development of second generation biofuels technology.

In order to support the domestic production of biofuels, some countries or regional trading blocs (*e.g.* the European Union) apply **tariffs on biofuel imports**. Besides direct import tariffs on processed renewable fuels, **imports tariffs on commodities** used as feedstocks or biomass to produce biofuels (*i.e.* sugar, wheat, corn, rape seed, sunflower oil, palm oil etc.,) are commonly applied to provide a measure of protection for the domestic production of these agricultural products. Rather than supporting the local biofuel industry, such tariffs or restrictions that involve market price support for agricultural products act like a tax by raising input prices on the production of bioenergy using domestically produced agricultural biomass or feedstocks. In addition to tariffs, other non tariff-barriers are used to support biofuels. Among theses, **fuel quality standards** set specific requirements on fossil fuels (volatility, blending ratio etc.) that might be difficult to replicate in biofuels and thus effectively limit their use.

Specific biofuel support policies in selected countries

In the **United States**, a large range of measures are used to support the production and use of biofuels, including fuel quality standards, alternative fuel requirement for public vehicles and tax incentives for flex-fuel vehicles. Blending obligations additionally apply in several US states. Finally, a range of research projects are underway with public support which relate to numerous aspects of biofuel production and use. The production of cellulose based biofuels represents a particular focus in this regard, with six cellulosic ethanol plant projects supported with a USD 385 million funding by the Department of Energy.[14] The two

14 F.O.Licht's (2008), p.181.

main instruments for the promotion of US biofuel production and use are, however, the fuel excise tax credit for biofuel blenders and the import tariff.

Biofuel blenders are granted an excise tax credit of USD 0.51 per gallon (USD 0.135 per litre) of ethanol blended into fossil gasoline, and USD 1 per gallon (USD 0.264 per litre) of biodiesel blended into fossil diesel. Additional tax exemptions apply in individual states, as well as for small biofuel producers with production capacities of up to 60 million gallons (227 million litres). The fact that this tax credit is provided to blenders means that neither biofuel producers nor final consumers are targeted directly, creating an incentive to import pure biofuels, blend them with small quantities of fossil fuels, and to reexport these high-level blends to third countries, in particular to those which support biofuel use, such as the European Union. Given the lower import tariffs when compared to ethanol (see below), this is particularly relevant for biodiesel.

Ethanol imports from outside NAFTA face a primary tariff of 1.9-2.5% plus an "other duty or charge (ODC)", often referred to as the secondary ethanol tariff, of USD 14.27 per hl. Using the 2007 average price for Brazilian dehydrated ethanol of USD 42.05 per hl as a benchmark, these tariffs were equivalent to an ad valorem of 34.6% and 36.4%, respectively. However, imports under the Caribbean Basin Initiative (CBI) enter the US tariff free within increasing import quotas. The MFN tariff applied for biodiesel is substantially lower than that for ethanol at 4.6%.

The Energy Independence and Security Act of 2007 established a 36 billion gallon (136 billion litres) Renewable Fuel Standard (RFS) until 2022. While maize based ethanol constitutes the main biofuel in the coming decade and is to increase to 15 billion gallons (56.8 billion litres) until 2015, other biofuels explicitly mentioned include cellulosic biofuels as well as biodiesel. The blending of biodiesel into fossil diesel is required starting with 500 million gallons (1.9 billion litres) by 2009 and to increase to at least 1 billion gallons (3.8 billion litres) by 2012.

It should be noted that the new RFS represents a mandate for renewable fuel use, not necessarily for production of biofuels, so it generally opens the possibility of increased imports. Given the mandate for conventional biofuels, defined as corn ethanol only[15] for which low-cost producers and potential exporters are unlikely to develop, this part implicitly defines a production mandate for US ethanol based on maize. In addition, all other types of biofuels are required to produce at least 50% less lifecycle greenhouse gas (GHG) emissions than gasoline, in the case of cellulosic ethanol at least 60% less. Depending on the design of the model used to calculate baseline and biofuel GHG emissions, these might limit the potential for imports complying with – and hence accounting to – the RFS. Finally, safeguards allow for waiving parts or all of the requirements in the RFS in the case of adverse impacts on feed grains, livestock, food, etc.

Canada is introducing mandatory blending requirements for ethanol in gasoline and for biodiesel in fossil diesel. On a federal level, gasoline has to contain at least 5 vol.%[16] of renewable content by 2010, whereas diesel fuels have to contain at least 2 vol.% of renewable content by 2012. Higher requirement are legislated e.g. in Manitoba and Saskatchewan and Ontario is still debating the possibility of reaching 10 vol.% by 2010.

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15 The RFS defines annual production quantities for total biofuels as well as for "advanced biofuels", defined as biofuels other than ethanol from corn starch. The mandate for ethanol from corn starch therefore is defined implicitly.

16 To avoid misunderstandings, biofuel shares in this report are given explicitly either on a volume basis ("vol.%") or on an energy basis ("ener.%") – the latter taking into account the lower energy content of ethanol and biodiesel compared to their fossil counterparts.

In addition to the mandates, the Government of Canada has provided CAD 2.2 billion for programs to boost domestic production. This funding supports direct producer incentives, programs to support farmer participation in the renewable fuels industry, and a fund to help commercialize next-generation renewable fuels. Biofuels also benefitted from excise tax exemptions on both federal and provincial levels. Concurrent with the implementation of the production incentive program in April 2008, Canada eliminated the federal tax exemptions for ethanol and biodiesel.

Canada applies a CAD 0.05/l tariff (11.1% in ad valorem terms using 2007 average prices and exchange rates) on ethanol imports from outside NAFTA. In addition to federal contributions, several provinces support biofuels through measures such as capital grants, direct subsidies and tax credits.

In the European Union, support to the production and use of biofuels is provided by the Member States rather than centrally. The Directive 2003/30/EC of the European Parliament and of the Council (the "2003 biofuel directive") stated that Member States should set target minimum shares of biofuels in their total petrol and diesel use for transport – as a reference value for these targets, the Directive states 5.75% to be achieved by the end of 2010. The EU explicitly mandated Member States to set up the necessary legislation to ensure compliance, and allowed for tax concessions for the promotion of biofuel use.

At the EU level, two support measures are relevant: The EU applies a tariff on denaturated and undenaturated ethanol imports of €10.20/hl and €19.20/hl (33.2% and 62.4% in ad valorem terms, again using 2007 average prices and exchange rates), respectively. Imports of biodiesel are taxed with a tariff of 6.5%. Furthermore, as noted above, the EU provides a specific area payment for crops used for energy generation. The Energy Crop Aid (EUR 45 per ha) is paid both for feedstocks used for biofuel production and for those used to generate heat and/or power. In addition to that the regulations permit the use of set-aside land for non-food crops.

A number of EU Member States have legislated minimum incorporation rates into the transport fuels sold. Rates differ across countries and often are increasing in time. On average for the EU, these mandates are equivalent to about 3.5% of total transport fuel use in energy terms from 2010.

Tax concessions are another measure widely applied in EU Member States. These concessions partly result in biofuels sold with not excise tax in some countries, while tax rates are reduced in others. Differences are partly made between biofuels used in low-level blends with fossil fuels and pure biofuels. On average, the tax for ethanol and biodiesel is about 50% lower than the rates for gasoline and fossil diesel. It should be noted that countries having legislated mandates often apply normal excise tax to the biofuels while mainly countries without biofuel mandates stimulate biofuel use via reduced excise tax rates.

A new Directive on Bioenergy, published as a Commission Proposal in early 2008, includes an increased and mandatory target of 10% of transport fuels to be replaced by biofuels by 2020. The proposal makes clear reference to second-generation biofuels which are to represent an important share of this target share. Furthermore, the Directive states minimum requirements for biofuels receiving public support and accounting to the mandatory incorporation share with respect to several sustainability criteria including, among others, their life-cycle greenhouse gas balances.

Following the signature of the Kyoto Protocol, the government of Japan decided to set a target for biomass-derived fuel use for transportation at 500 million litres (crude oil equivalent). Given the high production costs of domestic biofuels, Japan would have to provide significant support to stimulate domestic supplies or rely on imports from other countries, in particular on Brazilian ethanol. Biofuel production in Japan remains at exploration stage at the moment, mostly based on waste and residue materials. Current fuel ethanol output is estimated to be 30 000 litres. The Japanese budget for FY2007 includes expenditures for the promotion of biofuels of JPY 10.9 billion (USD 92.5 million).[17] Import tariffs have recently been reduced from 27.2% to now 20.3%.

In Brazil, ethanol use has been supported by tax reductions, and despite some reductions ethanol still benefits from advantages in a complex tax system, both on federal and state levels. The difference for the CIDE (Contribuicao de Intervencao no Dominio Economico) alone is estimated at a rate of BRL 0.28 per litre, while different rates of PIS/COFINS social taxes are charged for ethanol and gasoline as well.[18] This compares to average retail prices in 2006 for gasoline of about BRL 2.65 (USD 1.26) per litre.[19]

Blending of ethanol to gasoline fuels is regulated, with a required ethanol content of between 20% and 25% ethanol depending on government decision (which itself depends on market conditions). This blending ratio is not a minimum but has to be met exactly by the fuel industry. A 2% blending of biodiesel to diesel fuels from 2008, and a 5% blending from 2013 has been mandated recently.

Beside this, Brazil applies an import tariff of 20% on both undenatured (HS 220710) and denatured ethanol (HS 220720).

In 2002, China started a program to promote production and use of fuel ethanol by mandating the blending into gasoline in several big cities.[20] A compulsory use of a 10% blend was introduced in several provinces in October 2004, and extended to 27 other cities in 2006. To support domestic ethanol production, the government provides CNY 1.5 billion (USD 188 million) per year in financial subsidies to ethanol producers - in 2006, the production subsidy was CNY 1 373 (USD 172) per tonne. In addition, the value-added taxes are refunded for ethanol production, and the fuel is exempted from 5% consumption tax. Finally, the government covers any loss due to processing, transportation or sale of E10 blended fuel. Ethanol production in China is mainly based on corn, but other feedstocks such as wheat, cassava and others are used in limited quantities as well. Currently there are no programs to promote production and use of biodiesel in China other than at an experimental stage.

Several other developing countries have defined blending targets for ethanol, biodiesel or both, including Columbia (ethanol and biodiesel), Indonesia (ethanol and biodiesel), Malaysia (biodiesel), South Africa (ethanol) and Thailand (ethanol). At the same time, import tariffs are applied by Columbia for ethanol and by Indonesia for ethanol. A number of other countries have declared interest in the increased production and use of biofuels.[21]

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17 MAFF (2008).

18 USDA/FAS (2007), p. 16.

19 GTZ (2007)

20 Koizumi, T. and Ohga, K. (2007).

21 For information about biofuel programmes in different developing countries see FAO (2007): Recent Trends in the Law and Policy of Bioenergy Production, Promotion and Use. FAO Legal Papers Online #69. Rome: September 2007. Accessed in April 2008 from http://www.fao.org/legal/prs-ol/years/2007/list07.htm.

Trends in science and innovation[22]

Introduction

The volume goals for biofuels by the two main producing countries/regions in the OECD, i.e. the United States and the EU, are in the order of 25-30% of the transportation fuel market in these areas by 2030. Current shares in the US and the EU, however, are only 2 to 3%, and it is the large gap between actual biofuel use and official objectives that drives most of the search for new technologies.

The principal focus in this search is on technological progress to improve the economic viability of so-called 'second generation' production processes whereby lignocellulosic biomass is used as the starting material for biofuel production. This would replace current production technologies that are based on the fermentation of starchy food and feed plants (such as grains) into bioethanol. Lignocellulosic biomass[23] includes fast growing woody plants, grasses, unused portions of food plants (such as corn stover) and a number of industrial waste products.

However, despite much investment, and much scientific and technological advance, to date no commercial scale lignocellulosic biomass fermentation plant is in operation. The technological challenges to developing a bioethanol production process based on lignocelluloses as a substrate remain high and the US National Renewable Energy Laboratory's estimates that commercial production is unlikely before 2012 are broadly accepted by most in the field.

Budgets and key targets for R&D

Public financial support for biofuels R&D is widespread both amongst OECD countries and a number of non-member economies such as Brazil, China and Russia. Funding for applied research is also common and many countries fund demonstration projects and feasibility studies. This suggests that policymakers recognise the significance of this area and the importance of a solid R&D base.

With USD 90 million in 2006, the United States is by far the biggest spender on R&D for bioenergy, followed by Japan, Canada and Sweden with expenditures in 2006 in a range from USD 25 to USD 65 million. Much lower budgets are available in some of the other OECD countries (Figure 1.10).

80. Investment in so-called "second generation" (lignocellulosic) biofuels R&D is a clear priority of the US Department of Energy (DOE) and far exceeds that in other OECD countries. For example, in 2008 alone, DOE has announced USD 18.4 million funding for R&D into biomass, USD 34 million for enzymes for cellulosic ethanol projects, and USD 114 million for small scale cellulosic biorefineries. In the US, the public R&D budgets related to biomass added up to more than USD 800 million over the 1993 to 2004 period, more than 8 times the amount spent in the Netherlands and Sweden which came second and third (Figure 1.11).

In addition to the country specific support in the European Union, the EU Commission is expected to issue several calls-for-tender for projects targeting second generation as well as improvement of first-generation biofuels under the 7th EU Framework Programme (FP7). During the first calls in 2007 and 2008, some EUR 139 million has been allocated for biofuels and biorefinery research. Previously, both FP5 and FP6 provided provisions for support for biofuels R&D.

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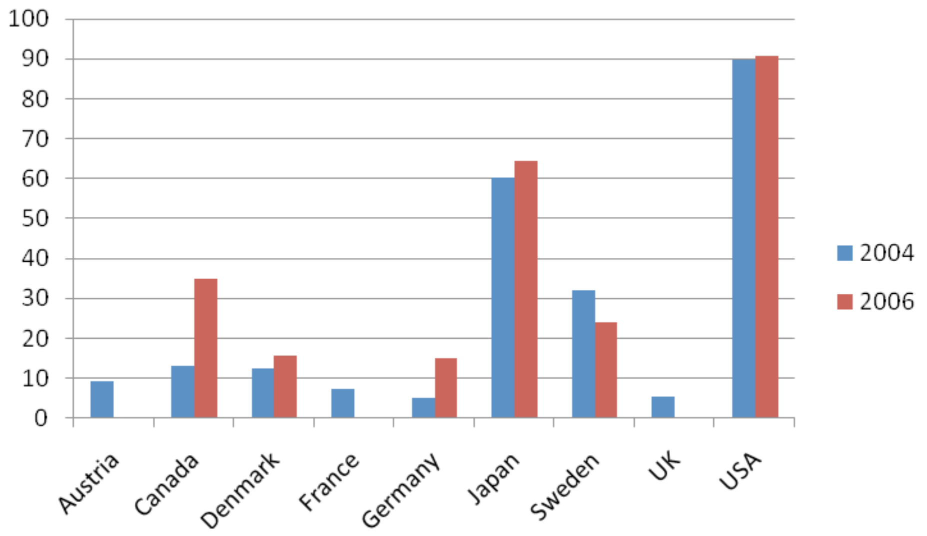
22 The contribution of the OECD Directorate for Science, Technology and Innovation (DSTI) which drafted this section is gratefully acknowledged.

23 Lignocellulosic biomass contains the parts of plants that give them structure and rigidity (such as cellulose, hemicelluloses and lignin). Such material does not include the edible – starchy – parts of plants.

China also has funded R&D for biodiesel and bioethanol projects at the laboratory and small pilot plant level since the 1980s under its successive five year plans. Currently, R&D support is available for cellulosic bioethanol and for thermo-chemical biomass conversion.

Figure 1.10. Total public R&D expenditures for bioenergy, 2004-2006 (USD million)



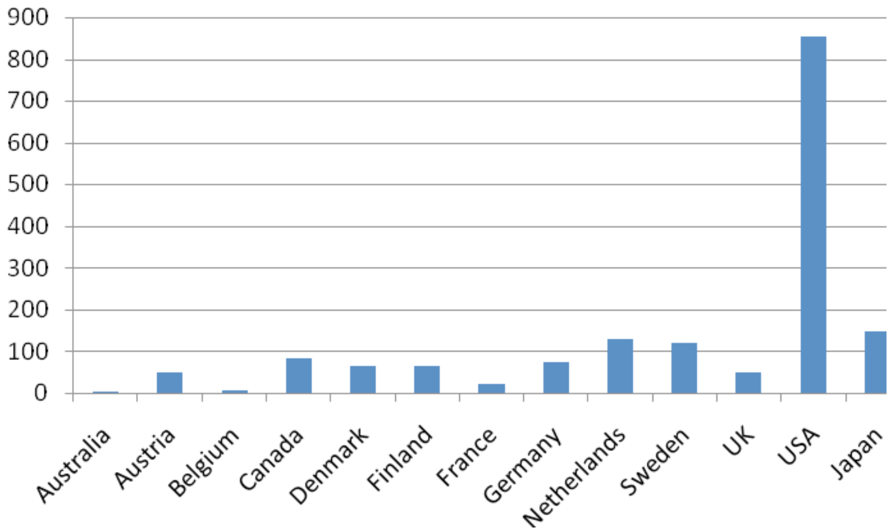
Source: IEA.

Canada and Australia are strong in rapeseed cultivation, and hence much of their biofuel programmes focus on biodiesel production. Significant research programmes in lignocellulosic bioethanol have not been announced. In Japan, such R&D activities also are modest though overall R&D expenditure on bioenergy is relatively high (Figure 1.10).

Broadly speaking, the key targets of bioenergy R&D activities are threefold: to reduce input costs to production; to increase the efficiency of conversion of feedstocks to biofuels, and; to increase the value-added of outputs. Currently, by far the greatest share of R&D effort is focused on process improvements for biofuels production.

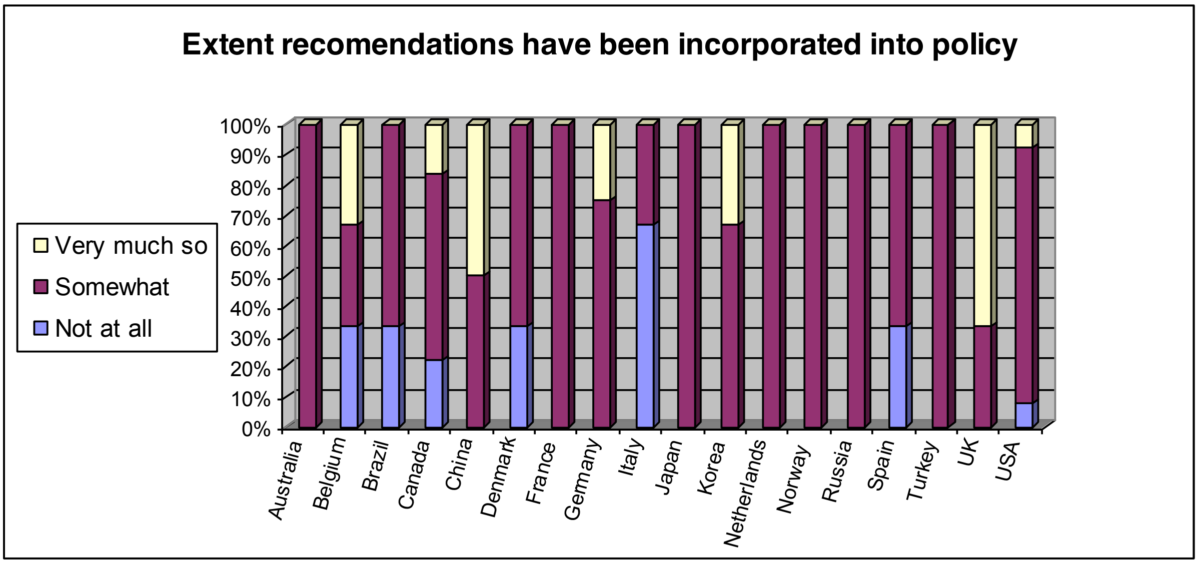
In setting these R&D targets, technology foresight, scenario planning, visioning and roadmapping have been widely used in countries to attempt to identify national strengths and opportunities in developing biobased feedstocks and biofuels. As is indicated in Figure 1.12, however, the implementation of the findings of such exercises into concrete policy action remains patchy.

Figure 1.11. Public R&D budgets related to biomass (Cumulative Budgets 1993-2004, USD million)



Source: IEA.

Figure 1.12. Incorporation of recommendations of visioning, scenario planning, foresighting etc. activities



Source: OECD.

Possible directions for R&D by Biofuel Type

As discussed earlier, the goals for bioenergy R&D are to reduce input costs, to increase conversion efficiency of feedstocks and to increase the value-added of outputs. Furthermore, one of the objectives pursued by government policies for bioenergy is the reduction of GHG emissions. Against this background, what are the directions for research and development that can be considered, or are presently undertaken, to achieve the above mentioned goals and objectives? The following section provides a brief overview of the various avenues for bioenergy R&D per biofuel type.

(i) Biodiesel

The production of biodiesel is a mature technology. Its energy content is close to diesel, but the yield per hectare of feedstock crops for biodiesel (primarily canola/ rapeseed) is much lower than that for sugar and starch crops. Thus canola yields 1 000 to 1 500 l/ha of biodiesel compared to 3 500 l/ha of corn based ethanol. Only oil palms have a significantly higher oil yield of 4 000 – 5 000 l/ha. Research could be focused on crop varieties with higher energy yields per hectare.

Natural glycerol is produced as by-product of biodiesel manufacture and has replaced synthetic glycerol as the dominant source for the pharmaceutical and the cosmetics industries. Research is focused now on using natural glycerol as a starting point for synthesis of a number of high value-added organic chemicals, including for polymer synthesis.

(ii) Biobutanol

Butanol is a C_4 alcohol with higher energy content than the C_2 ethanol alcohol. It offers further advantages to ethanol like better mixing with gasoline and safer logistics. A large industrial development partnership for biobutanol was established in 2006 but industrial-scale production is yet to come on line.

Significant technological improvements in fermentative production are required before biobutanol can be produced from lignocellulosic feedstocks, but the concept of "consolidated bioprocessing", whereby all fermentation steps can be carried out in a single process (and thus keeping costs and wastes down) may perhaps be easier to achieve than for bioethanol.

Similar to bio-ethanol, biobutanol is an attractive bulk intermediate for chemical synthesis and so a number of end products other than biofuels are possible.

(iii) Hydrogen and Hydrocarbon Production from algae

Biotechnological hydrogen production by photosynthetically active algae or by enzymatic or catalytic oxidation of organic molecules like glucose and ethanol is theoretically possible but looks economically unattractive. Photovoltaics seem to be a more efficient mode of energy/electricity generation which could then be used for hydrogen production.

Algal biomass production in special photobioreactors is, however, studied as a technology for CO2 sequestration from fossil fuel burning power plants. Whether and when this technology will become commercial is unpredictable.

(iv) Starch-based bioethanol

Baker´s yeast is the preferred fermentation organism of the corn and sugar ethanol industry, but does not ferment ethanol from xylose, a major constituent of the hemicellulose fraction in biomass feedstock. Recombinant xylose fermenting yeasts have been constructed, but so far are still slow in ethanol production. Industry is therefore working with recombinant bacterial strains which convert glucose, xylose, and cellobiose into ethanol. Bacterial fermenter yields of ethanol are typically lower than with yeast, and more expensive sterile fermentation technology has to be applied. It is unclear whether and when the industry might take up such technologies.

Significant advances have been made in developing enzymes that can be added to starch grains without the usual first step of "cooking" grain. Successful adoption of such technologies should reduce overall energy costs for processing.

(vi) Lignocellulosic bioethanol

As of early 2008 there is no commercial scale lignocellulosic bio-ethanol/biofuel plant on stream, but some 15–20 companies, most of them located in the U.S., are pursuing pilot plant studies with various biotechnological and thermo-chemical biomass conversion routes. A preferred route still does not exist.

Considering the efforts of the industry and the strong support by the U.S. DOE, the first commercial lignocellulosic plant, may be operational in 2012. For the fermentation route to bio-ethanol this means that the operators can manage the complex, multi-step operation on a routine basis throughout the year, and come close to cost break-even.

Enzyme performance is the major bottleneck in lignocellulosic ethanol fermentation. Significantly improved cellulases are needed in order to improve yield and speed of conversion. Industry is pursuing a number of routes simultaneously to improve performance and different competing pilot plants are operating.

Investment decisions regarding the first commercial biofuel plant using thermo-chemical lignocellulose decomposition and synthesis from syngas will mainly depend on cost competitiveness to corn ethanol, since the basic technology is already available.

System-Wide Strategies

In addition to the above-mentioned directions for biofuels R&D, a number of broader research strategies have also been developed that go beyond the specific objectives for biofuels.

In this context, three broad system-wide strategies exist that characterise the move to second-generation biorefineries that may also, but not exclusively, address the more narrowly defined goals and objectives for biofuel R&D.

1. consolidated bioprocessing: development of new strains of microorganisms that are able to carry out several chemical conversions needed in bioprocessing at the same time;

2. integrated bioenergy projects: in Brazil and elsewhere, operational design of biorefineries is developing in such as way as to integrate biofuel production with animal feed production as well as production of co-products for energy generation;

3. biorefinery technology platforms: this may integrate both the previous strategies as well as focus outputs not just on biofuels but on production of high added value precursors for the chemicals industry.

A good example of combining these approaches is the European Biofuels Technology Platform, which is in the process of implementing a Strategic Research Agenda for Biofuels comprising:

1. Utilisation of lignocellulosic biomass which can be grown in the wide range of climatic conditions existing in Europe;

2. Development of advanced conversion technologies such as (i) biological conversion of lignocellulosic biomass to ethanol, (ii) improvement of biodiesel technologies with better

catalytic conversion approaches, and (iii) efficient processes based on biological or thermochemical pathways for the production of "next generation" biofuels;

3. The development of biorefineries for the integrated production of energy (heat, power and fuels) and added-value products. Aiming at the integral use of the biomass resources, biorefineries improve the cost-effectiveness of the products and maximise their sustainability.

What the future may hold

The key challenges for biofuels R&D are to overcome some of the systems inefficiencies (around energy capture and conversion) and to move towards carbon neutral production. By and large these goals seem feasible, particularly if the predicted process improvements in lignocellulosic conversion come on stream. This is widely expected to happen, although the technological challenges remain high and commercial production is unlikely before 2012.

A move from sugar/starch to lignocellulosic feedstock together with more efficient enzyme catalysis in integrated biorefineries seems to be a clear direction of travel. Energy and economic efficiency of such processes should be significantly higher than is currently the case for starch/sugar based bioethanol.

To the extent this is the case, bioethanol and biodiesel can probably contribute to environmentally sustainable carbon-based fuel security in the medium term. However, in the longer term, innovations in solar energy generation, hydrogen fuel cells and the like are likely to produce energy more efficiently and can be expected to marginalise the use of biofuels again, except in local and niche markets.

Technology developments in lignocellulosic bio-ethanol and hydrocarbon production are probably more likely to pay off if developed as renewable feedstocks for the chemical industry. With the present bio-ethanol production cost in Brazil and an oil price greater than USD 90/ barrel, catalytic dehydration of bio-ethanol to “bio”-ethylene is already profitable.

Fossil carbon use as a raw material for the chemical industry is less than one fourth of the global oil demand for transportation. Nevertheless, it still represents some 400 million metric tonnes per year, making it a sizeable and attractive target for a future mature biomass converting industry.

Biofuel performance with respect to environmental and other criteria[24]

Introduction

Energy security, environmental factors, technological development, diversification of incomes of farmers and rural communities, as well as rural development, are the main reasons for recent biofuels policy targets.

The main environmental driver for the promotion of biofuels is the opportunity for reducing the greenhouse gas (GHG) emissions from transport. Several past studies covering the whole life cycle of biofuels confirmed that several biofuel chains show a reduction of net GHG emissions with respect to conventional transport fuels. The quantitative amount of these benefits strongly varies with the specific biofuel chain, the biomass feedstock, geographical scope and the inclusion of crop displacement effects.

[24] The contribution of the International Energy Agency (IEA) which drafted this section in co-operation with the United Nations Environment Programme (UNEP) and the European Environment Agency (EEA) is gratefully acknowledged.

However, increasing concerns have been expressed recently with regard to the sustainability profile of biofuels *(e.g.* Doornbosch and Steenblik, 2007; Searchinger *et al* 2008, Fargione *et al* 2008). Most frequently cited issues of concern include land occupation, carbon stock decrease, water depletion, water pollution, biodiversity losses and air quality degradation. In addition to these environmental problems, criticisms point to potential economic and social conflicts derived from energy-food source competition.

As a consequence of these concerns and potential side-effects of large-scale biofuel deployment, policies supporting biofuels are increasingly being debated. It is important, therefore, to carefully analyse the potential environmental costs and opportunities for biofuel production (and of other biomass to bioenergy pathways).

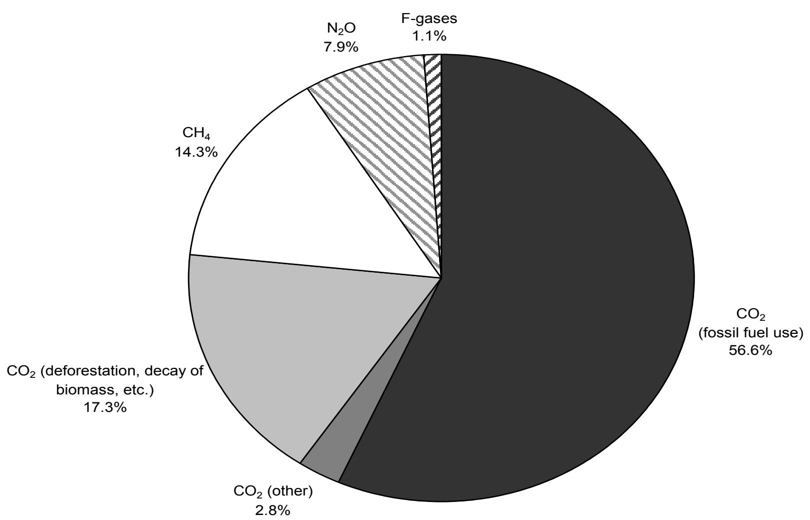
A particular concern relates to the interactions between land use, land use change and climate change patterns. This is briefly introduced in the next sections.

Global land use and climate trends

The issue of climate change is a global concern that is, at least in part, closely tied to both the production and use of energy as well as agricultural and forest land use. The concentration of GHG in the atmosphere has increased strongly during the last decades (IPCC, 2007a). The main sources of GHG emissions are linked to the use of fossil fuel energy in the industry, building and transport sectors, agricultural production, and deforestation (Figure 1.13).

Deforestation at the global level is a more important factor than emissions from transport (Stern, 2006). Deforestation and the combustion of vegetation happens mainly in the tropical countries of the world linked to legal and illegal logging (FAO, 2005), the expansion of cropping and pasture areas (FAO, 2003; Morton *et al.*, 2006) and the use of woody biomass for fuel (UN-Energy, 2007).

Figure 1.13. Share of different anthropogenic GHGs in total emissions in 2004 in terms of CO2-eq.



Source: IPCC, 2007b; SYR-AR4

The issue of land use change, preservation of indigenous forests, and expansion of forest resources as a mechanism for establishing carbon sinks, has therefore gained considerable attention (Righelato and Spracklen, 2007; Kindermann *et al.*, 2006), particularly in the context of the negotiations for the follow-up international agreement to the Kyoto protocol on climate change. In addition, the world's forests provide important ecosystem services that support nutrient, water and atmospheric cycles (UNEP, 2006; Scharlemann and Laurance, 2008). Given likely future impacts from climate change on agricultural productivity (IPCC, 2007a) and strongly increasing food demand over the coming decades (OECD, 2008) this requires that careful consideration be given to the uses to which the available agricultural land area is put.

There are strong agricultural and land use trends that impact on the world's ecosystems and their capacity to act as carbon sinks. These trends would continue independently of biofuel production. On the other hand, care needs to be taken that biomass produced for biofuels and other forms of bioenergy, does not aggravate the environmental issues associated with global land use trends.

Indeed, in some circumstances there can be potential win-win solutions in using biomass crops for favouring a better agro-environmental management. For example, short rotation coppice crops can reduce nutrient leaching and soil erosion risks compared to growing other arable crops. The use of grassland biomass from prairie grasses or semi-natural grasslands (EEA, 2007) for second generation ethanol production (Tilman *et al.*, 2006) can even have beneficial effects on biodiversity. However, the realisation of such opportunities requires careful planning, the right economic incentives, directed research and support for appropriate management practices.

In conclusion, the production of biomass for energy (whether for transport fuels or other purposes) constitutes a key nexus between the different societal and environmental functions of the available global land area (whether as cropland, forests or other land uses). The direction and scale of this emerging land use will have a strong influence on the societal and ecological benefits that human society can draw from the available productive land area.

Analytical tools for evaluating the efficiency and environmental trade-offs of bio-energy pathways

Analytical tools for evaluating the efficiency and environmental trade-offs of different bio-energy pathways need to be suited to the analytical question to be answered and allow a comparison of different energy crops and pathways.

Two different research approaches appear particularly relevant:

1. Life cycle assessment (LCA) for the determination of life cycle environmental profiles of different biofuel chains and their comparison with the ones of fossil transport fuels;

2. Agro-economic modelling for the assessment of land-use change impacts.

The different approaches and currently available results associated with them are briefly presented in the following sections.

Life Cycle Assessment

Assessing the environmental performances of biofuels is a complex issue. It covers many different biofuel chains, conversion technologies, land-use and land-use change related issues, as well as aspects relating to the substituted products. That includes fossil transport fuels, animal feed, sugar products, chemical products (*e.g.* glycerine) and electricity, which are co-products of biofuel production.

Life Cycle Assessment (LCA) studies can provide a valuable insight on such a complex reality.[25] In particular, LCA is capable of assessing the full chain of different biofuels from the plantation field to technology conversion and final fuel combustion in vehicle engines. For instance, LCA allows us to identify the different net energy and GHG balances for various biofuel pathways, which can then be compared to their fossil fuel equivalents. This potentially allows us to tailor policies to the environmental performance of biofuels, including the introduction of minimum standards and the fostering of the most efficient biofuel chains.

The objective of this section is to explore if and to what extent LCA is suitable to give clear answers about the potential contribution of biofuels with respect to the above-mentioned drivers of energy security, climate change protection and development; and to assess their potential negative side-effects. It presents and discusses the following questions:

- What are the main findings of existing LCA studies on biofuels?
- What are the main areas of convergence and divergence?
- What are the main information gaps?
- To what extent can policymakers rely on what is sometimes sub-optimal information in LCA results to develop future policies?
- How can be LCA best applied - possibly in conjunction with other evaluation tools - to improve the quantity and quality of scientific information for policymaking support?

Features of LCA

LCA is a methodology that studies and evaluates the environmental flows and potential impacts related to a product or service throughout all its life cycle stages, from the extraction of raw materials to its end of life. It is regulated by the ISO 14040:2006 and 14044:2006 standards which, respectively, provide the principles, framework, requirements and guidelines for conducting an LCA.

In the case of bioenergy, this encompasses the input of fossil fuels and fertilizers needed for the production of biomass, over the industrial conversion processes to the final combustion of the fuel destined for use in cars, heating installations or power plants.

LCA is used more and more as a support to policymaking in many countries and thematic areas such as eco-design, integrated product policy, waste prevention and recycling, and the sustainable use of natural resources. Looking at the whole life cycle of a product or service helps ensure that no environmental burdens are shifted to other life phases. At the same time, LCA helps to identify and avoid the shifting of burdens between different environmental impacts.

LCA is increasingly used by governments to assess the potential benefits and drawbacks of new regulatory policies, and to define targets and relative measurement methods. For instance, explicit reference to LCA is made in the European Commission Renewable Energy Sources Directive proposal, the US Energy Independency and Security Act, the German Sustainable Biofuel Obligation draft and the UK Renewable Transport Fuel Obligation.

[25] It is important to remember that the degree of detail and comprehensiveness of each LCA study depends on its specific goal and scope. More recent LCAs are increasingly suited to address relevant policy questions on biofuels

Table 1.3. presents an evaluation of the suitability of LCA methodology to address the main environmental policy drivers pertaining to biofuels.

Table 1.3. Main drivers and issues addressed by LCA

Main drivers / issues		Suitability of LCA to address issues
Climate change	Emissions from production and use of fossil fuels and fertilizers	Yes
	Soil carbon stock change	Method under development
Non GHG environmental issues	Soil quality preservation	No (no impact indicator)
	Land use, land use change	Partly (generally as land occupation)
	Water management	Partly (as water consumed and depleted)
	Water pollution	Partly (not at local level)
	Air quality	Partly (not at local level)
	Biodiversity	No (no consensus on impact indicator)
Energy Security		Partly (consumption of fossil energy)

LCA is best suited to assess the contribution of the studied product/system to environmental effects on a global scale, such as global warming or ozone depletion.

It is also suitable for calculating the primary energy consumption and total fossil energy depletion, therefore providing a measure for energy security.

LCA can also provide an aggregated global measure of environmental pressure relating to water management, pollution and air quality in terms of indicators which are relevant on a regional and/or local scale, *e.g.* acidification, eutrophication, photochemical ozone creation, human and eco-toxicity. This is an aggregated measure of the *potential* impact only. Since actual impacts depend on specific concentrations and receptor response pathways, LCA results *cannot* be used for the assessment of local pollution or site-specific effects, which may however have significant policy relevance. Possible trade-off judgements (e.g. between GHG versus non-GHG impacts) ultimately remain a decision-making issue, which depends on national and sometimes local circumstances.

To date, LCA has no agreed indicators on soil quality preservation and biodiversity.

LCA results can be combined with data on land carbon storage in order to take direct land-use change effects into account. The latter can be very significant, depending on the previous use of land before transformation into productive use for biofuel production. Given the importance of such assumptions, it is recommended that emissions relating to land-use change and other life cycle phases always be reported in a disaggregated and transparent way.

The effects of indirect land use are more difficult to assess, but are potentially as important. LCA on its own is not designed to assess absolute impacts of large-scale deployment of a certain technology or product.[26] However, it can be combined with other assessment tools (*e.g.* energy-economy-environment models, agro-economic market models) for this purpose.

[26] Recent so-called “consequential LCA” studies aim at assessing such effects through the combination of LCA with input/output analysis. This is out of the scope of the present report.

Review of studies

A review of 60 reports on the environmental profile of biofuels has been carried out. The majority of studies apply life cycle approaches but limit the focus to energy and greenhouse gas emission balances only. Although increasing, the number of full LCA studies targeting other non-GHG environmental impacts is still limited (18 out of the 60 reviewed studies).

Almost all studies have a geographical scope limited to European or Northern American conditions and are based on western agricultural processes and average conversion technologies. As far as bioenergy crops are concerned, most studies focus on the more "traditional" feedstocks of corn, sugar cane, rapeseed and wheat. Very few studies focus on new crops more recently evaluated for biofuel production, such as jatropha and sweet sorghum. Furthermore, less than 20 studies investigated second generation biofuel technologies.

The studies analysed focused almost entirely on biofuels for transportation use. Only a limited number of them also investigated the fuel performance for stationary applications.

Key determinants of LCA results and main parameters

Despite some discrepancies in results, and regardless of the crops analysed, most sources converge their attention on two main life cycle stages: the agricultural phase and the transformation process phase Within those, an isolated number of variables are responsible for the largest impact share.

The agricultural phase is responsible for a significant share of GHG emissions, and is by far the largest contributor to acidification and eutrophication.

The main cause is the emission of nitrous oxide (N_2O) associated with the use of fertilizers. N_2O emissions result from nitrogen fertilizer manufacture and fertilizer application in the field. The use of fertilizers is also responsible for the emissions of ammonia, sulphur oxides and nitrogen oxides.

Another issue which is strictly related to agricultural practice is the fate of co-products, such as straw from cereal crops used for combustion, protein meal from oilseed crops and animal feed from distillers grains. The treatment of co-products and the way impacts are allocated to them can significantly change the overall results of the analysis.

The impacts of energy use are significant in the technology conversion phase, in particular in the case of ethanol production. The quantity and type of process energy used (*e.g.* heat and power from coal, natural gas or biomass) can radically change the overall results. Furthermore, the allocation of impacts on co-products can also be very significant in this phase of the life cycle.

Three main assumptions significantly influence overall results and should be carefully looked at when comparing different LCA studies:

- the chosen allocation method for co-products,
- the N_2O emission factors
- the process energy inputs

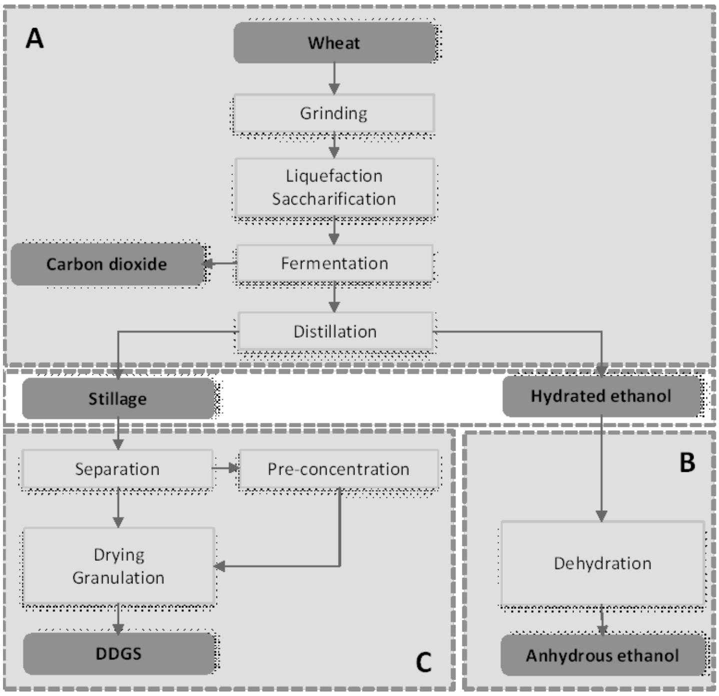
Using different assumptions will lead to significantly varying results.

Allocation is the method by which input energy and material flows and output emissions are distributed among the product and co-product(s). The International Standard ISO 14044 standard provides guidance on allocation methods and states the following options in order of preference.

- Substitution*: i.e.* expand the system boundaries to include co-product function.
- Physical allocation*: i.e.* allocate the inputs and outputs of the system to the product and co-product(s) in a way which reflects the underlying physical relationships between them, *e.g.* in terms of energy content or of mass.
- Economic allocation: *i.e.* allocate inputs and outputs to the product and co-product(s) in a way which reflects other relationship between them, e.g. based on the economic values of products.

Several allocation methods have been applied in the reviewed studies. The influence of the allocation method on final results is an issue that has been extensively debated in the LCA community for a long time (e.g. Weidema 2001). Using different allocation methods leads to varying results (Figure 1.14).

Figure 1.14 – Effects of different allocation methods on results



Allocation method		Energy use [MJ/l]	Allocation % Ethanol	Allocation % Stillage	E/R [MJ/MJ]
Whithout allocation	A	19.35	100	0	0.7
	B	1.93	100	0	
	C	8.95	100	0	
Economic value	A	19.35	95	5	1.08 (0.83)
	B	1.93	100	0	
	C	8.95	0	100	
Energy content	A	19.35	61	39	1.54
	B	1.93	100	0	
	C	8.95	0	100	
System extension	A	19.35	81	19	1.21
	B	1.93	100	0	
	C	8.95	0	100	
Mass	A	19.35	12	88	5.01 (1.56)
	B	1.93	100	0	
	C	8.95	0	100	

Source: Adapted from Gnansounou and Dauriat (2005).

All allocation methods have advantages and drawbacks, but, a distinction has to be made between analytical and regulatory purposes. The substitution method is the preferred option by ISO for analysis, however it requires arguable hypotheses about the substituted product. Economic allocation reflects more properly the actual market conditions. However, it also significantly increases the volatility of results and therefore their uncertainty. Ideally, this approach would require to reconduct the LCA study several times and adjust the results accordingly. For regulatory purposes, a more pragmatic approach might be to use energy allocation. Depending on use of co-products, this gives comparable results to those of the substitution method (Hodson, 2008). Both the European Commission Proposal for the Directive on Renewable Energy (EC 2008) and the draft for the German Sustainable Biofuels Ordinance (Fehrenbach *et* *al* 2008) apply the energy allocation method. The UK Renewable Transport Fuel Obligation uses a mixed allocation method instead (Chalmers 2008).

N_2O emissions in agriculture constitute a serious uncertainty source in the LCA results of many biofuel pathways (e.g. Crutzen et al., 2008).[27] According to the IPCC inventory guidelines, 1 kg of N_2O has the same effect of 298 kg of CO_2 emissions over a time horizon of 100 years (Solomon *et al.* 2007). As a consequence, even small changes in the N balance and rate of N_2O emissions can significantly affect the overall GHG balance results for biofuels. The use of fertilizers and related N balance and N_2O emissions strongly depend on site-specific aspects, and it is difficult to identify representative average emission factors. Currently, the most applied method is one developed by the IPCC, which provides a global average emission factor. This has the advantage to be acknowledged at international level as a common reference thus facilitating the comparability of results, but it is also affected by some limitations. In particular it cannot distinguish between crops or soils.

The type and quantity of process energy can significantly affect the overall results of biofuel LCA. For example the use of coal or lignite can totally off-set ethanol GHG emission reduction potential with respect to gasoline. On the contrary, the use of biomass or other renewable energy improves the environmental profile of the produced biofuel.

The present review revealed a wide range of discrepancies in process energy consumption rates. This can be also explained by the fact that some studies focus on state-of-the art installations properly designed for ethanol production, while others study older and inefficient plants, sometimes reconverted to biofuel manufacturing. This has to be duly taken into account when comparing results and deriving policy implications.

GHG balances for selected biofuel pathways

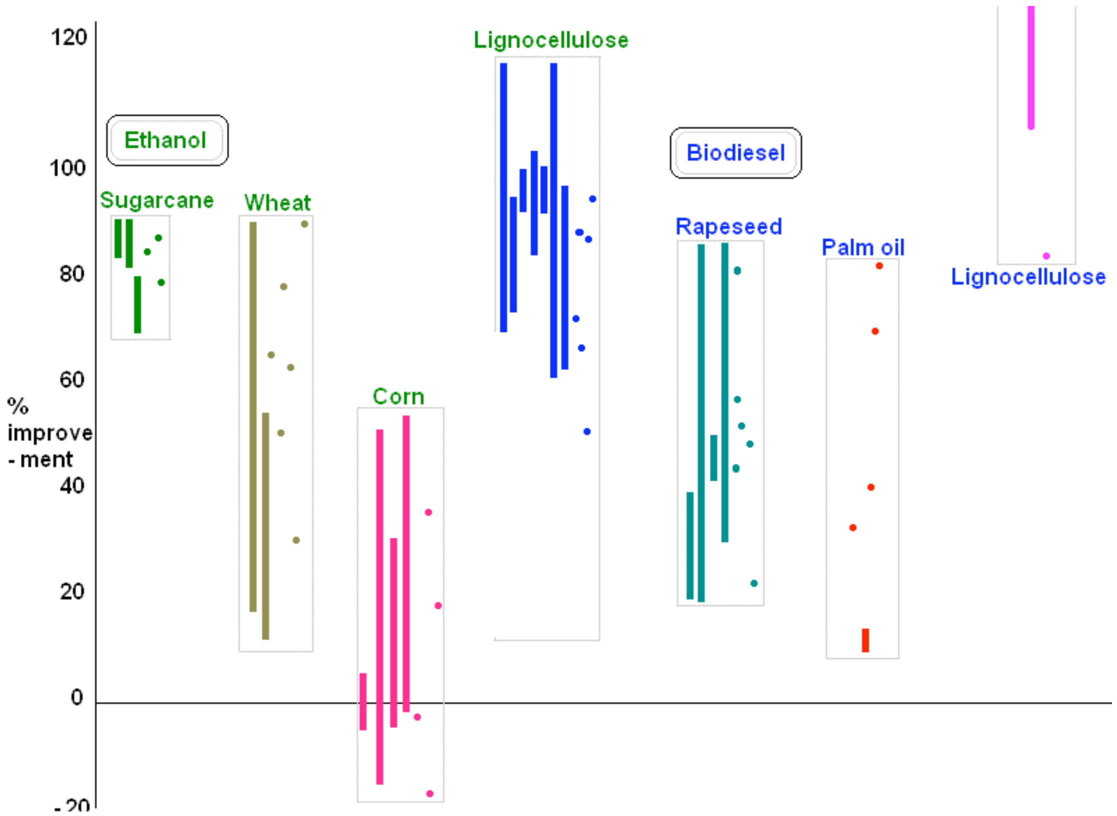
A grouping of the studies has been carried out according to a series of criteria including biofuel type, feedstock type, geographical scope, conversion technology process. This allowed the identification of comparable studies, the main results of which are presented in the following paragraphs.

In order to summarize and compare results, the latter are expressed in terms of percentage improvement with respect to conventional fuels. This percentage is sometimes indicated in the original studies. However, in many cases, it had to be re-calculated back using standard, non study-specific average parameters. This obviously introduces a certain level of uncertainty and error. Therefore the numbers presented in the following paragraphs should be read as indicative range figures and not as exact results.

Figure 1.15 summarises the relative net life cycle GHG emission improvement of selected biofuel pathways as compared to gasoline and diesel fuels.

27 They are particularly relevant for crops that receive significant amounts of mineral fertiliser, e.g. oilseed rape. Perennial crops, however, are fertilised less than usual annual crops, and the permanent soil cover they provide reduces the leaching of nutrients. Thus nitrous oxide emissions from perennial energy crops are likely to be significantly smaller than those from annual crops

Figure 1.15. Net life relative cycle GHG emission improvement of selected biofuel pathways as compared to gasoline and diesel fuels (without land use change)



Note: bars and dots shown in the graph indicate range and point estimates of improvements in net GHG emissions as elaborated from the data found in the reviewed studies.
Source: own elaboration from the reviewed studies.

Ethanol from sugar cane is the pathway where the most consistent results were found. All studies agree on the fact that ethanol from sugar cane can allow greenhouse gas emission reduction of over 70% compared to conventional gasoline. The large majority of reviewed studies converge on an average improvement around 85%. Higher values (also beyond 100%) are possible due to credits for co-products (including electricity) in the sugar cane industry. This reflects the recent trend in Brazilian industry towards more integrated concepts combining the production of ethanol with other non-energy products and selling surplus electricity to the grid.

Unlike sugar-cane ethanol, the case of ethanol from wheat is characterized by a wide range of results. While some of these differences reflect actual regional and site-specific conditions, other influencing factors are different assumptions with respect to allocation methods in the agricultural phase, N-balances and the type and quantity of process energy used. As far as the latter is concerned, most studies report the use of natural gas, electricity and small amounts of fuel oils. Edwards *et al.* (2007) also examine lignite and residue straw, which lead to extremely different results (respectively from -9% to 80% improvement). Another important assumption is whether conventional boilers or cogeneration heat and power (CHP) systems are used. Assuming the use of natural gas, a robust GHG improvement range under European conditions is between 30% and 55%.

In the case of ethanol production from corn, GHG net balances vary very significantly. In their review of some US studies, Farrell *et al.* (2006) explain a couple of negative results for ethanol can be explained by the lack of impact allocation to co-products and the use of old data. The authors also showed in sensitivity and modelling analyses that if consistent assumptions are used, the results extrapolated from the different studies become comparable. They also highlighted the importance of the energy mix. Several studies clearly indicate that the use of coal as fuel for process heat, mainly for distillation, leads to a worsened performance of corn ethanol with respect to gasoline. However, if natural gas or biomass are used, the improvement with respect to gasoline is respectively around 30% and 50%. Given the present mix and recent trends towards an increasing penetration of natural gas, several studies indicate a current average improvement around 20% of ethanol from US corn with respect to gasoline.

The case of biodiesel from rapeseed is another example of diverging results and assumptions. Two main aspects are at the basis of the discrepancies observed: the methodology followed for assessing N_2O emissions from fertilizers, and the assumptions for the treatment of by-products in the technology conversion phase. As for the former, the emission factor applied for the calculation of nitrogen release (as N_2O) range from 0.50% (Ecobilan 2002) up to 1.6-3.5% (Zah *et al.,* 2007, depending on the considered country). As a reference, the default value within the IPCC method is 1.25%. Moreover, in Ecobilan (2002) 46% of the impacts in the pressing phase are allocated in mass to rapeseed, while Zah *et al.* (2007) adopt an economic allocation, which leads to the opposite results. If the IPCC reference values and the energy allocation method are applied, a range of improvement between 40% and 55% under European conditions seems a reliable and robust result.

The availability of data for biodiesel from palm oil is much more limited compared to the previous crops analysed. Palm oil production results in a quite relevant improvement in terms of GHG emission compared to conventional diesel. However, the main issue is related to land use change. If previously non-cultivated areas are cleared for palm oil production, the net resulting balance can be dramatically negative. Beer *et al.* (2007) compare a base case scenario from cropland with palm oil from cleared rainforest and cleared peat forest. Results change from 80% improvement to an increase of overall emissions with respect to conventional diesel by 8 to 20 times respectively[28].

A range of results are provided with respect to second generation biofuels (both ethanol and biodiesel routes). All studies converge on determining considerable net improvements for second generation technologies (from around 60% to over 120%). The improvement with respect to gasoline and diesel can excess 100% because of the CO_2 credits relating to the co-production of electricity.

Non-GHG impacts

Given the small comparable sample of studies presenting results for non-GHG environmental impacts, it was difficult to provide a reasonable range of results for each crop and technology conversion pathway. Nevertheless, some general indications and conclusions can be drawn.

In terms of acidification potential, most studies indicate that biofuels underperform conventional fuels.[29] This is mainly due to the manufacturing and use of synthetic fertilizers. However, several studies concur that if new N_2O abatement technologies are applied in the fertilizer industry and proper agricultural practices are followed, biofuels can improve their environmental profile (*e.g.* through the use of

28 Making a quantitative link between biofuel production from palm oil and land use change is a complex issue. To date, around 80% of palm oil is used in the food sector. The remaining part goes into a variety of industrial products, including methyl ester (biodiesel).

29 However, in terms of local pollution, it is important highlighting that some combustion tests carried out by the Institut Francais du Petrole (IFP) show that the use of ethanol in flex fuel vehicles allows to reduce NO_x and HC (non-combusted hydrocarbons) emissions. The observed slight increase of aldehyde emissions can be controlled by post-combustion measures.

bioagriculture (Kägi *et al.,* 2007*)* or the use of ashes from residual biomass combustion (Lechón *et al.,* 2007)

The findings are less positive for eutrophication, which is caused by the release of ammonia and NO_x to air and phosphates to water. This is observed for almost all pathways and crops in the sample.

As for toxicity, results are very divergent. It is worth highlighting that at present there is no general consensus on the categorisation factors to be used while assessing toxicity effects. Therefore the results of different studies should be interpreted and compared carefully in order to avoid mislead conclusions.

For summer smog, on average slightly favourable results are observed in almost all studies for biofuels compared to fossil fuels. Notable exceptions are Zah *et al.* (2007) and Lechón *et al.* (2007), who estimate negative results for various ethanol and biodiesel chains.

With respect to second generation biofuels, only a few studies presented a comprehensive assessment including a wider set of environmental impact indicators. Zah *et al.* (2007) assessed ethanol produced from grass and wood. Results favour bioethanol in terms of acidification potential, summer smog and eco-toxicity. However, in the case of eutrophication, bioethanol from grass and wood underperform conventional gasoline. This is logical, since eutrophication is an agricultural issue.

In their LCA of Fischer-Tropsch (FT) biodiesel (biomass-to-liquid), Baitz *et al.,* showed very encouraging results ranging from 5 to 42% improvement for acidification, 3 to 29% for eutrophication and 89 to 94% in the case of summer smog, depending on the scenario considered. Reinhardt *et al.* (2006) assessed different FT diesel routes. All investigated pathways gave favourable results in terms of summer smog, but were mixed for acidification and eco-toxicity, and unfavourable in terms of eutrophication.

Effects on biodiversity and water resources

At present there are some methodological attempts to set up and include an impact indicator on biodiversity in LCA. However, so far no scientific consensus has been reached. None of the reviewed studies reported results in terms of biodiversity. Moreover, neither water consumption nor water quality and pollution are treated in the vast majority of LCAs. Given the water needs of some biofuel chains and the impact of the use of fertilizers and pesticides on water quality and pollution, this remains a potential important issue and a research gap.

From a policy perspective, banning the use of carbon-rich soils in the environmental criteria and standards of biofuels automatically covers part of the issue on biodiversity. However, the impacts on other land types remains to be assessed (*e.g* arid lands and local fauna and flora). The EC already excludes biofuels made from feedstocks obtained from land with recognised high biodiversity value, *i.e* forest undisturbed by significant human activity; conservation areas designated for nature protection purposes; highly biodiverse grassland.

The present lack of information in LCA studies with regard to the impact of bioenergy cropping on biodiversity and water resources also reflects the current limited amount of background data and analysis, which will require more extensive on-the-ground monitoring and modeling efforts. Nevertheless, some recent studies in Germany raised concerns about the ploughing up or intensification of species-rich grassland linked to biogas production (DVL/NABU, 2007) as well as impacts on water quality and quantity from energy cropping (Osterburg & Nitsch, 2007; Dworak *et al.*, 2007).

Two US studies investigated the environmental effects from land use change associated with corn-based ethanol production in the US. Donner & Kucharik (2008) modelled the effects of the US ethanol targets on nitrogen influx from farmland into the Gulf of Mexico. They warn that meeting the 2022 US ethanol targets with home grown feedstock may increase nitrogen loads carried by the Mississippi by 10-34%. This risks to render irreversible the dead zone in the Gulf of Mexico[30].

According to Marshall (2007) combined agro-economic and bio-physical model results, increasing US corn production to satisfy ethanol demand will lead to relatively larger increases in total agricultural nutrient losses, GHG emissions and soil erosion risks Further qualitative evidence of risks of bioenergy production on soil erosion and landscape effects is also presented in Pimentel & Lal (2007) and Jordan *et al.* (2007).

In order to carry out an objective assessment of the different non-GHG environmental impacts of biofuels, it is crucial to have similar LCA studies for fossil fuels, with a consistent methodology, scope, level of detail, and representativeness. To date, this is not always the case, for two main reasons:

- Some impacts of biofuels are characteristic of the agricultural sector (e.g. euthrophication, impacts due to emissions of N_2O, etc.). These are difficult to be compared to other impacts related to fossil fuel chains, including the degradation of environmental resources due to oil infrastructures, sea oil spills, environmental consequences of accidents, etc.

- There is a lack so far of updated LCA studies on fossil fuels assessing the recent emerging trends in extraction and use of oil (deep oil extraction, use of oil sands, shale oils and heavy oils).

Therefore, comparisons on non-GHG impacts have to be made with great care. This is an important research gap and priority for the future.

Agro-economic modelling and land use change

Converting forests, savannah or scrubland to cropland releases CO_2 due to burning or microbial decomposition of organic carbon stored in the plant biomass and soils.

Most LCA on biofuels carried out in the past, including most of the studies reviewed, did not take this phenomenon into account (at least quantitatively). However, more recent studies have emphasized the importance of land use change on the overall GHG balances. Some of them draw the conclusion that, in the worst case scenario, the effects of land use can completely off-set the potential GHG emission reduction of biofuels, i.e. the latter may actually substantially increase GHG emissions with respect to conventional transport fuels.

Land use change for biofuel production can occur in two ways:

- Directly, when non-crop land is converted to energy crop lands (e.g. permanent pasture is ploughed in to plant rapeseed for biodiesel[31], or rainforests cleared for palm oil plantations).

- Indirectly, if food and feed crops on existing cropland are displaced by energy crops to other parts of the world at the expense of native habitats in an attempt to compensate for the reduced

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30 The dead zone in the Gulf of Mexico exists since the 1970's, i.e. well before the mass development of ethanol in the US. This specific environmental issue is related to N-intense agricultural practices and not unequivocally connected to the development of ethanol.

31 The EU Community Agricultural Policy guarantees that the proportion between grassland/pasture land and arable land remains constant in average over time. It fosters the use of set-aside land, i.e. arable land temporarily out of agricultural production, for energy crop production. .

production of food and feed. Second order effects may also occur (e.g. the conversion of rainforests into pastureland to meet the demand for expanded soybean production).

The importance of land-use change is recognized by recent regulatory acts in various countries. The EC proposal for a Directive on Renewable Energy (DRE) and the German Sustainable Biofuels Ordinance (SBO) provide guidance and/or default values on how to calculate direct land-use change related emissions from carbon stock changes. The EU regulatory process plans to monitor a set of elements that will provide insights into indirect land use impacts, while Germany plans to promote further analysis in order to integrate indirect land-use change into the legislation in the future. As part of the UK Renewable Transport Fuel Obligation, indirect-land use change is not required as part of company reporting, but is calculated and added ex-post by the system administrator. The US Federal Energy Independence and Security Act passed in December 2007 mandates a consumption of 36 billion gallons of biofuels per year by 2022. Of this, 21 billion gallons will need to be supplied by “advanced” biofuels, requiring a 50-60% reduction in life cycle GHG emissions, including the effects of direct and indirect land use change.[32]

Land-use change effects can significantly affect the GHG balance net results of different biofuel chains. For this reason, it is recommended that the land-use change GHG contribution is always presented in a transparent and disaggregated way from the rest of the life cycle; and that all the assumptions about new and former land-use are clearly reported.

Direct land use change

When land is converted into arable land for growing energy crops for biofuel production, its carbon storage can change very significantly, depending on the type of land previously used. In order to take this important effect into account in the total GHG balance, the difference between the C-storage of the land before and after its change for biofuel production has to be calculated. This difference (either positive or negative) can be attributed to the biofuel by annualising the emissions over a certain amount of years and allocating them to a MJ of fuel produced. The convention generally used by European countries is an amortization time of 20 years.[33]

Carbon stocks from biomass above ground, biomass below ground and soil must be accounted for. It is very difficult to obtain reliable information on carbon storage above and below ground. Usually, the values of the IPCC 2006 GHG Reporting Guidelines (vol. 4) are used for references. However, these values report global average ranges and can be used in different ways. For example, different values are reported in the EC DRE proposal than in the German SBO draft (the respective nomenclature is used, all values expressed in t C / ha (Table 1.4)

32 The federal Act directs the government to develop a life cycle methodology for biofuels by December, 2008.

33 In their studies on indirect land-use change, American researchers tend to use the value of 30 years instead.

Table 1.4. Carbon stocks (t C / ha)

(tC / ha)	Arable land	Cultivated land	Permanent grassland	Grassland	Lightly forested area	Tropical rain forest (min. soil)	Savannah	Oil palm plantation
EC DRE	82		181		181			189
German SBO draft		55		70		265[34]	134	110

Combining these differences in nomenclature and references values with other methodological aspects such as allocation rules, causes the fact that default values used from different countries using IPCC guidelines (*e.g.* Germany and the UK) actually lead to very different results. This clearly poses an important harmonization issue for different legislations.

Fargione *et al* (2008) calculated the number of years needed for the reductions in GHG emissions from substituting ethanol for gasoline (20%) to "repay" their "carbon debt" caused by converting different types of land into energy crops. Payback times range from 17 years if additional sugarcane is produced on former wooded Cerrado land in Brazil, 48 years if abandoned cropland is transformed into energy crop in the US, 93 years if grassland is converted, up to the extreme case of 420 years for indirect land-use change from peat land rainforest into palm biodiesel in Indonesia and Malaysia.

Despite important numerical differences, the general message is clear: taking into account land use change from grassland or forest can radically affect the net GHG balance of biofuel chains[35]. If the UK default values for grassland to cropland conversion are used, the result is that all biofuels emit more than conventional fuels. German defaults[36] are not sufficient to meet 30% (German) or 35% (EU) minimum GHG saving and proof of land use is therefore necessary. On its turn, the EC DRE proposal excludes biofuels made from raw material obtained from land with high carbon stock, i.e. wetlands (including pristine peat land) and continuously forested areas.

Moreover, the EC DRE proposal excludes biofuels made from raw material obtained from land with recognised high biodiversity value, i.e. forest undisturbed by significant human activity; areas designated for nature protection purposes; highly biodiverse grassland

Indirect land use change

In their recent study, Searchinger *et al.* (2008) estimate that without land use change corn ethanol would reduce GHG emissions by 20% with respect to gasoline. However the authors argue that, with a very significant increase of ethanol production, the cropland increasingly diverted from food and feed to energy in the US would turn over 10 million hectares of additional land into cultivation in Brazil, China, India and other countries. This would lead to very high land-use change related emissions. If spread over a period of 30 years, this would result in GHG emissions from ethanol being 93% higher than for gasoline per unit of fuel energy (gCO_2/MJ).

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34 According to Fehrenbach et al (2007) and cited sources, the carbon stock in wetlands is much higher, i.e. in the range of 1 400 tC/ha.

35 Slash-and-burn emissions must further be summed up, but their values are one order of magnitude lower than those deriving from carbon stock changes.

36 The SBO draft assumes the following land-use changes for conservative default values: Savannah to cultivated land for Latin American sugar cane, Tropical rain forest to palm oil plantation in South Asia, Grassland to cultivated land for all other biofuels chains.

In contrast, the authors conclude that biofuels produced from crop or forest residues or from energy crops grown on degraded and abandoned agricultural lands, usually planted in perennials, incur little or non carbon debt and can offer immediate and sustained GHG advantages.

Combining assessment tools

The approach to combine a life cycle assessment study with a macro-economic agro-modelling is certainly very commendable to assess the impacts of both direct and indirect land use change. With this approach, changes in land use of different regions can be connected to information on carbon stocks and carbon release data to provide land-use related GHG emissions due to changes in biofuel support policies. The two mentioned studies represent a further important step into the right direction of aiming at evaluating potential absolute impacts of mass-scale deployment of biofuels, as opposed to marginal impacts as assessed by traditional LCA studies.

The quantitative results of Searchinger *et al.* (2008) and Fargione *et al.* (2008) are under intense scientific debate, see for example Morris (2008), Wang & Haq (2008), and cited work of Wang *et al.* 2007, Korves (2007). Some critical factors need to be further explored, including:

- The use of a static model, assuming constant annual GHG savings with respect to conventional fuels over 30 years. This does not take into account the current trends towards integrated concurrent production of ethanol, sugar and other sucrose co-products in the case of sugar-cane ethanol in Brazil and towards an increased use of biomass, integrated biogas energy systems and eventually multi-product bio-refineries in the US. The optimisation of process energy use, the development of biomass cogeneration and methanisation, the diversification and valorisation of bio-based chemical products show that a similar process of integration and optimisation of biofuel production into veritable agro-industrial complexes (biorefineries) can be observed in Europe as well.

- The proportion of additional biomass demand to be satisfied from virgin grass or forest land as there are opportunities for using currently abandoned or under-used agricultural land. This also relates to the fact that the land supply issue is likely to take on increasing importance with increasing scale of biofuel production, hence may be overestimated at the lower end. This needs to be investigated with dynamic agricultural sector models that have a sufficiently accurate land supply function and more detailed input data than currently available.

- The likely yield increases and farm management improvements that can be expected for wider range of current and novel biofuel crops than have been evaluated so far.

Despite uncertainties in quantitative results and methodological limitations, both studies identify and focus on a real concern: In a framework trend of growing population, food and feed demand and consequent crop-land needs, to what extent does the large scale deployment of biofuels risk to accelerate and worsen unsustainable trends of increasing de-forestation and depletion of carbon- and biodiversity-rich natural resources?

More and deeper analysis is needed to properly address this challenging issue. Further expansion and use of agro-economic market models at the global scale is required in order to address both direct and indirect land use changes associated with future, much expanded biofuel production. Considerable research on market-mediated effects of biofuel production are underway in various universities and research laboratories in the US, Canada and Europe. At the same time, LCA models need to be improved and further developed to treat future technologies with a reasonable level of uncertainty.

Research priorities and next steps for improvement

Research gaps and priorities

Most LCA studies are based on current technologies. But energy policies require long-term decisions. Therefore LCAs should be also based on consideration of expected future technology developments and improvements. Such long-term orientation is missing in most studies. For instance, the trend towards integrating systems into multi-fuel multi-product bio-refineries has not been taken into account to date.

Several studies on biofuel chains originating from plantations on degraded or abandoned land including cassava, jatropha and sweet sorghum are under preparation. More analysis is needed in this area, both in terms of their techno-economic feasibility and the life cycle environmental profile of these biofuel chains.

Much more attention is needed with respect to water consumption and pollution issues. They have been rarely addressed by LCAs so far, and should be carefully analysed in the future.

LCAs of fossil fuels used for baseline scenario comparison also present a certain range of varying results and of uncertainty, depending on the assumptions made and the geographical scope of the study. This should be considered in more detail, in particular in regional analyses. Moreover, some potential impact categories such as land use, land use change and water pollution, which are relevant for the comparison with biofuels, are very rarely reported in LCA studies on fossil fuels. Further attention should also be devoted to the impact of the fossil fuel chain in terms of toxicity impact indicators, as the methodology for assessing them improves over time. In any case, all relevant assumptions (*e.g.* on allocation methods) should be consistent with the ones made for biofuels, which is not always ensured today.

In addition, the entire chains of fossil fuels need to be updated due to recent technological developments such as deep oil extraction, and expected trends towards the increased use of non-conventional oils, *e.g.* from oil sands, shale oils and heavy oils. These changes in extraction modes and uses of oil resources are expected to increase the life cycle environmental impacts of fossil fuels, as opposed to the ones of biofuels, which are expected to decrease with the improvement of technologies and yields and with the progressive introduction of second generation biofuels A careful life cycle assessment of the marginal production of crude oil and fossil fuels is crucial for an objective prospective comparison with biofuels in the medium-term.

Recent studies highlight the potential very negative impact on GHG balances of deforestation and conversion of carbon-rich land into energy crop-land. Global average value are generally used to date, and more research and mapping is needed to assess these impacts in different world regions. While tropical rainforests and high-carbon stock areas are obviously of particular concern, the issue of GHG emissions due to land use change is also relevant for other land types. It is important to highlight that some land use change can be beneficial, e.g. marginal lands brought back into production through careful management of energy crops can increase the carbon sink.

Recent studies on potential indirect land-use change identify and focus on a real concern, *i.e.* the risk that biofuel deployment could accelerate and worsen the current unsustainable trends of de-forestation and depletion of natural resources, in a framework of accelerated growing population, food and feed demand, potentially leading to an increase of carbon emissions. More effort is needed to combine agro-economic models with LCA and this report provides an example in this direction. The key challenge is the development of global models that combine macro-economic and bio-physical modelling approaches. These need to analyse the interaction between food, feed, bioenergy and biomaterials markets and the environmental effects associated with biomass production in the different regions (or eco-zones) of the world.

Further work on the likely effects of (future) carbon markets appears necessary for establishing the relative societal benefits of different uses of a given area of land (*e.g.* food, biomass production or using vegetation for carbon sequestration) in different parts of the world. This needs to consider how best to combine the carbon sink functions of agriculture and forest land with their productive functions and how to provide economic compensation to land owners and land managers that forego economic benefits from land-use conversion.

Need for Harmonization

LCAs are already used today in recent or forthcoming regulatory proposals to set environmental criteria and standards on biofuels. However, LCA studies show a wide range of results which are at times contradictory. This partly reflects the complexity, technology choice and geographical scope dependency of the analysed reality. However, this is also the result of the many different methodological and numerical assumptions made during an LCA study. Different analyses (*e.g.* in different countries) use varying assumptions and hence come to a wide range of different results and conclusions that pose a clear harmonization issue when setting regulations at national and international level.

There is a clear need to develop a harmonized set of rules on how to carry out LCAs on biofuels. Ideally this should happen in a multi-stakeholder process at an international level, aiming first at a regional and then at a global agreement. An example is the Global BioEnergy Partnership (GBEP), which is preparing a checklist of items to be addressed in developing an appropriate GHG methodology for biofuels. Another example is the Roundtable on Sustainable Biofuels, which also aims at defining sustainability criteria in a global, transparent and multi-stakeholder approach. The experiences gained in the area of eco-labelling and environmental product declarations should be also considered in this process.

Most assumptions and data used in LCA studies so far are related to Europe or the US and rely on western technology patterns.[37] Effort is needed to set up harmonized, 3rd party verified and reliable information coming from other areas, including developing countries. This is a goal of both the UNEP Life Cycle Initiative and the European Platform for LCA, initiated by the European Commission.

37 With the possible exception of Brazil.

CHAPTER 2. QUANTITATIVE ANALYSIS OF BIOFUEL POLICIES AND DEVELOPMENTS

Model based analysis of policy effects on agricultural markets, land use and related environmental implications

The tool to analyse market and land use changes

To analyse the implications of support policies for biofuel supply and demand, as well as for agricultural commodity markets and land use, the OECD medium-term simulation model for world agricultural markets Aglink has been employed, complemented by the FAO-developed Cosimo model to cover a large set of developing countries. Aglink-Cosimo is a partial equilibrium model of domestic and international markets for major temperate-zone agricultural commodities, with detailed mapping of policies affecting these markets. In preparation of this analysis, the combined model has been extended to include the markets for sugar and other sweeteners. Furthermore, a specific module representing biofuel markets in major producing and consuming regions has been developed. At the same time, the FAO has developed biofuel modules for 13 developing countries.[38]

Generally speaking the biofuel modules include a rather complete representation of the whole biofuel chains. This includes the investment decisions of increased biofuel production capacities as well as the (short-term) decision of using the existing capacities; related feedstock use is directly linked to the production of biofuels from individual feedstocks, with limited substitution across feedstock types; distillers grains as a valuable by-product from grain-based ethanol production is specifically represented, together with its feed use in the livestock industries (differentiated between ruminant and non-ruminant production according to differences in using distillers grains across animal types). Similarly, the model reflects the increased availability of oilseed meals as oilseed crush for biodiesel expands.

The model also represents the production of second-generation biofuels – both the ethanol chain (cellulosic ethanol) and the biodiesel chain (BTL). Given the even more limited data availability representation of these chains is more reduced than that of first-generation fuels, but distinguishes between fuels from agricultural residues (straw, stover) and dedicated biomass (such as switchgrass or fast-growing trees). Additional incentives for cereal production from the use of residues and area requirements for dedicated biomass are derived from biofuel production quantities via coefficients that change over times, reflecting yield improvements and technical progress in the biomass conversion.

The ethanol demand system is set up to reflect both the high-value replacement of other additives by low-level ethanol blends, technical constraints in blending ethanol to gasoline at higher rates for unmodified vehicles, as well as the options of high-level blends for flex-fuel vehicles. The number of flex-fuel vehicles in the different countries covered is treated as exogenous, growing over time in line with observed trends. Details on the way biofuel production, use and trade as well as their links to agricultural markets have been modelled can be found in the Annex.

38 In particular, the FAO co-ordinated the representation of biofuels in the following developing countries: Columbia, Ethiopia, India, Indonesia, Malaysia, Mozambique, Peru, Philippines, South Africa, Tanzania, Thailand, Turkey, and Vietnam.

The analysis shown below is based on a preliminary baseline for the OECD/FAO Agricultural Outlook 2008-2017). In particular, this baseline projects a substantial further growth in the production and use of both ethanol and biodiesel, assuming a continuation of existing policies supporting biofuel production and use at different stages of the marketing chain. The US Energy Independence and Security Act (EISA) enacted in December 2007, the new EU Directive on Renewable Energy (DRE) currently in the legislative process, and the blending mandates for biodiesel in Brazil valid since early 2008 are not accounted for in the baseline. This baseline assumes crude oil prices to remain within the range of USD 90-104 per barrel for the decade to come. International prices for agricultural commodities are projected to remain at levels substantially higher than those observed in the past decade, reflecting a tightened balance for most products.

The baseline, as well as the model used for its generation, does not assume second-generation biofuels to become commercially relevant within the decade to come. For the analysis of potential implications of a faster development of these fuels, including cellulose based ethanol and biomass-to-liquid (BTL) fuels based on either crop residues (straw, stover) or dedicated biomass production (such as switch-grass and willow- or poplar trees), however, an add-on module for these fuels has been developed for four model regions, including the US, Canada, the EU and Brazil.[39]

The Aglink-Cosimo based analysis includes a sequence of scenarios aiming to shed light on a number of major questions related to biofuel markets and support policies. First, the effects of existing biofuel support policies on biofuel developments and agricultural markets are analysed by simulating an elimination of biofuel support policies. Second, two new programs affecting the supply and demand of biofuels are analysed, including the US EISA, and the new EU DRE. While both of these programs explicitly include the developments of second-generation biofuels, a third section looks at these developments more specifically and analyses their potential impacts by assuming future biofuel growth to come from these rather than first-generation fuels. Finally, in analysing alternative assumptions on crude oil prices, the relevance of biofuels in the link between agricultural and energy markets is discussed.

The tool to analyse environmental impacts

The Stylised Agri-environmental Policy Impact Model (SAPIM) has been developed to analyse the linkages between agricultural policies and their environmental effects. The SAPIM framework adopts an integrated approach: an economic model of decision making on representative farms is combined with a stylised site-specific biophysical model predicting the impacts of different policy instruments on production practices and then on the multiple environmental effects. Due to the site-specific nature of many agri-environmental issues analysis at a disaggregated level is necessary in order to capture the underlying heterogeneity of agricultural productivity and environmental sensitivity across different parcels of land. To this end the SAPIM is specifically developed to capture the environmental effects of different agricultural policies through their impacts at the intensive margin (input use intensity), the extensive margin (land use allocation) and the entry-exit margin under those heterogeneous conditions.

In the SAPIM framework the environmental process functions (*e.g.* nutrient and herbicide runoff or greenhouse gas emissions) are integrated into economic optimization models, which maximize an objective

39 Given the multitude of potential feedstocks for second-generation biofuels, these options are necessarily represented in a simplified manner. Results relating to second-generation biofuels therefore should be understood as largely indicative. In particular, the choice of feedstocks and the region considered imply differences in biomass yields and other variables from the assumptions used in this analysis. While some of these variables are subject to sensitivity analyses outlined below, these cannot reflect the whole range of possible outcomes. Details on related assumptions are provided in the context of the specific analysis below.

function (*e.g.* to maximize social benefits or private profits) subject to resource and technical endowments, and policy incentives. Incorporation of social valuation estimates for environmental effects – when reliable valuation estimates are available - provides a benchmark for policy analysis. SAPIM allows the analysis of many different types of policy instruments including area payments, input use taxes and regulations, payments for environmentally friendly production practices and technologies, green auctions and tradable permits. The results of the SAPIM modelling exercises thus have the potential to show the various environmental outcomes, farm income impacts and government budgetary expenditures as a result of different policy measures being applied in heterogeneous farm conditions, which can then be summarised in terms of outcomes of private and social benefits.

The impact of biofuel support policies

Potential implications of a removal of biofuel support policies

Several forms of public support for producing and using biofuels are represented in the model. In particular, these include budgetary support policies (tax concessions, tax credits and direct support for the production of biofuels), biofuel mandates (minimum rates of biofuel use in the overall consumption of gasoline and diesel type fuels), and import tariffs. To analyse the relevance of these different policies, the scenario was split in three steps, eliminating subsequently the three groups of biofuel support policies (budgetary support policies first, then biofuel mandates, and finally import tariffs).[40] In the results shown here, these policy changes are assumed to be implemented in all countries covered simultaneously. While it is of course possible, and certainly interesting, to also look at the impacts of isolated policy changes in only individual countries, such results are not presented here in the interest of brevity. It should be noted that the representation of ethanol markets in China (supply and demand) and Japan (net trade only) is not policy specific, while ethanol and biodiesel production and use in Australia *de facto* is exogenous to the model. Moreover, lacking data availability resulted in some policy measures not to be taken into account in the baseline (and hence in this analysis), most notably tax incentives for ethanol use in Brazil and state-level blending mandates for biofuels in the US.

A removal of the existing biofuel support policies taken into account in this analysis would significantly reduce medium-term biofuel use in major biofuel consuming regions. Given the structure of biofuel support across countries, the relative impact of removing budget support (in particular tax concessions) and mandates for biofuel use differ widely, as visible in Figure 2.1 and Figure 2.2 below.[41,42] In this analysis, however, the order in which policies are removed has implications as well: if policies were eliminated in the inverse order, *i.e.* tariffs, mandates, budget policies, these latter become more relevant particularly in Canadian and EU ethanol use, as well as in EU biodiesel use. This suggests that in these markets tax concessions and mandates strongly interact and complement each other. Globally, the results show that the use of biodiesel is much more dependent on public support than the use of ethanol: World biodiesel use would be cut by half relative to baseline projections – compared to a 14% decline in ethanol

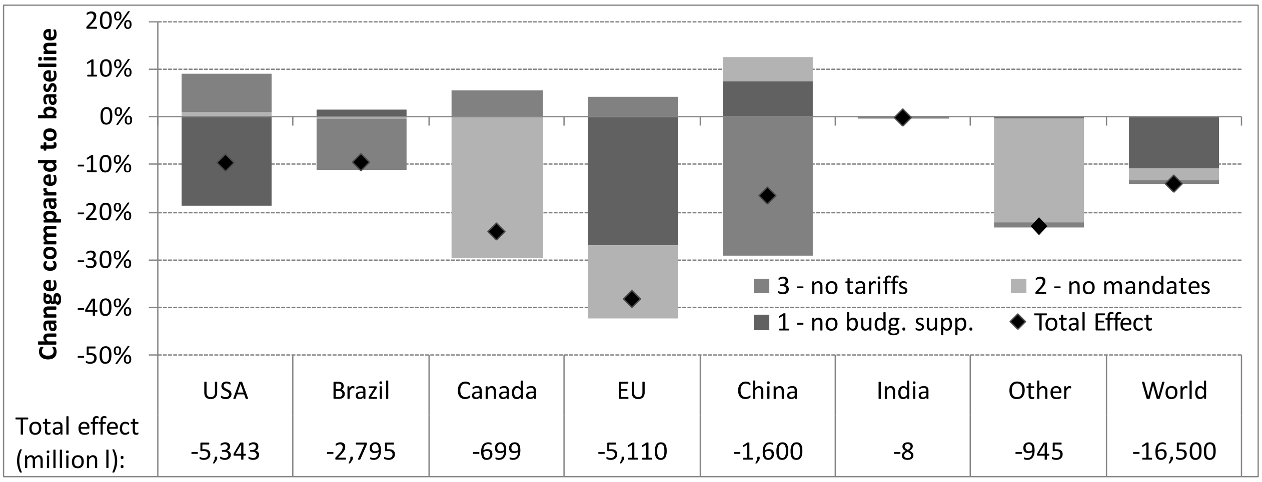
40 While the impact of removing each of these policy categories obviously is related to their relative importance in different countries, individual results also depend on the order in which policies are removed. This is discussed further below.

41 Lacking detailed data, existing biofuel mandates in several US states have not been included in the model analysis. The small positive effect of eliminating mandates on US biofuel use shown in Figures 2.1 and 2.2 may in fact be offset if such US mandates were removed.

42 Note that biodiesel use in many developing countries, including Malaysia, Indonesia and others, are assumed to be fixed by mandates – an elimination of these mandates therefore reduces biodiesel consumption to zero in those countries. While this obviously represents a simplification of actual developments, the quantities concerned are relatively small and global results are, therefore, largely unaffected.

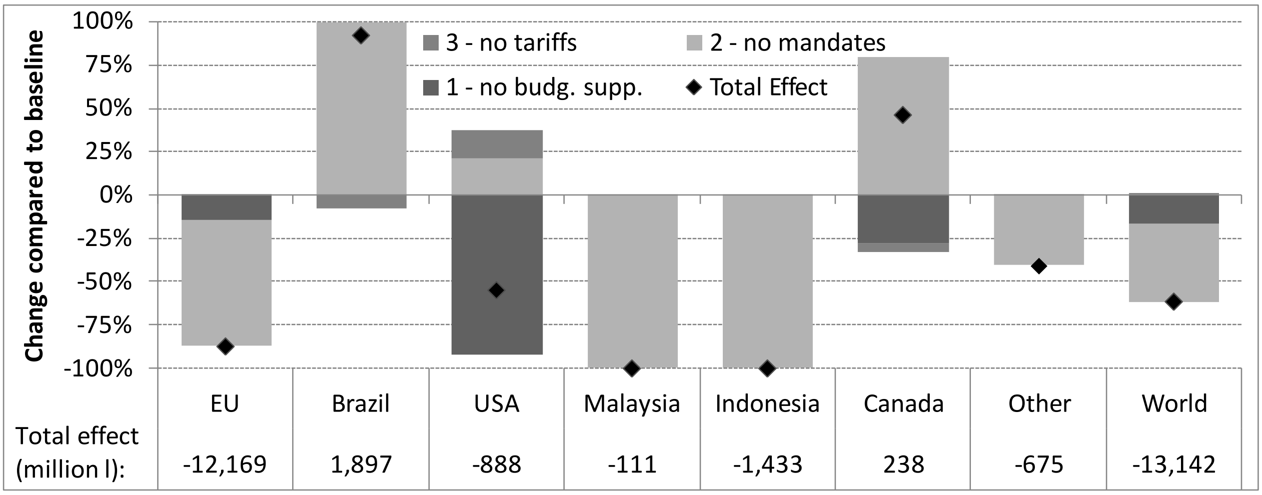
use. Without support, biodiesel demand in the EU and the US would be reduced by 87% and 55%, respectively. Biodiesel use in Brazil and Canada benefits from lower biodiesel prices following liberalisation in other countries – indeed, a removal of Canadian support policies only would lead to a reduction in biodiesel use by more than 80%. The strong response of biodiesel use in major biodiesel using countries reflects the higher production costs of biodiesel relative to ethanol (see Figure 1.7).

Figure 2.1. Impact of biofuel support removal on ethanol consumption, 2013-2017 average



Source: Aglink/Cosimo Simulation Results, OECD Secretariat.

Figure 2.2. Impact of biofuel support removal on biodiesel consumption, 2013-2017 average



Notes: The relative impact of removing different policies depends on the order of this removal as indicated in the text. Results for Malaysia and Indonesia are due to model-related simplifications and hence likely to overestimate the actual impact of the mandates.
Source: Aglink/Cosimo Simulation Results, OECD Secretariat.

Production incentives are not only affected through the market effects of reduced biofuel use as a result of elimination of budgetary support and mandates, but also directly by the elimination of tariffs in countries importing biofuels. Given that many countries charge significantly higher tariffs on ethanol imports (which are considered an agricultural product under WTO nomenclature) compared to biodiesel (considered a chemical product), tariff elimination mostly affects ethanol production (Figure 2.3 and Figure 2.4). While domestic market prices decline with tariffs eliminated, world prices benefit significantly, with the net effect different across countries.[43]

The simultaneous removal of support policies in all countries[44] results in substantial reductions in biofuel supply. Several changes are worth a more detailed discussion. The simulations suggest that ethanol production is cut particularly in Canada and the EU, while biodiesel production would be lower particularly in the EU and the US. Much of the differences across countries and biofuels has to do with differences in the economic viability and hence the relative dependences on public support in the different sectors. As shown in Figure 1.7 in Chapter 1, the gap between net production costs of biofuels and their economic value in replacing gasoline and diesel is particularly wide for biodiesel. Among the different ethanol chains, wheat (the main feedstock used in the EU) represents a feedstock that is substantially less economic than maize (principal feedstock used in the US). In Canada, both of these feedstocks are used in important quantities. Differences are, however, caused also by other factors, including the structure of biofuel support and the maturity of the biofuel industries.

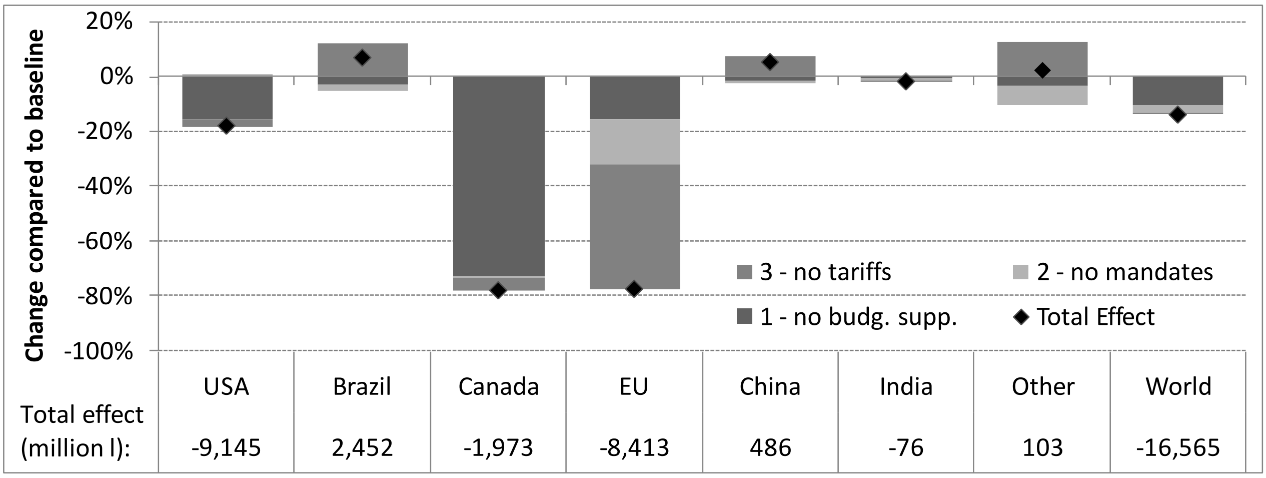
In the US, the budgetary support is given through tax credits for blenders - so producers are affected by an elimination only indirectly through its effects on ethanol prices. In Canada, in contrast, where producer prices would fall in line with the US prices, ethanol producers would additionally face the elimination of their direct production subsidy – on top of the cost disadvantage due to the wheat share in their feedstock mix – causing them to respond more strongly than the US producers. Finally the policy change would affect the existing capacities (which are already relatively large in the US) much less strongly than those to be built over the projection period with policies in place. While the baseline projections relative to which policy impacts are presented here expect ethanol production to increase by some 75% over the ten year period in the US, this growth is projected at some 170% in Canada and more than 300% in the EU.[45] This additionally explains the more significant effect the elimination of support has on ethanol production in these two countries when compared to the US. It is worth noting, however, that in absolute terms the medium-term reduction in ethanol production in the US following a removal of support to biofuels larger than in the EU and particularly in Canada.

43 Note that this analysis does not consider changes in support policies in China as these are not represented in the model. Changes in Chinese biofuel markets are therefore driven by price changes for biofuels and feedstock commodities.

44 As explained above, the lack of detailed data did not allow the full consideration of ethanol support in Brazil.

45 The relatively small impact of the policy change on Canadian biodiesel production is largely due to technical reasons in the model: a substantial share of Canadian biodiesel is produced from feedstocks other than vegetable (canola) oil and kept exogenous to the model. In consequence, the response to policy changes is likely to be underestimated here.

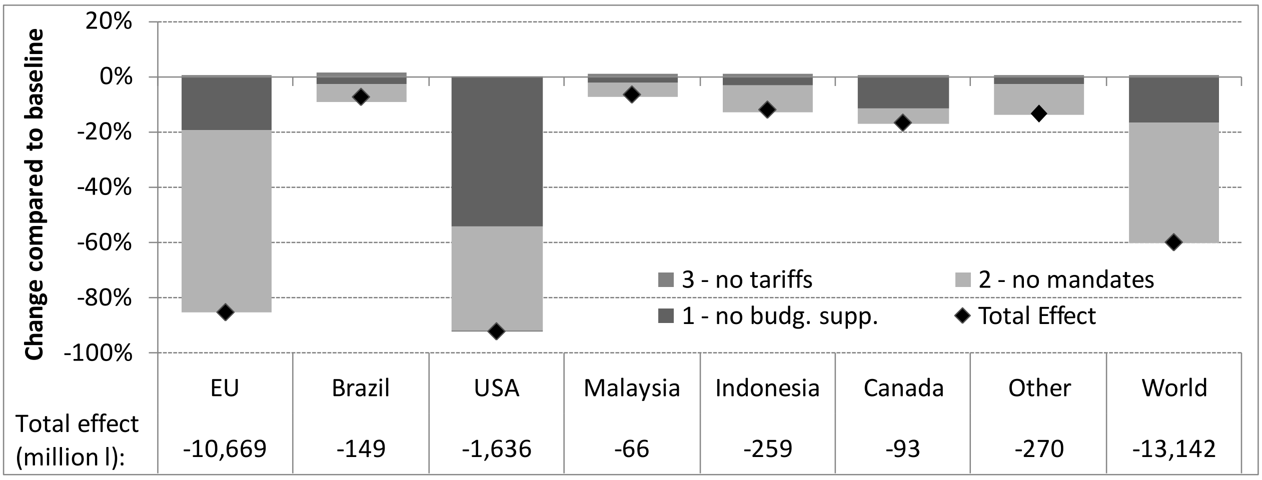
Figure 2.3. Impact of biofuel support removal on ethanol production, 2013-2017 average



Note: The relative impact of removing different policies depends on the order of this removal as indicated in the text.
Source: Aglink/Cosimo Simulation Results, OECD Secretariat.

International trade in ethanol would be reduced by the elimination of budget support and incorporation mandates. EU net imports in particular would be reduced by about two thirds as the removal of both mandate and tax concessions result in lower ethanol use, while US net imports would be cut by more than half. The elimination of import tariffs would, in contrast, result in an important increase in international trade, mainly as the EU tariff reduction would overcompensate the trade effects of budget and mandate policies by far. Both larger use and particularly the shrunken domestic ethanol supplies would result in a net increase in EU imports by some 130% on average for the 2013-2017 period. Both US and Canadian ethanol imports would strongly increase as well – largely supplied by expanding Brazilian exports. In consequence, a complete removal of biofuel support policies would result in a 90% expansion in total international ethanol trade during the 2013-2017 period.

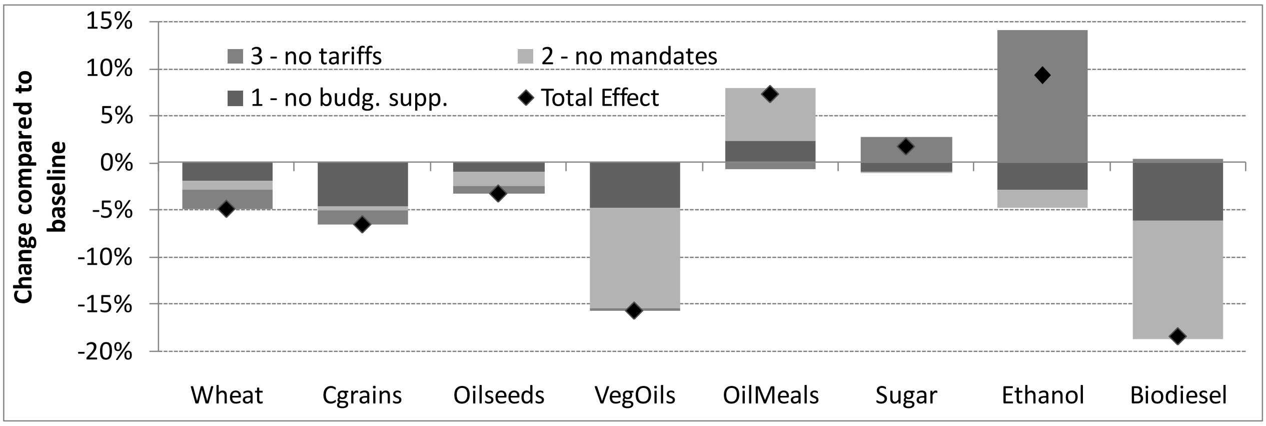
Figure 2.4. Impact of biofuel support removal on biodiesel production, 2013-2017 average



Note: The relative impact of removing different policies depends on the order of this removal as indicated in the text.
Source: Aglink/Cosimo Simulation Results, OECD Secretariat.

If all biofuels policies were removed, prices for biodiesel would drop by more than 20% in the initial years and recover only slightly as production and consumption adjust. On average over the 2013-17 period, biodiesel prices would decline by about 19%. In contrast, ethanol prices would drop only little initially, and would gain substantially from reduced tariffs, averaging around 9% higher than in the baseline for the 2013-17 period. With global production of ethanol and biodiesel reduced by 14% and 60% on average, respectively, the use of feedstock commodities would be substantially lower. While in absolute terms, the use of grains would be reduced most significantly (US maize use for ethanol would be lower by more than 23 million tonnes per year, wheat use for EU ethanol production by almost 16 million tonnes), the effect relative to global production is most pronounced in vegetable oil markets. The EU alone would use almost 10 million tonnes of vegetable oils less in the biodiesel sector per year on average during the 2013-2017 period, equivalent to 8% of global production. In consequence, international prices for vegetable oils would, on average, be about 16% lower than under baseline assumptions, those for wheat and coarse grains by some 5% and 7%, respectively (Figure 2.5). Due to the offsetting effect of higher prices for oilseed meals, world oilseed prices would drop by only 3%. Sugar prices, in contrast, would gain slightly, as Brazil ethanol producers take advantage of eventually higher ethanol prices, and as the slightly lower molasses-based ethanol production in a number of African and Asian countries reduces sugar supply.

Figure 2.5. Impact of biofuel support removal on world commodity prices, 2013-2017 average



Note: The relative impact of removing different policies depends on the order of this removal as indicated in the text.
Source: Aglink/Cosimo Simulation Results, OECD Secretariat.

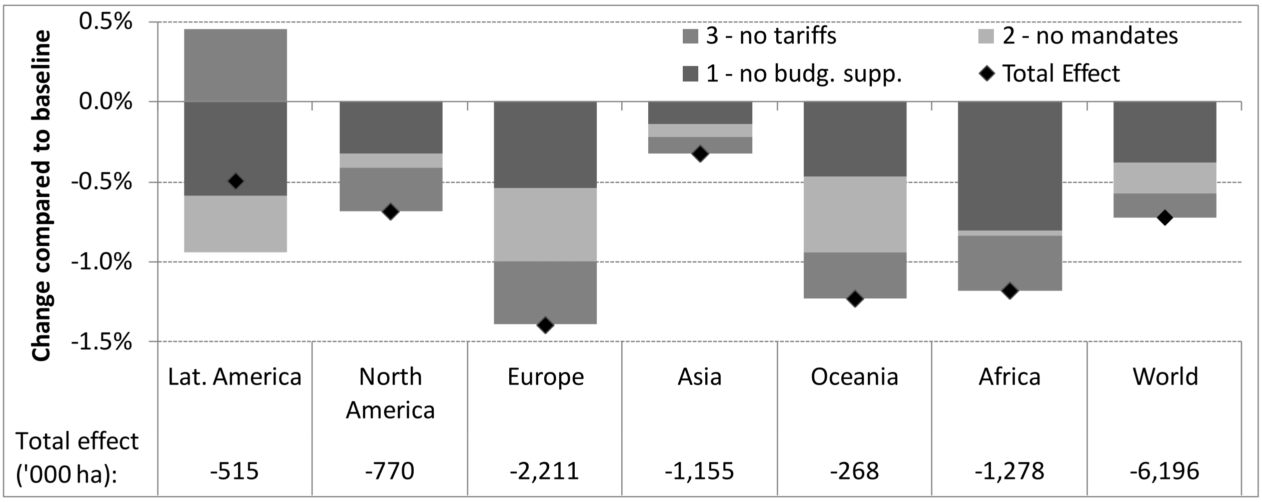
Land used for crop production would be affected mainly through lower crop prices and hence lower incentives for farmers, including the (partly offsetting) effects the lower production of feedable by-products (such as DDG) would have on animal feed markets. While this can be seen on a global scale, the effect is particularly pronounced in Europe, where production currently responds strongly to increased commodity use for biofuel production by slowing down longer-term trends in reduced overall crop area use[46,47] and where the reduced domestic use of feedstock commodities would result in particularly strong price adjustments especially on wheat and rapeseed markets. Globally, some 6.2 million hectares (0.7%) less would be used for main crops (Figure 2.6). This represents about 23% of the increase of global crop

46 Existing legislation on EU and national levels aim at ensuring the sustainability of agricultural expansion in response to, among others, increasing demand for biofuel feedstock commodities. The expansion seen in recent years refers, i.a., to the use of set-aside land for energy crops permitted by the regulations.

47 Note that the energy crop payment of EUR 45 per hectare has not been taken into account. This payment scheme would further increase the impact of a support removal on EU crop area use.

area projected over the coming decade. While some of this land would be used for other commodities instead[48], other parts may not go into production without biofuel support.[49]

Figure 2.6. Impact of biofuel support removal on total crop area (wheat, coarse grains, rice, oilseeds), 2013-2017 average



Note: The relative impact of removing different policies depends on the order of this removal as indicated in the text.
Source: Aglink/Cosimo Simulation Results, OECD Secretariat.

In summary this analysis shows that biofuel support policies remain crucially important in many countries. A removal of these policies would substantially affect the (private) profitability of biofuel production and use in those countries where production costs are particularly high. Ethanol production in the US would be affected to a lesser extent following somewhat better economics in this industry. This, and the large ethanol industry based on sugar cane in Brazil help to keep global ethanol production growing, although at substantially reduced rates, even without public support. In contrast, world biodiesel production (dominated by the EU industry) would decline by more than a fourth after removal of all support policies and grow much more slowly thereafter, ending up around 60% below the baseline in 2013-17.

Despite the importance of support policies for biofuel markets, the analysis also shows that the medium-term impact on crop markets should not be overestimated. With cereal and oilseed prices impacted by 5% to 7% and 3%, respectively, the medium-term effect of biofuel support policies is substantially smaller than recent price hikes on international markets. Of course, the effect of growing biofuel industries on crop markets is larger than that as shown further below, but some important parts of those industries would still keep growing even after removing the public support. This price-related conclusion also holds for land use which would grow some 20% more slowly without the existing biofuel support. But growth in land use is for a larger part independent from biofuel support policies.

48 The representation of agricultural commodities is incomplete and includes cereals, oilseeds, sugar crops (cane and beet), as well as, in developing countries, roots and tubers.

49 Note that the model does not explicitly take into account the various characteristics of land, such as different productivity irrigation or existing carbon stocks. This analysis therefore cannot provide detailed results of area use changes for alternative land types, but only aggregate changes in total land use for the main crops.

Even without a removal of domestic support policies, a liberalisation of trade in biofuels could have significant effects. Even though global production and use of biofuels would change only little, an elimination of import tariffs would cause higher ethanol prices in international trade and some relocation particularly of ethanol production and use across countries, with increased exports particularly from Brazil (+11 billion l) balanced by higher imports to the US, Canada and particularly to the EU (again, +11 billion l on average for the 2013-2017 period). In consequence, production of grain-based ethanol would decline, while cane-based ethanol would expand, causing lower cereal (-2% to -3% on average) but higher sugar prices (+3%). As one might expect, this would also cause changes in the land use allocation across regions, with increased crop area in Latin America more than offset by lower crop land use in other regions, particularly in Europe and in Africa.

Finally, however, it should also be noted that the response of biofuel use and, in particular, production on changes in economic incentives is heavily dependent on parameters that, in this analysis, are based on a limited amount of data. These parameters therefore exhibit a substantial degree of uncertainty. The use of ethanol as a fuel in spark-ignition engines can substitute for gasoline fairly easily in certain ranges of low-level blends as well as for users of flex-fuel vehicles, but less well as ethanol blends reach certain, technically defined levels. These factors can be modelled relatively accurately (though a certain degree of uncertainty remains). Biodiesel use does not have these technical thresholds, but required (modest) vehicle modifications should result in somewhat lower substitutability with fossil diesel at least in the short run. In contrast, the responsiveness of biofuel capacity building as well as that of capacity use is more uncertain. Higher parameters and hence stronger responsiveness of investment in biofuel plants to changes in production incentives would further increase the impact of biofuel support on production capacities and hence biofuel supply, thus resulting in more pronounced implications for commodity prices. Conversely, a weaker responsiveness of biofuel industries would imply less important price effects.

Potential implications of recently announced or enacted changes in biofuel policies

In December 2007, the US Energy Independence and Security Act (EISA) was signed into law. This new energy legislation defines, among other elements, a new Renewable Fuel Standard calling for US biofuel use to grow to a minimum of 36 billion gallons per year (bngy) or 136 billion litres per year (bnly) by 2022. Corn-based ethanol is to grow to 15 bngy or 57 bnly until 2015 and to remain constant thereafter. Given that the US is the only major producer of corn ethanol, this consumption requirement can be seen as a production mandate as well. Requirements for first-generation biodiesel are given only for the period 2009-2012. Beyond 2012, further growth in biodiesel use is included in a total for biofuels other than corn-based and cellulosic biofuels. Production of biofuels from cellulosic materials is scheduled to start in 2010 at low levels, but with 16 bngy (60.6 bnly) to represent the bulk of biofuel use in 2022. The EISA institutes several safeguards that allow waiving some or all of these requirements in the case of adverse impacts on agricultural markets or for fuel cost reasons.

A new EU Directive on Renewable Energy (DRE) is still in the legislation phase. In its part on transport fuels the current draft calls for biofuels to replace at least 10% of all transport fuel consumption in energy terms by 2020. In contrast to the existing Directive of 2003, this rate would be mandatory. While no specific rates are given to distinguish ethanol from biodiesel use (nor from any other biofuel such as biogas), nor does the Directive provide details about alternative feedstocks. It does, however, assume second-generation biofuels to become commercially available and to represent a substantial share of biofuel supplies in the target year.

As in the case of support removal, the scenario analysing these new regulations was performed in three steps. First, the realization of the EISA was analyzed. Second, the new EU DRE was simulated. Both these runs were performed assuming that second generation biofuels were not to become available at any significant scale within the decade analyzed. In consequence, and as foreseen in the respective regulations, shares of biofuel use in the US and the EU were assumed to reach lower levels than what the regulations would ask for otherwise.[50] A final step considered the increasing availability of second generation biofuels in both countries to fill the requirements set out in the legislations.[51,52] This third scenario assumes that second generation fuels can be offered to consumers at the prices projected for first generation biofuels - be it due to improvements in the economic viability of second generation biofuels, public support, or a combination of the two. Particularly in the US, second-generation biofuels would account for the majority of the growth of biofuel markets.

Figure 2.7 and Figure 2.8 show that the two programs in the US and the EU imply ambitious plans for growth in biofuel use, over and above the growth already implied in the baseline. By construction, the additional ethanol used in the US would be domestically produced – partly from maize, but to a larger degree from cellulosic material (from crop residues and, increasingly, dedicated biomass). In contrast, the increased first-generation ethanol use in the EU would be partly provided for by foreign supplies, in particular from Brazil, while cellulosic ethanol is assumed to be domestically produced.[53] Globally, and looking again at the 2013-2017 average, these two programmes call for medium-term use of ethanol higher by some 17%.

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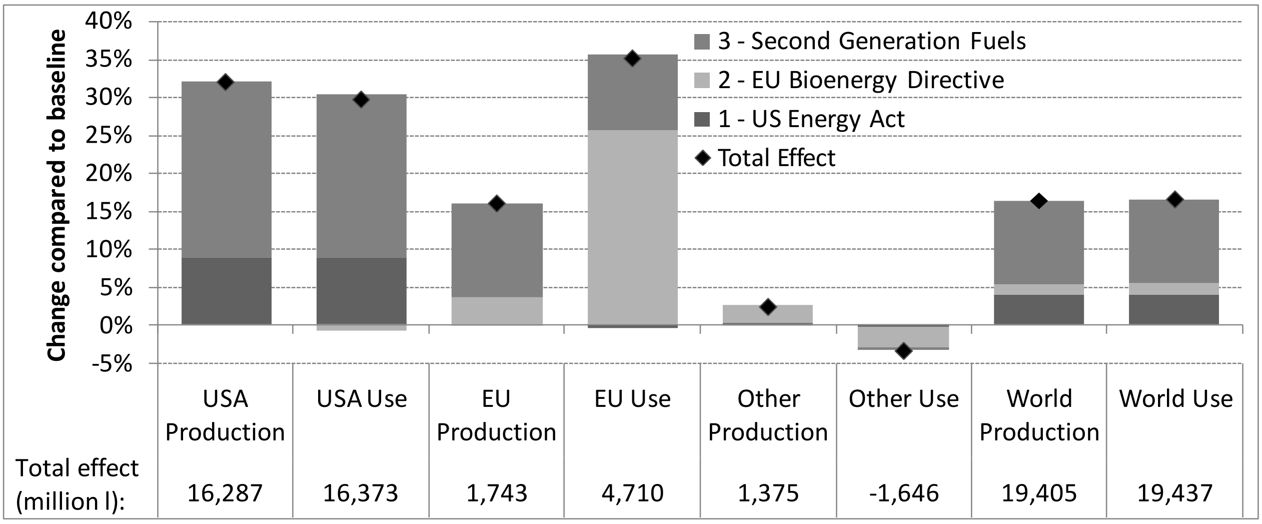
50 Note that, while requirements for individual years as well as for corn-based ethanol, biodiesel and cellulosic ethanol are provided in the US EISA (see, *e.g.*, F.O.Licht's World Ethanol and Biofuel Report Vol. 6 No. 10 for details), the EU DRE largely focuses on a global biofuel share of 10% in the target year 2020. It is assumed that in the absence of second-generation biofuels, this share is reduced to 8%, of which 6.67% were to be reached by the last year of this analysis, 2017.

51 Second-generation biofuels, once available on a commercial scale, are likely to play an increasing role over time. In consequence, this medium-term analysis (until 2017) probably underestimates the effects these new technologies might have in the longer run (e.g. by the target years of the EISA – 2022 – and the DRE – 2020).

52 Assumptions were necessary on the respective shares between crop residues (cereal straw) and dedicated biomass (*e.g.*, willow trees and switchgrass) in the feedstock requirements for second generation fuels. For this analysis, it is assumed that the year-to-year growth in second generation biofuel production would be based on crop residues with a share decreasing from 100% in 2009 to 0% from 2014, reflecting the more limited availability of crop residues when compared to dedicated biomass. Furthermore, assumptions were made on the biomass yield and conversion. Biomass yields are assumed to average 10.1 tons of dry mass per hectare in 2008, with conversion rates of 0.33 and 0.39 tons per hectoliter for the ethanol and biodiesel chain, respectively. These values improve over the projection period. It should be noted that specialized companies already today report substantially higher biomass yields. Given the small scale of current plants for second-generation biofuels and of related biomass production, an extrapolation of such higher yields is difficult. If realized, higher biomass yields will obviously reduce the market impacts of such biofuels.

53 Much of this obviously will depend on what shares of the total biofuel share will be attributed to ethanol and biodiesel, respectively. Historically, biodiesel played a predominant role in the EU biofuel markets, but the importance of ethanol has increased. As in the case of biofuel mandates in the underlying baseline, a further growth in the relevance of ethanol relative to biodiesel is assumed in this analysis as well. In consequence, the share of ethanol in total gasoline type fuel use, expressed in energy equivalent, would 7.5% by 2017 following the DRE, while that of biodiesel in total diesel type fuel use would reach 8.8% in that year (up from some 1.6% and 2.7% in 2007).

Figure 2.7. Impact of US EISA and EU DRE on ethanol production and use, 2013-2017 average



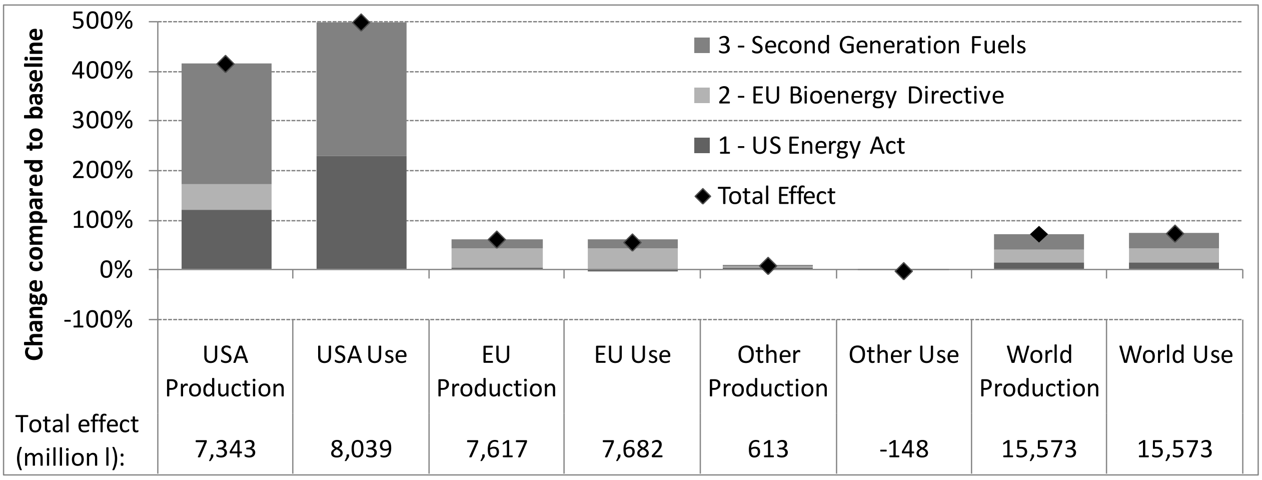
Source: Aglink/Cosimo Simulation Results, OECD Secretariat
Note: Total effects on world production and use differ slightly as world totals exclude Japan (net trade represented only)

Biodiesel use in the US is set to increase most in relative terms[54], but biodiesel use in the EU would increase substantially in absolute terms as well. Taken together, these two regions would consume some 16 bn litres per year more than without the new regulations on average over the 2013-2017 period – 9 bn litres of these would be first-generation biodiesel.[55]

54 As noted above, the Renewable Fuels Standard (RFS) of the EISA explicitly gives data on biodiesel use only until 2012, after which growth for biofuels other than corn-based and cellulosic ethanol can be calculated (note that these may include first- and/or second-generation biodiesel, but also imported ethanol from feedstocks other than corn starch). It is assumed that a decreasing share of the increments in this group would have to come from biodiesel made from vegetable oils, while the remainder would relate to biomass-based biodiesel ("Fischer-Tropsch diesel") produced in the US. The share relating to first-generation biodiesel, which according to the RFS shall be 50% in 2012, is assumed to decline from 50% in 2013 to 40%, 35%, 30% and 25% in the subsequent years until 2017, respectively. US use of biodiesel from vegetable oils would hence increase to 6.3 billion litres by 2017, more than four times the level in 2007.

55 It should be noted that biofuels from non-agricultural feedstocks, such as biodiesel from used cooking oils or ethanol from forest residues, are expected to play some role in total biofuel use both in the EU and the US. This is ignored in the present analysis but would obviously reduce the impacts found here to some extent.

Figure 2.8. Impact of US EISA and EU DRE on biodiesel production and use, 2013-2017 average



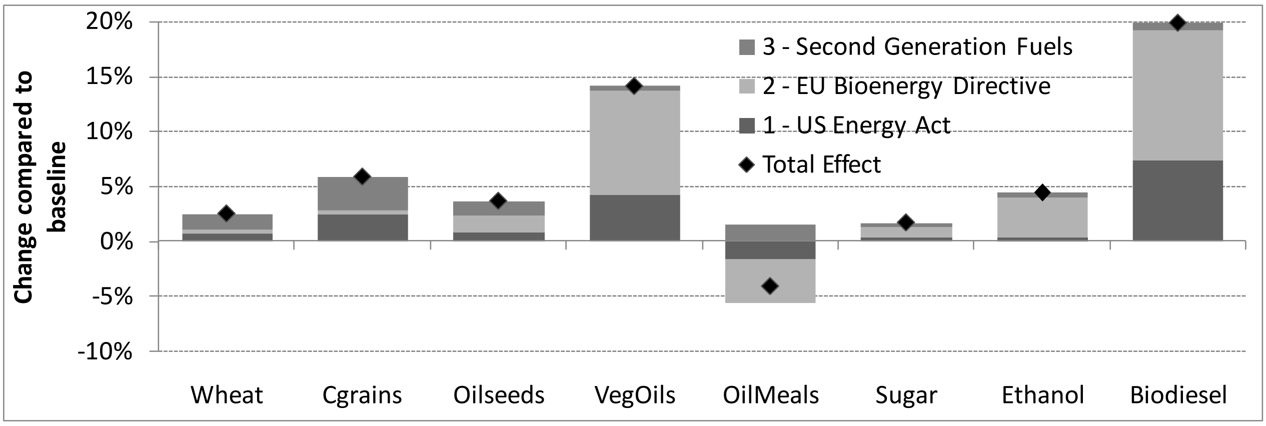
Source: Aglink/Cosimo Simulation Results, OECD Secretariat.

The additional production of first-generation biofuels following EISA and DRE as modeled for this analysis requires substantial quantities of feedstock commodities. This additional demand pushes up prices particularly for maize (due to larger maize-based ethanol production in the US), vegetable oils (biodiesel production in both the US and the EU) and sugar (due to larger Brazilian ethanol supplies destined to the EU), while wheat prices would gain through both ethanol production in the EU and through reduced wheat plantings following higher coarse grain prices. With +3% on average for coarse grains and +14% for vegetable oils the magnitude of these price changes is, however, smaller than the price effect of existing biofuel policies analysed in the previous section.

The impact of growing feedstock demand for second-generation biofuels, however, could be much larger, and would be concentrated on the commodities particularly important in the two regions considered: Assuming 50% of the biomass for second-generation biofuels to be produced on land otherwise used for food and feed production[56], prices for coarse grains would increase by another 3% on average over the 2013-2017 period; those for wheat and oilseeds would each be higher by another 1% (Figure 2.9). While the increased demand for ethanol in the US – and for second-generation biofuels in both US and EU – are assumed to be met by domestic production irrespective of biofuel prices (which in effect means that, to the degree technological improvements do not reduce production costs sufficiently far the supplies will be ensured by additional public support), biofuel prices are affected directly by the increased use of first-generation fuels in the EU and by biodiesel in the US. Given the relative magnitudes, this price effect is particularly pronounced for biodiesel, while increased ethanol use in the EU would drive up ethanol prices by some 4% on average over the final 5 years of the period analysed. Higher cereal and oilseed prices due to land reallocation for second-generation biofuels would, however, result in only slightly higher biofuel prices, causing biofuel production in a number of smaller markets (such as in Canada) to be reduced.

56 This assumption is subject to a sensitivity analysis discussed further below.

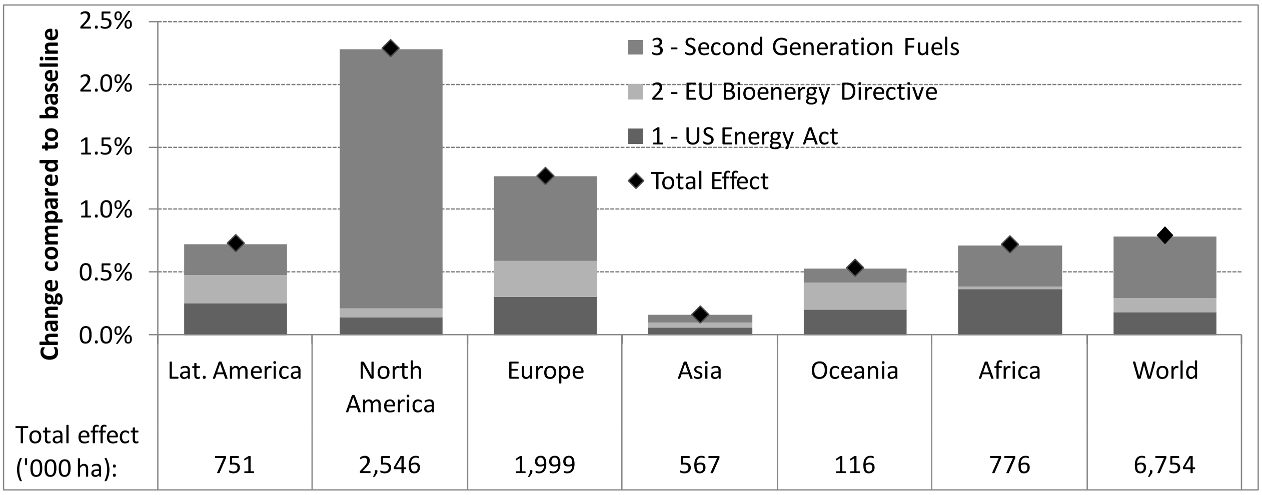
Figure 2.9. Impact of US EISA and EU DRE on world crop prices, 2013-2017 average



Source: Aglink/Cosimo Simulation Results, OECD Secretariat.

Increased use of biofuel feedstocks and hence higher commodity prices also result in more land to be used for the production of cereals, oilseeds and fuel-biomass (Figure 2.10). Consistent with the results found for the existing biofuel policies (see above), the extended use of first-generation biofuels affects land use in most parts of the world. The amount of land additionally used as second-generation biofuels are added to the picture can be substantial and would, by assumption, be mostly located in the two regions considered, *i.e.* the US and the EU. Other regions, however, would face area expansions as well following higher crop prices.

Figure 2.10. Impact of US EISA and EU DRE on total crop area (wheat, coarse grains, rice, oilseeds and biomass for second generation biofuels), 2013-2017 average



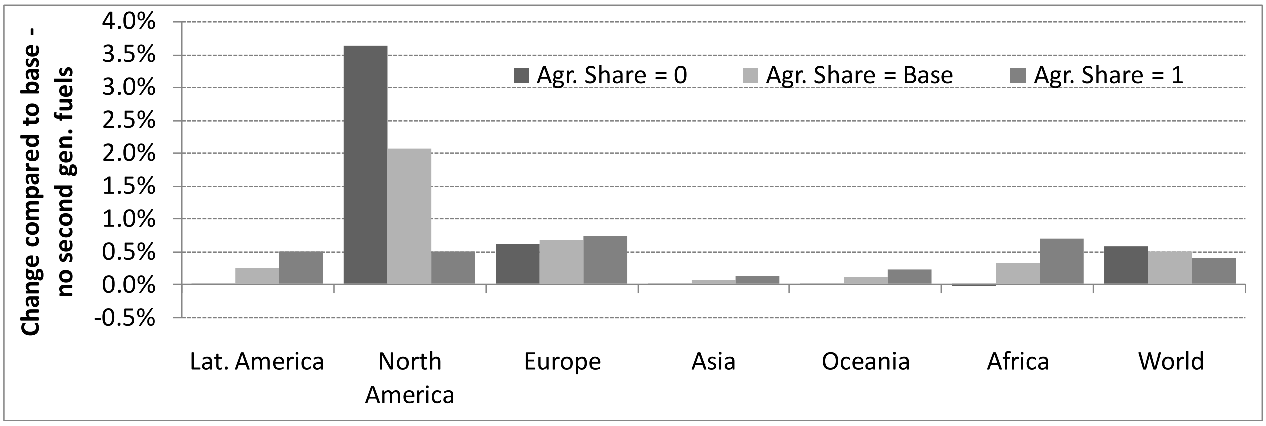
Source: Aglink/Cosimo Simulation Results, OECD Secretariat.

The results above assume that, in North America and the EU, 50% of the land required for dedicated biomass production would come from land that otherwise would be used for the production of cereals, oilseeds or sugar crops - for Brazil, this share is assumed to be 20%. The impact of increased second-generation biofuel production crucially depends on this parameter, as it directly determines the degree of competition between land for food production and land for energy production. The figures below (Figure 2.11 and Figure 2.12) show the impacts on area use and crop prices, corresponding to the third part of the above scenario (“3 – Second Generation Fuels”). Given the large quantities of biomass needed to replace the projected growth in US ethanol production, the bulk of the impact is caused by differences in North America: If all additional biomass were to be produced on land other than that used for crop production, the impact on land use would obviously be the strongest, whereas the impact on crop production would be least – the share of second generation biofuels produced from crop residues would increase cereal production and hence marginally reduce grain prices.

The magnitude of this negative price effect will depend on two factors: first, and most obviously, it will depend on the share of second-generation biofuels to be produced from crop residues such as straw and stover. In this analysis, this share is assumed to be high in the first years but to strongly decline as total quantities of cellulosic ethanol and BTL increase. Higher shares would increase the additional value of the cereal production and hence incentives to produce grains, causing lower crop prices. The second factor is the price biofuel plants will be able to pay for the straw and stover. While this price will need to cover farmers’ opportunity costs (*i.e.*, fertiliser value plus harvesting and transport costs), any revenues from the residuals beyond those will again increase the incentives to produce.[57]

In contrast, if the additional biomass were to be produced on land that otherwise was crop land, total land use would increase only because of higher crop prices, which result from the strong competition between energy and food/feed crops. As the quantities of second-generation biofuels are assumed to be much larger in the US compared to the EU, the additional land use in the US declines substantially as the share of agricultural land for biomass production increases, whereas higher crop prices offset lower biomass area in the total land use change in the EU.

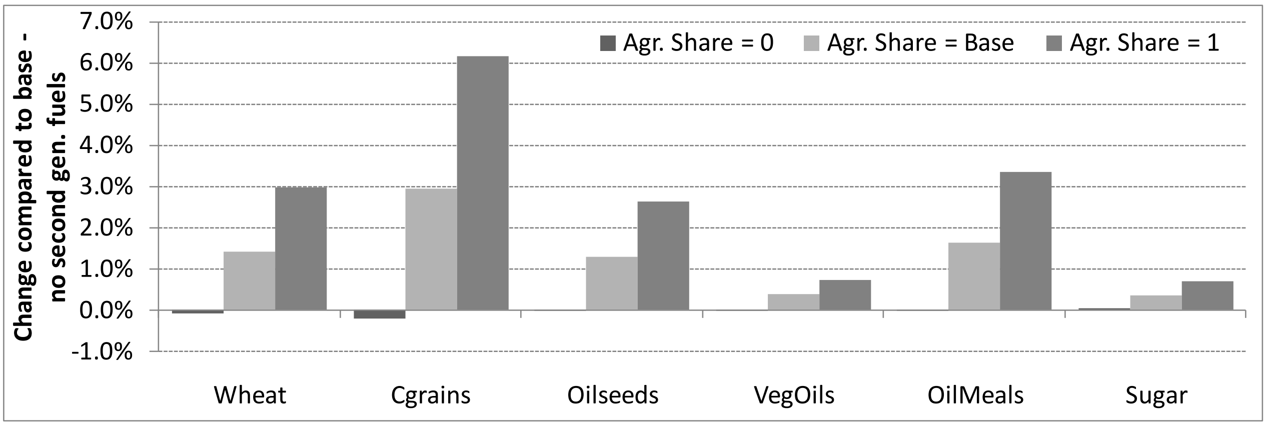
Figure 2.11. Alternative assumptions on the crop land share in the land used of biomass for biofuels – Impact on total crop area (wheat, coarse grains, rice, oilseeds and biomass for second generation biofuels), 2013-2017 average



Note: While in the base scenario (“Agr. Share = Base”) the share of agricultural crop land in the land used for fuel-biomass production is assumed to be 50% in Europe and North America, and 20% in Brazil, this share is changed to zero (“Agr. Share = 0”) and one (“Agr. Share = 1”) in the sensitivity scenarios shown as the first and third bar in each block in this and the figure below.
Source: Aglink/Cosimo Simulation Results, OECD Secretariat.

57 In effect, this additional incentive to increase cereal production is likely to be limited to farmers situated close to the biofuel plants due to the rather high transportation costs of the biomass.

Figure 2.12. Alternative assumptions on the crop land share in the land used of biomass for biofuels – Impact on world crop prices, 2013-2017 average



Source: Aglink/Cosimo Simulation Results, OECD Secretariat.

In summary, this analysis suggests that the two new biofuel regulations in the US and EU have the potential to substantially affect agricultural commodity markets and land use. Both programmes set ambitious biofuel targets which clearly depend on the rapid commercialisation of second-generation biofuels, including cellulosic ethanol and BTL. While on a per unit basis these advanced fuels have the potential to affect agricultural commodity markets much less than ethanol and biodiesel from cereals and oilseeds, the large quantities scheduled in the two regulations can still have strong impacts. Much will depend on how the feedstock biomass for these new biofuels will be produced. If large quantities are to be produced on crop land these compete with food and feed commodities and may have similar market effects as current production chains. On the other hand, biomass production on land other than current crop land will significantly expand total production area. Policies will then need to ensure the protection of sensitive areas and high-carbon soils to avoid negative environmental effects, including increased greenhouse gas emissions.

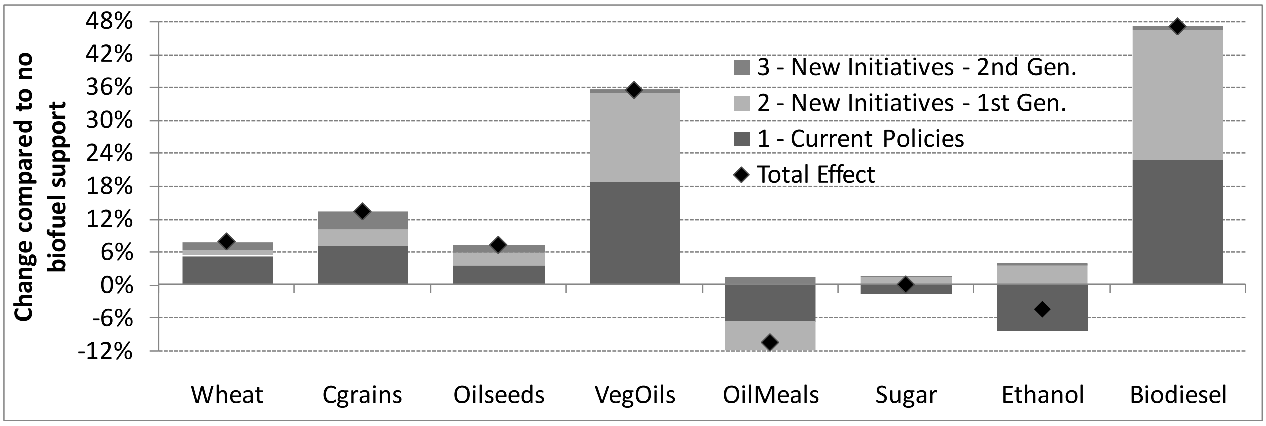
Overall effect of biofuel policies

The impacts of existing support policies and those of the US EISA and the EU DRE on agricultural markets and land use are largely additive. The overall effects of all the policies involved are of particular interest and will be briefly outlined here.

The combined impact of current and new policies on projected commodity markets is relatively pronounced (Figure 2.13). Compared to a situation without biofuel support, international prices for wheat, coarse grains and oilseeds would by about 8%, 13% and 7% higher on average for the 2013-2017 period. While prices for vegetable oils are increased by 35% following the strong increase in biodiesel production, those for oilmeals are reduced by 11% due to the higher crush and DDG supplies. Sugar prices would be little affected in the medium term.

As discussed above, these results strongly depend on the amount of crop land used for second-generation fuel biomass – as opposed to land not otherwise used for crops. Depending on that share, the total price effect for coarse grains may range from +10% to +17%, while that for wheat and oilseeds would both range from +6% to +9%. These ranges show that on the one hand the use of alternative land resources for second-generation biofuels matters, but that on the other hand biofuel policies have a significant impact on agricultural markets even if no food-crop land is used for second-generation biomass production.

Figure 2.13. Impact of existing and new biofuel policy programmes on world crop prices, 2013-2017 average

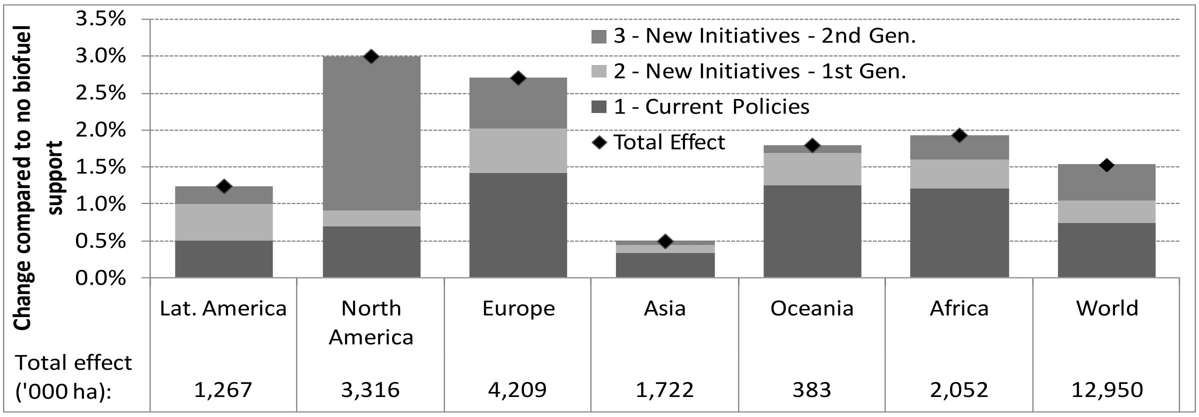


Source: Aglink/Cosimo Simulation Results, OECD Secretariat.

Both the feedstock production for second-generation biofuels and the higher prices for many crops would result in a significant larger area used for the crops and feedstocks considered. When compared to the scenario without biofuel support, global land used for cereals, oilseeds, sugar crops and fuel biomass would be some 13 million ha or 1.5% larger on average over the five year period. While again some of that increase would be in fact a reduction of declining trends in land use for crops, area expansion would be accelerated significantly in large parts of Africa, Latin America and Asia. Here, the biofuel support programmes would result in 6.5 million ha additionally used.

In contrast to the impact on agricultural market prices, the effect on global land use depends very little on the share of fuel biomass to be produced on crop land. However, the differences in the impacts for different regions are important, as discussed in the previous section: The changed effect for the United States is largely offset by the opposite effects for other regions responding to the price changes shown above (Figure 2.14).

Figure 2.14. Impact of existing and new biofuel policy programmes on total crop area (wheat, coarse grains, rice, oilseeds and biomass for second generation biofuels), 2013-2017 average



Source: Aglink/Cosimo Simulation Results, OECD Secretariat.

The use of feedstock commodities is directly linked to the production incentives and therefore for some biofuel chains strongly depends on the policy environment. This is particularly true in the case of vegetable oil use for biodiesel which, without support, would represent some 5% of global supplies for the 2013-2017 average (Table 2.1). Under current (pre-EISA) policies, this share would increase to 14% of world production, whereas the new initiatives in the US and the EU could boost this share to almost 20% on average over the 2013-2017 period. Higher shares are found in the case for sugar cane, largely dominated by Brazil's ethanol industry, but these are much less sensitive to the policy scenarios discussed here[58] and range between 27% and 28% of global production. Coarse grain use for ethanol, dominated by the United States, would represent some 10% of world production without support, but could exceed 13% of global supplies under the Energy Independence and Security Act.

Table 2.1. Use of feedstock commodities in global biofuel production under alternative policies, 1 000 tonnes, 2007 and 2013-2017 average

Feedstock commodity		Actual 2007	Policy Scenario, 2013-2017 average: No Support	Current policies	New Initiatives
Coarse grains	Total	89,394	117,813	147,242	159,540
	of which USA	81,286	106,081	129,317	140,872
Share in global production		8.4%	10.1%	12.4%	13.4%
Wheat	Total	3,551	2,113	19,403	19,979
	of which EU	2,851	1,659	17,614	18,122
Share in global production		0.6%	0.3%	2.9%	2.9%
Sugar cane	Total	255,968	532,209	500,688	513,429
	of which Brazil	243,602	489,530	458,396	470,216
Share in global production		17.3%	28.4%	27.1%	27.7%
Sugar beet	Total	9,281	5,204	12,789	13,475
	of which EU	9,281	5,204	12,789	13,475
Share in global production		3.8%	2.0%	4.9%	5.1%
Vegetable oils	Total	9,267	6,842	19,040	27,215
	of which EU	5,698	1,698	11,648	16,505
Share in global production		8.7%	5.2%	14.0%	19.6%

Note: Vegetable oils include rapeseed oil, sunflower oil, soya oil and palm oil.
Source: Aglink/Cosimo Simulation Results, OECD Secretariat.

The potential impact of "next-generation biofuels" replacing commodity-based biofuels

This scenario analyses the hypothetical implications of second-generation biofuels replacing the growth in first generation biofuels projected in the baseline. It is clearly a purely synthetic scenario as neither are second-generation biofuels commercially available today nor are first-generation biofuels expected to stop their significant growth. Instead, this part of the analysis aims to illustrate two questions: first, the impact the growing biofuel industries (as opposed to biofuel support, see above) on agricultural commodity markets, and second, the relative impact equivalent quantities of second-generation biofuels would have.

In consequence, this scenario again is cut in three steps: First, all biofuel quantities are assumed to be fixed to their respective 2007 levels, thus assuming the absence of any growth in biofuel supply and demand. Second, biofuel production and use is assumed to grow as under baseline conditions in most

58 Note that these results would change with full representation of all support measures in Brazil, information on which are lacking in detail.

countries, but to remain at their 2007 levels in the four countries with specific representation of second generation biofuels (US, Canada, EU and Brazil). Third, second generation biofuels are assumed to grow along the path projected for first generation biofuels in these four countries, *i.e.* first generation biofuels remain at their 2007 level, and the growth that they would otherwise have exhibited is now assumed to be realised through second generation biofuels.[59]

Figure 2.15 and Figure 2.16 show the implications of these hypothetical developments for international crop prices as well as land use. Without further growth in biofuel production (as opposed to a removal of support as discussed above), medium term world prices for coarse grains and sugar would be about 13% and 23% lower on average than projected in the baseline, *i.e.* than under the continuation of current policies. Relative to future market developments to be expected with implementation of the recent US and EC initiatives, keeping biofuel production constant at 2007 levels would have even more pronounced effects in terms of reducing agricultural commodity prices. These price changes compare to -7% and +2% found for a removal of biofuel support policies, respectively. The differences stem from the fact that, even in the absence of support, ethanol production in the US (and hence the use of maize in this industry) would, according to the model analysis used here, still grow even though at lower rates, whereas higher ethanol prices would increase ethanol production in Brazil (and hence the use of sugar cane) beyond baseline levels.

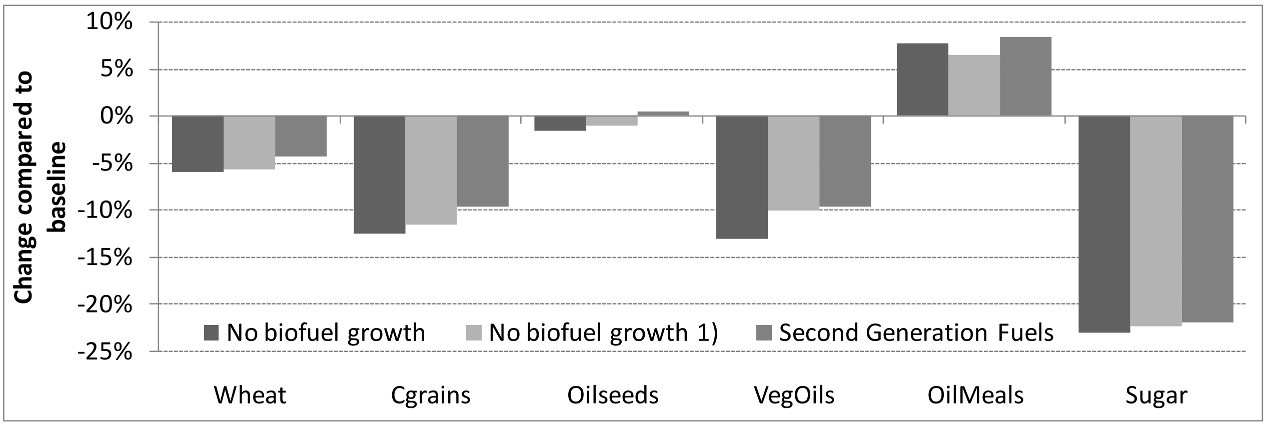
The impact on prices in the oilseed sector are similar to those found for a removal of biofuel support policies – given that without support biodiesel production would effectively stop growing (and in fact decline in some countries) the two scenarios are largely equivalent for the oilseed sector.

Most of this price change stems from biofuel production in the four regions Brazil, US, Canada and the EU – growth in biofuel production in other countries affects international commodity prices only little. This is a direct consequence of most other countries producing only small quantities of biofuels, and given the use of other feedstocks (including jatropha and cassava) in some of them, the impact on cereal and oilseed use as biofuel feedstocks is even smaller.

Growth in second generation biofuel production comparable to the projected growth in first generation fuels would increase commodity prices through competition in land markets, but depending on the share of biomass produced on current crop land, the effect is substantially smaller than the price effect of the projected feedstock use in first generation biofuel production. The increased use of biomass for second-generation biofuels would increase cereal prices by about one fifth of the price the projected growth in impact first-generation ethanol has in the medium term. The effect of second-generation fuels on sugar prices is even smaller – a consequence of a larger share of fuel-biomass in Brazil to be produced on land other than projected crop area.

59 As above, assumptions need to be made on how feedstock for second generation fuels are split between crop residues and dedicated biomass. As the relevant quantities are much larger than those discussed in the previous scenario, the share coming from crop residues – based on the year-to-year growth – is assumed to decline from 50% in 2008 to 0% in and after 2013. Again assumptions are needed on the share of fuel-biomass to be produced on land otherwise used for crop production – in line with the former scenario this share is assumed to be 50% for the US, Canada and the EU and 20% for Brazil, reflecting in principle larger land reserves in Latin America compared to North America and Europe. Despite this reasoning, however, it should be noted that these shares are rather arbitrary assumptions which are subjected to sensitivity analyses, discussed briefly at the end of this section.

Figure 2.15. Impact of second-generation biofuels replacing growth in first-generation biofuels on world crop prices, 2013-2017 average

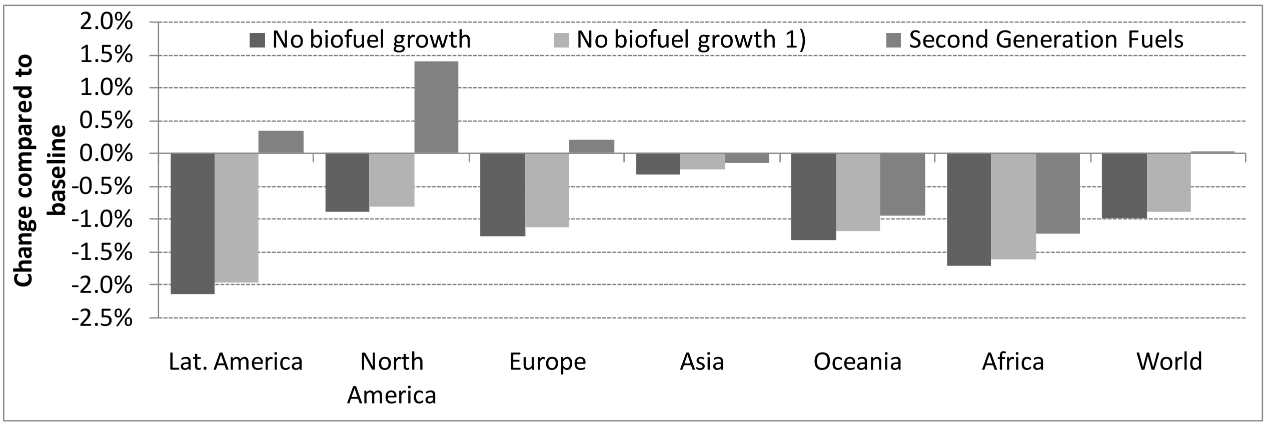


Note: "No biofuels growth" refers to constant biofuel quantities in all regions; "No biofuel growth 1)" refers to constant biofuel quantities in Brazil, the US, Canada and the EU, the four regions with explicit representation of second-generation biofuel production. Biofuel markets in other regions were kept unchanged relative to the baseline; "Second Generation Fuels" refers to growth in second-generation biofuel production replacing that of first-generation fuels in the four regions mentioned. Biofuel production in other regions, as well as biofuel demand in all regions, were kept unchanged relative to the baseline.
Source: Aglink/Cosimo Simulation Results, OECD Secretariat.

Land use would be affected significantly, both by eliminating the projected growth in first-generation biofuel production and by assuming it to be replaced by second-generation fuels. The results suggest that the projected growth in first-generation biofuels is responsible for about a third of the crop area expansion globally, equivalent to some 9 million hectares. The effect shows both in countries with a high importance of the biofuel sector such as Brazil, and in countries where biofuels are not expected to play a major role in land use such as large parts of Africa and developing Asia. In other countries, the growth in first-generation biofuels is found to slow down the decline in crop area, such as in the US. For the EU, the baseline projections imply largely unchanged harvested land after some initial increase, while without the biofuel production crop area would decline – in line with historical patterns.

With second-generation fuels growing in line with projected biofuel markets, total land use would in fact be equally affected as with first-generation fuels, at least on a global scale. Regionally, however, the impact on land use is quite different, with the decline in land use stopped in the US and accelerated area expansion in Brazil on the one end, and substantially lower land use compared to the first-generation biofuel baseline in large parts of Africa on the other end.

Figure 2.16. Impact of second-generation biofuels replacing growth in first-generation biofuels on total crop area (wheat, coarse grains, rice, oilseeds and biomass for second generation biofuels), 2013-2017 average



Note: For the definition of the scenarios see note to the previous figure.
Source: Aglink/Cosimo Simulation Results, OECD Secretariat.

As shown above in the case of the US EISA and the EU DRE, the impact of second-generation biofuels strongly depends on the share of feedstock-biomass produced on cropland. Indeed, most of the area increase shown above for North America disappears if the biomass is produced on land otherwise used for food and feed commodities. Similarly, the increase in Latin America would be substantially smaller. Much of these differences would be offset by inverse differences in other regions. Globally, the difference between none and all of the fuel-biomass coming from crop land is less than 0.3%-points on total land use for cereals, oilseeds, sugar crops and fuel-biomass.

This assumption has, however, major effects on world commodity prices, with fuel biomass competing for crop land causing higher commodity prices. Even with all fuel biomass for second generation biofuels coming from land otherwise used for food and feed commodities, however, cereal and sugar prices would be substantially lower than those projected with growing first-generation biofuels.

The impact of alternative crude oil prices

This section looks at the relevance of one of the main external factors outside the biofuel markets. As discussed above, crude oil prices have increased significantly over the past few years and have exceeded the mark of USD 100 per barrel in early 2008. While the base assumptions for this analysis include crude oil prices remaining at levels between USD 90 and just over USD 100 per barrel, different levels of crude oil prices are likely to affect agricultural and biofuel markets from two angles: first, fossil fuel prices are directly linked to crude oil. Consequently, the higher crude oil prices are, the stronger will be, all other factors unchanged, the demand for biofuels.[60] Second, as energy represents an important share in agricultural production costs and is also required in the conversion of feedstocks to biofuels[61], higher

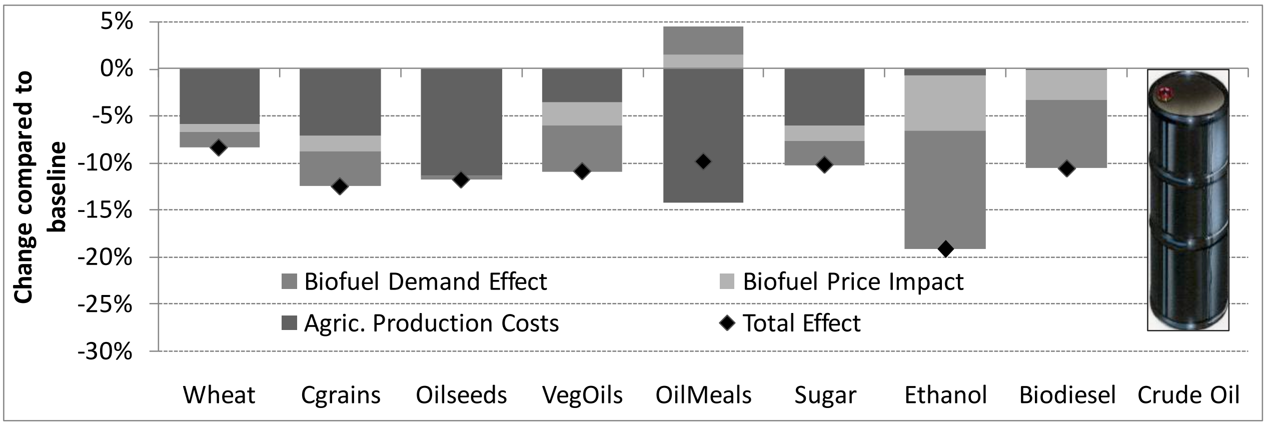
60 In the case of fixed blending mandates, the demand for biofuels obviously does not increase with higher crude oil prices. The model therefore differentiates between the price-responsive demand for biofuels and the minimum set by public mandates in several countries.

61 Note that in both agricultural production and biofuel conversion processes energy is not only used in the form of crude oil derivatives, but also in other forms such as coal, natural gas or nuclear and water power. While not all the energy costs in biofuel production are therefore assumed to be linked to crude oil prices, petroleum is used as an energy cost indicator as in the medium term prices for other forms of energy are assumed to move with crude oil prices.

energy prices will reduce agricultural production, increase agricultural commodity prices and hence will reduce biofuel supply.

A return of crude oil prices to the level of USD 30 per barrel is not expected. However, the annual average oil price in 2007 was just over USD 72 per barrel[62], and a return to such prices from the current level of around USD 100 per barrel might be seen as a possible, though perhaps not likely scenario, while on the other hand prices could rise further to persistent levels of USD 130 per barrel or above. These two benchmarks are therefore used to analyse the implications that substantially different oil prices could have on biofuel markets and agriculture. In order to better understand the relevance of different levels in the biofuel economy, the scenarios are broken down into several subjects: first, the impact through changed costs in agricultural production is shown by keeping both fossil and biofuel prices at their original levels. Second, by letting biofuel prices adjust to the impact of crude oil prices on production costs, the impact of changes in feedstock markets on biofuel supply and prices are shown. Finally, changed prices for fossil fuels are allowed to affect the demand for biofuels, thus showing the implications of alternative crude oil prices from the biofuel use side.[63]

Figure 2.17. Impact of lower oil prices on world crop and biofuel prices, 2013-2017 average effect relative to baseline



Source: Aglink/Cosimo Simulation Results, OECD Secretariat.

Figure 2.17 shows the global price impacts of alternative assumptions on crude oil prices for the average of the final quintennium of the simulation period, 2013-2017. Lower energy prices have an important impact on production costs in agricultural production and hence commodity prices. With oil prices being some 28% lower than in the baseline on average, and energy costs in agricultural production moving with oil price changes to some degree[64], world crop prices would decline by between 6% and 12% on average even without considering response in biofuel prices. Their downward response further reduces

62 Brent crude averaged USD 72.35 per barrel in 2007 (OECD: Aglink Database, 2008).

63 In principle, crude oil prices might in turn be affected by the production and use of biofuels as these tend to reduce demand for fossil fuels to some degree. This possible effect is not considered here – more in-depth analysis is needed to explore the effect of biofuel-induced reductions in crude oil use on international energy markets.

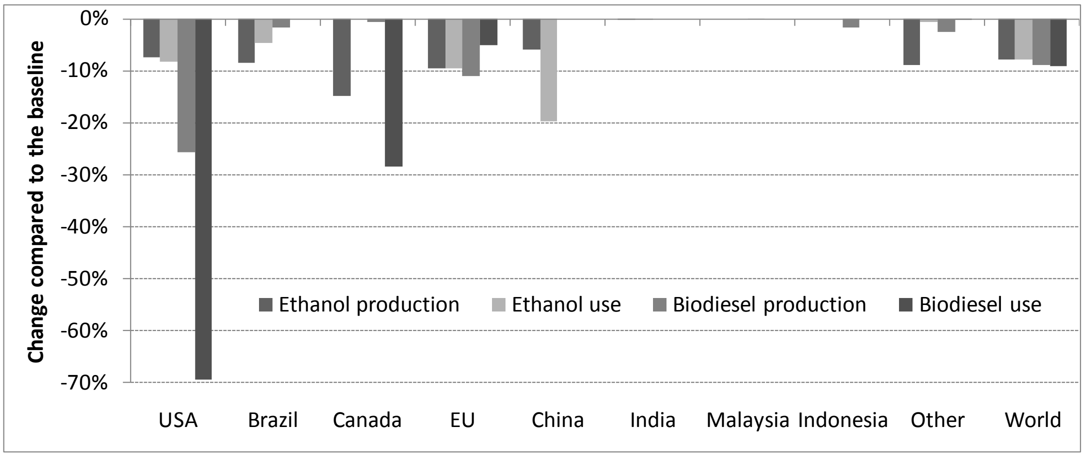
64 Note that, while fuels used in tractors and transport are obviously directly linked to crude oil prices, other forms of energy (natural gas, coal, etc.) are often use in the production of energy intensive inputs such as fertilizers and pesticides. See Annex 3 of OECD (2006) for details on the modeling of production cost impacts of crude oil prices.

the crops use in biofuel production and hence commodity prices. Finally, biofuel use would decline with lower crude oil prices, putting further pressure on both biofuel and agricultural commodity prices.

In total, world ethanol and biodiesel prices would be some 19% and 11% lower than in the baseline on that five-year average, respectively. These reductions are smaller than the change in oil prices mainly for three reasons: First, while substitution between biofuels and fossil fuels is assumed to be fairly high, it is less than perfect due to technical differences in the fuels and hence engine modifications needed to run higher biofuel blends. Second, domestic fuel prices generally are subject to relatively high taxes, causing gasoline and diesel prices to decline by less than crude oil in relative terms. Third, blending requirements effectively limit the response in biofuel demand in a number of countries as blenders have no flexibility to react to price changes. For instance, as visible in Figure 2.18, biodiesel use in the EU, the largest biodiesel producing and consuming region, hardly changes with lower crude oil prices, as in fact biodiesel use in the EU is bound by mandates to a large extent. The same holds for a number of Non-Member Economies including India, Malaysia and Indonesia, for which the use of ethanol and biodiesel is assumed to be fixed to blending mandates in the projection period. Blending mandates also keep the biodiesel use in Brazil unchanged, while in Canada, biodiesel use would fall with lower crude oil prices, but given existing mandates the effect is limited. In contrast, biodiesel use in the US, where no blending requirements are considered in the baseline[65], would be substantially lower as fossil fuels become cheaper.

The decline in ethanol use generally is much smaller in comparison, even though a lesser part is supported by mandates: as the ethanol price declines more significantly in response to falling crude oil prices, a larger share of this biofuel remains in use despite lower crude oil prices.

Figure 2.18. Impact of lower oil prices on biofuel production and use, 2013-2017 average effect relative to baseline



Note: Results for biodiesel use in India, Malaysia and Indonesia are due to model-related simplifications and hence likely to underestimate the actual impact of oil price changes to biodiesel use.
Source: Aglink/Cosimo Simulation Results, OECD Secretariat.

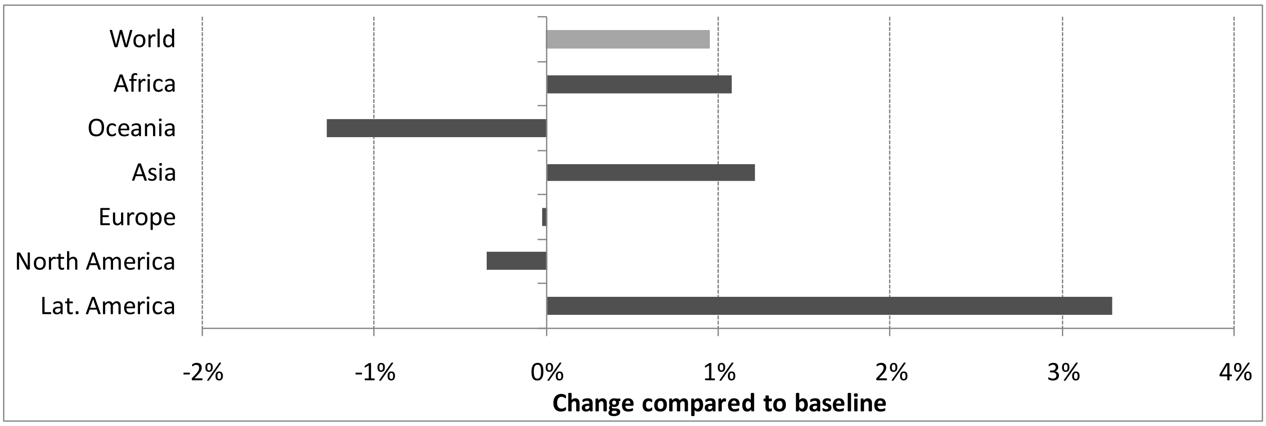
The total impact on crop prices is smaller again, with a reduction by 8% to 13% for the different commodities. This reflects the fact that it takes a reduction in biofuel producers' margins to stimulate a

65 Lacking detailed data, existing state-level mandates in the US are not accounted for in the baseline. The response particularly in biodiesel demand in this country is therefore likely to overestimate the actual responsiveness to crude oil prices. It should also be noted that in some countries a quota system applies to government support, again reducing price responsiveness in these countries.

decline in biofuel production, even though crop prices also and particularly decline due to lower production costs in agriculture. Overall, the existence of biofuel industries in various countries tends to increase the responsiveness of crop markets to changes in energy costs: about 20-30% of the price change in cereal and sugar markets results from the demand for these crops as a fuel energy source. This effect is more limited for oilseeds due to the opposite effect biodiesel production has on the markets for vegetable oils and for oilseed meals.

Global use of crop land would be slightly higher with lower crude oil prices mainly due to reduced agricultural production costs and hence increased output. This is particularly the case in developing countries, where the energy part of agricultural production costs, though lower in absolute terms, has a larger share in total production costs due to lower prices for land and labour. In large parts of the OECD, in contrast, lower crop prices outweigh or even overcompensate for lower production costs, resulting in a reduction of land used for crop production.

Figure 2.19. Impact of lower oil prices on crop land use, 2013-2017 average effect relative to baseline



Source: Aglink/Cosimo Simulation Results, OECD Secretariat.

In summary, this analysis shows that agricultural markets are sensitive to changes in energy prices, and that this sensitivity has increased with the emergence of biofuels. While the question whether biofuel industries create a more or less price responsive demand for feedstock crops very much depends on the individual country and the feedstock used – the established cane-based ethanol industry in Brazil can be expected to respond much more directly to changes in feedstock markets than *e.g.* the still relatively small grain-based ethanol industry in the EU where capacity tends to be a more limiting factor – the demand for crops as a source of fuel energy creates an additional link to crude oil markets. The relevance of this new demand for the link between energy and agricultural markets again depends on the feedstock crop. These results are confirmed by the second scenario assuming higher crude oil prices, though the results of that scenario are not shown here in detail: At USD 130 per barrel, medium-term crop prices would be higher by between 9% and 13%. Again the effect of higher fossil fuel prices on biofuel demand accounts for an important share of this overall crop price response.

Environmental effects of agricultural land allocation between bioenergy crops and food-feed crops using SAPIM[66]

Background

There is a lot of public interest not only in the economic and market effects of biofuel production and consumption, but also the various environmental effects. A significant amount of research has explored the effects of biofuels on greenhouse gases, but very little on the multiple environmental effects. Moreover, integrating both the economic and environmental effects has been absent. The Stylized Agri-environmental Policy Impact Model (SAPIM), which adopts an integrated economic and natural science modelling approach, has the capacity to undertake such analysis. SAPIM combines an economic model of farmers' decision making with a biophysical model predicting the effects of farming practices on crop yields and multiple environmental effects. The environmental effects include GHG emissions, nitrogen and phosphorus runoff, herbicide runoff and the quality of wildlife habitats. As the focus of the application is on multiple environmental effects of alternative land use options, crop prices are exogenous and taken from the OECD AGLINK scenario results. The illustrative example below is an empirical application based on data from south-western Finland.

Environmental effects

This application of SAPIM focuses on three environmental issues: surface water quality, climate, and biodiversity. Moreover, the model addresses land allocation between different uses, each of which is associated with certain input use intensities and management practices. As regards CO_2-equivalent life cycle effects, the focus is on agricultural production activity, and thus the conversion of feedstock into end-products and final consumption are not considered in this application (see Annex B Figure B.1).

In this application, both nitrogen and phosphorus runoff from cultivated fields to watercourses is estimated. As regards pesticide runoff, the focus is on herbicide runoff (MCPA as an active ingredient).[67]

Greenhouse gas emissions are modelled on the basis of life cycle assessment (LCA) estimates provided by Mäkinen *et al.* (2006). In this application the following elements are included: (i) CO_2-eq emissions related to the transportation of crops, (ii) CO_2-eq emissions related to the manufacturing, transportation and application of fertilizers, herbicide, and lime (iii) CO_2 emissions from soil and (iv) CO_2-eq emissions from tillage practices, such as ploughing, harrowing and planting as well as CO_2-eq emissions from harvesting and grain drying.

The effects of land allocation on biodiversity are quantified by a wildlife habitat indicator - a habitat quality index, developed in Lehtonen *et al.* (2008). This index measures the impacts of land use on the quality of wildlife habitats.

The monetary valuation of environmental effects is used to aggregate the environmental effects in alternative policy scenarios. These valuation estimates are based on published Finnish valuation studies quantifying the consumers' willingness to pay for reducing nutrient and herbicide runoff or to promote biodiversity. The price of emission allowances is used as a proxy for the climate damage (CO_2-eq emissions).

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66 Background paper (OECD, 2008b) provides a detailed description of this application.

67 For details of nutrient and herbicide runoff modeling see Lankoski *et al.* (2006) or OECD (2008).

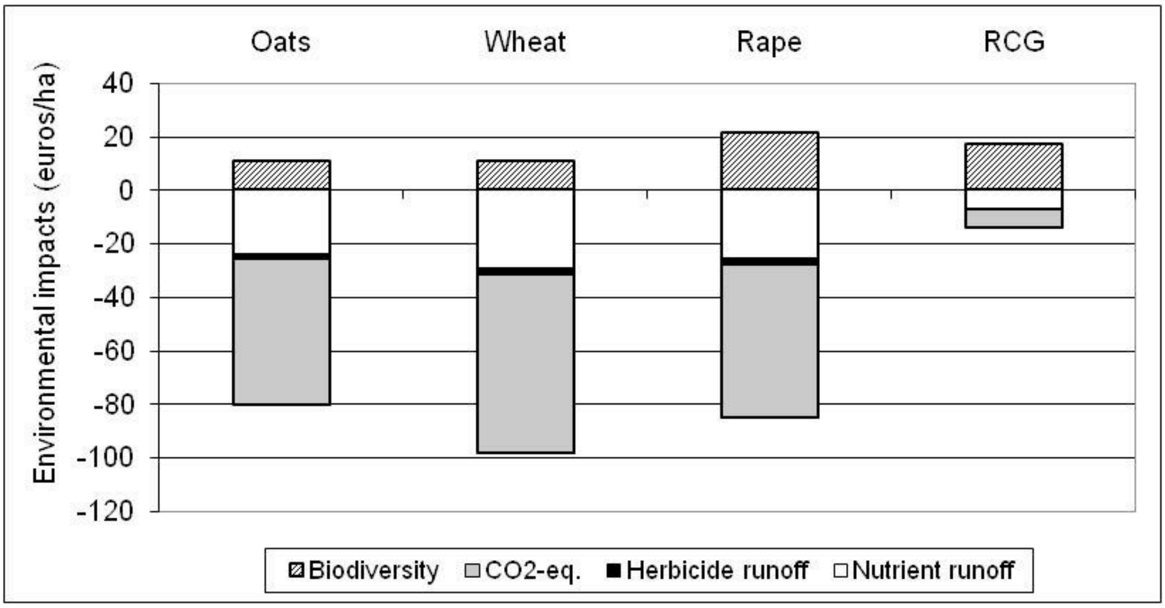
Results

Results are presented for three scenarios: Baseline, Policy scenario 1 (Removal of biofuel support) and Policy scenario 2 (New EU and US biofuel legislation). The Policy scenario 1 incorporates the forecast average EU prices for wheat, barley, oats and rapeseed in 2013-2017. In this price scenario, all biofuel-related policy instruments are removed (budgetary support, mandates and tariffs). The Policy scenario 2 also incorporates the forecast average EU prices for wheat, barley, oats and rapeseed in 2013-2017, but in this price scenario, the following policies and technology developments are taken into account: the US Energy Act, the EU Bioenergy Directive, and second generation biofuels.

Reed canary grass (RCG) - a perennial grass with 14 years rotation period - represents second generation biodiesel, while rape represents first generation biodiesel, barley is used for ethanol, oats is used for feed, and wheat is the food crop.

For all scenarios the basic results regarding land allocation, input use intensity, production and profits are presented in Annex C, Table C.1. Detailed empirical results concerning the environmental effects of alternative crops and policy scenarios are presented in Annex C, Table C.2.

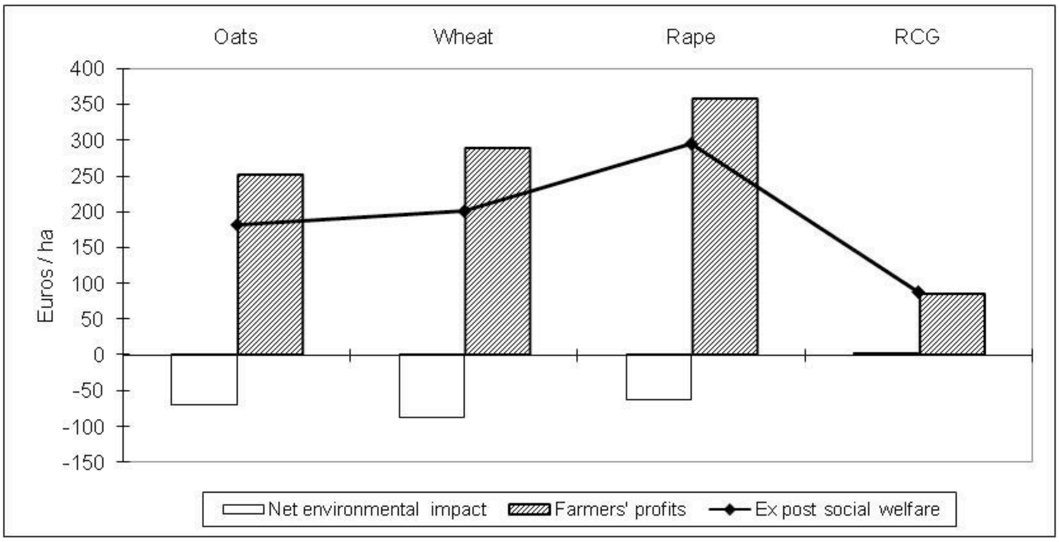
Figure 2.20. Environmental profile of alternative land uses in the Baseline scenario, EUR/ha



Concerning the environmental effects, Figure 2.20 illustrates that reed canary grass (RCG) performs well. Its good environmental performance is mainly driven by its low CO_2-eq emissions. This is largely explained by the fact that RCG is a perennial crop that sequesters carbon and thus soil CO_2 emissions are in fact negative, whereas for other crops, which are annual crops and cultivated with conventional tillage, soil CO_2 emissions are significant. Moreover, RCG is cultivated with low fertilizer intensity and thus low CO_2-eq emissions related to fertilizer use. Because of high fertilizer and herbicide use intensity wheat performs poorly with respect to both CO_2-eq emissions and nutrient runoff. With respect to the biodiversity benefits provided, rape is the highest ranked of the land use types in the Baseline scenario. This is because the wildlife habitat index uses butterflies as the key species and rape provides a higher quality habitat for butterflies than cereals. The overall environmental performance of alternative land use types is mainly driven by the value of CO_2-eq emissions and nutrient runoff damage. Herbicide use intensity and resulting herbicide runoff damage have only a marginal effect on the environmental performance of alternative land use types. Incorporation of biodiversity benefits favour rape and reed canary grass over cereals.

Concerning **social welfare** (defined as the combination of the social valuation of environmental effects and farmers' private profits, without considering transfers from governments/taxpayers and consumers), Figure 2.21 illustrates the social profitability of alternative land uses in the Baseline. Profits are short-run estimates (revenue from production minus variable costs of production) augmented with the social value of retaining land in agriculture (which is represented here by LFA payments). The results show that the land use type that delivers the best environmental performance (reed canary grass) is the least profitable for farmers. Overall, first generation biodiesel crop rape provides the highest ex-post social welfare, since it provides a combination of the highest farm profits with the second lowest negative net environmental impact. This social welfare ranking illustrates that in this example ex-post social welfare of alternative land use types is mainly driven by profitability of land use rather than the social valuation of environmental effects.

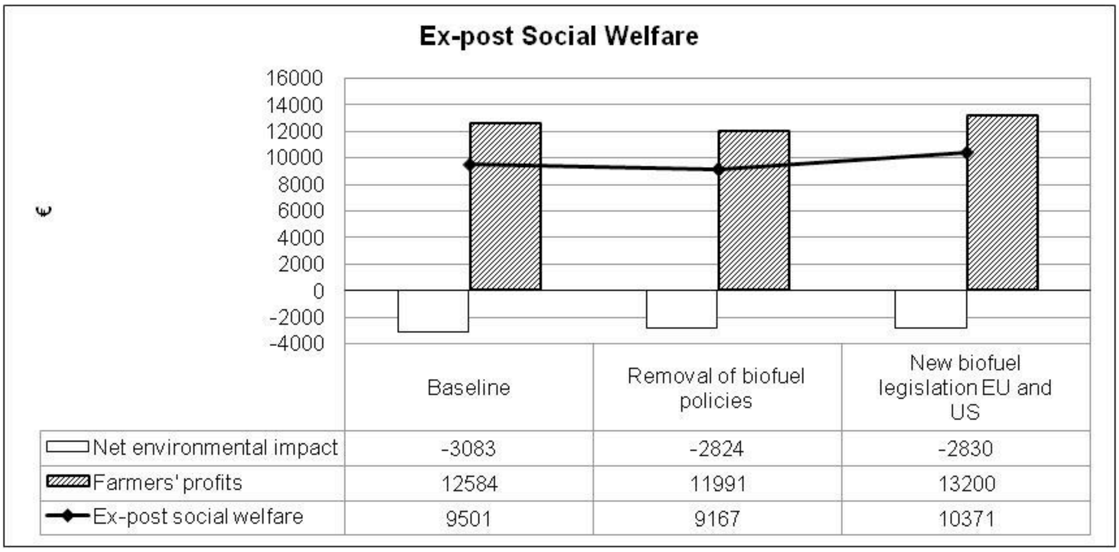
Figure 2.21. Social welfare under alternative land uses in the Baseline scenario, EUR/ha.



Extending the analysis to the ex-post social welfare estimates for alternative policy scenarios, the results presented in Figure 2.22 show that the removal of biofuel policies results in the lowest negative environmental impacts, although the difference is not very large when compared to the environmental impacts of new EU and US biofuel legislation. Improved environmental performance of these policy scenarios relative to the Baseline is mainly because of decreased CO_2-eq emissions under both policy scenarios, decreased nitrogen runoff in the scenario of the removal of biofuel policies, and increased value of wildlife habitats in the scenario of new EU and US biofuel legislation.

From overall social welfare perspective the policy scenario of new EU and US legislations clearly dominate other policy scenarios due to increased profits for farmers. The ex-post social welfare of alternative land use types and policy scenarios is driven mainly by farmers' private profitability of alternative land uses rather than the social valuation of environmental effects. Naturally, socially optimal allocation of land between food, feed and bioenergy crops changes when relative prices change, including social valuation of environmental goods and services.

Figure 2.22. Ex-post social welfare under alternative scenarios, €.



This application of SAPIM is illustrative and depends on many assumptions, characteristics of farming systems and land productivities, and policy parameters. Clearly, the results will likely be different in a different set of circumstances. However, the value of this analysis is in using a model that can combine several economic, policy and environmental variables to provide both results on farmers' profits and social welfare. If policy makers wish to pay particular attention to, for example, the multiple environmental effects of biofuel production then this has implications for the adoption of policy measures that will provide the correct incentives to achieve balanced outcome.

CHAPTER 3. COSTS AND BENEFITS OF BIOFUEL SUPPORT POLICIES

The preceding chapter presented and discussed the results of model-based analyses. Existing and new biofuel support policies were in the centre of the set of scenarios that were calculated using a large-scale economic modelling system Aglink-Cosimo, complemented by a stylised model on environmental implications of the policy changes, SAPIM. As for the results of any modelling system, those discussed above are subject to a certain degree of uncertainty, related to parameters and structures in the represented markets.

This chapter now aims at combining the model results with the factual information provided in Chapter 1 in order to derive conclusions on the effectiveness and efficiency of biofuel support policies. In doing so, it is important to bear in mind the limitations of the modelling approach caused by the high degree of complexity in this area.

The elaborations below will follow the list of main objectives behind public support for biofuel production and use. This chapter will hence discuss the effectiveness of support policies with respect to the avoidance of greenhouse gas emissions, to savings in fossil fuel use, and to rural development, before further exploring possible side effects including the risk of food price inflation and environmental degradation. The results shown are limited to the policies in the US, the EU and Canada, and relate to the overall impact of their policies (as opposed to policies in individual countries).

The objective of GHG mitigation – impacts and cost effectiveness

The quantitative analysis above shows that currently policy regimes and recent and envisaged policy changes have considerable impacts on biofuel markets. Indeed, on average for the 2013-2017 period, existing biofuel support policies (*i.e.* the recent US Energy Improvement and Security Act and the proposed EU Directive on Renewable Energy not included) are found to increase total supply and use of biofuels by about 13 billion litres of biodiesel and 17 billion litres of ethanol. In particular, this includes the use of a variety of feedstocks in the four regions considered in more detail here, *i.e.* Brazil, the US, Canada and the EU. While biofuel production in the US, Canada and the EU is increased through those countries' support policies, ethanol production in Brazil, based on sugar cane, is slightly reduced.

To calculate total GHG avoidance from these policy-induced quantities, we use robust ranges of values for GHG improvement rates from biofuels as discussed in Chapter 1 as well as a standard GHG emission level for a litre of gasoline or fossil diesel, respectively. These values are, as discussed above, subject to a certain degree of uncertainty and in particular will not be exact under all conditions prevailing in the different countries. The ranges given can, however, serve as proxies for average conditions and hence are appropriate for calculating total GHG avoidance figures. These global totals are particularly relevant as the reduction of GHG emissions is aiming at solving a genuinely global problem – in contrast to other issues discussed below the regional distribution is of lesser importance.

Table 3.1. Impact of current biofuel support on GHG savings through ethanol and biodiesel production, 2013-2017 average

	Biofuel production			GHG emissions (CO_2 eq.)				
	Base	No support	Difference	Fossil standard	Average reduction		Avoided	
	Million litres per year			*kg/l*	*from %*	*to %*	*from kt*	*to kt*
Ethanol from wheat	7,405	803	6,602	2.682	30	55	3,558	6,524
Ethanol from coarse grains	54,274	42,109	12,165	2.682	10	30	2,186	6,557
Ethanol from sugar cane	36,093	38,546	-2,452	2.682	80	90	-3,525	-3,965
Ethanol from sugar beet	1,288	524	764	2.682	40	60	549	824
Biodiesel from vegetable oil	16,270	3,723	12,547	3.017	40	55	12,113	16,655
Total 5 biofuels	115,331	85,705	29,626	n.a.	n.a.	n.a.	14,881	26,594

Source: Aglink/Cosimo Simulation Results; standard emissions based on EC (2008), p. 56; average GHG reduction rates based on Chapter 1 of this report; OECD Secretariat.

Table 3.1 shows that grain-based ethanol as well as biodiesel from vegetable oils – predominantly from rapeseed or canola oil – represent the vast majority of the biofuels boosted by support policies in North America and Europe. Ethanol from sugar cane, among the most important feedstock commodities worldwide in absolute numbers, is reduced by biofuel support policies, as support within Brazil is not fully taken into account in this analysis and as the effect of additional incentives from support to ethanol use in export destinations is largely offset by trade barriers.

Using average GHG reduction rates, the additional biofuel quantities created by public policies in Brazil, the US, Canada and the EU tend to avoid between 15 and 27 million tonnes of greenhouse gases (CO2-eq.) per year between 2013 and 2017. This compares to current global energy-related GHG emissions of some 27 billion tonnes per year, of which 3 billion tonnes of CO2-eq. are caused by oil use in the North-American and EU transport sectors. These transport-related emissions are estimated to further increase to some 3.3 billion tonnes of CO2-eq. by 2015.[68] In other words, existing support in the US, Canada and the EU is estimated to reduce transport-related GHG emissions by between 0.5% and 0.8% of transport fuel related emissions in these regions projected for 2015.[69]

Support to biofuels in the US, Canada and the EU has been estimated by the Global Subsidies Initiative to total about USD 11 billion in 2006.[70] Extrapolated for the 2013-2017 average production numbers in these three regions[71] this amount increases to about USD 27 billion per year[72] - more recent

68 IEA: World Energy Outlook (WEO) 2006 and 2007. All these numbers are projected to keep growing, although projected growth rates have been revised downwards in the 2007 edition of the WEO. As the 2007 edition does not provide transport-related emissions specifically, these were estimated using the emissions related to oil use from the 2007 WEO and the share of transport related emission in total oil use related emissions provided in the 2006 edition of the WEO.

69 Total biofuel production has a larger effect: Taking into account all biofuels produced (as opposed to those generated by future support) in North America and the EU (as we look at support in these countries only we exclude Brazilian ethanol here) during the 2013-2017 average, the reduction in GHG emissions would range from 0.9% to 1.8% of their total transport related GHG emissions projected for 2015. Not all of these reductions are caused by support over the decade to come, but result partly from support provided in the past. The values in this footnote are given here for transparency reasons but should not be read in terms of efficiency of support.

70 Source: Global Subsidies Initiative (2007). Updated on the basis of data contained in Koplow (2007).

71 The data provided in the GSI source includes an estimate of the shares of total support vary with biofuel quantities – the projections referred to here extrapolate this part using the projected biofuel quantities as published in OECD (2008a).

72 This extrapolation assumes that current forms of biofuel support remain maintained over the decade to come – as do the market projections presented in OECD (2008a) underlying the present analysis. It should be noted here that with technological advances in both existing and future biofuel chains the required

updates of the GSI data would suggest extrapolated support to be as high as USD 31 billion per year. This report does not use the GSI estimates but projects levels of support based on the OECD/FAO Aglink-Cosimo model as used for the analysis underlying the present report. Taxation and tariff measures accounted for in this analysis amount to a total of USD 25.4 billion, on average, for the 2013-2017 period, up from USD 11 billion in 2006. Using these numbers as proxies for actual support, and not taking into account other objectives targeted with the same support (see below), lowering GHG through policy support to biofuels would cost taxpayers and consumers on average between USD 960 and 1 700 per ton of CO2-equivalent avoided in those countries. This rough and average value is not only much higher than the carbon value at European and US carbon markets (CO2-futures for 2012 at the European Trading Scheme have been floating between EUR 22 and EUR 26 per tonne until late March 2008 and have increased somewhat thereafter, while futures for 2014 traded around EUR 31 per tonne in mid April[73]), but also above most of the avoidance costs calculated in the GSI studies (ranging from USD 250 to USD 5 500 per tonne CO2-eq for ethanol and from USD 250 to USD 1 000 per tonne CO2-eq. for biodiesel in the three regions considered here). The main reason is that here only the extra biofuel quantities actually generated by the public support are taken into consideration, as opposed to total biofuel output accounted for in the GSI studies. Much of the projected biofuel production is linked to support that has been provided in the past.[74]

These figures obviously need to be read with great care given the large uncertainties around several parameters in the calculation, and should therefore be taken as indicative only. In particular, they do not account for possible improvements in the environmental performance of biofuels over the decade to come. With shrinking crude oil reserves the environmental characteristics of fossil fuels may worsen in the future, improving the relative performance of biofuels. The figures discussed here also do not account for any effects from land use changes triggered by the expanded biofuel production. As discussed in Chapter 1, the conversion of natural habitats can generate substantial emissions of greenhouse gases, while conversely the use of marginal land for extensive energy production such as short rotation coppice may increase carbon sequestration.

The Aglink-Cosimo simulations indicate that biofuel support is responsible for more than one fifth of the 27 million hectares expansion of the area globally used for cereals, oilseeds and sugar crops between 2007 and 2017. Some of the increased land use, however, reflects a slowing of area reduction trends rather than actual expansions, so the risk of environmental damage from this land use change is likely to be small.[75] This concerns in particular the USA and the EU where a combined 2.5 million hectares would additionally go out of crop production without biofuel support. Area expansion is accelerated, however, in large parts of Latin America, Asia and Developing Africa, affecting about 3 million hectares. Some of that land may be covered by agricultural crops not considered in this analysis, such as permanent crops, fruits and vegetables, but most of this land is not likely to be converted into arable land as these former uses are generally of higher value and hence less likely to become converted. Assuming that the land were mainly converted from permanent grassland, the (relatively low) values in the German SBO draft (see Chapter 1) would suggest that the conversion would result in carbon losses of about 15 t per hectare, equivalent to 55 t of CO2. Conversion of 2 million hectares – this consequently assumes a certain share of the additional land

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support per unit of output might decline. While lower support would likely reduce biofuel output as well, the per unit support costs of biofuel-related GHG savings and, for that matter, achievement of other policy objectives might be reduced as well.

73 www.co2prices.eu accessed June 2008.

74 If the total biofuel production in those three regions were considered, the above numbers would suggest costs for taxpayers and consumers of between USD 430 and 840 per ton of CO2-equivalent avoided. These values are given here for transparency reasons but should not be read in terms of efficiency of support.

75 This of course depends on the fate of the abandoned land and may therefore not be true in all cases.

not to come from non-agricultural land types – caused by biofuel support would hence result in an additional one-off emission of 110 Mt of CO2 – roughly five times the annual GHG avoidance created by the support. Converting more sensitive land such as forests or savannahs would create substantially higher emissions than the 55 t per hectare.

Again, these numbers have to be read with great care, as they represent no more than an indicative figure. With increased awareness about climate change issues and the link between land use changes and GHG emissions, as well as with increased consideration of land use change related effects in biofuel policy frameworks, it can be hoped that in most cases sensitive areas will be excluded from crop land expansions. Efforts are being made to convert marginal land in Africa and Asia to produce Jatropha for biodiesel, and although the related quantities are not expected to become large relative to global biofuel or crop production, this conversion may actually create additional carbon sinks and improve GHG balances beyond the pure LCA improvement rates. In any case, however, great care has to be taken in the design of biofuel support policies – and in fact in a more general policy framework to reduce global GHG emissions – to avoid land use change related emissions to the largest extent possible.

An elimination of import tariffs for biofuels – mainly ethanol – could have already significant effects on the amount of GHG avoided via biofuels. Using the same approach as above, a tariff elimination alone would reduce the production of grain- and sugar beet-based ethanol by more than the increase in sugar-cane based ethanol. Due to higher GHG reduction rates for cane-ethanol, however, total GHG avoidance would increase by between 3.5 and 6 Mt of CO2-equivalent per year – about 20% of the GHG savings expected to result from existing support policies. Again, of course, these gains would have to be balanced against potential emissions from additional land use changes: In particular, about 0.8 million ha would additionally go into crop production in Latin America for the 2013-2017 average, with a potential one-of carbon release of some 44 Mt of CO2-equivalent, using the same figures as above. On the other hand, lower cereal and oilseed prices would reduce the area expansion in Asia and Africa by more than one million ha, potentially offsetting the increased land use in Latin America. Clearly, more in-depth analysis about the land types affected in the different regions is necessary to assess the impact the land use changes could have on global GHG emissions.

Second-generation biofuels clearly have the potential to reduce land pressure if feedstock biomass can be produced on ecological low-value land. In particular the use of degraded land, covering increasing areas in a number of regions, would offer to improve the GHG performance of biofuels beyond the levels found in LCA studies and could create substantial benefits in non-GHG environmental issues. Biomass yields in these areas, however, tend to be substantially lower than on more productive land, a fact that is unlikely to change even as varieties are being developed that are more resistant against dry, salinized or otherwise unfavourable conditions. In consequence, policy frameworks must ensure specific incentives to bring these areas into production as opposed to using environmentally sensitive land. This is particularly relevant in the context of the two major regulatory frameworks recently enacted (US EISA) or currently discussed (EU DRE). Both these frameworks take land use change related GHG emissions into account, and administrative details should ensure that the requirements are rigorously enforced for both domestic and imported biofuels – knowing that the consideration of direct and particularly of indirect land use changes is very difficult to handle.

The objective of energy savings – impacts and cost effectiveness

Reducing fossil energy use is one of the key determinants for the reduction of GHG emissions even though other elements contribute to the latter as discussed in Chapter 1. Generally, energy replacement shares are slightly lower for the various ethanol pathways than GHG improvement rates. For oilseed based biodiesel, the opposite is true due to the importance of nitrous oxide emissions.[76]

As discussed above, substituting gasoline and diesel use in the transport sector by increased shares of ethanol and biodiesel heavily depends on public support. In fact, biodiesel shares in the EU and US diesel fuel consumption would be only marginal (less than half a percent) in the medium term without support while existing support measures should maintain a considerable growth in the EU biodiesel share (while maintaining the existing US biodiesel share). With the new regulations, both countries are set to increase these shares significantly. While ethanol use probably could grow even without support in Brazil and in the US, existing support generates incentives to significantly accelerate this growth.

Given the fossil energy needed in the production of biofuels – both in agriculture and in the processing phase – the share of fossil fuels actually replaced by biofuels is, however, substantially lower than the fuel replacement at the pump. Table 3.2 shows that the EU biodiesel market is the only case where current support in North America and Europe generates a replacement of fossil fuels through biofuels by more than 2%. On average, the existing support results in a medium-term replacement of fossil fuel worth about 0.9% to 1.3% of diesel use and about 0.1 to 0.4% of gasoline use in the three regions considered.[77]

Table 3.2. Impact of current biofuel support on fossil fuel savings through ethanol and biodiesel use, 2013-2017 average

		Corresponding fuel use, total	Biofuel use (million litres)			Fossil fuel replacement						
			Base	No Support	Difference	at pump	net rate, % of at pump		net, absolute		net of total fuel use	
		Million litres (ML) per year					From %	To %	From ML/y	To ML/y	From %	To %
USA	Ethanol	603,652	55,091	49,748	5,343	3,580	7.7%	23.0%	274	823	0.05%	0.14%
	Biodiesel	275,348	1,613	726	888	710	48.3%	66.4%	343	472	0.12%	0.17%
EU	Ethanol	160,013	13,405	8,295	5,110	3,424	23.0%	42.2%	787	1,444	0.49%	0.90%
	Biodiesel	231,408	13,931	1,762	12,169	9,736	48.3%	66.4%	4,702	6,466	2.03%	2.79%
Canada	Ethanol	44,119	2,905	2,206	699	468	15.3%	32.6%	72	153	0.16%	0.35%
	Biodiesel	18,587	521	760	-238	-191	48.3%	66.4%	-92	-127	-0.50%	-0.68%
Total	Ethanol	807,785	71,401	60,249	11,152	7,472	n.a.	n.a.	1,134	2,420	0.14%	0.30%
	Biodiesel	525,343	16,066	3,247	12,819	10,255	n.a.	n.a.	4,953	6,811	0.94%	1.30%

Notes:
"Corresponding fuel use" represents total fuel use in spark-ignition engines and compression-ignition engines in the countries' transport sectors, respectively.
"Fossil fuel replacement at pump" is calculated as the amount of biofuels generated through support policies ("Biofuel use Difference"), corrected for the lower energy content in biofuels compared to their fossil counterparts.
The net replacement rates are the net energy gains to be achieved from biofuels. These rates are calculated from the GHG emission reductions shown in Table 3.1, using the relative differences in fossil fuel and GHG reductions documented in Concawe (2006).
Source: Aglink/Cosimo Simulation Results, calculations by OECD Secretariat.

It needs to be noted, however, that much of the fossil energy used in the production of biofuels – again both in agriculture and during processing – is not in the form of petroleum products, but in the form of coal or natural gas. As at least in some of the countries in question (notably the US and Canada, but also some of the EU Member States) both coal and natural gas are domestically available to a much larger degree than crude oil, the support to biofuels can also be seen as a replacement of (imported) crude oil by (domestic) other fossil energy.

Again, these numbers need to be put in relation to the amount of support generating this additional replacement. The total support figures as used above suggest that the US, the EU and Canada will use some USD 17.5 bn and USD 8 bn per year on average over the 2013-2017 period to support their ethanol

76 Concawe (2006)

77 Again, total biofuel use in these regions obviously has a larger fuel replacement effect, equivalent to about 1.5% to 2% of medium-term diesel use and 1% to 2.4% of gasoline use in the countries considered.

and biodiesel industries, respectively. Using these numbers (and again not considering other objectives for the moment) suggests that the medium-term replacement of fossil fuels by supporting ethanol use would cost between USD 7 and USD 15 per litre of gasoline equivalent on average. The support for biodiesel use seems more efficient in these countries at between USD 1.20 and 1.60 per litre of diesel equivalent.[78]

The picture changes significantly when only the imported crude oil is taken into account. In this case, and making the (simplifying) assumption that no crude oil is used in the production of biofuels, oil imports are replaced by the domestic use of other forms of energy (*e.g.* coal, natural gas) using biofuels as a means to make these energy carriers combustible in transport vehicles, with average replacement costs per unit of crude oil-based fuels significantly lower than the figures shown above at around USD 2.35 per litre of gasoline and USD 0.80 per litre of diesel.[79]

The objective of rural development – impacts on agricultural markets

Clearly expanding first-generation biofuel production is directly linked to increased demand for feedstock commodities. Maize in the US, sugar cane in Brazil and wheat in the EU are the primary feedstocks used in the ethanol industry, whereas rapeseed or canola oil currently constitutes the feedstock the bulk of biodiesel produced, particularly in the EU.

The medium-term effect of current (pre-EISA) biofuel support programs is considerable, but should not be overestimated. Without this support, international cereal prices would be about 5% to 7% lower over the 2013-2017 period than what is projected under current regimes. Prices for vegetable oils are more affected, but due to the opposite effect on oilseed meal prices (both because of decreased oilseed crush and because of lower availability of distillers grains, an important feed by-product from grain-based ethanol production replacing partly feedgrains, partly oilseed meals in the feed ratios) the effect on oilseed prices is relatively modest. Sugar prices would even be slightly higher without biofuel support – higher ethanol prices would create additional incentives for Brazil to increase its fuel production from sugar cane, leaving less cane for sugar production. In addition, a number of developing countries focus on ethanol from molasses – without their programs, incentives to produce molasses and hence sugar would decline.

These effects only partly represent the total impact of biofuels on agricultural markets for two reasons. First, even without biofuel support production of ethanol would grow in a number of countries. Were biofuel production forced to remain at its current level, prices for sugar and maize would be affected much more significantly, with medium-term levels lower by 23% and 13%, respectively. Growth in biofuel markets hence remains one of the major driving forces in agricultural markets and prices and is responsible for a significant share of the change in average historical price levels and those projected for the decade to come, as outlined in the *OECD/FAO Agricultural Outlook 2008-2017*.

Second, however, the price effect on crop markets represents an indicator for revenues of crop producers only. Livestock producers, however, face changes in their feed costs. Here, obviously, the increased biofuel production due to existing support measures drive up prices for feed grains as discussed in the previous paragraph. At the same time, costs for protein feed are lower due to the higher oilseed crush. Finally, the increased availability of distillers' grains at somewhat lower prices provides an

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78 Taking total biofuel use into account, these replacement costs would be lower at USD 0.90 to 2.30 per litre of gasoline equivalent and USD 0.75 to 1.00 per litre of diesel equivalent on average. These values are given here for transparency reasons but should not be read in terms of efficiency of support. Due to the various cross-country effects the different support measures have, a calculation of replacement costs for individual countries is not possible in a meaningful way based on this analysis.

79 USD 0.40 per litre of gasoline and USD 0.60 per litre of diesel if the total biofuel use is considered. These values are given here for transparency reasons but should not be read in terms of efficiency of support.

interesting feed particularly to ruminant meat producers located relatively close to grain-based ethanol plants. This is obviously of particular relevance to the US markets due to the large quantities of distillers grains produced there and the importance of the US beef industry.

These offsetting factors together – increasing feed grain costs caused by grain-based ethanol versus reduced protein costs particularly due to increased biodiesel production – result in little change in average feed costs. Differences result in the different relative quantities of the various feedstuffs fed across countries: without the biofuel support, feed costs would be slightly higher in the US and the EU, but slightly lower in Canada as well as in countries without grain-based ethanol production. In all cases, however, these changes are modest in size, and consequently international prices for meat and dairy products change very little – with the notable exception of butter the medium-term price of which would be about 3% lower without biofuel support due to its substitution with vegetable oils.

Similar results are found for the combined implications of the US Energy Independence and Security Act (EISA) and the EU Directive for Renewable Energy (DRE), at least for the expansion of first-generation biofuels called for therein. Higher overall feed costs due to increased cereal use in ethanol production particularly in the US offset by lower feed costs due to increased oilseed crush for biodiesel leave average feed costs slightly lower than without these programmes.

In contrast, depending on the share of second-generation biofuel feedstocks produced on crop land, increased cellulosic ethanol and BTL production raises prices for all crops and their derived products – in consequence, the production of second-generation biofuels tends to increase overall feed costs by about 2% in most regions, depending to the abovementioned share of feedstock biomass to be produced on crop land and on the degree to which countries are linked to international market prices. In consequence, international pork and beef prices increase by about 1 percent in the medium term – slightly more for pork than for beef as beef production is partly grass based. Income prospects therefore, while positively affected by biofuel policies for crop farmers, on average are largely unaffected on average for livestock producers by existing and new policies on first-generation biofuels; negative effects from support to grain-based ethanol are offset by positive effects from support to oilseed-based biodiesel. Second-generation fuels are reducing margins for meat and dairy producers, although changes are relatively modest in the medium term.

In addition to the effects that can be described by price and income changes, the land use for agricultural production represents an important indicator for rural development as well. The simulations suggest that the support for biofuels results in less area being removed from crop production both in the US and in the EU, in the order of 0.7 million ha and 1.7 million ha in the medium term. A more detailed analysis of the regional effects within the EU and the US would be needed to derive final conclusions on what these area effects would mean, but as less productive areas are likely to be affected more by changed economic incentives than good soils, it seems plausible to expect the existing and new support policies for biofuels to have a positive effect on agricultural activity in remote and marginal areas. While rural development obviously is much more than keeping land in agricultural production and farmers in remote areas, this constitutes an objective for a number of countries. Earlier work by the OECD[80] has shown, though, that targeted measures such as direct payment schemes are more likely to achieve such objectives in an efficient way than support via higher commodity prices, which is the path of biofuel policies affecting land use.

Clearly, the objective of rural development goes beyond the pure effects on agricultural commodity markets even though an expansion of agricultural activity can be seen as an important development in this regard. But the installation of biofuel plants, the development of the rural infrastructure and in particular

80 See e.g. OECD (2002).

the creation of additional jobs in the biofuel production and in related industries is seen by many as an important result of increased biofuel markets. This study cannot analyse the effects on rural employment and livelihood in detail. These effects depend, however, crucially on the way biofuel industries and agriculture are structured and work in the different countries. With the consolidation of biofuel companies in numerous countries and the internationalisation of the industry, both of which have started after the first years of rapid expansion of the sector[81], the share of biofuel plants owned by farmers and other parts of the rural community is declining. Given the required technology for second-generation biofuels[82] and the related levels of necessary investments it seems likely that this development will continue.

Combined assessment of biofuel support policies in view of underlying objectives

The analysis of effects of biofuel support policies, as outlined above, is partial in several dimensions. Most importantly, attributing total policy costs to the different policy objectives individually obviously ignores the fact that, with the same set of policy measures, a range of objectives are addressed at the same time. In principle, it would therefore be necessary to attach values to each of the individual objectives addressed by biofuel support, to quantify the monetary benefits of these policies (including the unintended effects, such as those discussed below) and to compare those to the expenditures for the support. While the future prices for emission rights under the European Trading Scheme may be considered to be a (rough) proxi for the value of GHG avoidance, the value for the reduction in fossil fuel use is more difficult to assess (note that the current prices of fossil energy are not necessarily a good indicator as the support is given over and above existing market incentives which include these prices). Developing rural areas, as well as the reduction of crude oil imports considered as less secure for geopolitical reasons, has values that are even less obvious to quantify. Therefore, and while a full cost-benefit analysis of these measures does not seem possible within the scope of this report, the calculation of support costs per tonne of CO2-equivalent avoided by biofuels, or per unit of fossil energy saved, can only give a partial answer to the efficiency question raised.

More importantly, however, it seems that all these objectives seem likely to be achievable in an efficient way with policy measures that are more targeted to the problems themselves: GHG emissions, scarcity of fossil fuels and undesired fuel imports have their origins much more in the level of fossil energy used than in the lack of alternative supplies. Measures helping to reduce the overall energy use, and particularly that in the transport sector, can achieve the related objectives in a more cost-effective manner and with lower risk of negative side effects. Similarly, targeted measures to prevent depopulation of remote parts of countries and to stimulate non-agricultural economic activities in rural areas are likely to be more efficient to stimulate rural development than measures that tend to raise crop prices.

The risk of food inflation – implications for food prices and food security

The consequences of existing and new biofuel policies on agricultural commodity prices in international markets have been discussed above. Clearly, the increased production of cereal-based ethanol and of oilseed-based biodiesel causes prices for grains and vegetable oils to be higher than what they would be without this support. For livestock products the price effects differs between grain-based ethanol (resulting in somewhat higher meat and dairy prices) and oilseed-based biodiesel (lowering livestock prices) as the former creates an additional net demand for feed products while the latter increases supply of protein feed. The implications for food prices and particularly for food security are, however, much more complex than those for basic commodity prices and can be discussed here only broadly.

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81 For a discussion in developments in the market structure of bioenergy industries see van Vaals, M. (2007): Market Structures and International Investments in Bio-energy Markets. Paper presented at the OECD Workshop on Bioenergy Policy Analysis. Umea, Sweden.

82 See the discussion on biofuel technologies and equipments in Chapter 3 of this report.

Food prices generally are linked to basic commodity prices to a certain degree but also include costs for manufacturing, packaging, retailing etc. These additional costs are more important in high-income industrialized countries than in many developing countries where the share of basic foodstuffs in food expenditure is higher. Furthermore, lower incomes in most cases are linked to higher shares of cereals, roots and tubers as staple food, prices of which tend to increase more strongly due to biofuel expansion, whereas the consumption of meat and dairy products – less affected by biofuels – represents lower shares in low-income populations. In consequence, food expenditure is affected much more strongly for poor population groups than for high-income populations. Given on top of this the high share of food in consumer expenditure for these groups the higher prices for basic food commodities represents a substantial threat to low-income consumers in developing countries. This is even more the case in a situation of high prices for most food commodities, with projections suggesting that prices are unlikely to come down to levels observed in the past.

On the other hand, higher prices due to biofuel expansions as well as the development of adapted biofuel production systems in developing countries can create new income opportunities for rural and agricultural communities. Differentiation has to be made between subsistence and market producers in developing countries – while the former group will be largely unaffected by higher crop prices, net sellers of agricultural produce will be able to benefit from higher prices to the degree they are connected to markets that are integrated with international trading systems. Better income opportunities might also derive for landless workers in developing countries' agriculture given the incentives to intensify agricultural production.

Finally, the production of biofuels in developing countries can in itself generate income to low-income groups. Several developing countries have specifically targeted poor households and small farms in setting up biofuel programmes[83]. As most of these programmes are still in their initial phase, the actual impact of local biofuel projects on the livelihood in these countries will need further analysis.

The risk of environmental degradation – impacts of intensification and land use changes

To give a full picture of the implications of continued support to biofuels, a range of environmental impacts other than the change in GHG emissions needs to be taken into account. Some of these have been analysed in a stylized way using the SAPIM Model.

Support for biofuels and related higher prices in particular for feedstock crops has environmental effects linked to agriculture through at least three different channels: bringing land otherwise not under crops into production; changing the crop structure within the existing arable land; and changing the intensity of variable inputs for individual crops.

Land use changes have been discussed to some degree above. Both existing legislations and new programmes to support biofuel expansion result in higher land use for cereals, oilseeds, sugar crops and, with the emergence of second-generation biofuels, biomass. Apart from related GHG emissions, these changes may have important consequences on biodiversity and natural habitats, but also runoffs of nutrients and pesticides etc. All these variables strongly depend on the occupation of the land before conversion into crop land, which in turn is likely to depend on the endowment of the different countries with alternative land types. The importance of land use changes is recognised by recent regulatory acts in various countries and is not limited to – even though accentuated by – the expansion of biofuel production.

[83] For information about biofuel programmes in different developing countries see FAO (2007): Recent Trends in the Law and Policy of Bioenergy Production, Promotion and Use. FAO Legal Papers Online #69. Rome: September 2007. Accessed in April 2008 from http://www.fao.org/legal/prs-ol/years/2007/list07.htm.

Monitoring and effectively controlling land use changes are therefore key measures in response to environmental pressures in sensitive areas beyond the current debate about biofuel support.

With changes in the crop price structure due to the biofuel use of specific commodities including particularly maize (US, Canada), wheat, rapeseed (EU, Canada), and sugar cane (Brazil), these crops are seen to expand significantly at the cost of other commodities used less in this sector. As discussed briefly above, the environmental performance can differ significantly across crops, and an expansion of wheat and rapeseed at the cost of oats tends to go along with substantially higher fertilizer and herbicide use and runoff, even though for certain environmental variables such as biodiversity there may be positive effects in some cases (see Annex C for SAPIM data for Finland). At the same time, these crops generally are associated with more intensive soil preparation, higher water use and erosion risks. Higher prices for these comparatively intensively produced commodities therefore tend to create or aggravate environmental pressures which, however, heavily depend on the local conditions. Again these problems, while potentially enforced by strong growth in biofuel production, are of more general nature, and existing and future regulatory frameworks need to ensure best agricultural practices to minimize adverse environmental effects from agricultural production. Where sufficient control mechanisms do not exist, changed cropping patterns due to market conditions changed by biofuel support may cause negative effects on the environment.

This also holds for intensification effects within individual cropping systems. Higher prices for crop commodities generally tend to increase optimal input rates of fertilizers, pesticides, irrigation etc. While in some cases this increase may be relatively small, the analysis for Finland exemplified that the aggregate impact on the environment is likely to be detrimental. Existing regulations in numerous countries explicitly take these effects in consideration as it is imperative to carefully monitor and control the environmental effects of agricultural production to avoid longer-term degradation of soils, ground and surface water.

CHAPTER 4. SUMMARY, CONCLUSIONS AND POLICY RECOMMENDATIONS

Production and use of biofuels – mainly ethanol based on cereals and sugar crops, and biodiesel based on vegetable oils such as rapeseed or canola oil – have grown rapidly over the past few years and are expected to further double in the decade to come. The United States and Brazil remain the largest ethanol producers while biodiesel production is particularly relevant in the European Union, but a large number of other countries have begun or are considering promoting biofuel production and use.

Most production chains for biofuels, however, show costs per unit of fuel energy significantly above those for the fossil fuels for which they aim to substitute. Despite the important increase in crude oil prices and hence in the costs for gasoline and fossil diesel, the cost disadvantage of biofuels has widened in the past two years as agricultural commodity prices soared and feedstock costs have increased. In consequence, the sometimes predicted improved economic viability of biofuels with higher crude oil prices so far has not been realised, and biofuels in most countries remain highly dependent on public support.

This support is being provided in a large range of forms affecting all stages of the biofuel production and use chain. Three general groups of measures can be distinguished:

- **Budgetary support** comes either as tax concessions for biofuel producers (refiners), retailers or users, or as direct support to biomass supply, biofuel production capacities, output, blending, specific infrastructure or equipment for biofuel users. All these measures directly affect the public budget either in the form of foregone tax revenues or of additional outlays, and hence create a transfer from taxpayers to biofuel producers.

- **Blending or use mandates** require biofuels to represent a minimum share or quantity in the transport fuel market. While these measures generally are neutral for public budgets, the higher production costs of biofuels result in increased fuel prices for the final consumer who thus makes a transfer to biofuel producers.

- **Trade restrictions**, mainly in the form of import tariffs, protect the less cost-efficient domestic biofuel industry against competition from lower-cost foreign suppliers and result in higher domestic biofuel prices. These measures limit development perspectives for more competitive suppliers from other parts of the world. Trade restrictions generate a transfer from users to producers of biofuels.

A range of reasons are behind the public interest in, and public support for, biofuels. Prioritising these policy objectives is difficult and varies by country, over time and across government ministries. With increased concerns about climate change, however, the reduction of greenhouse gas emissions can safely be counted among the prime reasons to support biofuel production and use. Other objectives relate to fossil energy savings and energy security, other environmental benefits, and rural development.

The environmental performance of current biofuels tends to vary a lot, and for many biofuel chains it is not easy to get a uniform picture of their environmental performance from the many studies that have been published on this matter. Measuring the environmental performance of biofuels requires the consideration of the full life cycle of these products, *i.e.* from agricultural production and its use of various inputs to the conversion of agricultural feedstocks to liquid fuels and to the use of the biofuel in combustion engines. Recently, additional consideration has been given to the effects of land use changes either directly (*i.e.*, where land not used for agricultural production gets converted to produce biofuel feedstocks) or indirectly (*i.e.*, where land not used for agricultural production gets converted to produce agricultural commodities in response to biofuel-driven displacement of commodity production in a different region, country or even continent). While direct land use changes are partially considered in a small number of studies, indirect land use changes generally are not and require the combination of economic modelling with the analysis of carbon stocks in areas affected from land use change.

Generally speaking, and without land use changes taken into account, all studies available agree on fairly positive greenhouse gas reductions for ethanol based on sugar cane of 80% or more compared to the use of fossil gasoline. Rates above 100% are possible due to the energetic utilisation of the bagasse and electricity sales. Reduction of GHG emissions of cereal-based ethanol and of oilseed-based biodiesel compared to their respective fossil counterparts is found to be significantly lower, and studies give much more diverging results due to regional and data differences, but in particular because of methodological differences *e.g.* with respect to the allocation of GHG emissions between the biofuel and by-products. On average, these improvements rates for wheat, corn, sugar beet and rapeseed based biofuels can be taken to be 30%-55%, 10%-30%, 40%-60% and 40%-55%, respectively. On the other hand it seems likely that second-generation biofuels (both cellulose-based ethanol and BTL-diesel) could generate rates of GHG avoidance similar or even above those for sugar cane-based ethanol. Similarly, first-generation biodiesel made from used cooking oils or animal fats could provide significant GHG savings.

The quantitative analysis of biofuel policies and markets suggests that despite the assumed persistence of oil prices around USD 100 per barrel, biofuel production and use remains dependent on public support to a significant degree. This is even more so for biodiesel than for bio-ethanol. A removal of global support to biofuels would substantially affect the (private) profitability of biofuel production and use particularly in those markets where production costs are very high; biodiesel markets in general and bio-ethanol markets in Europe would be much more affected than bio-ethanol in the US. Bio-ethanol production in Brazil is largely competitive with fossil gasoline as long as sugar prices do not increase dramatically above current and projected levels.

There has been much debate recently about the impact of biofuels on global food prices. Indeed, the baseline as presented in the 2008 OECD/FAO Agricultural Outlook projects future agricultural commodity prices to rise significantly above their historical levels. However, if biofuel quantities were to remain at current levels in all countries, rather than growing at their projected rates under current policies, medium-term coarse grain and sugar prices would remain 13% and 23% lower than currently projected, respectively. [84] The baseline does not include the impact of the recent US Energy Improvement and Security Act (EISA) and the proposed EU Directive on Renewable Energies (DRE). As these initiatives will provide further stimulus to biofuels, a scenario in which biofuel production was kept constant at 2007 levels would in reality have even more pronounced price-dampening effects in terms of reducing agricultural commodity prices. This indicates that the growth in the global biofuel industry is responsible for an important share of the increase in projected price levels compared to the historical average. Not all of this price impact of further biofuels growth, though, is a result of current and future biofuel policies.

84 The baseline underlying this analysis (see OECD, 2008a) projects e.g. international prices in nominal terms for wheat, maize and vegetable oils on average over the 2013-2017 period to be about 37%, 49% and 80% above their 2002-2006 averages, respectively. Without further growth in biofuel production, this price rise would be lower at 29%, 30% and 56% above this historical average, respectively. Note that, while it is clear that biofuel growth together with other longer-term factors also contributed to the price hikes observed in 2007 and 2008, these were also caused by a range of short-term disruptions in international commodity markets. The price effects discussed here therefore cannot be translated into estimates regarding the importance of biofuels in current price hikes.

Even if these policies were eliminated, production and use of biofuels would continue to grow somewhat. The basis for that future growth in biofuel production has to some extent been laid by biofuel support in the past (and indeed in the case of Brazil over a long period of time).

Current biofuels support policies, in the form of budgetary support, mandates and tariffs, provide substantial stimulus for further growth of biofuels sectors. The medium-term impacts of biofuel policies in place in mid-2007 on agricultural commodity markets are therefore noticeable, but should also not be overestimated. These policies are estimated to increase average wheat, maize and vegetable oil prices for the 2013-2017 period by about 5%, 7% and 19%, respectively. Prices for sugar and particularly for oilseed meals are actually reduced by these policies – a result of slightly lower production of sugar cane-based ethanol in Brazil and significantly higher biodiesel-related oilseed crush. The new US and EU initiatives are estimated to further increase commodity prices by a similar amount in the medium term. Depending on how much of the feedstock biomass will be produced on land otherwise used for food production, about half of this additional price increase for cereals and oilseeds may come from the second-generation biofuel parts of the programmes.

Apart from the price effects, however, it is important to note that existing support to biofuels – and even more so for the new legislation recently enacted (USA) or currently discussed (EU) might have important implications for global land use and are likely to accelerate the expansion of land under crops particularly in Latin America and large parts of Africa. While on the one hand this may provide additional income opportunities to generally poor rural populations it bears the risk of significant and barely reversible environmental damages. This might include substantial release of greenhouse gases, but also the loss of biodiversity and the risk of runoff of nutrients and pesticides.

Current support policies in the US, the EU and in Canada tend to reduce GHG emissions by much less than expected. An elimination of budgetary support, mandates and tariffs for biofuels under current policies (not considering the new US and EU initiatives) would increase net GHG emissions in 2013-2017 by between 15 and 27 Mt of CO_2-eq. – equivalent to no more than 0.5%-0.8% of the emissions from transport in these countries estimated for 2015. This does not even assume any GHG emissions from land use changes, which depending on the type of land converted may worsen the GHG balance of the biofuels supported. Similarly, fossil fuel use would increase by less than 1% for most of these transport sectors, but by between 2% and 3% in the EU diesel sector. These relatively modest effects come at considerable costs in terms of transfers from taxpayers and consumers of some USD 25 billion on average for the 2013-2017 period, equivalent to between USD 960 and USD 1 700 per tonne CO2-eq. saved, or of between USD 0.80 and USD 7 per litre of fossil fuel not used.

Once available on a commercial scale, second-generation biofuels may help to reduce the competition between food and feed production on the one hand and energy production on the other. This would be the case where biomass comes from wastes such as urban wastes, or where residues from agricultural or forest production (such as straw or forest residues) are used. In this case, competition may even turn into complementary conditions. For most soils, the extraction of a part of the residue biomass is not considered a problem. Care needs to be taken, however, that the supply of organic matter and nutrients to the soil is not overly reduced, and that soil fertility and ability of the soil to provide other ecological services (such as providing fauna habitat, carbon sequestration, water purification etc.) are maintained.

Where biomass for second-generation fuels is produced from dedicated crops, the impact on crop markets and land use strongly depends on the land used. Areas not otherwise used for crop production obviously provide the potential to minimise the area competition, but yields on marginal land tend to be much lower than on land currently in crop use, which may lead farmers to use crop land for biomass production. In addition, special care needs to be taken that sensitive areas are excluded from conversion to crop land or biomass production and that GHG emissions from existing carbon stocks in the soil are minimised. Both these concerns obviously apply independently of whether the converted land is used directly for the production of fuel-biomass or for food and feed commodities.[85]

The analysis also shows that with the increased relevance of biofuels, agricultural markets have become more sensitive to changes in energy prices. Oil prices have always had an impact on production costs in agriculture, and hence on agricultural commodity prices. But with the expansion of biofuels, oil prices additionally impact demand for feedstock commodities – an additional channel for the influence of oil prices on agricultural commodity prices. Some 20-30% of the impact of crude oil prices on agricultural commodity prices can now be attributed to biofuels – a link that has not existed to the same degree in the past.

Based on this analysis, a number of policy-relevant recommendations are offered:

- The objectives behind public support for biofuels are multifold, and so are the potential side effects of biofuel production and use. Tackling these problems requires differentiated and suitable policy approaches. "One measure fits all" is unlikely to give satisfactory results. Instead, a policy mix is needed that depends on countries' priorities and natural conditions. There are also global challenges, such as the increasing concentration of greenhouse gases in the atmosphere, which need internationally concerted action.
- The stated rationale for support to biofuels generally includes the reduction of fossil energy use. A priority focus therefore needs to be given to reducing energy consumption. This is especially important in the transport sector where the growth in energy use and related environmental problems is most pronounced. In particular, this includes the gradual move from highly energy intensive modes of transport to less intensive ones, and improvement in fuel efficiency in all transport sectors. Generally the costs of reducing GHG emissions by saving energy are lower than by switching to alternative energy sources, in particular biofuels. It should also be clear that, while the strong increase of GHG emissions in the transport sector is of particular concern, the costs of emission reductions are often substantially lower in other sectors, *e.g.* by better insulation of buildings.[86]
- To the extent that a reduction of fossil fuel use and GHG emissions is intended to be achieved by means of alternative transport fuels, a clear focus needs to be placed on those alternative fuels that provide high improvement rates. Defining minimum criteria for these variables, as it has been done in the context of the US Energy Independence and Security Act and as foreseen for the new EU Directive on Renewable Energy, is an important step in the right direction. Given the uncertainties on, and the variability of, the performance of different biofuel chains, these minimum criteria should be set at rather ambitious levels and should be tightened over time to ensure the full deployment of technological progress in this rapidly developing area.
- Mitigating climate change is a global concern. Biofuels should, therefore, be produced in those parts of the world where they can make the most effective and efficient contribution to reducing GHG emissions. The improved production of first generation biofuels from tropical and semi-tropical countries should be looked at carefully. Despite the risk of deforestation and the unsustainable (at times, illegal) use of natural resources in those countries, the very high productivity of arable crops and biofuel production in these countries deserves particular

85 For a full analysis of the implications second-generation biofuels could have, longer-term developments need to be taken into account that clearly go beyond the horizon of this study.

86 One may argue that measures to reduce overall energy and transport fuel use may (and in fact do) go in parallel with support to biofuel production and use, and that these measures are not in competition with each other. In reality, however, policy measures are subject to resource constraints (*e.g.* in terms of government budgets, or in terms of consumer charges).

attention. The potential environmental but also socio-economic impacts of biofuels expansion in African, Asian and Latin American regions should be assessed. A policy mix is needed to ensure that biofuel production occurs in an optimal way, thereby minimizing the risks of environmental drawbacks from land-use changes in carbon rich soils.

- Import tariffs on feedstock or biomass to protect domestic production impose an implicit tax on biofuels production by raising input prices. Tariffs are also applied to biofuel imports, distorting resource allocation and imposing a burden on users. In addition to other policy changes discussed here, opening markets for biofuels and related feedstocks would allow for more efficient and lower cost production, and at the same time could improve both environmental outcomes and reduce reliance on fossil fuels. It should, again, be remembered that the global nature of the climate change concern means that it does not matter whether biofuels are produced domestically or in other parts of the world: they should be produced where they can make the most effective and efficient contribution to reducing GHG emissions.
- The problem of land use changes resulting from biofuels expansion, both direct and indirect ones, deserves particular attention. Additional research is needed to better understand the environmental risks related to land use changes. This research needs to be of an interdisciplinary nature to capture the interrelationships between economic and environmental effects. The analysis in this report gives some indication as to the potentially significant magnitude of such problems, but clearly remains at too aggregate a level to provide conclusive answers. It should be clear, however, that the problem of land use changes is not only related to biofuels produced in sensitive areas themselves as indirect land use changes can create quite similar negative effects. Effective monitoring of land use trends and of environmental effects of cropping practices at field level – for energy purposes or not – is important to allow for a better analysis of policy impacts and to minimize their negative implications.
- A clear focus should be on the development of improved and new technologies in the production of biofuels. Both the commercial-scale development of advanced and second-generation biofuel technologies and the exploitation of the improvement potential of different first-generation biofuel chains will need sustained R&D efforts. Biogas from organic waste or other biomass, an option not discussed in detail in this study, exhibits good energy efficiency and is produced in several countries today. The use of waste material for BTL fuels deserves attention as it provides feedstocks at potentially very low or even negative costs. Forest and crop residues could represent another relatively low-cost source of biomass for cellulose-based ethanol or BTL. Second-generation biofuels from dedicated biomass – annual and perennial crops – may offer higher energy yields. In any case, with lower pressures on land use and agricultural markets per unit of biofuels, the production of large quantities may well have an important impact that needs to be carefully monitored. The proposed EU DRE giving a double value to biofuels produced from wastes, residues, non-food cellulosic material, and ligno-cellulosic material is a step in the right direction. In the long run, however, innovations in electrical energy from other renewable sources, hydrogen fuel cells and other technologies, also offer much promise.
- Most biofuel chains clearly contribute to increasing food prices, yet the impact must not be exaggerated. Developments in the biofuels sector may thus contribute to food insecurity for the most vulnerable population groups in developing countries. This unintended impact is significant, relative to the modest benefits and high costs associated with current biofuels policies, and further review of alternative policy approaches is warranted.

ANNEX A. SPECIFICATION OF BIOFUEL MARKETS IN THE AGLINK MODEL

General description of the Aglink Biofuel Modules

Explicit biofuel modules have been developed for four Aglink regions which currently represent some 94% of global fuel ethanol production and 81% of world biodiesel production. These regions include the USA, Canada, the European Union and Brazil. The general module represents the production of biofuels, the production and use of by-products, and the biofuel use for transport. Furthermore, it considers foreign net trade which is balanced by world equilibrium prices on the global level. Separate markets are represented for the two major types of biofuels: ethanol, and biodiesel.

Within both types, the supply side of the model structure distinguishes between first-generation biofuels from agricultural commodities (cereals and sugar crops in the case of ethanol, vegetable oils in the case of biodiesel), second-generation biofuels from dedicated biomass production (*i.e.* cellulose based ethanol from crops such as fast-growing wood or grasses, and synthetic biodiesel from biomass crops), second-generation biofuels from crop residues (in particular from straw), and other biofuels (including fuels derived from, *e.g.*, algae, municipal waste, used frying oil etc.). Among these types, first-generation biofuels from agricultural commodities are modelled fully endogenously in the model, while the production of second-generation and other biofuels enter as exogenous variables. Implications of second-generation biofuels on agricultural markets, however, are reflected through endogenous links to crop area, crop revenues and the feed-livestock links.

Production of biofuels is generally represented by the production capacity and the capacity use rate. Production capacity growth is modelled as a function of the net revenues from biofuel production, *i.e.* the difference between the output value (biofuel price and any subsidies directly linked to biofuel production) and the production costs per unit of biofuels (net of the value of by-products). Capacity growth generally responds to these net revenues with several time lags, given the time required to plan and construct new facilities. The capacity use rate, in contrast, depends on net revenues not considering capital fixed costs, and responds to market signals without lags. Generally, biofuel production is modelled separately for individual feedstocks and added up for the total production of each type where several feedstocks are used for a type of biofuels in a given country.

Second-generation biofuel production from dedicated biomass production partly competes with the production of commodities for other usages. In consequence, the area required is estimated from the production quantity, and a share of this area is deduced from the land used for agricultural market commodities. In contrast, second-generation biofuel production from crop residues complements the production of agricultural commodities. The added value therefore is taken into consideration in the calculation of the crop revenues and hence in the crop allocation system.

By-products from biofuel production form an integral element in the production costs. At the same time, however, some of these by-products go back into the agricultural production process. In particular, distillers grains, a by-product from grain based ethanol production, deserves special attention. As the market for distillers grains are not represented in Aglink (and a full market representation for distillers grains is not intended), a market price for distillers grains is derived from the prices for oilmeals and coarse grains, the two main feed products distillers grains can replace in the feed ratios. For the two main livestock types – ruminant and non-ruminant livestock – the feed cost index then is modified to take into account the different use of distillers' grains in the ratios for these animals. Finally, the feed use of coarse grains and of oilmeals is adjusted for the use of distillers' grains.

The demand for ethanol generally is split up into three components: an additive component where ethanol replaces other (chemical) additives in the blend with gasoline; a low-level blend (or fuel extender) component where the lower energy content in ethanol compared to gasoline is offset by superior other qualities (such as the higher oxygen content and octane number); and ethanol as a neat fuel consumed by specifically modified vehicles, so-called flex-fuel vehicles. These three demand components are explicitly taken into account in estimating the ethanol demand, all considering the price ratio between ethanol and fossil gasoline as the driving variable. Biodiesel use, in contrast, is modelled as a simple equation depending on the price ratio between biodiesel and fossil diesel. Where biofuel mandates exist and data are available, these are modeled as minimum biofuel shares, and the link between biofuel demand and the price ratio is cut unless demand exceeds the specified minimum. [87]

Finally, markets are cleared by a net trade position residual from domestic supply and demand, with the domestic prices for biofuels depending on their respective world prices taking into account import tariffs in the net import situation. World prices for ethanol and biodiesel clear the markets on the global level.

The following sections describe the modelling approach in greater detail.

Biofuel production

First-generation biofuels from agricultural commodities

Net Cost estimates (NC) for alternative biofuels as modelled in the 2006 report, but separate for different technologies / feedstocks, based on actual prices without support linked to biofuels. Where relevant, revenues for by-products should explicitly account for Distillers Dried Grains (DDG):

$$\begin{aligned} NC_{r,t}^{i,j} &= \alpha_{r,t}^{i,j} * PP_{r,t}^{i} \\ &+ \beta 0_{r,t}^{i,j} + \beta_{r,t}^{i,j} * XP_{t}^{OIL} * XR_{r,t} \\ &+ \gamma 0_{r,t}^{i,j} + \gamma 1_{r,t}^{i,j} \\ &- \delta_{r,t}^{i,j,DDG} * WP_{r,t}^{DDG} - \delta_{r,t}^{i,j,EF} * PP_{r,t}^{CG} - \delta_{r,t}^{i,j,PF} * PP_{r,t}^{OM} - \delta_{r,t}^{i,j,OBP} \end{aligned}$$

with

i	commodity index for feedstocks
j	product index for biofuels
r	region index
t	time index
NC	net costs of biofuel production (average, LC/hl)
PP,WP	domestic prices (producer, wholesale, LC/hl)
XP^{OIL}	world crude oil price (USD/barrel)
XR	exchange rate (LC/USD)
DDG	distillers dried grains
EF	energy-rich feed
PF	protein-rich feed

87 For the EU, mandated biofuel use and consumption in Member States without mandates but providing tax concessions are modelled separately to account for the regional differences within the Union.

CG	coarse grains
OM	oilseed meals
OBP	other by-products
α,β,δ	coefficients
$\gamma 0$	capital cost element in production costs
$\gamma 1$	other exogenous elements in production costs (operation and maintenance costs)

In addition, Variable Net Costs (VNC) exclude fixed costs, *i.e.* capital costs which are not relevant for production decision based on existing capacities:

$$
\begin{aligned}
VNC_{r,t}^{i,j} = {} & \alpha_{r,t}^{i,j} * PP_{r,t}^{i} \\
& + \beta 0_{r,t}^{i,j} + \beta_{r,t}^{i,j} * XP_{t}^{OIL} * XR_{r,t} \\
& + \gamma 1_{r,t}^{i,j} \\
& - \delta_{r,t}^{i,j,DDG} * WP_{r,t}^{DDG} - \delta_{r,t}^{i,j,EF} * PP_{r,t}^{CG} - \delta_{r,t}^{i,j,PF} * PP_{r,t}^{OM} - \delta_{r,t}^{i,j,OBP}
\end{aligned}
$$

with

VNC	variable net costs (average, LC/hl)

Growth in Production Capacities (QPC) should depend on returns over investments expected for biofuel production facilities, which would be modelled as returns (including support directly related to production quantities) net of net production costs, relative to capital costs. Given that it takes about 18 months to set up a biofuel plant, and that expected returns largely depend on past returns, the lag structure needs to take into account t-1 till t-4. As it is possible to speed up the building process to some degree, the current period also enters but the coefficient would be small. The size of the parameters for different lags are, therefore, likely to be ordered as follows: t-2 > t-1 > t-3 > t-4 > t. We assume that biofuel producers are aware of policy changes and take them into account immediately. Market developments are seen as volatile, however, and hence more than just the available year's data are taken into account in investment decisions.

The US could provide sufficient data to back a general capacity building function, but US data need to be scaled by appropriate measures to make them comparable to other countries88. A proxy for total industry investment, corrected for foreign direct investment, needs to be identified.

$$
QPC_{r,t}^{i,j} = \begin{pmatrix}
QPC_{r,t-1}^{i,j} + \chi_{r}^{i,j} \\
+ \phi 0_{r}^{i,j} * \left(WP_{r,t}^{j} + DP_{r,t}^{i,j} - NC_{r,t}^{i,j}\right) / \gamma 0_{r,t}^{i,j} * INV_{r,t} / GDPD_{r,t} \\
+ \phi 1_{r}^{i,j} * \left(WP_{r,t-1}^{j} + DP_{r,t-1}^{i,j} - NC_{r,t-1}^{i,j}\right) / \gamma 0_{r,t-1}^{i,j} * INV_{r,t-1} / GDPD_{r,t-1} \\
+ \phi 2_{r}^{i,j} * \left(WP_{r,t-2}^{j} + DP_{r,t-2}^{i,j} - NC_{r,t-2}^{i,j}\right) / \gamma 0_{r,t-2}^{i,j} * INV_{r,t-2} / GDPD_{r,t-2} \\
+ \phi 3_{r}^{i,j} * \left(WP_{r,t-3}^{j} + DP_{r,t-3}^{i,j} - NC_{r,t-3}^{i,j}\right) / \gamma 0_{r,t-3}^{i,j} * INV_{r,t-3} / GDPD_{r,t-3} \\
+ \phi 4_{r}^{i,j} * \left(WP_{r,t-4}^{j} + DP_{r,t-4}^{i,j} - NC_{r,t-4}^{i,j}\right) / \gamma 0_{r,t-4}^{i,j} * INV_{r,t-4} / GDPD_{r,t-4}
\end{pmatrix} * R.QPC_{r,t}^{i,j}
$$

with

88 The comparability to other countries obviously depends on a range of factors, including, among others, similarities in capital markets and investor behaviour. While scaling by the proxy for industry investment account for such factors to some degree, other adjustments may be necessary in the parameterisation of the capacity functions of other countries.

QPC biofuel production capacity
DP direct support for biofuel output
INV available investment capital in country r (including foreign direct investment)
GDPD GDP deflator

Capacity Use Rates (QPR) will depend on variable net costs rather than total net costs as explanatory variable:

$$QPR_{r,t}^{j} = QPRL_{r,t}^{j} + \frac{QPRU_{r,t}^{j} - QPRL_{r,t}^{j}}{1 + LOGA_{r}^{j} * e^{\left(LOGB_{r}^{j} * \left(VNC_{r,t}^{i,j} / \left(WP_{r,t}^{j} + DP_{r,t}^{i,j}\right)\right)\right)}}$$

with
QPR biofuel production capacity use rate
QPRL, QPRU lower and upper bounds for the use rate
LOGA, LOGB parameters in logistic function

Total production of biofuels will be discussed after the modelling of second-generation fuels.

Second-generation biofuels

Second-generation biofuels can be categorised in three groups, depending on their links to agricultural production. Ethanol and Fischer-Tropsch fuels can be produced either from dedicated crops produced in agricultural production systems (*e.g.* from grasses such as miscanthus or switchgrass or from fast-growing trees such as willow, poplar or eucalyptus), from agricultural residues (*e.g.* straw, stover etc.), or from biomass not produced in agricultural systems (*e.g.* from forestry, household waste, algae etc.). Consistent with their different relationships to agricultural production systems, these three groups of biofuels need to be modelled differently in the agricultural market model Aglink-Cosimo. Given that data on second-generation biofuels (production, feedstocks, costs etc.) are even more difficult to find than on first-generation fuels, the representation of any kind of second-generation biofuels will need to be more ad hoc and of a less sophisticated nature.[89]

Second-generation biofuels from dedicated crops

Dedicated crops that provide cellulose for ethanol, or biomass for Fischer-Tropsch synthesis fuels, are often, but not always, produced on land that alternatively could be used for food or feed production, and hence have the potential to negatively impact the supply of those products. Given the uncertainties related to second-generation biofuel technologies and economic, the less than perfect data situation, and the wide range of production and conversion technologies, we propose a relatively simple model representation where ethanol and Fischer-Tropsch-Diesel are produced directly on the agricultural land, *i.e.* the feedstock production, transport, and conversion to biofuels are combined in a single, synthetic production process. While this simplification obviously ignores the large variability of production and conversion systems, and assumes that the biomass produced in one country is also converted in that same country, it allows for a relatively generic specification in the model that, in addition, could also include other forms of bioenergy sourced from agricultural biomass and/or production of first-generation biofuels from feedstocks not covered by the model (*e.g.* jatropha) in a similar manner. Depending on the country in question, parameters would differ and thus allow for a differentiation according to the relative advantages of individual production systems in alternative regions.

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89 Technical parameters on second-generation biofuel production were obtained from Dornburg *et al.*

Net production costs consist of biomass costs, transport costs and conversion costs, and thus can be represented as follows:

$$NC_{r,t}^{i,j} = \alpha_{r,t}^{i,j} * \left(PC_{r,t}^{i} + TC_{r,t}^{i}\right) + CC_{r,t}^{i,j}$$

Where:

$$PC_{r,t}^{i} = MC_{r,t}^{i} + LC_{r,t}^{i} + LR_{r,t} \big/ YLD_{r,t}^{i}$$

$$TC_{r,t}^{i} = TC_{r,t}^{i,spec} + \sum_{ts}\left(TC_{r,t,ts}^{i,lc} + dist_{r,t,ts}^{i} * \left(TC_{r,t,ts}^{i,ec} + TC_{r,t,ts}^{i,mc}\right)\right)$$

$$CC_{r,t}^{i,j} = \gamma 0_{r,t}^{i,j} + \gamma 1_{r,t}^{i,j} - \delta_{r,t}^{i,j,OBP}$$

With:

NC	net production costs (average, LC/hl)
α	conversion rate, t of biomass per hl of biofuel
PC	biomass production costs (LC/t)
TC	biomass transport costs (LC/t)
CC	conversion costs (LC/hl)
MC	capital and management costs of biomass production (LC/t)
LC	labour costs of biomass production (LC/t)
LR	land rent (LC/ha)
YLD	biomass yield (t/ha)
TC^{spec}	specific costs of pelletising (LC/t)
TC^{lc}	loading/unloading costs (LC/t)
dist	distance, km
TC^{ec}	energy costs of transportation (LC/km/t)
TC^{mc}	management costs of transportation (LC/km/t)
$\gamma 0$	capital cost element in production costs
$\gamma 1$	other exogenous elements in production costs (operation and maintenance costs)
δ^{OBP}	value of by-products not specified
i	biomass type (BME: biomass for cellulosic ethanol; BMD: biomass for FT-Diesel)

In the equation above, land rents are obviously crucial for the interaction between second-generation biofuel production and agricultural markets. In future it will therefore be important to endogenise this cost element.

The total area required for the biomass production related to exogenously assumed biofuel quantities[90] is calculated from exogenously assumed yields – in the case of multiple biofuels produced from a given type of biomass these are summed up:

$$AH_{r,t}^{i} = \sum_{j}\left(\alpha_{r,t}^{i,j} * QP_{r,t}^{i,j}\right) \Big/ YLD_{r,t}^{i}$$

As biomass for biofuel production often is produced on land not suitable for food production, the food area required is calculated from an exogenous share which depends on the type of biomass produced. This factor also depends on policy decisions, such as the permission to use set-aside land:

$$AH_{r,t}^{i,eff} = AH_{r,t}^{i} * AH_{r,t}^{i,shr}$$

[90] Estimating the supply response of second-generation biofuels remains a major research topic that needs to be addressed once commercial data on such an industry becomes available.

The area used for individual food crops is then reduced proportionally to the alternative use for biomass production[91]:

$$AH_{r,t}^{c} = \exp\left(const + f\left(RH_{r,t-1}^{c'}\right) + \varepsilon_{r}^{c,BM} * \ln\left(\frac{\left(\sum_{c'} AH_{r,t-1}^{c'} + \sum_{i} AH_{r,t-1}^{i,eff} - \sum_{i} AH_{r,t}^{i,eff} \right)}{\sum_{c'} AH_{r,t-1}^{c'} + \sum_{i} AH_{r,t-1}^{i,eff}} \right) \right)$$

With

c crop index [WT, CG, OS]

The elasticities with respect to the effective biomass area reflect the different displacement of different crops by biomass for energy. They need to be calibrated such that, in the base period:

$$\frac{\sum_{c} \varepsilon_{r}^{c,BM} * AH_{r}^{c}}{\sum_{c} AH_{r}^{c}} = 1$$

Second-generation biofuels from agricultural residues

Agricultural residues such as straw or stover can be used for the production of ethanol via gasification, or of other biofuels via the Fischer-Tropsch synthesis. Its modelling has to be different to that of biofuels from dedicated biomass production as, in general, no or little additional costs occur with the production of that biomass (there may be additional costs associated with harvesting). In contrast, transport costs may be higher than in the case of dedicated biomass production given the lower yield per hectare and hence the larger distances on average between the production area and the processing plant.

However, a minimum price for the agricultural residues can be defined by the opportunity costs of the biomass, such as its fertiliser value, possibly adjusted by the difference between the costs for harvesting the biomass and those for applying the fertiliser. Opportunity costs may higher if other uses prevail, such as animal bedding, which in a large scale is more common in developing countries than in developed countries today. Finally, the opportunity costs would increase significantly as the removal of organic matter would threaten the fertility of the soil, which in general can be assumed not to be relevant as long as at least two thirds of the residues remain on the farm[92,93].

An additional difference to biofuels from dedicated biomass production is that, as a co-product, the revenues for agricultural residues will increase incentives for the production of the main product.

In consequence, costs of biofuel production are calculated on the basis of the fertiliser value of the crop residues – this value should increase once the threshold value of one third of the residues is used for biofuels:

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91 Note that for simplicity, the crop areas of the preceding period are used to estimate the share of biomass land

92 It is assumed that per tonne of cereals one tonne of residues are produced on average. This assumption obviously abstracts from important differences across cereal types and regions.

93 Note that, considering the stylised model of equally sized circles around biofuel plants, only a maximum of some 90% ($\pi / \sqrt{12}$) can be used for second-generation biofuels from agricultural residues. In consequence, the one third of the residues maximum available for biofuels would reduce to 30%. Given the approximative character of all these calculations we abstract from this detail.

$$NC_{r,t}^{RES,j} = \alpha_{r,t}^{RES,j} * \left(FV_{r,t}^{RES} + SV_{r,t}^{RES} + TC_{r,t}^{RES}\right) + CC_{r,t}^{RES,j}$$

$$SV_{r,t}^{RES} = \begin{bmatrix} \text{if } \dfrac{BF_{r,t}^{RES}}{QP_{r,t}^{WT} + QP_{r,t}^{CG}} < \dfrac{1}{3} \text{ then } 0 \\ \text{else } SF_{r,t} * \left(\dfrac{3 * BF_{r,t}^{RES}}{QP_{r,t}^{WT} + QP_{r,t}^{CG}} - 1\right)^2 \end{bmatrix}$$

$$CC_{r,t}^{RES,j} = \gamma 0_{r,t}^{RES,j} + \gamma 1_{r,t}^{RES,j} - \delta_{r,t}^{RES,j,OBP}$$

Where:
RES crop residues
FV fertiliser value per tonne of crop residues
SV soil quality value of crop residues
SF soil quality factor
BF^{RES} use of crop residues for biofuels
QP^{WT}, QP^{CG} production quantity of wheat, coarse grains

The soil quality factor will need to be set to a rather large number to prevent the residue use from becoming significantly greater than a third of residue production.

As farmers will engage in harvesting the additional biomass only if the additional revenues exceed the fertiliser value, it is assumed that the profit margin, per tonne of biomass, is split equally between the agricultural producer and the processing plant. In consequence, 50% of the margin add value to the cereal production on farm[94], with its total effect again depending on the exogenously assumed production of the biofuels:

$$RV_{r,t}^{RES,j} = 0.5 * \left(WP_{r,t}^{j} + DP_{r,t}^{RES,j} - NC_{r,t}^{RES,j}\right) / \alpha_{r,t}^{RES,j}$$

$$BF_{r,t}^{RES,j} = QP_{r,t}^{RES,j} / \alpha_{r,t}^{RES,j}$$

With:
RV residue value per tonne of biomass
$BF^{RES,j}$ use of crop residues for biofuel type j

Both residue value and the residue quantity used for biofuel production can be aggregated across biofuel types:

$$BF_{r,t}^{RES} = \sum_j BF_{r,t}^{RES,j}$$

$$RV_{r,t}^{RES} = \sum_j BF_{r,t}^{RES,j} * RV_{r,t}^{RES,j} \Big/ BF_{r,t}^{RES}$$

Assuming that the share of residues used for biofuel production is the same across cereal types, net returns of crop production can be expressed as

94 Note that in principle, residues from other crops can be used for biofuel production as well. This principle possibility is ignored at this point, as research under way suggests that cellulose-based ethanol from crop residues would be mostly from straw and stover.

$$RH^{i}_{r,t} = f\left(YLD^{i}_{r}, PP^{i}_{r,t} + RV^{RES}_{r,t} * \frac{BF^{RES}_{r,t}}{AH^{WT}_{r,t} + AH^{CG}_{r,t}} \right)$$

Biofuels from non-agricultural sources

Biofuels from non-agricultural sources include biodiesel from used cooking oils, synthesis fuels (BTL) from municipal wastes or algae, ethanol from forest residues and wood chips, and a number of other forms of organic matter which have no or very little link to agricultural production. While their production processes do not affect agriculture directly, this additional supply impacts on biofuel markets and can hence have indirect effects on biofuel prices and agricultural biomass use. Biofuels from non-agricultural sources are therefore included exogenously in the model for completeness reasons.

$$QP^{nonag,j}_{r,t} = \overline{QP^{nonag,j}_{r,t}}$$

Total biofuel production

Total production of any type of biofuel (ethanol and biodiesel) will be the simple sum of the individual quantities by feedstock, with first-generation fuels depending on the Capacity Use Rate and the Capacity itself. As the Capacity is for the end year point in time, the average of t and t-1 should be taken into account:

$$QP^{j}_{r,t} = \sum_{i} QPS^{i,j}_{r,t} * \left(QPC^{i,j}_{r,t} + QPC^{i,j}_{r,t-1} \right) / 2 + QP^{BMj,j}_{r,t} + QP^{RES,j}_{r,t} + QP^{nonag,j}_{r,t}$$

By-products

A number of by-products are relevant in the context of biofuel markets. While oilseed meals are directly linked to the oilseed crush (with the vegetable oil being used partly for the production of biodiesel) and have been covered by the model before, distillers' grains, either in liquid or in dried form (DDG) deserve particular attention. DDG is co-produced with cereal-based ethanol in the dry milling process and increasingly important for animal feed markets in North America and Europe.

Price of DDG

Based on US data, the link between the price of DDG and the prices of maize and soyabean meal is not that strong: using wholesale prices for DDG and soyabean meal, market prices for maize and annual data from 1981 to 2006 shows an R^2 of only 57%. The quantity of maize used for the production of ethanol – as a proxi for the DDG quantity produced – proves to be an important explanatory variable: the following equation has an R^2 of 85%:

$$WP^{USA}_{DDG,t} = 204.8869 + 0.384775 * WP^{USA}_{SBM,t} + 0.545321 * MP^{USA}_{MA,t} - 22.09 * \ln\left(MABF^{USA}_{t} \right)$$

(t-stats: 5.52 5.16 4.21 6.12)

with:

WP wholesale price, USD per metric tonne
MP market price, USD per metric tonne
DDG distillers dried grains, Laurenceburg, Indiana, marketing year data (Oct-Sep)

SBM soyabean meal, 44% protein[95], Central Illinois, marketing year data (Oct-Sep)
MA maize, No. 2 Yellow, Central Illinois, marketing year data (Sep-Aug)
MABF maize use in biofuel (ethanol) production, 1 000 metric tonnes, marketing year data (Sep-Aug)

Using the quantity of maize used for the production of ethanol divided by the ruminant production, or alternatively the beef production, yields only lower coefficients of determination at around 83%[96].

Feed-cost index

The model already contains share estimates for feed used in the ruminant versus non-ruminant sectors. DDG, however, would be shared differently as ruminants can digest this feed at higher ratios than non-ruminants. In addition, DDG replaces coarse grains and oil meals at different rates across livestock types. These replacement quantities would be calculated as follows:

$$FE_{DDG}^{RU,CG} = QP_{DDG} * SHR_{DDG}^{RU} * SHR_{DDG}^{RU,CG}$$

with

$FE_{DDG}^{RU,CG}$ quantity of DDG replacing coarse grains in ruminant livestock feed ratio
SHR_{DDG}^{RU} share of domestic DDG feed to ruminant livestock
$SHR_{DDG}^{RU,CG}$ amount of coarse grains replaced by one tonne of DDG in ruminant feed ratio

In consequence, a – lower – blended coarse grains price for feed in ruminant livestock can be derived from the CG and DDG prices and the respective feed quantities:

$$PP_{CG}^{bld,RU} = \frac{PP_{CG} * \left(\left(FE_{CG} + FE_{DDG}^{RU,CG} + FE_{DDG}^{NR,CG}\right) * PSH^{RU} - FE_{DDG}^{RU,CG}\right) + WP_{DDG} * FE_{DDG}^{RU,CG}}{\left(\left(FE_{CG} + FE_{DDG}^{RU,CG} + FE_{DDG}^{NR,CG}\right) * PSH^{RU} - FE_{DDG}^{RU,CG}\right) + FE_{DDG}^{RU,CG}}$$

with:

PSH^{RU} share coefficient denoting the share of ruminant livestock in feed demand; = $1-PSH^{NR}$

Similar equations would define blended feed prices for coarse grains in non-ruminants, and for oil meals in both ruminants and non-ruminants.

For the purpose of defining livestock-type specific feed-cost indices, blended feed quantities would be defined in a straight-forward manner:

$$FE_{CG}^{bld,RU} = \left(FE_{CG} + FE_{DDG}^{RU,CG} + FE_{DDG}^{NR,CG}\right) * PSH^{RU}$$

For wheat, the blended feed use is simply calculated from the livestock type share alone, while the blended price remains unchanged:

$$FE_{WT}^{bld,RU} = FE_{WT} * PSH^{RU}$$

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95 Prices for soyabean meal 44% protein (SBM44) are reported until 2001/02 only. Data for 2002/03 to 2006/07 are calculated from prices reported for soyabean meal, 49-50% protein, Illinois points (SBM50), based on the equation SBM44 = -3.43176 [3.07] + 0.953679 [184.5] * SBM50 (estimated on monthly data, $R^2 = 99.34\%$, t-statistics in brackets).

96 Given that statistics on DDG markets are less readily available for other countries, however, the ruminant production in the base period can help to scale the US equation to those of other countries.

$$PP_{WT}^{bld,RU} = PP_{WT}$$

With that, the two feed cost indices can be constructed in line with the original one:

$$\ln\left(FECI_{RU}\right) = \frac{\sum_{i=WT,CG,OM} FE_i^{bld,RU} * PP_i^{bld,RU} * \ln\left(PP_i^{bld,RU}\right)}{\sum_{i=WT,CG,OM} FE_i^{bld,RU} * PP_i^{bld,RU}}$$

Feed use of coarse grains, oil meals

Feed use of individual commodities is modelled on a national level rather than for individual livestock types. An average blended feed price is there calculated using the livestock type shares:

$$PP_i^{bld} = PSH^{NR} * PP_i^{bld,NR} + \left(1 - PSH^{NR}\right) * PP_i^{bld,RU}$$

As the blended coarse grains price declines with increased ddg use, the comparative profitability of feeding the coarse grain – ddg blend increases relative to other feed commodities, notably wheat:

$$\ln\left(FE_{CG} + FE_{DDG}\right) = f\left(\left(PP_i^{bld} \middle| i = WT, CG, OM\right), \left(QP_i \middle| i = RU, NR\right)\right)$$

Where

$$FE_{DDG} = QP_{DDG} * \left(SHR_{DDG}^{RU} * SHR_{DDG}^{RU,CG} + SHR_{DDG}^{NR} * SHR_{DDG}^{NR,CG}\right)$$

Effects of increased ethanol and DDG production on feed use

In consequence, an increased production of grain-based ethanol has the following implications for cereal feed use:

- With higher demand for cereals, prices increase, and feed use of cereals declines
- Higher feed costs also reduce livestock production, so again feed use of cereals declines
- Increased availability of DDG, marketed at a discount compared to feed cereals, reduces the price of the CG-DDG blend, which partly offsets the higher feed costs and hence the reduction in livestock production.
- As the blended price of CG-DDG declines, the feed share of the CG-DDG blend increases at the cost of other feed commodities, particularly wheat.

Biofuel demand

Price ratios driving biofuel demand

Generally speaking, demand of biofuels, expressed as a share of total demand for a given fuel type (*i.e.* gasoline and ethanol, or diesel and biodiesel) responds to the market price of the biofuel relative to the price of its fossil competitor. All prices are calculated at the retail level and denominated in LC/hl of fuel, *i.e.* no conversion is being made to account for the different energy content of the fuels.

Ethanol

Given the properties of ethanol relative to gasoline, the use of fuel ethanol can be separated in three broad groups: Ethanol as an additive, ethanol in low-level blends, and ethanol as a neat fuel. The use of biofuels generally responds to changes in the market retail prices rather than wholesale prices – the difference being explained by any remaining fuel taxes and the retail margin:

$$RP_{r,t}^{j} = WP_{r,t}^{j} + TAX_{r,t}^{j} + MAR_{r,t}^{j}$$

Ethanol as an additive

If used as an additive, ethanol does not compete with gasoline, but with other additives, to the degree these are (legally and economically) available. In the simplest form, if no alternative additive is available, the ethanol use is a fixed share of the total gasoline use. In other cases, ethanol will replace other additives as its price approaches or falls below the price of the substitute. As most additives are crude oil based products, this trigger price will be related to that of gasoline. As in the case of low-level blends and neat fuels, we use a sine function to mirror the substitution process:

$$QCS_{ET}^{ADD} = \begin{Bmatrix} \text{if no alternative}: BLD_{ET,GAS}^{ADD,GE} \\ \text{else if } \mathrm{PR}_{\mathrm{ET,Gas}} > MP_{Add}^{spl} + MP_{Add}^{spr} : 0 \\ \text{else if } \mathrm{PR}_{\mathrm{ET,Gas}} < MP_{Add}^{spl} - MP_{Add}^{spr} : BLD_{ET,GAS}^{ADD,GE} \\ \text{else}: \left(\sin\left(\frac{\left(\mathrm{PR}_{\mathrm{ET,Gas}} - MP_{Add}^{spl} + 2 * MP_{Add}^{spr}\right) * \pi}{2 * MP_{Add}^{spr}} \right) \Big/ 2 + 0.5 \right) * BLD_{ET,GAS}^{ADD,GE} \end{Bmatrix}$$

with:
QCS_{ET}^{ADD} Ethanol share in gasoline as an additive, energy equivalent
$BLD_{ET,GAS}^{ADD,GE}$ Additive share in gasoline
PR_{ET}^{Gas} Price ratio between ethanol and gasoline, market prices
MP_{Add}^{spl} Price of additive relative to gasoline
MP_{Add}^{spr} Price spread in which substitution for additives occurs

Ethanol in low-level blends

Low-level blends are characterised by the fact that the lower energy content of ethanol compared to gasoline is offset by the higher octane number and oxygen content. In some cases, ethanol may additionally be preferred by consumers for non-economic reasons (*i.e.* due to its image of a "green" fuel). In consequence, ethanol competes with gasoline without a price discount (and in fact may even receive a premium over gasoline on a per litre basis). As the share of ethanol increases, the lower energy content becomes more relevant, resulting in a price discount on a per litre basis. In contrast to the case of high-level blends or neat fuels, the decision about low-level blends is taken by the fuel blenders and distributors rather than the final consumers. In any case, mandatory blending requirements represent a lower bound for the amount of ethanol sold in low-level blends.

As above, we use sine functions to represent the substitution process:

$$QCS_{ET}^{LBLD} = \max\left(QCS_{ET}^{OBL} - QCS_{ET}^{ADD}, \left\{ \begin{array}{l} \text{if } PR_{ET,Gas} > MP_{ET}^{prem} : 0 \\ \text{else if } PR_{ET,Gas} < ERAT_{ET,Gas} : QCS_{ET}^{Limit} - QCS_{ET}^{ADD} \\ \text{else} : \dfrac{\sin\left(\dfrac{\left(2 * PR_{ET,Gas} + MP_{ET}^{prem} - 3 * ERAT_{ET,Gas}\right) * \pi}{2 * \left(MP_{ET}^{prem} - ERAT_{ET,Gas}\right)} \right) + 1}{2} * \left(QCS_{ET}^{Limit} - QCS_{ET}^{ADD}\right) \end{array} \right\} \right)$$

with:
QCS_{ET}^{LBLD} Ethanol share in gasoline in a low level blend, energy equivalent
QCS_{ET}^{OBL} Blending obligation, share, energy equivalent
MP_{ET}^{prem} Maximum premium price of ethanol in low-level blends, relative to gasoline price, ratio
$ERAT_{ET,Gas}$ Energy content ratio between ethanol and gasoline
QCS_{ET}^{Limit} Upper limit for ethanol in low-level blends, share

Ethanol as neat fuel

Ethanol as a neat fuel can be consumed only by holders of dedicated cars. Today, the share of vehicles that can run on ethanol only is minuscule. Instead, flexi-fuel vehicles (FFVs) provide the option to be run on pure ethanol (or any high-level blend offered by the industry), pure gasoline (or any low-level blend offered as the standard blend) or any mixture of the two. It can be expected that, after some adjustments, FFV-owners will chose ethanol (or the high-level blend) whenever its price falls below the gasoline price adjusted for the lower energy content. If the ethanol price is higher than that, FFV-owners will chose gasoline (or the low-level blend). A substitution process can be expected to take place at ethanol prices close to that level, which, again, is represented by sine functions:

$$QCS_{ET}^{FFV} = \left\{ \begin{array}{l} \text{if } PR_{ET,Gas} > ERAT_{ET,Gas} + MP_{FFV}^{spr} : 0 \\ \text{else if } PR_{ET,Gas} < ERAT_{ET,Gas} - MP_{FFV}^{spr} : 1 \\ \text{else} : \left(\sin\left(\dfrac{\left(PR_{ET,Gas} - ERAT_{ET,Gas} + 2 * MP_{FFV}^{spr}\right) * \pi}{2 * MP_{FFV}^{spr}} \right) \Big/ 2 + 0.5 \right) \end{array} \right\}$$
$$* FFV * QCS_{ET}^{HBLD} * \left(1 - QCS_{ET}^{ADD} - QCS_{ET}^{LBLD}\right)$$

with:
QCS_{ET}^{FFV} Ethanol used as neat fuel by flexi-fuel vehicles, share, energy equivalent
MP_{FFV}^{spr} Price spread in which substitution for FFVs occurs
FFV Share of FFVs in total vehicle fleet – changing exogenously over time
QCS_{ET}^{HBLD} Ethanol share in high-level blends used in FFVs, energy equivalent

It should be noted that many of these variables – and in particular the share of FFVs in the total vehicle fleet, are likely to evolve over time – a time index has been omitted for readability, but needs to be taken into account in the modelling.

Non-fuel use of ethanol

Ethanol is a product that is widely used in a large number of sectors, most notably in beverages and the chemical and pharmaceutical industry. As a priori ethanol for fuel use cannot be differentiated from ethanol destined for other utilisations, the latter need to be taken into account as well.

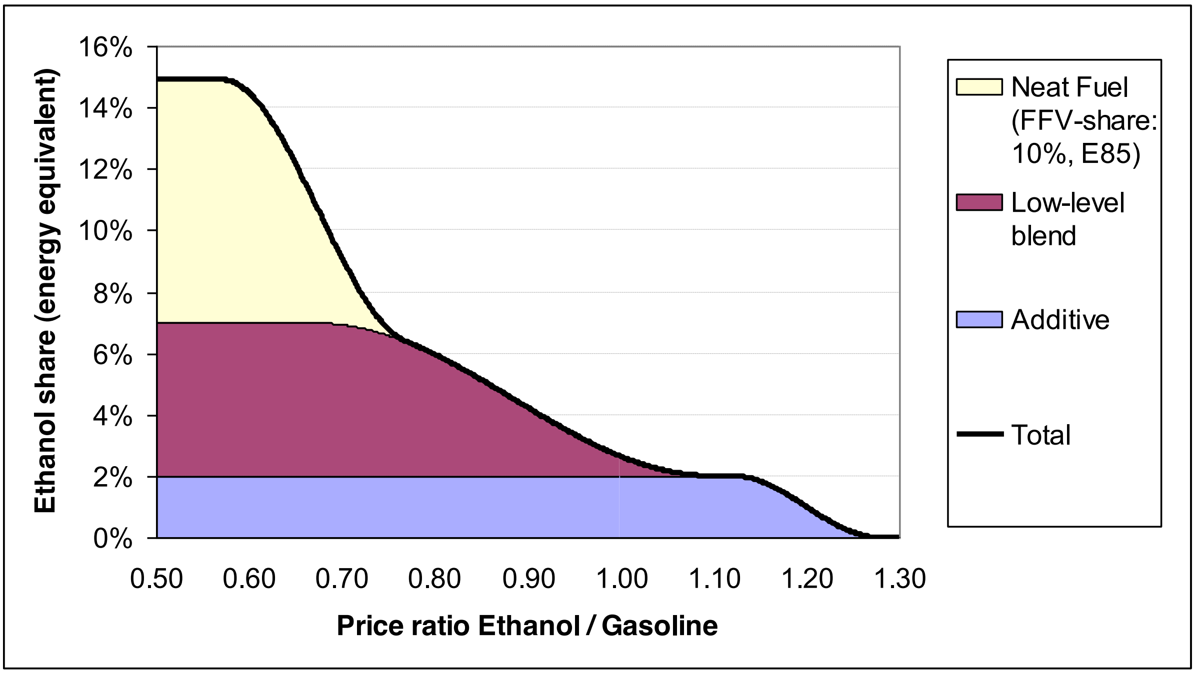
$$QC_{ET}^{other} = \overline{QC_{ET}^{other}}$$

Total ethanol use

The total share of ethanol in spark-ingestion vehicles is the simple sum of the three elements presented above:

$$QCS_{ET} = QCS_{ET}^{ADD} + QCS_{ET}^{LBLD} + QCS_{ET}^{FFV}$$

Annex Figure A.1. Graphical representation of ethanol demand as a function of the ethanol-gasoline price ratio at a given point in time



As these shares are on an energy basis, the ethanol quantity used can be calculated based on the total use of gasoline and equivalent fuels, and the relative energy content of ethanol:

$$QC_{ET} = \frac{QCS_{ET} * QC_{Gas}}{ERAT_{ET,Gas}} + QC_{ET}^{other}$$

Biodiesel

There is no such thing as FFVs using biodiesel, and there also is not any 'additive' effect of low-level blends in fossil diesel fuel. However, most vehicles can stand only low-level blends without modification. Within those bands, vehicle owners largely rely on the blending industries' decisions on the biodiesel blending rates – which themselves depend on legal conditions and standards. In consequence, a simpler representation of biodiesel use is deployed:

$$\ln\left(QCS_{BD}\right) = \max\left\{\begin{array}{l} QCS_{BD}^{OBL}, \\ const + \sum_{n=0}^{2} \alpha^{n} * \ln\left(PR_{BD,Die}^{t-n}\right) + \beta * \ln(t) \end{array}\right\}$$

Again, the absolute consumption of biodiesel would be based on the total use of diesel fuels:

$$QC_{BD} = \frac{QCS_{BD} * QC_{Die}}{ERAT_{BD,Die}}$$

Trade

The model for biofuels represents net trade only and abstracts from stock changes:

$$NT_{r,t}^{j} = QP_{r,t}^{j} - QC_{r,t}^{j}$$

Domestic price determination

Domestic prices are assumed to be determined by the world price[97], including, in the case of (substantial) imports, any tariffs the country may impose. To represent the shift of the price regime in a the case of a change of net trade position, a logistic function is used that describes the price differential between domestic and world price relative to the applied tariff (including natural barriers if any) as a function of the net trade position relative to the sum of domestic production and consumption as follows:

$$\frac{WP_{r,t}^{j} - XP_{t}^{j}}{XP_{t}^{j} * TARA_{t}^{j} + TARS_{t}^{j}} = \frac{a}{1 + b * c^{-\left(\frac{NT_{r,t}^{j}}{QP_{r,t}^{j} + QC_{r,t}^{j}}\right)}}$$

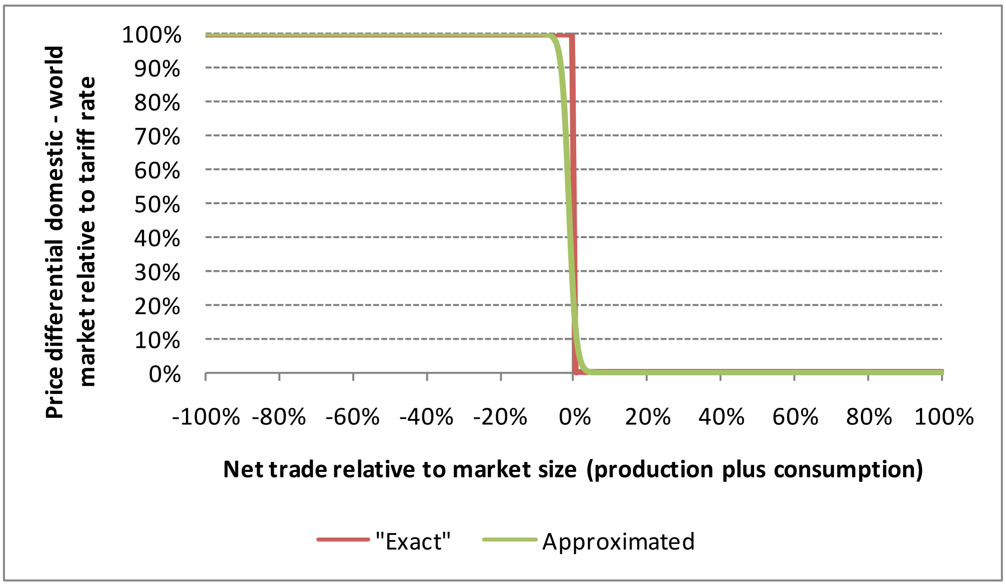
The parameters are chosen such that

- The range of the resulting relative price differentials is [0 - 1], *i.e.*, a=1
- The function is strictly monotonously decreasing with falling net imports and growing net exports, *i.e.*, 0<c<1
- The range of net trade positions with the relative price differential being significantly different from both 0 and 1 is narrow, *i.e.*, c is small in value
- The function is squewed to the left to avoid import tariffs from being relevant in (substantially) net exporting countries, *i.e.*, b>1

97 The exception is the Canadian ethanol price which is linked directly to the US price given the close link between US producing and Canadian demand areas.

Parameter values used in this analysis are b = 4 and c = 10^{-45}. While the choice of these parameters is somewhat arbitrary, the values represent a compromise between the need to closely approximate the real relationship (i.e., strong pass-through of the tariff in a net import situation, no pass-through in a net export situation) on the one hand, and of ensuring smooth and plausible model responses on the other. With these parameters, the relationship between a country's net trade position and its price link to world markets can be represented by the following figure:

Annex Figure A.2. Graphical representation of the price link between domestic and world markets as a function of the net trade position

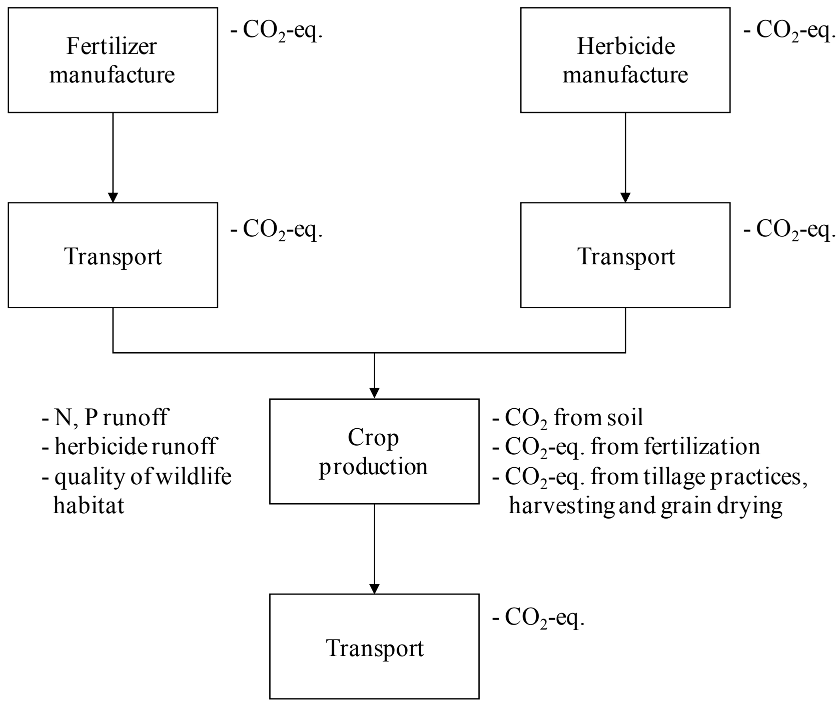


Global price determination

A unique world price for each type of biofuels is used to clear international markets, *i.e.* to ensure that global net exports equal global net imports:

$$XP_t^j = XP_t^j + \sum_r NT_{r,t}^j$$

Annex Figure B.1. Environmental effects covered in the empirical application



ANNEX C. ECONOMIC AND ENVIRONMENTAL OUTCOMES UNDER ALTERNATIVE SCENARIOS IN THE SAPIM APPLICATION

Annex Table C1. Baseline, Policy scenario 1, and Policy scenario 2: land allocation, input use intensity, production and farmers' profits

Crop	Land area, ha	Nitrogen use, kg/ha	Herbicide use, kg/ha	Production, kg/ha	Total production, kg	Profits, EUR/ha	Total profits, EUR
				Baseline			
RCG	2	33.7	-	4 609	9 219	221	443
Oats	4	72.4	0.82	3 112	12 449	226	903
Wheat	21	130.2	0.91	3 397	71 327	263	5 513
Rape	15	93.8	0.96	1 749	26 229	333	4 997
Total	42	-	-	-	119 224	-	11 856
				Policy scenario 1 – Removal of biofuel support			
Oats	27	74.5	0.84	3 302	89 167	240	6 473
Rape	15	89.2	0.94	1 728	25 914	298	4 468
Total	42	-	-	-	115 081	-	10 941
				Policy scenario 2 – New biofuel legislation EU and US			
RCG	4	39.6	-	4 913	19 651	236	944
Wheat	16	130.3	0.91	3 293	52 686	263	4 201
Rape	22	93.7	0.97	1 686	37 098	348	7 649
Total	42	-	-	-	109 435	-	12 794

In the Baseline, Reed Canary Grass (RCG) is cultivated in the 2 lowest productivity parcels with low nitrogen use intensity. The low nitrogen application rate is due to the high unit transportation costs and thus a low effective output price for RCG. However, support payments and low production costs make it profitable to cultivate RCG in the lowest productivity parcels. Oats cultivation takes place in the second lowest land productivities with low nitrogen and herbicide use intensities.

In comparison to the Baseline Policy scenario 1 shifts the land allocation towards oats and rape. Land allocated to RCG and wheat in the Baseline is now allocated to oats. Due to changes in price ratios and land allocation, the average nitrogen and herbicide application rate decreases for rape, while for oats both of these increases slightly, since oats cultivation shifts to higher land productivities. Relative to the Baseline, total profits slightly decrease.

The Policy scenario 2 makes RCG cultivation profitable and lowest productivity land is allocated to it. This policy scenario increases the profitability of wheat and rape cultivation, and thus these two crops exhaust the remaining land available for production. The fertilizer use intensity increases clearly for reed canary grass and slightly for wheat relative to the Baseline, whereas it slightly decreases for rape.

Annex Table C2. Baseline, Policy scenario 1, and Policy scenario 2: total nitrogen runoff, total phosphorus runoff, total herbicide runoff, total CO2-eq emissions and habitat index value

Crop	N-runoff, kg	P-runoff, kg	Herbicide runoff, kg	CO_2-eq emissions, tons	Habitat index value
			Baseline		
RCG	9	1	-	1	
Oats	24	5	0.04	11	
Wheat	192	27	0.22	70	
Rape	106	19	0.17	43	
Total	332	52	0.42	125	138.6
			Policy scenario 1 – Removal of biofuel support		
Oats	167	33	0.26	74	
Rape	103	19	0.16	42	
Total	270	52	0.42	116	135.7
			Policy scenario 2 – New EU and US biofuel legislation		
RCG	19	3	-	2	
Wheat	146	21	0.17	53	
Rape	156	28	0.24	63	
Total	321	52	0.41	118	158.1

Annex Table C2 presents total environmental effects under Baseline, Policy scenario 1 and Policy scenario 2. Relative to the Baseline the total nitrogen runoff decreases in Policy scenario 1. This result is mainly driven by land allocation shift from fertilizer intensive wheat to the less fertilizer intensive crops oats and rape. Decreased input use intensity in Policy scenario 1 also results in a decrease of the total CO_2-eq emissions when compared to the Baseline. The habitat index value decreases in Policy scenario 1 relative to the Baseline, because of less diversified land use and no allocation of land to RCG which is almost twice as valuable habitat to butterflies than cereals.

In the Policy scenario 2, higher application rates of fertilizer and herbicide inputs for wheat and rape is offset by increased allocation of land to RCG, which is cultivated with low fertilizer intensity and no herbicide use. Decrease in CO_2-eq emissions is mainly driven by an increase in the land allocated to RCG, which has low fertilizer intensity and thus low CO_2-eq emissions. Moreover, unlike other crops RCG sequesters carbon and thus its CO_2 emissions for soil are negative.

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