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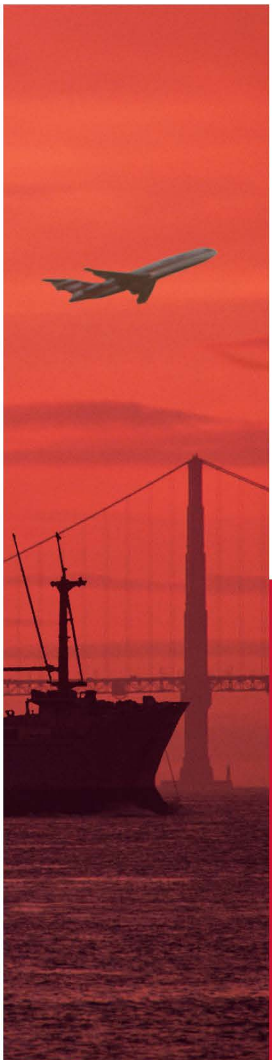
STRUCTURAL AND COHESION POLICIES



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THE IMPACT OF BIOFUELS ON TRANSPORT AND THE ENVIRONMENT, AND THEIR CONNECTION WITH AGRICULTURAL DEVELOPMENT IN EUROPE

STUDY

EN

2015

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This document was requested by the European Parliament's Committee on Transport and Tourism.

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Abstract

The use of biofuels in transport is being promoted as a means of tackling climate change, diversifying energy sources and securing energy supply. Biofuels production also provides new options for using agricultural crops. However, it also gives rise to environmental, social and economic concerns which are the subject of intense debate worldwide.

This study provides a detailed overview of biofuels production and consumption and of related policies worldwide. It also contains comprehensive analysis and discussion of key aspects affecting the overall sustainability of biofuels. These include, in particular, their impact on agricultural markets, emissions from indirect land-use change, and greenhouse gas emissions.

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LIST OF ACRONYMS

AEZ	Agro-ecological zone
AFOLU	Agriculture, forestry and other land use
AGLINK-COSIMO	Worldwide Agribusiness Linkage Program + Commodity Simulation MOdel
ASTM	American Society for Testing and Materials
BAU	Business as usual
BC	Black carbon
BSFC	Brake-specific fuel consumption
BTL	Biomass-to-liquid
CAP	Common agricultural policy
CAPRI	Common Agricultural Policy Regional Impact Analysis
CARD	Center for Agricultural and Rural Development
CEN	Comité Européen de Normalisation
CGE	Computational general equilibrium
CHP	Combined heat and power
CN	Carbon-neutrality factor
CNG	Compressed natural gas
CO	Carbon monoxide
CONCAWE	Oil companies' European association for environment, health and safety in refining and distribution
CRF	Cumulative radiative forcing
CSAM	Cropland spatial allocation model
DDGS	Dried distiller's grains with solubles
DICI	Direct-injection compression ignition
DISI	Direct-injection spark ignition
EBB	European Biodiesel Board
EC	European Commission
ECOFYS	Consulting company for energy and climate policy issues

EEA	European Environment Agency
EFSOS	European Forest Sector Outlook Study
EIA	US Energy Information Administration
EPA	US Environmental Protection Agency
ESIM	European simulation model
ET	Evapotranspiration
EU	European Union
EUCAR	European Council for Automotive Research
EurObserv'ER	Observatoire des Energies Renouvelables
FAME	Fatty acid methyl ether
FAO	Food and Agriculture Organization
FAPRI	Food and Agricultural Policy Research Institute
FFSM	French forest sector model
FQD	Fuel Quality Directive
GHG	Greenhouse gas
GSI	Global Subsidies Initiative
GtL	Gas-to-liquid
GTAP	Global Trade Analysis Project
GWP	Global warming potential
HC	Hydrocarbons
HDV	Heavy-duty vehicles
HEFA	Hydroprocessed esters and fatty acids
HVO	Hydrotreated vegetable oil
HWP	Harvested wood products
IA	Impact assessment
ICCT	International Council on Clean Transportation
IEA	International Energy Agency
IFA	International Fertilizer Industry Association
IFPRI	Food Policy Research Institute
iFUC	Indirect fuel-use change

IIASA	International Institute for Applied Systems Analysis
IISD	International Institute for Sustainable Development
ILUC	Indirect land-use change
IMF	International Monetary Fund
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
ISO	International Organization for Standardization
IWUC	Indirect wood-use change
JEC	JRC-EUCAR-CONCAWE research collaboration
JRC	Joint Research Centre
LCA	Life-cycle analysis / life-cycle assessment
LCFS	California Low-Carbon Fuel Standard
LEI	Agricultural Economics Research Institute
LHV	Lower heating value
LUC	Land-use change
LULUCF	Land use, land-use change and forestry
MIRAGE	Modeling International Relationships in Applied General Equilibrium
NAI	Net annual increment
NEDC	New European Driving Cycle
NMVOC	Non-methane volatile organic compound
N_2O	Nitrous oxide
NOx	Nitrogen oxides
NREAP	National Renewable Energy Action Plan
OC	Organic carbon
OECD	Organisation for Economic Cooperation and Development
OEM	Original equipment manufacturer
PE	Partial equilibrium (models)

PM	Particulate matter
RED	Renewable Energy Directive
REN21	Renewable Energy Policy Network for the 21st Century
RFS2	US Renewable Fuel Standard 2
SFM	Sustainable forest management
SOC	Soil organic carbon
SRC	Short-rotation coppice
SRF	Short-rotation forestry
TTW	Tank-to-wheels
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USDA	US Department of Agriculture Foreign Agricultural Service
WF	Water footprint
WTT	Well-to-tank
WTW	Well-to-wheels (also well-to-wheel)

GLOSSARY

Aerosol — A collection of airborne solid or liquid particles (excluding pure water) with a typical size of between 0.01 and 10 micrometres (µm) and which resides in the atmosphere for several hours at least. Aerosols may be of either natural or anthropogenic origin. They can influence climate in two ways: directly by scattering and absorbing radiation, and indirectly by acting as condensation nuclei for cloud formation or modifying the optical properties and lifetime of clouds.

Afforestation — The direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding and/or the human-induced promotion of natural seed sources.

Albedo — The fraction of solar radiation reflected by a surface or object, often expressed as a percentage. Snow-covered surfaces have a high albedo; the albedo of soils ranges from high to low; vegetation-covered surfaces and oceans have a low albedo. The Earth's albedo varies, mainly on account of variations in cloudiness, snow, ice, leaf area and land-cover changes.

Atmospheric carbon parity point — Net zero carbon emissions to the atmosphere, achieved by balancing the amount of carbon released with an equivalent amount sequestered or offset in comparison with the reference scenario.

Biodiesel — A methyl ester produced from vegetable or animal oil, of diesel quality, to be used as biofuel.

Biodiversity — Biological diversity (or biodiversity) is defined in the UN Convention on Biological Diversity as 'the variability among living organisms from all sources, including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems'.

Bioethanol — Ethanol production from the fermentation of plants rich in sugar/starch, to be used as biofuel.

Biofuel — Liquid or gaseous fuel used for transport and produced from biomass.

Biomass — Organic material above or below ground, and living or dead (trees, crops, grasses, tree litter, roots, etc.). Biomass includes the pool definition for above- and below-ground biomass.

Black carbon — Operationally defined aerosol species based on measurement of light absorption and chemical reactivity and/or thermal stability. Black carbon is formed through the incomplete combustion of fossil fuels, biofuel and biomass, and is emitted in both anthropogenic and naturally occurring soot. It consists of pure carbon in several linked forms. Black carbon warms the Earth by absorbing heat in the atmosphere and by reducing albedo, the ability to reflect sunlight, when deposited on snow and ice.

Boreal forest	Forest that grows in regions of the northern hemisphere with cold temperatures. Made up mostly of cold-tolerant coniferous species such as spruce and fir.
Branch	A division of a stem, or a secondary stem arising from the main stem of a plant.
Brake-specific fuel consumption (BSFC)	BSFC is a measure of the fuel efficiency of a shaft reciprocating engine. It is the rate of fuel consumption divided by the power produced. For this reason, it may also be thought of as power-specific fuel consumption. BSFC allows direct comparison of the fuel efficiency of different reciprocating engines.
Business-as-usual scenario	The scenario that examines the consequences of continuing current trends as regards population, the economy, technology and human behaviour.
Captive fleet	A collection of vehicles with clearly defined boundaries, typically owned or managed by one party.
Carbon debt	The initial emission of biogenic CO_2 from forest bioenergy when it is higher than the level of emissions from a reference fossil system. This is called a 'debt' because the forest regrowth combined with the continuous substitution of fossil fuels may, in time, repay the 'debt'.
Carbon dioxide equivalent	Carbon dioxide equivalent describes how much global warming a given type and amount of greenhouse gas may cause, taking the functionally equivalent amount or concentration of carbon dioxide (CO_2) as the reference.
Carbon neutrality	Net zero carbon emissions to the atmosphere during the energy production process (excluding infrastructure).
Carbon pool	A component of the climate system which has the capacity to store, accumulate or release carbon. Oceans, soils, the atmosphere and forests are examples of carbon pools.
Carbon sequestration parity	The moment in time when the bioenergy system has displaced the same amount of fossil carbon as would be absorbed in the forest if this were not harvested for bioenergy.
Carbon stock	The absolute quantity of carbon held within a carbon pool at a specified time.
CEN (Comité Européen de Normalisation)	The CEN is a major provider of European Standards and technical specifications. It is the only European organisation recognised under Directive 98/34/EC for the planning, drafting and adoption of European Standards in all areas of economic activity, with the exception of electrotechnology (covered by the European Committee for Electrotechnical Standardisation (CENELEC)) and telecommunications (covered by the European Telecommunications Standards Institute (ETSI)).

Climate change	The long-term fluctuations in temperature, precipitation, wind and all other aspects of the Earth's climate. Also defined by the United Nations Convention on Climate Change as 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'.
Cropland	Land under temporary agricultural crops.
C-segment car	C-segment is a car size classification defined by the European Commission as the third-smallest segment (after the A- and B-segments) in the European market. It corresponds approximately to the compact car segment in North America and the small family car in British English terminology. The C-segment is confined to hatchback, sedan and station wagon configurations.
Dead wood	Includes all non-living woody biomass not contained in the litter, either standing, lying on the ground or in the soil. Dead wood includes wood lying on the surface, dead roots and stumps, larger than or equal to 10 cm in diameter.
Deforestation	Direct human-induced conversion of forested land to non-forested land.
Degraded land	Land that has experienced the long-term loss of ecosystem function and services as a result of disturbances from which the system cannot recover unaided.
Direct wood	Supply of wood extracted directly from forests (traditional firewood, forest chips, forest logging residues, complementary fellings).
Disturbances	Events including wildfires, insect and disease infestations, extreme weather events and geological disturbances, but not harvesting.
'E' and 'B' blends	Ethanol fuel blends have 'E' numbers which describe the (maximum) percentage of ethanol fuel in the mixture by volume: for example, E85 is 85 % anhydrous ethanol and 15 % petrol. Similarly, biodiesel fuel blends have 'B' numbers which describe the maximum percentage of biodiesel in the mixture by volume: for example, B7 is up to 7 % fatty acid methyl ether (FAME) and at least 93 % fossil diesel fuel.
Economic models	Theoretical constructs which represent economic processes by a set of variables and the relationships between them.
Elementary carbon (C)	Element number 6 in the periodic table of elements. Atomic number = 6. Atomic weight = 12.011 g/mol.
Elementary nitrogen (N)	Element number 7 in the periodic table of elements. Atomic number = 7. Atomic weight = 14.007 g/mol.
Elementary phosphorus (P)	Element number 15 in the periodic table of elements. Atomic number = 15. Atomic weight = 30.973762 g/mol.

Elementary potassium (K)	Element number 19 in the periodic table of elements. Atomic number = 19. Atomic weight = 39.0983 g/mol.
Evapotranspiration	Water lost to the atmosphere from the ground surface, evaporation from the capillary fringe of the groundwater table, and the transpiration of groundwater by plants whose roots tap the capillary fringe of the groundwater table.
Fellings	Volume (over bark) of all trees, living or dead, above a diameter of 10 cm at breast height, felled annually in forests or on wooded land. Includes the volume of all felled trees, regardless of whether or not they are removed.
Flash point	The flash point of a volatile material is the lowest temperature at which it can vaporise to form an ignitable mixture in air. At the flash point, the vapour may cease to burn when the source of ignition is removed. The flash point is often used as a descriptive characteristic of liquid fuel, and is also used to help characterise the fire hazards of liquids.
Forest	Land with tree crown cover (or equivalent stocking level) of more than 10 % and an area of more than 0.5 hectares (ha). The trees should be able to reach a minimum height of 5 metres (m) at maturity in situ. May consist either of closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground, or of open forest formations with a continuous vegetation cover in which tree crown cover exceeds 10 %. Young natural stands and all plantations established for forestry purposes which have yet to reach a crown density of 10 % or a tree height of 5 m are included under ‘forest’, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention or natural causes but are expected to revert to forest.
Forest management	Any activity resulting from a system applicable to a forest and aimed at improving any ecological, economic or social function of the forest.
Forest residues	Tops, branches, bark, defective stems and other portions of trees produced as a by-product during the normal course of harvesting stemwood as sawlogs, pulpwood or cordwood.
Forestry	Management of forestland.
Fossil fuel parity	The moment in time (payback time) when the bioenergy system and the fossil reference have emitted the same amount of carbon.
Fossil fuels	Coal, oil, petroleum and natural gas and other hydrocarbons are called fossil fuels because they are made of fossilised, carbon-rich plant and animal remains. These remains were buried in sediments and compressed over geological time, slowly being converted to fuel.
Fuel ladder	A firefighting term for live or dead vegetation that allows a fire to climb up from the landscape or forest floor into the tree canopy. Common fuel ladders include tall grasses, shrubs and tree branches, both living and dead.

Fungible fuels	Fuels with equivalent physical and chemical properties to be distributed mingled, and with sufficient specifications and quality control that they can, within a given type, be substituted for one another.
Gallon	1 US gallon = 3.785 litres.
Global warming	An average increase in the temperature of the atmosphere near the Earth's surface and in the troposphere, which can contribute to changes in global climate patterns. Global warming can result from a variety of causes, both natural and human-induced. In common usage, 'global warming' often refers to the warming that can occur as a result of increased emissions of greenhouse gases from human activities.
Global warming potential (GWP)	The global warming potential of a gas or particle is an estimate of the total contribution to global warming over a particular period of time that results from the emission of one unit of that gas or particle relative to one unit of the reference gas, carbon dioxide, which is assigned a value of 1.
Grassland	Land used on a permanent basis to grow herbaceous forage crops, either cultivated or growing wild.
Greenhouse gas (GHG)	Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, by the atmosphere itself and by clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. There are also a number of entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances dealt with under the Montreal Protocol. In addition to CO_2, N_2O and CH_4, the Kyoto Protocol deals with the greenhouse gases sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).
Habitat	The place or type of site where an organism or population naturally occurs.
Harvest residues	The wood usually left in the forest after stem wood removal, such as stem tops, stumps, branches, foliage and roots.
HEFA	Hydroprocessed or hydrotreated esters and fatty acids. Any form of native fat or oil can be used to produce biofuels from hydroprocessed esters and fatty acids. Apart from waste fats left over from the food industry, vegetable oils and fatty acids from oil and fat refining processes are the most common forms used.
HVO	Hydrotreated vegetable oil. Defined in the EU Renewable Energy Directive as vegetable oil thermochemically treated with hydrogen.
Hydrotreatment	Hydrotreatment is a process that produces a higher-quality fuel by removing sulphur and nitrogen compounds and saturating aromatics and other unsaturated compounds.

ILUC (indirect land-use change)
The indirect land-use change impact of biofuels, also known as ILUC, relates to the unintended consequences of releasing more carbon emissions as a result of land-use changes around the world induced by the expansion of croplands for ethanol or biodiesel production in response to the increased global demand for biofuels.

Indirect wood
Supply of processed or unprocessed wood co-products and post-consumer recycled wood.

Invasive species
Invasive species are animals and plants that are introduced accidentally or deliberately into a natural environment where they are not normally found, with serious negative consequences for their new environment.

IPCC (Intergovernmental Panel on Climate Change)
A scientific body under the auspices of the United Nations. It reviews and assesses the most recent scientific, technical and socio-economic information produced worldwide which is relevant to the understanding of climate change. It publishes the Guidelines for National Greenhouse Gas Inventories.

Joule (J)
An International System of Units (SI) unit commonly used to describe a quantity of energy or the energy content of a fuel. A joule represents the work done (or energy expended) by applying a force equal to 1 newton for a distance of 1 metre. A common unit used to describe the energy content of a fuel is the MJ (megajoule), which is equal to 1 x 106 J.

Kilowatt hour (kWh)
A non-SI unit of measurement used to describe energy. It is commonly used for electrical applications, since 1 kWh is the energy consumption of a device requiring an input of 1000 W of electric power for one hour. One kWh is equivalent to 3.6 MJ.

Land use, land-use change and forestry (LULUCF)
Land use refers to the total of arrangements, activities and inputs undertaken in a certain land cover type (a set of human actions). The term is also used in the sense of the social and economic purposes for which land is managed (e.g. grazing, timber extraction and conservation). Land-use change refers to a change in the use or management of land by humans, which may lead to a change in land cover. Land cover and land-use change may have an impact on the surface albedo, evapotranspiration, sources and sinks of greenhouse gases, or other properties of the climate system and may thus give rise to radiative forcing and/or other climate impacts, locally or globally.

Life-cycle assessment (LCA)
Set of methodologies aimed at quantifying the environmental impact of a product. The LCA approach takes into consideration not only energy and greenhouse gas emissions (as in the well-to-wheel approach) but also the consumption of all the materials needed for the production process (including power plants and refineries as well as the materials needed to manufacture vehicles and vehicle components), water requirements, emissions of many kinds of pollutant (liquid and gaseous), etc.

Logging residues The wood usually left in the forest after typical forestry logging operations such as stem wood removal. These residues generally include slash from final fellings (branches, needles, leaves, stumps, roots and low-grade and decayed wood tops), slash and small trees from thinning and clearing operations, and unmerchantable stemwood.

Lower heating value (LHV) Also known as net calorific value or lower calorific value. It represents the amount of heat released during combustion of a specified amount of fuel in specific conditions. A distinction can be made between HHV (high heating value, also known as gross calorific value or gross heating value) and LHV depending on whether the water produced during the combustion process (physical moisture and moisture produced during oxidation) is condensed to liquid form (HHV) or released as vapour (LHV). The methodology for measuring the calorific values of solid biofuels is defined by European Standard EN 14918:2009. The definition of LHV used in the Renewable Energy Directive for co-products allocation is: LHV (wet) = LHV (dry) (1 – moisture content) – 2.441 * (moisture content).

Marginal land Land on which cost-effective food and feed production is not possible under given site conditions and cultivation techniques.

Net annual increment Average annual volume of gross increment over the given reference period minus mortality of all trees to a specified minimum diameter at breast height.

New European Driving Cycle (NEDC) The New European Driving Cycle, or 'type approval driving cycle', is a driving cycle designed to assess the emission levels of car engines and fuel economy in passenger cars (excluding light trucks and commercial vehicles). The NEDC is supposed to represent typical car usage in Europe. It consists of four repeated ECE-15 urban driving cycles (UDCs) and an extra-urban driving cycle (EUDC).

Nitrous oxide Chemical compound with the formula N_2O. Nitrous oxide generates NO (nitric oxide) on reaction with oxygen atoms, and this NO in turn reacts with ozone. It is also a major greenhouse gas and air pollutant. It has about 300 times more impact per unit mass (global warming potential) than carbon dioxide, according to the IPCC.

Nutrient Chemical compound that an organism needs in order to live and grow, or a substance used in an organism's metabolism which must be taken in from its environment.

Ozone Ozone (O_3), the triatomic form of oxygen, is a gaseous atmospheric constituent. In the troposphere, it is created both naturally and by photochemical reactions involving gases which result from human activities (it is a primary component of photochemical smog). Tropospheric ozone acts as a greenhouse gas. In the stratosphere, ozone is created by the interaction between solar ultraviolet radiation and molecular oxygen (O_2). Stratospheric ozone plays a decisive role in the stratospheric radiative balance.

Peatland	Peatlands are terrestrial carbon pools. Tropical peatlands contribute to terrestrial carbon storage in both their aboveground biomass and the underlying thick deposits of peat.
Pathway	A chain of processes necessary for the production of a fuel (e.g. for a biofuel: cultivation of crop, land use, transport of crop, processing into biofuel, transport and distribution of biofuel to end-users).
Protection grade(s)	Provisions indicating the vehicle model year from which engines are to be compatible with higher blends or – conversely – indicating the vehicle model year up to which lower blending grades must be made available at the pump.
Radiative forcing	The change in the net vertical irradiance (expressed in watts per square metre) at the tropopause owing to an internal change or a change in the external forcing of the climate system, such as a change in the concentration of carbon dioxide or the output of the sun.
Salvage logging wood	Damaged, dying or dead trees removed on account of injurious agents, such as wind or ice storms or the spread of invasive epidemic forest pathogens, insects and diseases or other epidemic biological risks to the forest, but not on account of competition.
Sequestration	The process of increasing the carbon content of a carbon pool other than the atmosphere.
Set-aside land	Land that farmers do not use for agricultural production.
Short-rotation forestry	The silvicultural practice through which high-density, sustainable plantations of fast-growing tree species produce woody biomass on agricultural land or on fertile but degraded forest land.
Sink	The rate of build-up of CO_2 in the atmosphere can be reduced by taking advantage of the fact that carbon can accumulate in vegetation and soils in terrestrial ecosystems. Any process, activity or mechanism which removes a greenhouse gas from the atmosphere is referred to as a 'sink'.
Soil carbon	Organic carbon in mineral and organic soils (including peat) to a specified depth.
Soil organic carbon (SOC)	The amount of elemental carbon contained in soil organic matter (SOM). It is generally agreed that this amounts to about 58 % of SOM.
Soil organic matter (SOM)	A mixture of materials including particulate organics, humus and charcoal, together with living microbial biomass and fine plant roots.
Stemwood	Wood from the main part of a tree, but not from the branches, stump or roots. Does not include salvage logging wood, thinnings, landscape care wood or other similar sources of wood that can be considered to be by-products/residues.
Stumps	The part of a plant, and especially of a tree, remaining attached to the root after the trunk is cut.

Sustainable forest management	'The stewardship and use of forest lands in a way and at a rate that maintains their productivity, biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil now and in the future relevant ecological, economic and social functions at local, national and global levels and that does not cause damage to other ecosystems.'
Temporary framework	Short-term = 5-10 years (e.g. 2020); medium-term = 30-50 years (e.g. 2050); long-term = 100 years or more (e.g. 2100).
Thinnings	Trees removed during thinning operations, the purpose of which is to reduce stand density and enhance diameter growth and the volume of the residual stand. Unacceptable growing stock, which is defined as trees considered to be structurally weak or to have low vigour and which do not have the potential to eventually yield a 12-foot sawlog or to survive for at least the next 10 years. Also includes trees removed to reduce fire hazard.
Toe	The tonne of oil equivalent (toe) is a unit of energy: the amount of energy released by burning one tonne of crude oil, or approximately 42 GJ (as different crude oils have different calorific values, the exact value of the toe is defined by convention). Multiples of the toe are used, in particular the megatoe (Mtoe, or one million toe) and the gigatoe (Gtoe, or one billion toe).
United Nations Framework Convention on Climate Change (UNFCCC)	This convention was adopted on 9 May 1992 in New York and signed at the 1992 Earth Summit in Rio de Janeiro by more than 150 countries and the European Community. Its ultimate objective is the 'stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'. It contains commitments for all the Parties. Under the convention, the Parties included in Annex I (all OECD countries and countries with economies in transition) aim to return greenhouse gas emissions not controlled by the Montreal Protocol to 1990 levels by the year 2000. The convention entered in force in March 1994. In 1997, the UNFCCC adopted the Kyoto Protocol.
Upstream emissions	Upstream emissions for biomass fuels are considered to be the greenhouse gas (GHG) emissions (usually including all fossil GHG emissions and biomass non-CO_2 GHG emissions) occurring during the extraction, processing and transportation of the biofuel to the end-user. They are generally associated with the emissions calculated in accordance with Directives 2009/28/EC and 2009/30 (in Annexes V and IV, respectively). They may be associated with the 'direct emissions' described in section 3.1 of this report. They do not include emissions associated with direct or indirect land-use change, nor any provision for possible imbalances in the timing of the emission and re-absorption of biogenic carbon or for any displacement effect on other markets.
Volume-volume percentage (v/v %)	A measure of the concentration of a substance in solution, expressed as the ratio of the volume of the substance to the total volume of the solution, multiplied by 100 %.

Water footprint	An indicator of direct and indirect appropriation of freshwater resources over the entire supply chain.
Water stress	Occurs when water demand exceeds the available usable water resources.
Watt (W)	The watt is the International System of Units (SI) measure of the rate of energy conversion or transfer, or power in simple terms, defined as one joule per second (J/s). Often expressed in kW (kilowatts, or one thousand watts) for transport applications, or MW (megawatts, or one million watts) for power generation applications.
Well-to-wheel (WTW, WTT, TTW)	Methodology aimed at quantifying the energy required for, and the GHG emissions resulting from, the production, transport, distribution and combustion of conventional and alternative road transportation fuels. It is commonly divided into WTT (well-to-tank) and TTW (tank-to-wheel).

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EXECUTIVE SUMMARY

Biofuels are liquid or gaseous fuels produced from biomass. Their use in transport is promoted as a means of tackling climate change, diversifying energy sources and securing energy supply.

In the EU, the Renewable Energy Directive (RED) requires 10 % of all transport fuels to be delivered from renewable sources by 2020 in every Member State. In addition, the Fuel Quality Directive (FQD) introduces a mandatory target of a 6 % reduction in the greenhouse gas (GHG) intensity of fuels used in road transport and non-road mobile machinery by 2020 (compared with the EU-average 2010 level of emissions from fossil fuels). Both directives define sustainability criteria that must be met if biofuels are to count towards national targets and be eligible for support.

According to the trajectories declared by the Member States in the National Renewable Action Plans (NREAPs), more than 85 % of the RED transport target is expected to come from biofuels[1] (mainly biodiesel), which therefore increases the demand for biofuel feedstocks obtained predominantly from agricultural crops. Although biofuels production provides new options for using agricultural crops, it gives rise to environmental, social and economic concerns which are the subject of intense debate worldwide. This report contains comprehensive analysis and discussion of key aspects affecting overall biofuel sustainability.

General information on biofuels

Bioethanol and biodiesel are the most common biofuels used in transport. Other biofuels are also in use, such as pure vegetable oil and compressed biomethane, although with a more limited market penetration.

Biofuels are normally referred to as first-, second- or third-generation biofuels.

First-generation biofuels include well-established technologies for the production of bioethanol from sugar and starch crops, biodiesel from oil crops and animal fats, and biomethane produced by anaerobic digestion.

Second-generation biofuels encompass a broad range of biofuels produced from feedstock that is not used as food or feed, e.g. lignocellulosic materials (such as short-rotation forestry or coppice), the organic part of municipal solid waste, and forest and agricultural residues. They may also include bioethanol and biodiesel produced by conventional technologies but based on novel starch or energy crops such as jatropha. The hydrotreatment of vegetable oils, animal fats or waste cooking oils has also been gaining ground as a solution to the increasing pressure to find alternatives to fossil fuels for transport.

Production technologies are usually more complex and expensive than for first-generation biofuels, but second-generation biofuels are generally considered to be more sustainable, with the potential for greater GHG emission savings compared with first-generation biofuels[2].

1 With the rest coming from renewable electricity (10 %) or from hydrogen and other sources (2.3 %). Hydrogen use from renewable sources is expected to be negligible.

2 Dedicated energy crops such as miscanthus and switchgrass could also be grown on marginal/degraded land. However, this may often require intensive use of water/fertilisers. Sometimes energy crops are also grown on agricultural land, thus competing with food/feed crops and possibly causing indirect land-use change (ILUC).

Third-generation biofuels generally include biofuel production routes which are in the earlier stages of research and development or are significantly further from commercialisation (e.g. biofuels from algae, hydrogen from biomass, etc.).

From 2005 to 2010, the EU experienced a rapid expansion in biodiesel and bioethanol fuels production[3]. The share of biofuels as a proportion of liquid transport fuels reached 4.7 % in 2011. Biodiesel is the main biofuel in the EU transport sector, with a 78.2 % share of total consumption (by energy) as against 20.9 % for bioethanol (EU-27)[4].

At the moment the EU is the largest producer of biodiesel worldwide, accounting for approximately 40 % of global production, with Germany and France being the top European producers (the other main biodiesel producers are the USA, Argentina, Brazil, Indonesia and Malaysia). In 2011 EU biodiesel production amounted to 339.6 petajoules (PJ), while consumption in transport came to 445.6 PJ. According to the biofuels projections presented in this report, global biodiesel production is expected to increase from 776 PJ in 2011 to almost 1 400 PJ by 2021 (with the EU remaining the largest producer and user of biodiesel).

As regards bioethanol, the USA and Brazil are the main producers and exporters. Exports are directed mainly towards the EU, Canada, Japan and South Korea. In 2011 EU bioethanol production amounted to 73.3 PJ, and consumption in transport came to a total of 121.1 PJ. Global bioethanol production is projected to increase from 1844 PJ in 2011 to over 3 800 PJ in 2021. The three major producers are expected to remain the USA, Brazil and the EU, followed by China and India.

The number of large-scale operations purifying biogas to biomethane is also increasing; the EU is in the lead with 69 % of world capacity. However, the use of biomethane in transport is still very limited (0.5 % of transport fuel in 2011) and is confined to a few Member States, notably Sweden and Germany.

Impact of biofuels on agricultural markets

The impact of biofuels on agriculture depends not only on the crops which go directly to biofuel factories but also on the consequences for overall commodity markets in terms of production, trade and prices. Economic models are needed in order to understand these processes properly, but in the case of biodiesel the effects are so significant that historical analysis gives some robust indications.

It is important to consider vegetable oil in all its forms: oilseeds, oil and finished biodiesel.

Analysis shows that European biodiesel has had a major impact on world vegetable oil markets. Biodiesel is wholly responsible for the increase in European vegetable oil demand from 2001 to 2011. More than half of that increase was supplied by increased net imports, about half of which were palm oil. It is particularly important to look at the effect of biofuel on palm oil imports, given the very high emissions from oil palm expansion onto tropical peatland. In addition to the palm oil used directly for biodiesel, part of the (mostly rapeseed) oil diverted to biofuel from other uses in the EU was replaced by palm oil imports. In other developed countries without biodiesel policies, the percentage increase in palm oil imports was actually much lower.

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3 Biodiesel production is expected to contract slightly by 2020 according to the trajectories presented by the Member States in their National Renewable Action Plans (Banja et al, 2013).

4 Eurostat (2013).

EU ethanol production is much more limited than EU biodiesel production, and total cereals production far exceeds vegetable oil production. Accordingly, cereals used for ethanol in the EU represent only a small part of the total market, so it is not possible to distinguish the market effects of bioethanol by means of simple historical analysis. Almost all the feedstock used by EU ethanol factories is produced domestically.

In terms of prices, biofuels may have a role in the shift towards higher agricultural commodity prices. Forward-looking studies suggest that in 2020 EU biofuel policy is likely to have some impact on future commodity prices, in particular on world prices for oilseeds and vegetable oils, and to a lesser extent for cereals and sugar. On the other hand, food security is more sensitive to cereal prices than to vegetable oil prices. However, there is a considerable range in the estimates.

Different economic models all show that the effect of biofuels on the EU livestock industry is roughly neutral. This is because biofuels have by-products which are used for animal feed, thereby compensating the part of biofuel feedstock that is diverted from the animal feed market.

Indirect land-use change emissions (ILUC)

Land-use change is one of the main concerns relating to the impact of first-generation (and to lesser extent of second-generation) biofuels: increased EU demand has an impact on land use in both EU and non-EU countries. If biofuels crops are grown on uncultivated land, this will cause direct land-use change. If biofuels crops are grown on existing arable land instead of crops for food, indirect land-use change (ILUC) occurs because of the necessity of maintaining food production: the ‘hole’ in the food supply is filled partly by the expansion of cropland around the world.

The main agro-economic models used to estimate ILUC agree that extra biofuels demand in the EU would result in significant land-use change[5], most of it outside Europe. The models derive only a part – often a small part – of the extra feedstock needed for biofuel from land-use change. Usually more feedstock comes ILUC-free from other sources: reduced food consumption, price-driven yield increases, and use of by-products.

Alternative methods developed by the authors in order to make rough estimates of ILUC confirm the magnitude of the ILUC effects, and also confirm that EU bioethanol has lower ILUC emissions than EU biodiesel.

ILUC cannot be avoided by means of fixed sustainability criteria. It could, however, be avoided by approving biofuels only on a project basis (e.g. as part of a suitable voluntary scheme), where the project specifies how it would ensure extra carbon sequestration in biomass, for example by replanting abandoned or degraded land, or through additional yield improvements linked to biofuels.

Yields, fertilisers and marginal emissions

Some of the extra feedstock needed for biofuels production is expected to come from additional yield increases generated by the rise in crop prices (driven by growth in feedstock demand); the more yields respond, the lower the ILUC area becomes. Logically,

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5 The increase in land-use change due to biofuels is small in absolute terms, for example in comparison with cropland expansions projected to feed an increasing world population. However, the authors consider it significant that such a small area is responsible for considerable CO_2 emissions‘’.

one expects yield to respond to price, but the response is very difficult to detect. In recent years, yields have stagnated in north-west Europe despite large increases in crop prices, and recent research suggests that yields may respond less to price than is assumed in economic models used to estimate ILUC.

Increasing the use of nitrogen fertilisers is just one way for farmers to increase yields in response to crop price rises. However, the extra production deriving from extra nitrogen comes at a high price in terms of GHG emissions[6]: if even a small part of the extra yield comes from additional fertiliser, the emissions (per tonne of extra crop) are higher than average. These extra intensification emissions are rarely taken into consideration in models estimating ILUC emissions. Neither are the extra direct cultivation emissions which arise from spreading cultivation onto land with lower yields.

Biofuels and biodiversity

The use of biofuels can potentially have a positive impact on biodiversity thanks to climate change mitigation resulting from the substitution of fossil fuels. However, the immediate impact, relating primarily to the production of biofuel feedstock, including habitat loss and fragmentation and the use of agrochemicals, can be significant. The net impact varies considerably, ranging from negative to positive, depending on the feedstock used, the previous land use and the management practices applied. Using annual crops for biofuels causes habitat loss through indirect land-use change. Biofuels from perennial crops can perform better because their production uses fewer agrochemicals and they can be grown on less productive land, although this implies lower yields and often reduced profitability. The use of biomass residues does not require additional land, but removing forest residues may cause significant loss of forest biodiversity. Harvesting semi-natural grassland can benefit biodiversity by preventing succession of these habitats.

Different management practices could improve biodiversity on agricultural land. However, consideration has to be given to the trade-off between reducing management intensity and minimising land-use requirements. ILUC impact on biodiversity as a result of biofuels production on productive agricultural land is significant. Nevertheless, some biofuels crops could improve biodiversity by helping to reclaim certain categories of degraded and marginal land.

Biofuels and water

The water footprint (WF) of biofuels, defined as direct and indirect water use over the entire supply chain, is larger than that of fossil fuels. The water consumption of bioenergy systems occurs predominantly during feedstock production and depends on feedstock type, the vegetation replaced by energy crops, site-specific characteristics and the management practices applied. The WFs of biofuels show large variations. It is expected that the share of water used in biofuels production will increase, accounting for more than 2 % of evapotranspired water and around 5 % of withdrawn water. Although global shares are not too large, this could heighten the risks in regions which already experience water shortages. Moreover, studies usually do not consider the seasonal and spatial variability of water availability and consumption and the impact of future climate change.

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[6] Emissions from fertiliser production and the extra nitrous oxide emissions it generates from farm soils.

Availability of biomass for energy

Apart from biofuels from annual crops, there is considerable potential for bioenergy from wastes and residues. Using a given amount of biomass for heat and electricity generally saves more GHG emissions than making it into a transport fuel at a lower cost. On the other hand, there are more readily available renewable alternatives for power production, such as wind and solar.

Agricultural residues account for more than 25 % of the technical potential of biomass[7] in the EU, while forestry residues account for a further 23 %. The use of straw and primary forest residues is forecast to more than double between 2010 and 2020. However, studies have tended to underestimate the costs involved in biomass mobilisation. Resource efficiency and sustainability criteria would strongly incentivise the use of biomass residues such as manures, straws and logging residues.

Biofuels in vehicles

Biofuels are used as blends with conventional fuels in existing engines. Blending limits in the EU are set according to fuel specification standards designed to ensure compatibility with conventional power trains and refuelling infrastructure. Current fuel standards allow up to 7 volume% FAME (the most common type of biodiesel, B7) in diesel fuel of fossil origin and up to 10 volume% ethanol (E10) in petrol. Hydrotreated vegetable oil (HVO) can be blended with conventional diesel even at higher volumes in the order of 30 % v/v (30 % HVO, 70 % diesel). However, the regulatory landscape across the Member States is fragmented. At low percentage blends (e.g. B7 or E5 (5 % ethanol, mixed with petrol), biofuels can work with current engine and powertrain technologies and can be pumped directly into the tank of any vehicle. Car engines and powertrains need to be modified to run smoothly with higher blends. It is worth noting that even when vehicles are compatible with higher blends (E10 can be used in 85 % of cars in the EU and in all new cars produced after 2010 at the latest)[8], market uptake does not automatically follow: customer preferences play an important role in modifying the mix of fuel volumes sold.

Although in general terms biofuels have slightly lower energy content than fossil fuels, tailpipe emissions give mixed results. The impact of biodiesel on regulated pollutants (nitrogen oxides (NOx), particulate matter (PM), carbon monoxide (CO), hydrocarbons (HC), etc.) is not straightforward, since it depends on the blending ratio, the physical properties of the biodiesel, the vehicle/engine technology and the driving conditions.

Up until now, the main focus has been on the impact of biodiesel on heavy-duty engines, and extensive studies have been carried out. For example, the US Environmental Protection Agency (EPA) has extensively assessed the outcomes of more than 80 scientific studies in order to evaluate emissions from heavy-duty diesel engines fuelled with biodiesel (EPA, 2002). The general trend is that CO, HC and PM emissions reduce as the blending ratio increases, while NOx emissions increase, reaching a maximum with neat biodiesel.

However, the effect of biodiesel may be different when it comes to emissions from passenger cars – particularly those fitted with high-pressure injection systems. In general, available data from laboratory tests on passenger cars and light-duty trucks indicate that particulate matter, carbon monoxide and unburned hydrocarbons seem to decrease as the

[7] The technical potential of biomass is the fraction of the total (theoretical) biomass that it is possible to collect using current technologies/infrastructure (harvesting techniques, accessibility, etc.).

[8] CE Delft, TNO (2013).

concentration of biodiesel in fuel increases. On the other hand, according to most of the studies, fuel consumption and nitrogen oxides increase. As regards the latter, the increase is much higher than in the case of heavy-duty vehicles (HDVs).

With regard to petrol/ethanol blends, one of the major concerns is the possible increase in evaporative emissions: these are highly dependent on temperature, vehicle activity and vehicle system materials. The majority of evaporative emissions occur when the car is sitting or refuelling. Because low levels of ethanol can cause petrol to evaporate more easily, low-level ethanol blends can increase evaporative emissions from vehicles.

Greenhouse gas emissions

Sustainability criteria in EU legislation require minimum GHG savings for biofuels compared with the fossil fuels replaced. Taking into account only 'direct life-cycle emissions' (e.g. GHG emissions from cultivation, processing, transport and distribution), in general the use of biofuels generates GHG savings, with considerable variability depending on the feedstock used and the specific production processes adopted. However, if emissions due to indirect land-use change (ILUC) are estimated properly and taken into consideration, the potential GHG savings are reduced, and for some biofuel pathways there may not be any savings at all.

Calculations of 'direct' GHG emissions based on the well-to-wheel (WTW) methodology show higher GHG savings with respect to the fossil fuel replaced (from 67 % to 83 %) for ethanol produced from sugar feedstocks and wheat straw, while GHG savings for bioethanol from cereals (wheat/maize) are significantly lower (in the order of 23 % and 14 %, respectively). The 'direct' GHG savings for the main biodiesel fuels (from palm oil, soya beans, sunflower and rapeseed) are in the order of 35 % to 50 % compared with fossil diesel[9].

However, if ILUC emissions are also taken into account, GHG saving performance decreases by roughly 15 % for the ethanol pathways, and there are no GHG savings for any biodiesel pathway (except biodiesel from waste).

Electric cars (charged with EU-mix electricity) save about half the GHG emissions of conventional fossil-fuel-powered cars. Obviously savings are even higher if the vehicles are charged with electricity from biomass or other renewables.

Cost of GHG savings for various first-generation biofuels

Among biofuels produced from crops, bioethanol from sugar cane and sugar beet has the lowest cost for GHG emission savings; however, even if ILUC emissions are ignored, this is in the range of 100 to 200 EUR/tonne of CO_2e avoided, according to the authors' calculations. For wheat ethanol, the cost is 300 to 800 EUR/tCO_2e (ignoring ILUC emissions).

Biodiesels from conventional crops emit more greenhouse gases than fossil diesel, if ILUC emissions are included. If ILUC emissions are ignored, palm oil biodiesel actually has the lowest cost for emissions reduction (100 EUR/tCO_2e); on the other hand, it has the highest level of ILUC emissions, because of the large contribution of emissions from drainage of

[9] The WTW methodology used to calculate GHG savings for biofuels differs significantly from the methodology used in EU legislation (RED and FQD). Accordingly, these values cannot be compared directly with the GHG savings referred to in Annex V to the RED.

tropical peatland. Ignoring ILUC emissions, rapeseed biodiesel is the biodiesel with the highest cost for GHG savings: ~330 EUR/tonne.

Although the high capital cost of second-generation biofuels factories makes their products more expensive than first-generation biofuels, their better performance in terms of GHG savings means that the cost of GHG savings is comparable to that of bioethanol from sugar crops. In addition, compared with first-generation biofuels, the operational costs of second-generation biofuels are less dependent on feedstock costs.

Total cost of EU biofuel policy

The authors estimated the 2011 production cost of EU biofuels from raw materials, including investment costs, and found that it was close to the EU wholesale price of biodiesel and ethanol. This indicates efficient competition between EU biofuels producers.

Literature estimates of the cost of supporting biofuels in EU Member States in 2011 vary from EUR 7 billion to EUR 8.4 billion, which corresponds to EUR 14 to EUR 17 per person or about EUR 26 to EUR 32 per vehicle.

Most of this policy cost is accounted for by the extra production cost of EU biofuels compared with the production cost of the fossil fuels they replace: the authors estimated that this amounted to EUR 5.6 billion in 2011. The difference corresponds to the additional cost of blending and administration, together with the profits of blenders and distributors.

Overall benefits of EU biofuels: emissions savings

In 2011 ethanol use in the EU saved about 6 million tonnes (Mt) of CO_2 equivalent (CO_2e) in emissions, without taking into account ILUC emissions. If ILUC emissions are included, the savings from ethanol fall to 4.3 Mt of CO_2e.

In 2011 biodiesel use in the EU saved about 18 Mt of CO_2e emissions, without taking into account ILUC emissions. If ILUC emissions are included, biodiesel no longer saves emissions, but increases them. The increase in emissions totalled 8 Mt of CO_2e in 2011.

Without taking into account ILUC emissions, EU biofuels saved about 24 Mt of CO_2 equivalent GHG emissions in 2011. Taking into account ILUC emissions calculated for the European Commission by IFPRI (Laborde 2011), biofuels in the EU increased GHG emissions by a net ~3.7 Mt of CO_2 equivalent in 2011.

Overall benefits of EU biofuels: security of supply

Biofuels replaced 5.1 % of EU road fuels and up to 2.2 % of EU crude oil use in 2011. However, some of the biofuel was imported: 23 % of biodiesel and 24 % of bioethanol were imported directly as finished products (in 2011), while, in indirect terms, a considerable proportion of the vegetable oil feedstock was imported. Furthermore, some of the feedstock produced domestically displaces food production, resulting in relatively higher food commodity imports and prices. However, even for the part of the feedstock which is imported, it can be said that biofuels increase the range of sources of transport fuel supply.

Overall benefits of EU biofuels: impact on employment

Job creation is one of the objectives of EU biofuel policy, but there is still insufficient information on the effects on employment.

Eurobserver estimates of employment in the biofuels sector show that about 115 000 jobs were created in the EU in 2012[10]. However, the impact on employment should be evaluated in the light of the net effects on all sectors of the economy.

Many of the farm-related jobs would likely have existed with or without biofuels, especially if the alternative to biofuels were more EU crop exports. The additional jobs created by the biofuels sector are likely those associated with biofuel processing facilities or transport, and they may be offset at least partially by losses in petroleum processing facilities, for example. More important is the depressive effect of taxation (to make up for tax income lost through the detaxation of biofuels at the pump) or, alternatively, increases in transport fuel prices. It is well known that almost any policy which increases public spending without compensating this with tax increases will result in job creation, but at the cost of a budget deficit. Accordingly, the evaluation of any policy which requires more public spending should include the effects of the extra taxation needed to balance the extra spending.

In general, those studies which account for the increase in taxation to pay for biofuel subsidies conclude that employment effects are neutral.

Impact of biofuels on the future of the EU refining industry

EU total crude oil demand is forecast to decline by 2020, as a result mainly of economic trends but also of the increasing use of alternative fuels and of improvements in energy efficiency (not only in the automotive sector).

The achievement of the RED renewable energy target for transport in 2020, mostly through biofuels, will make it possible to save, in volume terms, the equivalent of 10 billion litres of petrol and 20 billion litres of road diesel. In the 2010-2020 period, the impact of biofuels on refining economics remains low. In particular, the increase in biodiesel production will not eliminate excess European demand for ‘middle distillate’ (diesel and kerosene) compared with other petroleum components. However, in a longer-range perspective (up to 2030), biofuels could contribute a fifth of the overall reduction in demand for refined oil products (compared with the 2005 value).

Sustainability of second-generation biofuels

Second-generation biofuels produced from non-food materials are currently receiving much attention, as they are seen as a solution to many of the sustainability issues posed by crop-based biofuels. However, a pre-assessment of their environmental impact is essential in order to avoid making poorly directed investments. For example, relying heavily on wastes and residues without having first performed an analysis of their direct and indirect impact could lead to an underestimation of potential environmental risks (or benefits). Similarly, the carbon implications of increased use of forest biomass for bioenergy need to be well understood.

[10] Eurobserver 2013.

Diverting biomass from use for heat and/or electricity generation would generally increase GHG emissions, as these routes generally save more emissions per MJ of biomass than second-generation biofuels, as well as being much cheaper. Accordingly, it only makes sense to look at additional sources of supply of biomass for second-generation biofuels.

Forest biomass

In the current European renewable energy policy framework, forest biomass used for energy and transport is considered to be a 'carbon-neutral' source, given that biomass combustion releases the same amount of CO_2 that was absorbed by the plant growth.

Without this 'carbon-neutral' assumption, wood-derived energy would have higher carbon emissions than any fossil fuel, because wood actually contains more carbon per unit of useful energy. Even more carbon is emitted if wood is used in a complex and relatively inefficient process to make liquid biofuels, instead of being burned for heat or electricity.

If the policy incentivises more cutting of existing forest, this high release of carbon by burning is more or less immediate, but even if the forest is replanted and the rate of cutting is within the 'maximum sustainable yield', the assumed absorption of the carbon by faster growth of younger trees can occur more than a century in the future; in the meantime there is a 'carbon debt'. The initial rate of carbon sequestration by saplings is very slow, and only reaches a maximum well into the cycle time of the forest. Accordingly, if trees (stemwood) are felled specifically for biofuels or bioenergy, GHG savings only start many decades or even centuries in the future, and will not contribute to reaching Kyoto targets.

Before incentivising the use of trees for making second-generation biofuels, the climate impact on all the economic sectors using wood should be assessed:

- Displacement of wood for products, or indirect wood-use change (IWUC), e.g. the use of wood for furniture and buildings or, more likely, for the pulp, paper and panel board industries. This can lead to the use of more carbon-intensive materials, such as concrete or steel.
- Displacement of wood from other energy sectors, or indirect fuel-use change (IFUC). Those other sectors may then have to replace the raw materials with more GHG-intensive energy sources.
- Competition for land, i.e. indirect land-use change (ILUC) in the event of new plantations, especially of short-rotation forestry or coppice on agricultural land.
- Management intensification (increased and improved management, fertilisation, suppression of natural disturbances, etc.). This may lead to an increase in productivity, which may shorten the payback times.

The impact of other climate forcers (e.g. surface albedo changes, organic and black carbon and short-lived GHG emissions) should be included in the analysis in addition to long-lived GHG accounting, as should the occurrence and impact of natural disturbances.

Better statistical data on forestry and wood products will be essential in order to develop more precise models.

Residues

In the EU, straw is used predominantly for soil improvement, animal bedding and horticulture. This review reveals that the utilisation of straw for energy generally generates GHG savings even when possible changes in soil organic carbon are taken into account, owing mostly to lower N_2O emissions when straw is not incorporated into the soil.

However, the increased removal of straw from cropland can have a negative impact on soil quality, which can ultimately affect crop yields. This would in turn increase emissions per tonne of crops and generate ILUC emissions associated with straw use. More work needs to be done on the subject, but the authors consider the effect to be moderate in suitable areas. Changes in management practices could minimise the adverse impact.

Pruning residues from orchards, olive groves and vineyards are generally landfilled or burned near the fields. Either using them for bioenergy or ploughing them into fields, thereby protecting the soil and providing nutrients, would bring environmental and economic benefits.

Only a few per cent of the manure produced in the EU is currently treated by anaerobic digestion to produce biogas. Biogas from manure may replace fossil fuels and normally generates significant GHG savings, in particular because of the avoided emissions from manure storage. Digestate is used as organic fertiliser, so nutrients are not lost compared with using manure, although there could be a small loss in soil carbon in the long term. On the other hand, digestate is less unpleasant to transport and handle, so it could also substitute synthetic nitrogen fertilisers.

Logging residues are the branches and other remains which are traditionally left in the forest after harvest; they are expected to provide most of the additional EU biomass for biofuels by 2020. Collecting residues generates a carbon debt which typically lasts only in the order of 10 to 20 years. The long term effects are site- and feedstock-specific, and are still uncertain. The main concern is forest biodiversity loss due primarily to the removal of niche habitats (i.e. dead and downed wood). There are already local guidelines requiring that a certain proportion of such residues be left on the forest floor to protect soil health and biodiversity. These requirements should be taken into account when promoting their removal for bioenergy use.

Although biogas production from residues and waste is fairly advantageous in terms of GHG emissions, the use of agricultural crops (such as fodder maize) results in much lower GHG savings and also in direct or indirect emissions from land-use change.

Simple biogas installations often store the digestate in open tanks, which generate some methane and N_2O emissions. These are much smaller than the emissions from manure storage, but in the case of biogas production from energy crops they can even negate the overall GHG savings compared with natural gas. Methane emissions from leaks and venting can be significant too; CH_4 emissions should therefore be avoided by means of proper management and flaring of off-gases. Best practices significantly lower GHG emissions from biogas plants and should therefore be strongly promoted.

Outlook for improvement in biofuels emissions and costs

The processing of first-generation biofuels is still making incremental but steady progress in terms of conversion efficiency, energy efficiency, the utilisation of residues and the valorisation of waste streams. The International Energy Agency (IEA) predicts that the costs of existing first-generation bioethanol production in the EU will achieve parity with fossil petrol by about 2018. This compares with 2014 for bioethanol made from sugar cane in Brazil. For first-generation biodiesel, however, the IEA does not expect the production cost to achieve parity with fossil-derived diesel before 2050. Of course, these results depend very much on the assumptions made as regards future crude oil and crop prices.

The progress in second-generation biofuels technology has been slower than was anticipated when the RED was drafted. Several small-scale plants in the EU have demonstrated that cellulosic ethanol production from residues such as straw is technically feasible. However, improvements in economics are needed to counter the very high capital cost of the plant: cheaper feedstock, scale-up, and valuable co-products. Scale-up is happening: three large US cellulosic ethanol plants are starting up (one in September 2014 and two in the course of 2015), and one was commissioned in Crescentino, Italy, in October 2013.

However, without consideration of subsidies, siting a cellulosic ethanol plant next to an existing Brazilian sugar cane ethanol factory is much more economically attractive than in Europe, as ethanol distillation can be shared with the existing plant and bagasse feedstock is available without collection and transport costs.

The specific investment costs for second-generation plants will come down if more of them are made, or if their scale is increased. However, it is debatable whether, or when, costs will become comparable with those of first-generation biofuels, let alone fossil fuels. The IEA has given estimates ranging from 2026 to after 2050 depending on the particular biofuel, but the result depends to a critical extent on the assumptions made as regards crude oil prices, interest rates and feedstock prices.

The Joint Research Centre (JRC) identified the most promising new biofuel route to be via black liquor gasification, integrated into a wood pulp mill. This has now been demonstrated in one pulp mill, but even there costs are significantly higher than for fossil fuel. For a free-standing gasification-based biofuel plant, costs are much higher, as demonstrated by the closure of the Choren demonstration plant. Several second-generation plants have closed soon after construction.

Thermochemical conversion of biomass via gasification can produce many types of fuel, including hydrocarbons with similar chemistry to diesel, or specially tailored for use in aviation. The main challenges relate to cleaning the intermediate product, the syngas from gasification or the bio-oil from pyrolysis, before the conversion to fuel can be carried out. A medium- to large-scale gasification demonstration project for the production of biomethane (with the same composition as natural gas) started in Sweden in 2013.

It is often stated that second-generation biofuels can only be 'economic' if there are valuable chemical by-products: the 'biorefinery' concept. There are indeed many possibilities for co-producing complex organic chemicals; the challenge is to find ones with a large enough potential market to support a large-scale plant.

'Third-generation biofuel' usually means biofuel from algae. This offers a number of potential advantages: no competition for land or crops, no carbon debt and potentially high yields. Many different approaches are being investigated, and it is far too early to pick winners. The main possibilities are the low-cost approach of open ponds and natural algae, or the high-yield approach of using selected or genetically modified algae to produce high yields of chosen products. There could be a practical problem with scaling up the second approach: the whole plant needs to be kept sterile in order to avoid invasion by natural organisms.

The choice of technology and of the fuel to be produced is influenced in large part by the availability of feedstock and locally available resources. Integration of biofuels production and biorefineries installations with other industrial facilities offers opportunities to optimise energy efficiency. A large number of biofuels plants in Europe are sited on major transport routes, often at sea ports, in order to take advantage of low-cost bulk transport systems. This approach reflects the growing need for Europe to import feedstocks for biofuels and bioenergy. Wood pellets produced for the global trade in biomass are very suitable as a starting material for a range of biofuel production technologies, including gasification and pyrolysis, although the sustainability of wood pellet production also needs to be taken into consideration.

Financial support for advanced biofuels in Europe is now increasing to significant levels. Starting in 2013, the NER300 funding programme for innovative low-carbon energy has made a significant contribution to financing industrial-scale demonstration projects. Eight of the 23 projects selected involve bioenergy or biofuels. The European Bioenergy Industrial Initiative (EIBI) monitors the progress of biofuels technology development and coordinates some of the funding possibilities for technology implementation in the EU.

INTRODUCTION

94 % of energy needs in the EU transport sector are currently met by oil products

In April 2009, the European Parliament and the Council adopted a Directive on the promotion of the use of energy from renewable sources (Renewable Energy Directive) as part of the EU climate and energy package. This package aims to combat climate change and increase EU energy security, to promote technological development and innovation, and to provide opportunities for employment and regional development, particularly in rural and isolated areas.

A set of specific mandatory targets for the EU transport sector aims at achieving the overall objective of a sustainably fuelled European transport system, implying that 'alternative' fuels must ultimately come from sustainable renewable sources:

- The aforementioned Directive 2009/28/EC (Renewable Energy Directive – RED) includes, in addition to the 20 % overall target for the share of renewable energy by 2020, a 10 % target for each Member State for the share of renewable energy in transport by 2020.
- Directive 2009/30/EC (amendment to the Fuel Quality Directive – FQD) sets a target for fuel suppliers to reduce life-cycle GHG emissions from fuel and energy in transport by at least 6 % by 2020 compared with the EU average level of fossil fuels in 2010.

The implementation of the directives, including the mix of renewable energy sources and the support schemes promoting the development of renewable energy in the transport sector, is the responsibility of the Member States.

Biofuels are expected to play a crucial role in achieving the mandatory targets set by the two directives. According to the National Renewable Energy Action Plans (NREAPs) adopted by the Member States in 2010, about 6.6 % of road transport energy is expected to be biodiesel in 2020 and 2.2 % bioethanol. This expected development certainly poses important questions about the sustainability of the targets, which will mainly be achieved through first-generation 'land-produced' biofuels: social and economic concerns will have to be addressed if it is recognised that biofuel production can provide new options for using agricultural crops.

Many of the policy objectives hinge upon the call for the production of biofuels to be 'sustainable'. A minimum set of sustainability criteria is laid down in the RED and FQD directives: biofuels need to fulfil these criteria to be eligible for financial support for the consumption of biofuels and bioliquids[11].

[11] Bioliquids are liquid fuels made from biomass for energy purposes other than transport.

Box 1: EU legislative context

Renewable Energy Directive	Fuel Quality Directive
The Renewable Energy Directive (RED) establishes mandatory targets to be achieved by 2020: • 20 % overall share (based on energy content) of renewable energy in the EU in the electricity, heat and transport sectors. • 10 % share of renewable energy in the transport sector.	The Fuel Quality Directive (FQD) requires: • 6 % reduction compared with 2010 in the GHG intensity of fuels by 2020 (indicative targets of 2 % by 2014 and 4 % by 2017). • 2 % reduction from developments in new technologies, such as carbon capture and storage (CCS) (compared with 2010). • 2 % reduction from the purchase of Clean Development Mechanism (CDM) credits (compared with 2010).

The two directives specify a minimum set of sustainability criteria for biofuels and bioliquids, with a threshold of 35 % savings of GHG emissions with respect to the fossil fuels they replace. The use of specific land-use categories, such as primary forest, highly biodiverse grassland, wetlands and peatlands, is explicitly excluded.

SUSTAINABILITY CRITERIA OF THE DIRECTIVES	
GHG impact	• Minimum 35 % GHG emissions saving (50 % from 2017, 60 % from 2018 for new installations) compared with the fossil fuel they replace.
Biodiversity	• Not to be made from raw materials obtained from biodiverse areas (including primary forests).
Land use	• Not to be made from land with high carbon stock (i.e. wetlands, forested areas, etc.). • Not to be grown on peatlands.

In accordance with the FQD Directive, it is possible to obtain certification of compliance with the harmonised EU sustainability criteria for biofuels and bioliquids through different means, at the choice of the economic operator:

- in accordance with the implementation rules of the Member State in which the biofuel benefits from a support scheme;
- in accordance with a 'voluntary scheme' approved by the European Commission;
- in accordance with a specific bilateral or multilateral agreement.

The two directives set out the rules for the calculation of the GHG savings for individual plants and biofuel pathways. Emissions from cultivation (including direct land-use change if it occurs), processing and distribution are included in the methodology. Emissions from indirect land-use change (ILUC) are not included. Both directives mandate the Commission to assess the impact of ILUC and to examine regulatory options for addressing it. This obligation was the object of Commission proposal COM(2012)0595 of 17 October 2012 (see Box 3, Chapter 2).

According to the criteria established in the RED and the FQD, the overall sustainability of biofuels depends on several factors. These include the biodiversity value and the carbon stock of the land from which raw material is obtained, the agricultural practices employed in growing feedstock[12] and the effective GHG savings obtained along the full production process.

The diversity of feedstock and the large number and complexity of biofuel pathways lead to a high degree of uncertainty over the performance of biofuels in terms of GHG emission reductions compared with fossil fuels, particularly if land use change is involved. Additional uncertainties occur if indirect effects are considered. These include indirect land use changes, the effects of diverting materials from existing uses to make biofuels, and the impact on food and feed.

The future of biofuels development depends to a large extent on the policy support for, and technological improvement of, promising new options that use lignocellulosic biomass[13], aquatic biomass, etc. These 'advanced' biofuels can widen the feedstock options and produce a larger volume of fuel for the market, with the potential for greater GHG emission savings compared with first-generation biofuels. However, production is quite limited on a commercial scale because technological issues are still present, although there have been a number of significant advances in technology development.

Moreover, the demand for waste-based biofuels is also expected to increase further in the near future, particularly in light of the debate about the sustainability of first-generation biofuels and in response to the 'double counting' provisions. The RED and the FQD state that: 'for the purposes of demonstrating compliance with [the target], the contribution made by biofuels produced from wastes, residues, non-food cellulosic material and lignocellulosic material shall be considered to be twice that made by other biofuels'. This 'double counting mechanism' has two primary aims: to encourage the use of more efficient, 'cleaner' resources, and to diversify the base of raw materials used to produce biofuels by compensating for the higher production costs associated with the innovative processing technologies needed for these new feedstocks. Demand for waste-based biofuels is expected to increase in response to this incentive, and owing to the fact that waste/residues are widespread and relatively cheap, do not compete with food/feed or other land uses and have low or no upstream GHG emissions[14]. However, since many of these materials also have existing uses, which may save more carbon emissions than their use as biofuels feedstock, the consequences of diverting waste and residues to biofuel production must be taken into consideration (an assessment of the environmental impact of diverting wastes and residues from existing uses will be discussed in the following chapters).

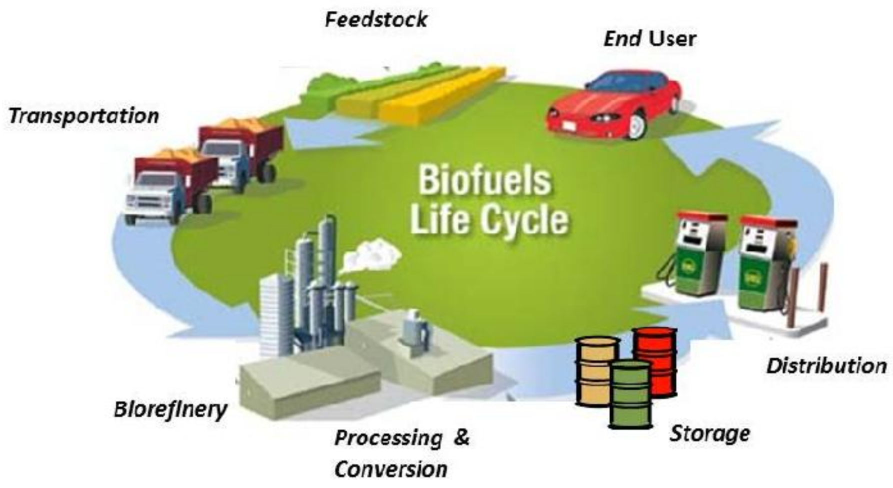
The cost, GHG savings and emissions performance of vehicles when using biofuels are analysed and compared with those of fossil fuels.

[12] Cross-compliance criteria for agricultural practices are only relevant for feedstocks cultivated within the EU (see Article 17(6) of the RED).

[13] Lignocellulosic material is any of a group of substances in woody plant cells consisting of cellulose and lignin (McGraw-Hill Dictionary of Scientific & Technical Terms).

[14] Upstream (or well-to-tank) emissions are the emissions associated with the production, processing, transmission, storage and distribution of the fuel, beginning with the extraction of raw materials and ending with the delivery to the site of use.

Figure 1: Life cycle of biofuels



1. BACKGROUND INFORMATION ON DIFFERENT BIOFUEL TYPES

KEY FINDINGS

- World production of biofuels has increased during the last decade, in particular between 2005 and 2010, owing to government policies promoting the use of biofuels in the transport sector.
- Policies supporting the use of biofuels have been set in over 50 countries. Blending mandates, in particular, have been introduced in 27 countries at national level and in 27 states/provinces.
- The EU is the largest producer, consumer and importer of biodiesel. The USA and Brazil are the world's leading producers and exporters of bioethanol. The EU is also a net importer of bioethanol. In 2012, global production of fuel ethanol reached 83.1 billion litres while biodiesel production reached 22.5 billion litres.
- Biodiesel makes up the major part of EU biofuel consumption in transport (78.2 % by energy in 2011) followed by bioethanol (20.9 % by energy in 2011).
- The number of biomethane plants has increased in recent years, but the use of biomethane in transport is still very insignificant (0.5 % in 2011) and its use is limited to a few Member States, mainly Germany and Sweden.
- Hydrotreatment of vegetable oils, used cooking oils or animal fats (HVO/HEFA) is a modern way of producing biobased diesel fuels of high quality which are highly compatible with existing fuel logistics, engines or exhaust after-treatment devices. It offers a solution to the increasing pressure to find fungible alternatives for fossil diesel fuels in transport (as well as other synthetic biodiesel substitutes).
- Advanced biofuels (second- and third-generation biofuels), such as those made from wastes and algae, lead to high GHG savings with a low risk of causing indirect land-use change. If they do not originate from dedicated energy crops grown on cropland, they do not compete directly for agricultural land for the food and feed markets, in contrast to first-generation biofuels.
- Policy support for advanced biofuels has stimulated the construction of the first commercial-scale advanced biofuels plants.
- Algae are likely to play an important role in third-generation biofuel production, and are recognised as the most promising advanced biofuels, considering their potential high yield and environmental benefits. However, production of algae-based biofuels is still at the research and development stage and additional innovation is needed.
- Any changes in EU law regarding biofuels are likely to shape the future development strategy for biofuels use in transport, including the rate at which advanced biofuels penetrate the market - which at the moment is still unclear.

Biofuels are liquid or gaseous fuels primarily produced from biomass[15]. Bioethanol and biodiesel are the most common biofuels used in transport worldwide. Other biofuels are also in use, such as pure vegetable oil and biogas[16], although with a more limited market penetration. Biofuels are normally referred to as first-, second- or third-generation biofuels. The main difference between the three generations of biofuels relates to the way each of them impact on specific parameters, such as:

- Is the feedstock edible?
- Is the feedstock a by-product of solid or municipal wastes?
- What approach will be followed for the production of the specific biofuel?

The most common approach is to label a biofuel as a ‘first-generation biofuel’ when the feedstock is generally edible. Second-generation biofuels are defined as fuels produced from a wide array of different feedstocks, ranging from lignocellulosic feedstocks to municipal solid wastes. Usually, ‘second-generation biofuels’ refers to biofuels that are being produced from waste-based materials (i.e. used cooking oils). Finally, third-generation biofuels are at this point related to algal biomass but can also to a certain extent be linked to the use of CO_2 as feedstock.

There is a difference between conventional and advanced biofuels in terms of feedstock and different generations depending on technology.

As regards feedstock, the European Sustainable Biofuels Forum considers the following biofuels to be advanced:

(1) Having low carbon dioxide emission or high GHG reduction,

(2) Demonstrating high sustainability,

(3) Originating from lignocellulosic biomass, municipal or industrial waste, residue streams or process by-products, algae, microorganisms.

In terms of technology, the following classification is commonly used for research programmes:

First-generation biofuels: bioethanol produced from sugar or starch via fermentation; biodiesel (fatty acid methyl ester) produced from esterification of vegetable oils, fats and waste streams; and biomethane produced from upgrading biogas or landfill gas.
Second-generation biofuels: alcohols and synthetic biofuels produced from lignocellulosic biomass or waste streams; hydrogenated vegetable oils or used vegetable oils; industrial residues;

Advanced biofuels or third-generation biofuels: biofuels produced from non-lignocellulosic biomass such as aquatic biomass, direct sugar and/or alcohol conversion to paraffinic biofuels, and those produced through microbial conversion and other microorganisms.

[15] Biomass is biological material derived from living, or recently living, organisms. It most often refers to plants or plant-derived materials. As a renewable energy source, biomass can either be used directly via combustion to produce heat, or indirectly after having been converted to various forms of biofuel.

[16] Biogas typically refers to a gas produced by the breakdown of organic matter in the absence of oxygen. It is a renewable energy source, like solar and wind energy, and can be produced from regionally available raw materials such as recycled waste.

1.1 First-generation biofuels

The production of first-generation biofuels is characterised by mature and well-established technologies.

1.1.1 Biodiesel

Biodiesel is mainly made from rapeseed (in the EU), soya bean and palm oil through transesterification

FAME (fatty acid methyl ester) biodiesel, the most common biofuel in the EU, is usually derived from vegetable oils and animal fats by a chemical process known as transesterification[17]. The process involves filtering the feedstock to remove water and contaminants, and then mixing it with an alcohol (usually methanol) and a catalyst. This causes the oil molecules (triglycerides) to break apart and reform into methyl esters (biodiesel) and glycerol, which are then separated from each other and purified. The process also produces glycerine, which can be used as animal feed and chemical feedstocks, and also has many other small-scale uses. The feedstock can be vegetable oil, such as that derived from oilseed crops (e.g. rapeseed, sunflower, soya bean, palm oil), used oil (e.g. frying oil) or animal fat. Methyl esters can either be blended with conventional diesel or used as pure biodiesel.

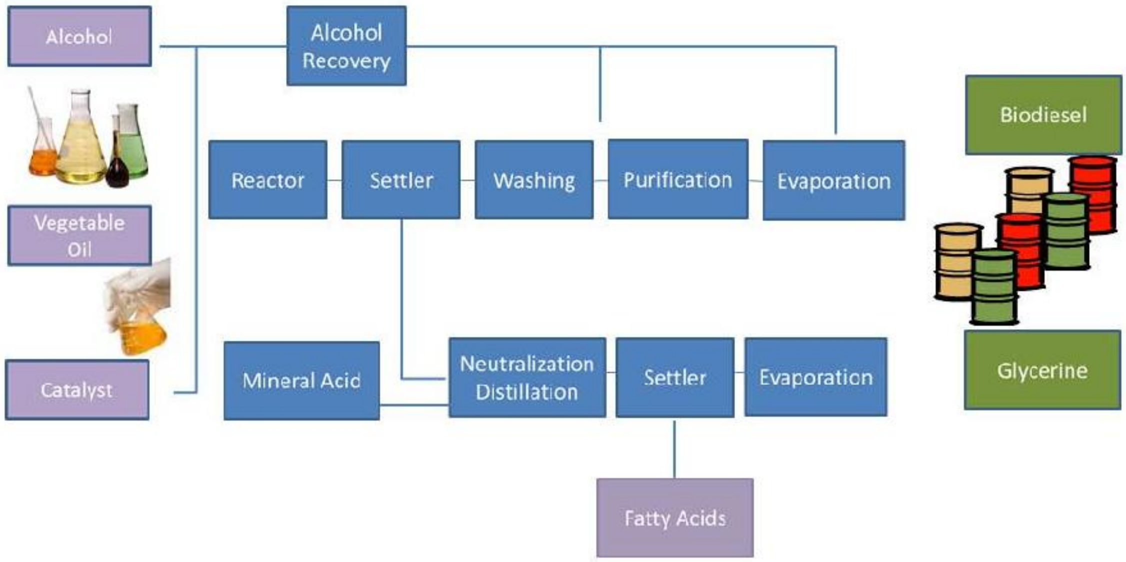
Soya bean is the main feedstock used for biodiesel production in the USA and Argentina, while rapeseed and sunflower are mainly used in Europe. Other feedstocks include palm oil and coconut (mainly in Indonesia and Malaysia) (EurObserv'ER, 2012; IEA 2011; IRENA, 2013). Since the feedstock of biodiesel may vary according to location, it is important to know how the various fatty acid profiles of the different sources can influence the properties of the fuel (Kousoulidou et al., 2012).

Blending of biodiesel with conventional fuels up to 7 % does not require engine modifications

Most biodiesel is blended with conventional fuel at different ratios. One of the major issues that concern the automotive and fuel industries is the fuel compatibility of diesel and biodiesel blends. This issue needs to be considered when using biodiesel in any particular engine. Generally, the effect of biodiesel on engines and after-treatment systems depends on the blend level used. Biodiesel use in blends up to 7 % does not require engine modifications in passenger cars (heavy duty vehicles are compatible with up to 30 % FAME; however they have difficulties meeting the EURO VI emission requirements), while some modifications on vehicle engines might be necessary when using pure biodiesel (see Chapter 3 for more details).

[17] Transesterification is the chemical reaction in which one ester is converted into another in the presence of a catalyst (acid or base catalyst). It is the main process in the production of biodiesel.

Figure 2: Simplified schematic of biodiesel production



1.1.2 Bioethanol, butanol, methanol and dimethyl ether

- Bioethanol

Bioethanol is made by fermentation and distillation of cereals and sugar-based crops

Bioethanol is the most widely produced biofuel globally. The largest producers are the USA, Brazil, the EU, China and India (IEA, 2012). First-generation bioethanol production is a well-established technology, based on a fermentation process followed by distillation. Bioethanol is produced from a wide variety of feedstocks. In Brazil, sugar cane is the preferred feedstock owing to its very high sugar content and fuel yield. In North America, about 200 production plants produce about 53 billion litres of ethanol annually from starch crops such as maize. Most European ethanol is produced using sugar beet and grains, while in China and India the main feedstocks used are maize and sugar-cane molasses respectively. Less popular bioethanol feedstocks include cassava (South-East Asia and China), sweet sorghum (China), and sweet potato (China). The cultivation of alternative sugar crops such as sweet sorghum opens up new possibilities in Europe, especially in hotter and drier regions such as southern and eastern Europe. Sweet sorghum requires less water or nutrients and has a higher fermentable sugar content than sugar cane as well as a shorter growing period.

By-products vary according to the bioethanol production method and the feedstock used. For example, ethanol from starchy crops produces useful livestock feed, typically in the form of dried distiller's grains with solubles (DDGS).

Bioethanol can be used at low blends (10 %) without the need to modify engines

Bioethanol can be used in petrol (gasoline) engines at low blends such as E10 (also known in Brazil and the USA as 'gasohol') – a mix of up to 10 % bioethanol and at least 90 % petrol – with no or little engine modification for most cars (around 85 %) circulating in the EU (and all cars manufactured after 2010). It can be supplied in the same way as petrol through existing retail outlets. Higher blends of bioethanol to petrol (such as E85 – 85 % of ethanol blend, or in pure form) require several modifications to engines.

Flexible fuel vehicles (FFVs) are commercialised in Brazil and Sweden and are becoming increasingly common in the USA. They can operate with pure ethanol, petrol, or any blend of the two.

Finally, bioethanol can also be used as a blend with diesel in diesel engines (also known as 'E-diesel'/ED95 fuel blends), or as a blend with biodiesel in diesel engines (also known as 'BE-diesel' fuel blends).

- Butanol

Butanol is an alcohol that can be used as a transport fuel. It is a higher member of the series of straight-chain alcohols, with each molecule of butanol (C4H10O) containing four carbon atoms rather than two as in ethanol.

Butanol was traditionally produced by acetone-butanol-ethanol (ABE) fermentation (the anaerobic conversion of carbohydrates by strains of Clostridium into acetone, butanol and ethanol). However, because of cost, relatively low-yield and sluggish fermentations, and problems caused by end-product inhibition and phage infections, ABE butanol could not compete on a commercial scale with synthetically produced butanol. Consequently, almost all ABE production has ceased as the petrochemical industry has evolved.

However, there is increasing interest in use of biobutanol as a transport fuel. Indeed, 85 % butanol/petrol blends can be used in unmodified petrol engines. Butanol can also be transported in existing petrol pipelines, and it produces more power than ethanol. Biobutanol can be produced from cereal crops, sugar cane, sugar beet, etc. It can also be produced from cellulosic raw materials.

In October 2013, specification ASTM D7862 was announced for blends of butanol with petrol at 1 to 12.5 % volume in automotive spark ignition engines. This specification covers three butanol isomers: 1-butanol, 2-butanol, and 2-methyl-1-propanol. It specifically excludes 2-methyl-2-propanol (that is, tert-butyl alcohol).

- Methanol

As the most basic alcohol, methanol is a desirable choice as a transportation fuel owing to its efficient combustion, ease of distribution and wide availability around the globe. Methanol is used in transportation in 3 main ways – directly as fuel or blended with petrol; converted into dimethyl ether (DME) to be used as a diesel replacement; or as a part of the biodiesel production process.

Methanol is an ideal fuel for transportation, in large part because of its efficient combustion and low cost compared to all other fuels. When combusted, reformulated petrol produces a number of harmful and toxic by-products that are reduced or eliminated by replacement with methanol. Emissions of unburned carbons and carbon monoxide are much lower when consuming methanol fuel, and methanol also greatly reduces NOx emissions.

Methanol also burns with almost no particulate matter (which can lead to respiratory problems such as asthma). Emissions from methanol fuel are also less reactive and create less ground-level ozone and smog.

Methanol is a high octane fuel that enables very efficient and powerful engine performance. Engines optimised for methanol are as much as 75 % more efficient than conventional petrol-fuelled engines. The power-producing qualities of methanol are well known and it is

used by several professional and amateur racing sanctioning organisations (e.g. the National Hot Rod Association and the United States Auto Club). However, at high levels, methanol fuel can lead to corrosion of certain materials commonly used in engines. In order to be able to run on high-level blends such as M-85 (a mixture of 85 % methanol and 15 % petrol), small modifications must be made to an engine to include methanol-compatible components. Low-level blends of methanol do not have adverse effects on a car's engine however, and can be used in cars today, where available, without any adverse effects. Methanol is also used as a denaturant for ethanol fuel in many countries.

- Dimethyl ether

Dimethyl ether (DME) and bioDME have a number of uses in products, and are most commonly used as a replacement for propane in liquid petroleum gas (LPG). They can also be used as a replacement for diesel fuel in transportation.

Today, DME is primarily produced by converting hydrocarbons via gasification into synthesis gas (syngas). Synthesis gas is then converted into methanol in the presence of a catalyst (usually copper-based), with subsequent methanol dehydration in the presence of a different catalyst (for example, silica-alumina) resulting in the production of DME.

Besides being able to be produced from a number of renewable and sustainable resources, DME also has an advantage over traditional diesel fuel because of its high cetane number – which measures the combustion quality of diesel fuel during compression ignition. By combusting more thoroughly, an engine customised to run on DME can achieve higher efficiency, better mileage and emission reductions.

1.1.3 Compressed biomethane

Biogas is composed mostly of methane and carbon dioxide produced from organic material. Like natural gas, it is a versatile fuel that can be used directly to generate electricity, to provide heat at low or high temperatures, or to power vehicles.

For transport, it can be upgraded, compressed and used in dedicated or flexible fuel vehicles (IRENA, 2013). However, biogas that has been upgraded to the quality of natural gas (biomethane), produced through anaerobic digestion in order to be used as gaseous biofuel in modified gas engines, needs additional cleaning. A number of upgrading technologies are used commercially (e.g. absorption and pressure-swing adsorption) and new systems using membranes and cryogenics are at the demonstration stage. Biogas is used mainly to produce heat and electricity and only a small amount is used as fuel gas for transport. However, the numbers show a clear increasing trend (REN21, 2013). Biomethane can also be converted into the renewable fuel hydrogen and (via GtL) into renewable jetfuel. A fuel quality standard for biomethane is being developed (standardisation work started in 2011 under the EC mandate M/475).

Biomethane is obtained from waste or crops

Biomethane can be made from manure and food waste, from purpose-grown crops, or from a mixture of these. In Germany, for example, there are many facilities using a large proportion of fodder-maize as the feedstock to produce biogas. This biogas is usually burnt for local heat and electricity, but is now increasingly being upgraded to biomethane with natural-gas-pipeline quality (typically 97 % methane). One can also compress biomethane for transport fuel, either instead of putting it into the gas grid, or afterwards (although in this case one can argue that it is still displacing natural gas, not petrol).

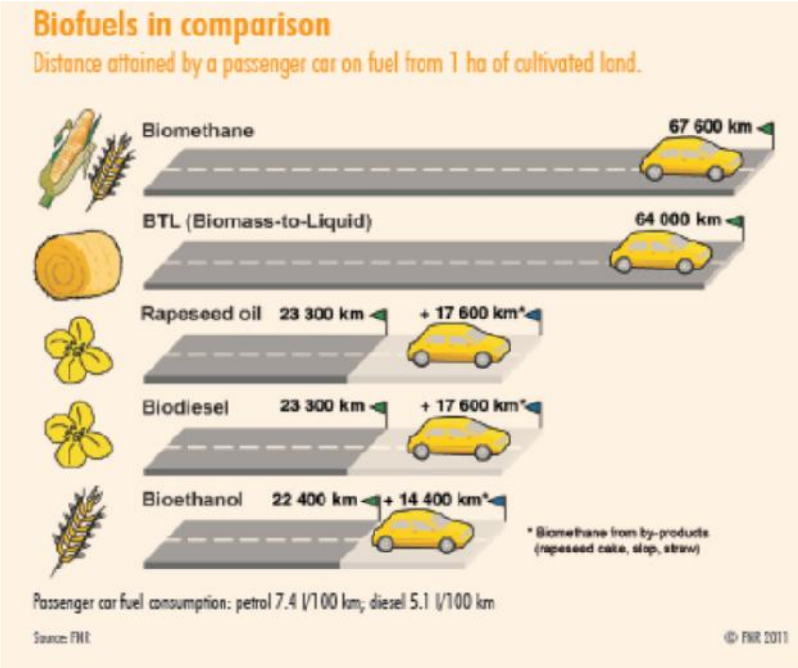
The energy yield of biomethane is higher than for other biofuels

Production of biomethane gives a higher energy yield per hectare of crop than either bioethanol or biodiesel (Figure 3). The residues can be readily recycled, along with the nutrients and trace elements, back to agricultural land, thereby helping to close the nutrient loop. On the other hand, in this case there is no by-product.

But methane leaks can be a problem

While methane is a high-value fuel, whether in the form of biomethane or natural gas, it is also a greenhouse gas with a global warming potential 25 times that of carbon dioxide (measured over 100 years). For that reason, a number of measures must be taken to minimise losses during production, storage and transport.

Figure 3: Comparison of energy yield per hectare of biofuels made by different processes



Source: FNR, 2012.

During 2012, in Germany the share of biomethane in natural gas increased from 6 % to more than 15 %, and the number of fuelling stations selling 100 % biomethane more than tripled, from 35 to 119 (Muller et al., 2013). Furthermore, 10 % of the natural gas vehicles in Germany used compressed biomethane fuel rather than compressed natural gas (CNG) (European NGV Statistics)[18]. In Sweden, 50 % of Stockholm city council's fleet of 800 cars ran on biomethane in October 2012[19].

The biogas sector is very diverse across Europe. Countries have structured their financial incentives to favour different feedstocks depending on their national priorities, i.e. whether biogas production is primarily seen as a component of waste management, as a means of generating renewable energy, or as a combination of the two. In any case, the future use of biogas in transport will depend on policy supporting actions.

[18] European NGV Statistics, www.ngvaeurope.eu/european-ngv-statistics.
[19] Reference: Stockholm City Fleet Now 98 % Green, 50 % Biomethane, ngvglobal.com, 4 October 2012.

Synthetic Natural Gas (SNG) is expected to be available soon. This is a second-generation form of gaseous methane fuel produced by gasification of biomass. The technology for SNG production is expected to become rapidly more widespread between now and 2020.

1.2 Second-generation biofuels

Second-generation biofuels are mainly obtained from woody crops and wastes/residues

Second-generation biofuels are produced from lignocellulosic biomass or woody crops, agricultural and forest residues, wood wastes, the organic part of municipal solid wastes (MSW) and energy crops. If made from forest or crop residues, they do not have to be grown on pasture or arable land and do not, therefore, compete with food supplies. Advanced biofuels also have the potential for much higher levels of production, very low GHG emissions and reduced volatility in production costs (IRENA, 2013).

Production technologies are more complex and expensive than for first-generation biofuels, but they are considered to be more sustainable providing land-use change does not occur. At the same time, second-generation biofuel production costs are more stable compared with first-generation biofuels owing to a much lower dependency on the feedstock price

First-generation biofuels are made from the sugars, starch and vegetable oils found in arable crops, which can be easily extracted using conventional technology. However, the processing of cellulosic feedstocks is more complex than processing sugar or starch-based feedstocks. Therefore, the production of second-generation biofuels requires more complex technologies to extract and process the fuel.

Compared with 'conventional' first-generation feedstock, the use of these materials would imply greater sustainability and less competition for land used for food and feed production, in particular if crop residues are used. However, where the lignocellulosic feedstock is to be produced from specialist energy crops grown on arable land, several concerns remain over competing land use – although energy yields in terms of gigajoule[20] per hectare (GJ/ha) are likely to be higher than if crops grown for first-generation biofuels are produced on the same land. One advantage is that in many cases energy crops can be produced on 'low-quality' or degraded land (IEA, 2008). Integrated and resource-efficient production systems (such as local enzyme production or production close to feedstock) and full use of the co-products (such as the 'biorefinery' concept) can contribute to cost reduction.

There can also be competition between the potential use of cellulosic materials for liquid biofuels and current (rapidly expanding) use for heat and power generation through combustion as solid biofuels.

Hydrotreatment of used oils has been proposed as an alternative to fossil fuels in transport

In the past few years, the hydrotreatment[21] of vegetable oils, animal fats or waste cooking oils has been proposed as an alternative process to transesterification (the conventional process to make biodiesel) for producing biofuels. Hydrotreatment of vegetable oils and

[20] 1 gigajoule = 10^9 joule. It is a standard unit of energy, used to indicate the energy content of biofuels (and fuels in general).

[21] Hydrotreating is a process that accomplishes the production of a higher quality fuel by removing the sulphur and nitrogen compounds and by saturating aromatics and other unsaturated compounds.

animal fats is a way of producing biobased diesel fuels of high quality with a high degree of compatibility with existing fuel logistics, engines or exhaust after-treatment devices. On the other hand, like second-generation Fischer-Tropsch diesel, hydrotreatment produces pure hydrocarbons (containing only carbon and hydrogen) which present fewer compatibility issues for engines (but need to be blended in order to meet the density parameter of the diesel fuel standard). As a consequence, HEFA/HVO (hydroprocessed esters and fatty acids, or, more simply, hydrotreated vegetable oil) are already being used in demonstration flights by commercial airlines.

Hydrotreatment has been proposed as a solution to the increasing pressure to find alternatives for fossil fuels in transport (Aatola et al., 2008). HVO/HEFAs are mixtures of paraffinic hydrocarbons and are free of sulphur and aromatics. The cetane number[22] of HEFAs is very high, and other properties are very similar to the gas-to-liquid (GTL) and biomass-to-liquid (BTL) diesel fuels produced by Fischer-Tropsch (FT) synthesis (Aatola et al. 2008, Kousoulidou et al. 2013).

Used cooking oil (UCO) is available in large quantities and is becoming widely exploited

Recently, used cooking oil (UCO) has been gaining ground as a feedstock for second-generation biofuel production via the hydrotreatment process. In general, the hydrotreatment of used/waste oils and animal fats has been seen as important for low-cost biodiesel production from recycled feedstocks (Kousoulidou et al. 2013; Yang et al., 2007). Large quantities of UCO are available. The US Energy Information Administration estimates that globally approximately 378 million litres (100 million gallons) are generated each day, and projections for 2020 are even higher (Radich, 2006). In the EU, it is likely that up to 1.6 million tonnes of UCO could realistically be recovered each year, providing all Member States have a well-developed UCO recycling network (see Appendix 1 for more details). According to Yang et al. (2007), large amounts of UCO were illegally dumped into rivers and landfills in several countries in the period covered by the report, causing environmental pollution. A more recent study (Paraiba et al., 2012) found that illegal disposal of UCO is still taking place. This increases the cost and the energy consumption of domestic waste-water treatment, as well as the GHG emissions associated with its biodegradation.

Recycling UCO as fuel for diesel engines would reduce such environmental degradation. According to Spottle et al. (2013), many countries have introduced legal restrictions on the use of UCO. UCO which has come into contact with meat falls under the EU Animal By-Products Regulation and cannot be processed into animal feed in the EU following the bovine spongiform encephalopathy crisis in the early 2000s. Such UCO can only be used to produce biodiesel and oleochemical products. In the USA, China, Argentina and Indonesia, the use of UCO to produce animal feed is permitted. In the EU, UCO which has been used only to cook vegetables (for example in large crisp factories) is still permitted for use in animal feed.

Given the incentives for second-generation biofuels made from waste, which are strongly increasing the market value of UCO, this feedstock became, in some instances, more attractive than fresh vegetable oil to make biofuels, but with a risk of fraud (fresh oil sold and declared as UCO). This market effect is detailed further in Appendix 1.

[22] The cetane number expresses the combustion quality of diesel fuel during compression ignition.

Second-generation biofuel production remains very low

Policy support for advanced biofuels – from lignocellulosic feedstocks based on biomass, such as wood and agricultural residues – has stimulated the construction of the first commercial-scale advanced biofuel plants, notably in Europe and the US. Advanced biofuels offer some clear advantages over conventional biofuels derived from food crops.

In 2012, US production of advanced biofuels from lignocellulosic feedstocks reached 2 million litres. It was anticipated that 36 million litres would be produced in 2013, driven partly by demand from the military (Hendon et al., 2012; REN21, 2013). These volumes, however, remain only a small proportion of the original US mandate under the Renewable Fuel Standard (RFS) that was subsequently waived (EPA, 2013). China also made progress on advanced biofuels in 2012, producing about 3 million litres of ethanol from maize cobs for use in blends with petrol. Europe has one commercial and several demonstration plants in operation but each has only produced small volumes to date (REN21, 2013).

1.3 Third-generation biofuels

Production of third-generation biofuels (mainly from algae) is still at the research and development stage

The most accepted definition of third-generation biofuels is 'fuels that are produced from algae-derived biomass'. This has a very distinctive growth yield compared with classical lignocellulosic biomass (Brennana and Owendea, 2010).

Algae-based fuels are likely to play an important role in third-generation biofuel production, as they are considered a sustainable feedstock for biofuels and bioproducts from biorefineries.

Many types of algae could be used: some cultivated specifically for biofuel production and some that are wastes collected from polluted waters. Production of biofuels from algae usually relies on the lipid content of the microorganisms. Species such as Chlorella are therefore targeted because of their high lipid content (around 60 to 70 %) (Liang et al., 2009) and their high productivity at 7.4 grams per litre per day (g/L/d) for Chlorella protothecoides (Chen et al., 2011). In addition, there are types of algae that contain high proportions of vegetable oil that could be used for biodiesel or HVO, and types that contain sugars and starch for ethanol production. Biomethane could also be produced, as could valuable co-products such as oils, proteins and carbohydrates.

Lipids obtained from algae can be processed via transesterification by the previously described biodiesel process or can be submitted to hydrogenolysis to produce kerosene-grade alkane that is suitable as a 'drop-in' substitute for conventional aviation fuel (Tran et al., 2010).

The potential oil yields (litre/hectare) for algae are significantly higher than yields of oilseed crops: theoretically, algae could produce around 45 000 litres of biodiesel/ha (compared with 1 500 litres of biodiesel/ha from rapeseed, 4 500 litres of biodiesel/ha from palm oil and 2 500 litres of bioethanol/ha from maize).

Biofuel production from algae is presently at the research and development stage, and uncertainty surrounds the economics of future commercial-scale algal production. According to IRENA (2013), production of advanced biodiesel from algae is only at the pilot stage, so costs for this option are even higher and more uncertain. It will take some time for reliable

data to emerge, owing to the numerous difficulties involved in scaling up process designs from pilot- and demonstration-scale projects.

Hydrogen is considered a promising alternative in the longer term (2030)

Hydrogen produced from biomass, which can be used to power vehicles via fuel cells or internal combustion engines, is sometimes considered to be another type of third-generation biofuel. Hydrogen is expected to play an important role in building a low-carbon economy in the longer term (2030) if low-temperature fuel cells fulfil their promise. At the moment, several different approaches to producing hydrogen are at the research and development stage and could potentially play a role in the future (Hamelinck, 2002; Claassen, de Vrije, 2009; Foglia et al., 2011). Pure hydrogen is very expensive to transport and store. Thus, it is only considered an interesting renewable fuel if it enables the use of fuel cells in transport, with a large efficiency gain. Biological generation of hydrogen (biohydrogen) technologies provide a wide range of approaches for generating hydrogen, including direct biophotolysis, indirect biophotolysis, photo-fermentations and dark fermentation. Biogas can also be transformed into hydrogen. Biological hydrogen production processes are found to be more environmentally friendly and less energy-intensive than thermochemical and electrochemical processes. However, they are still at the laboratory stage.

1.4 Global and European policies and objectives on biofuels

During the last decade, biofuel production has been stimulated by different government policies

To date, the production and use of biofuels have been driven by government policies in order to reduce oil dependency, increase the share of renewable energies and contribute to declining farm incomes. Common policies include biofuel production subsidies, biofuel blend mandates and tax incentives. Biofuel obligations/mandates have been identified in 51 countries (REN21, 2013). However, only a few regions, such as the EU and the USA, have dedicated policies in place to support biofuels (see Chapter 3.1.2).

1.4.1 Policies in major economies

The EU Member States plan to meet their renewable energy targets in transport predominantly through conventional biofuels, although advanced biofuels are perceived to have less impact on the environment and food markets

The main features of the two principal EU regulations on the production and use of biofuels are detailed in Box 1 above. Major instruments for supporting biofuel policies are blending mandates and tax exemptions (Member States are allowed to exempt biofuels from excise duties, or reduce these duties, through the Energy Tax Directive – 2003/96/EC). A variety of other, often complementary, policies also exist: grants to production facilities, promotion of dedicated biofuel vehicles and R&D funding (Cansino et al, 2012; Wiesenthal et al, 2009). In 2003, the Common Agricultural Policy (CAP) reform introduced a (now abandoned) crop premium for the production of energy crops (Sorda et al., 2010). This measure – together with the also discontinued set-aside rules – has played a role in developing the supply of biomass for biofuels. Although it does not set production targets and give direct support, the 'new CAP' for the period 2014-2020 could also provide an opportunity for supporting renewable energy and production of feedstock (Gumbert, 2013).

The National Renewable Energy Action Plans (NREAPs) have been submitted by the Member States to the European Commission as a mandatory requirement of the reporting mechanism established by the RED Directive. The NREAPs show that Member States plan to

meet the target of 10 % renewable energy in transport predominantly (in over 85 % of cases) through conventional biofuels, derived from cereals and other starch-rich crops, sugars and oil crops (ECN, 2011).

According to the Joint Research Centre's Institute for Energy and Transport (JRC-IET), 2013b, to meet the 2020 targets in the transport sector (see Box 1 above), renewable transport fuels should increase from 631 petajoules (PJ)[23] in 2010 to 1 346 PJ in 2020 – corresponding to total annual growth rates of 11.6 %. However, this will depend on changes in fuel consumption in the future, and the development of advanced biofuels and other renewable technologies. This challenging target raises questions regarding the efficiency of current policies to commercialise advanced biofuels. Although perceived as being more 'environmentally friendly' than conventional biofuels, their uptake has been relatively slow. In fact, several countries do not expect advanced biofuels to make any contribution in their transport sectors (Austria, Estonia, Greece, Lithuania, Luxembourg, Slovenia and the UK).

In 2022, 58.3 % of the US target for renewable fuels has to be met through advanced biofuels (GHG savings above 50 %)

In the USA, polices to support biofuels are of similar complexity to those in the EU, since the implementation of federal targets and policies varies from state to state. The USA started to move towards the use of biofuels in the 1990s as a way of reducing its dependence on imported fuels. In 2005, the US Energy Policy Act gave the government more power in regulating the biofuel industry, and strongly encouraged the use of biofuels such as ethanol and biodiesel. The Energy Independence and Security Act (EISA) of 2007 uses economic incentives, as well as production standards, to support biofuels.

In 2010, the updated Renewable Fuel Standard (RFS2) came into effect, incorporating changes mandated by the 2007 Energy Independence and Security Act (EISA). RFS2 requires total annual production of renewable fuel to have reached 136.3 billion litres by 2022. Conventional biofuels (maize starch ethanol) will be allowed to contribute 56.8 billion litres and they are required to reduce life-cycle GHG emissions in relation to life-cycle emissions from fossil fuels by at least 20 %.

Advanced biofuels must cover the remaining 79.5 billion litres. The biodiesel share of the advanced biofuels cannot be less than 3.8 billion litres and the GHG savings have to be at least 50 %, while the cellulosic biofuel share must be at least 60.6 billion litres (Lamers et al., 2011a; ICCT, 2010; ICCT, 2011) and they must reduce emissions by 60 %. The 50 % GHG emissions reduction requirement may be adjusted to a lower percentage (no less than 40 %), as may the 60 % threshold for cellulosic biofuels (minimum 50 %) (RFA, 2014).

In order to ensure the availability of feedstocks for biofuel production, the Biomass Crop Assistance Program (BCAP, 2008) was established to provide the framework for farmers to invest in biomass production. Financial support is determined via various mechanisms at either federal or state level.

Moreover, the American Jobs Creation Act introduced volumetric excise tax credits (VETC) for the blending of fuel ethanol and biodiesel, which represent the single largest subsidy for biofuels in the USA. Additional subsidies are provided in the form of capital investment

[23] 1 PJ (petajoule) = 10^{15} joule.

support via loans, grants and guarantees for the construction of biofuel plants, governmental investment in infrastructure for transport, storage, and distribution of biofuels, and crop subsidies (Sorda et al, 2010; Lamers et al., 2011a; Hess et al, 2010).

The USA is the largest producer of first-generation bioethanol and is also the leader in development and scale-up of advanced biofuels technologies

US corn ethanol has been subsidised on both the production and the consumption side. At times of sugar shortage, it is even cheaper on the market than Brazilian ethanol. The volumetric ethanol excise tax credit (VEETC) expired in 2011; however, various other subsidies still exist. The experience in first-generation technology has no doubt helped US industry to respond to the massive incentives to develop second-generation cellulosic ethanol plants, based mostly on corn stover. The tax credit for cellulosic biofuel production, set to expire at the end of 2012, has been extended by three years (Post, 2013).

Brazil has the most developed biofuel programme in the world based on the production of ethanol from sugar cane

The most developed biofuel programme in the world has been set up in Brazil. It was initiated by the oil crisis of the early 1970s, and by 1975 the National Alcohol Program Proàlcool had been introduced, offering government subsidies to the sugar cane and ethanol industry. Government support allowed large-scale investment in research and technology developments which perfected the transformation processes and lowered manufacturing costs. Bioethanol has been made in Brazil from sugar cane and used as a transport fuel for about 40 years, with continual improvements in technology. The technology used for bioethanol production from sugar cane has been continuously improved over the years and there are schemes to increase export of cogenerated electricity and to transform excess bagasse into animal feed.

Currently, there are no direct subsidies for ethanol production. However, the government maintains preferential treatment of the ethanol industry compared with petrol producers by means of preferential tax policies (Sorda et al., 2010; Lamers et al., 2011a; Walter, 2012).

The level of bioethanol consumption reached the equivalent of 50 % of petrol consumption, and production costs came close to the world price of petrol. However, in 2011-2012, bioethanol production fell by about 20 % and fuel prices increased to the point that the fuel was no longer attractive for vehicle owners. In response, the government reduced the minimum required ethanol blend in petrol from 24 % to 18 %–20 %, in order to reduce demand and avoid further price rises, and partly in response to poor sugar cane yields in recent years (REN21, 2013). In 2013, the government put the blend requirement in petrol back up to 25 % (EIA, 2013). Brazil has also introduced a 5 % mandate for biodiesel (REN21, 2013). Biodiesel production is encouraged through purchase auctions (for the local market) and tax reductions/exemptions. Total or partial tax exemptions are granted to biodiesel producers which support family farming (Walter, 2012). Moreover, producers are shielded by a 14 % biodiesel import tariff through Mercosur's common external tariff (Lamers et al., 2011a; USDA, 2013).

As leading biodiesel exporters, Argentina and Indonesia have also introduced blending requirements for biodiesel and bioethanol

Argentina and Indonesia, as leading biodiesel exporters, have also implemented biofuel blending mandates. Argentina has introduced blending requirements of 7 % for biodiesel and 5 % for ethanol (REN21, 2013). Biodiesel and ethanol sold on the internal market are granted financial support. Producers can opt for the reimbursement of the value added tax

or accelerated depreciation on capital investments. On the other hand, biofuel exports are not granted direct financial incentives but receive favourable export tariffs in comparison with feedstock (Sorda et al., 2010). In 2013, the Indonesian Government introduced mandatory biodiesel blending requirements of 10 % in the transport and industry sectors and 20 % in the electricity sector as from January 2014. The mandatory blending rates for biodiesel are foreseen to reach 20 % in transport and industry and 30 % in the electricity sector by 2020. Bioethanol share is expected to reach 2 % in the transport sector and 10 % in the electricity sector by 2016, and 20 % in both sectors by 2025. (MMER, 2014). Additional support is provided to biofuel infrastructure developments, plantation improvement, training and R&D (Lamers et al., 2011a).

Nine provinces in China have set a 10 % ethanol mandate for transport. The Indian Government has set ambitious biofuel targets for 2017, but implementation is still slow

China's biofuel policies focus on ethanol production. According to REN21 (2012), the country has set a 10 % ethanol mandate for transport in nine provinces. Although diesel vehicles are the predominant form of mechanised transport in China, the government's promotion of biodiesel production and use has been negligible because China is a net importer of vegetable oils (Sorda et al., 2010).

In India, the National Biofuel Policy has set the ambitious target of replacing 20 % of the fossil fuels consumed in the transport sector with biofuels (bioethanol and biodiesel) by 2017. However, only in 2012 did India begin enforcing a national 5 % mandate for ethanol that was initially intended to be applied in 2006 (REN21, 2013).

1.4.2 Blending limits of biofuels in the EU

Three standards cover the quality of automotive fuels and are periodically updated

The quality of automotive fuels in the EU is specified by standards developed by the European Committee for Standardization (CEN[24]). The first set of standards for automotive fuels was adopted by all Member States in September 1993. Three standards cover the quality of automotive fuels: EN 590 for diesel, EN 228 for petrol, and EN 589 for automotive liquefied petroleum gas (LPG).

Regarding biofuels, EN 14214 is the European standard that describes the requirements and test methods for fatty acid methyl esters (FAME), the most common type of pure biodiesel. EN15376 applies to ethanol as a blend component and EN5376 applies to E85 in the EU. The standards are periodically updated to reflect changes in specifications, such as the mandatory reductions in sulphur content.

TS15940 lays down technical specifications for paraffinic diesel fuels (including HVO and BTL). A fuel quality standard for biomethane for use in the transport sector and injection into natural gas pipelines is being developed under the Commission's mandate M/475. Another mandate for development of a standard for pyrolysis oils was issued in 2013. The jet fuel standards between the USA and the EU are coordinated (and identical): ASTM

[24] The ''Comité européen de normalization'' (CEN) is a major provider of European standards and technical specifications. It is the only recognised European organisation (Directive 98/34/EC) for the planning, drafting and adoption of European standards in all areas of economic activity, with the exception of electrotechnology (CENELEC) and telecommunications (ETSI).

D1655 and (UK/Europe) Def Stan 91-91 – specifications for drop-in concept of semi-synthetic jet fuel including biofuel.

According to the FQD Directive, biodiesel can be blended with conventional market diesel fuel in blends up to 7 % v/v (B7 corresponds to 7 % of biodiesel over total volume of fuel), while Member States can permit higher blends on their markets. Ethanol can be blended with conventional market petrol fuel in blends up to 10 % v/v ratio (E10 corresponds to 10 % of ethanol over total volume of fuel).

1.4.3 Policy context on evaporative emissions

Ethanol has higher volatility than petrol and can create problems with volatile emissions

In addition to stipulating provisions on the maximum sulphur content of petrol and diesel fuel from 2005, Directive 2003/17/EC required the European Commission to review a number of other fuel specifications for possible amendments. One specific requirement is to assess the current petrol summer vapour pressure limits of ethanol directly blended into petrol. Ethanol has a higher volatility than petrol and this can create problems with volatile emissions, especially in the summer months.

The Fuel Quality Directive 98/70/EC defines petrol volatility classes and their vapour pressure limits. Each Member State applies one or more volatility classes depending on its climate and on the season. All petrol, including petrol/ethanol blends, must comply with the relevant dry vapour pressure equivalent (DVPE) limits. A vapour pressure waiver for petrol/ethanol blends has been proposed in order to facilitate the spread of ethanol usage and consequently to increase its market penetration. Ethanol is normally distributed separately from petrol, and only blended at the terminal into road tankers for final distribution. However, there is concern about the possible consequences of the increased vapour pressure of the petrol/ethanol blends on evaporative emissions from petrol cars (technical details about evaporative emissions are further explained in Chapter 3.2.5).

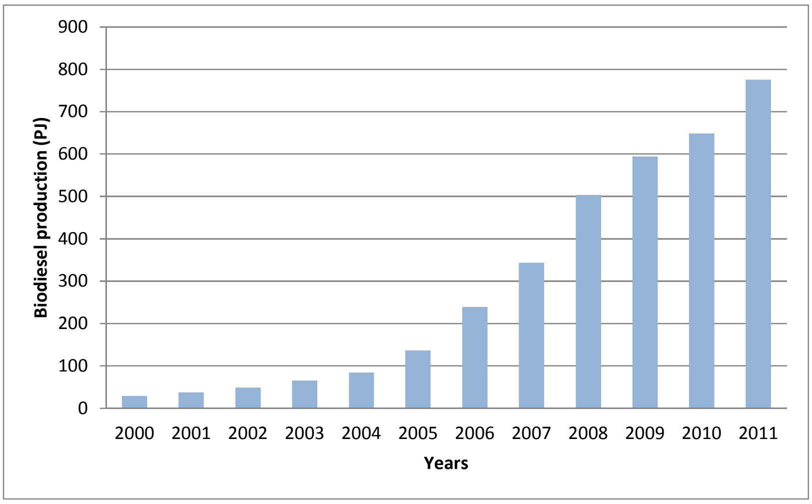
1.5 Production, consumption, imports and exports of biofuels and feedstocks

1.5.1 Biodiesel

Biodiesel production has increased continuously in the last decade, reaching 776 PJ in 2011

Global biodiesel production increased continuously from 29 PJ in 2000 to 776 PJ in 2011 (source: US Energy Information Administration – EIA).

Figure 4: Global biodiesel production (PJ)



Source: EIA.

The EU represents 44 % of global biodiesel production, but is also the main importer of biodiesel. The main exporting countries are Argentina, Indonesia and Malaysia

The EU is the largest producer of biodiesel (Table 1). The EU is also the main market for biodiesel exports, and the main exporting countries are Argentina, Indonesia and Malaysia. Other countries mainly produce biodiesel for domestic use.

Table 1: World biodiesel production (PJ)

Year	2005	2006	2007	2008	2009	2010	2011
EU27[1]	103.3	181.5	247.3	298.1	332.7	356.8	339.6
US [2]	11.4	31.4	61.4	84.8	64.6	43.0	121.3
Argentina[3]		0.7	7.1	27.5	45.0	68.5	91.4
Brazil[4]		2.3	13.4	38.6	53.3	79.0	88.5
Indonesia[2]	0.4	0.8	1.9	3.8	11.5	15.4	38.4
Thailand[2]	0.8	0.8	2.3	14.8	20.2	21.1	19.6
Colombia[5]			0.3	2.7	10.9	13.9	17.8
China[2]	1.5	7.7	3.8	9.6	11.5	11.5	15.0
South Korea[2]	0.4	1.7	3.3	6.1	9.6	12.5	12.1
Philippines[2]	0.4	0.8	1.2	2.1	3.8	4.6	4.8
Australia[4]	0.4	0.8	1.4	1.9	3.5	2.9	3.3
Malaysia[4]		2.3	5.2	9.3	9.3	4.1	2.1

Sources: [1]Eurostat; [2]EIA; [3]USDA; [4]ANP; [5]USDA.

The EU biodiesel trade balance for the period 2005-2011, based on Eurostat data, is presented in Table 2. In 2011, the majority of EU imports came from Argentina (52.9 PJ) and Indonesia (40.5 PJ) (Eurostat).

Table 2: EU biodiesel trade balance (PJ)

Year	2005	2006	2007	2008	2009	2010	2011
Production	103.3	181.5	247.3	298.1	332.7	356.8	339.6
Imports*	3.2	14.9	46.6	92.7	106.7	142.6	190.4
Exports*	48.2	98.6	104.6	95.3	52.6	80.1	80.3
Stock change	-0.5	-0.3	-4.6	-4.7	0.8	-0.4	-3.1
Recycled							4.1
Consumption in transport	57.5	97.1	178.0	286.3	381.2	416.0	445.6

Source: Eurostat-Energy *Includes intra-EU trade.

According to the European Biodiesel Board (EBB)[25], EU biodiesel production amounted to 320.2 PJ in 2011. EBB data are considered to be more up to date than Eurostat data because they are based on annual industry interviews (Lamers et al., 2011a). However, EBB statistics do not include consumption and trade data, which is why the Eurostat figures have been used in Table 2.

The US biodiesel trade balance for the period 2005-2011 is presented in Table 3. The majority of biodiesel imports came from Canada, and export was oriented predominately to Canada and Norway (EIA).

Table 3: US biodiesel trade balance (PJ)

Year	2005	2006	2007	2008	2009	2010	2011
Production	11.4	31.4	61.4	84.8	64.6	43.0	121.3
Import	1.1	5.6	17.6	39.5	9.7	2.9	4.5
Export	1.1	4.4	34.1	84.9	33.3	13.2	9.2
Stock change	NA	NA	NA	NA	3.7	-0.2	5.4
Consumption in transport	11.4	32.7	44.9	39.6	40.8	32.9	111.2

Source: EIA 2013.

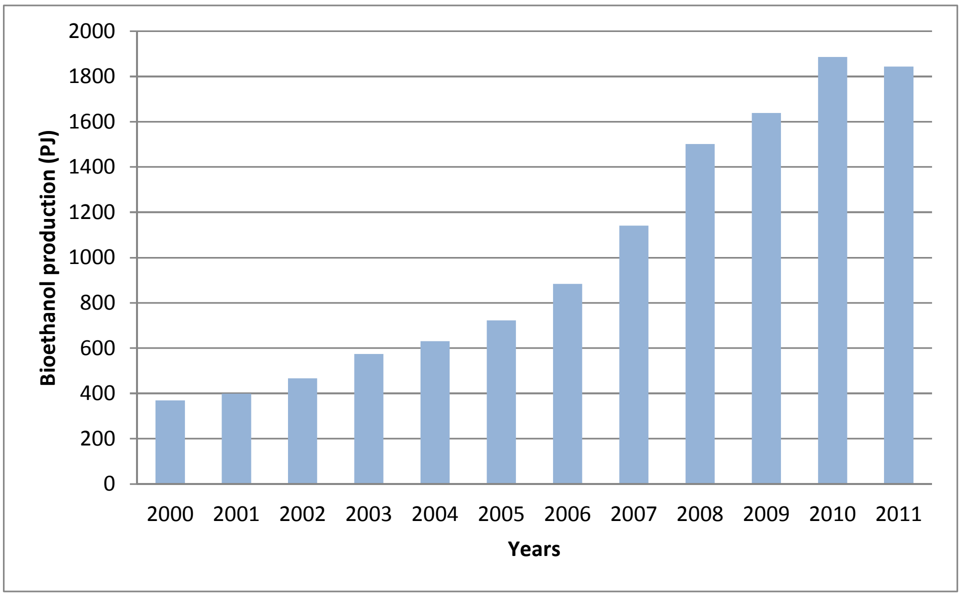
1.5.2 Bioethanol

Bioethanol production has also increased continuously since 2000. Global production was 1 844 PJ in 2011

World bioethanol production increased from around 370 PJ in 2000 to 1 844 PJ in 2011 (EIA).

[25] The EBB represents the major European biodiesel producers.

Figure 5: Global bioethanol production (PJ)



The USA and Brazil are the main producers and exporters of bioethanol. Exports mainly go to the EU, Canada, Japan and South Korea.

The USA is the world's leading producer of bioethanol, followed by Brazil. The main bioethanol producers are presented in Table 4. The USA and Brazil are also the leading exporters of bioethanol. The EU is a net importer of bioethanol, while other countries produce it predominantly for domestic use.

Table 4: World bioethanol production (PJ)

Year	2005	2006	2007	2008	2009	2010	2011
USA[1]	314.5	393.5	525.3	749.9	881.1	1 071.2	1 122.0
Brazil[2]	338.9	376.9	477.1	585.5	546.8	582.5	482.6
EU27[3]	19.6	30.9	42.2	60.1	74.8	83.0	73.3
China[1]	25.6	34.6	35.4	42.5	45.7	45.7	48.2
Canada[1]	5.4	5.4	17.0	18.5	24.7	29.6	37.0
India[4]		40.4	51.0	45.8	22.8	32.4	35.8
Thailand[1]	1.5	2.7	3.7	7.0	8.5	9.3	11.0
Australia[1]	0.5	1.6	1.7	3.1	4.3	8.0	9.3

([1]EIA; [2] UNICA; [3]Eurostat; [4]USDA).

The EU bioethanol trade balance for the period 2005-2011, based on Eurostat data, is presented in Table 5. In 2011, the majority of bioethanol came from Brazil and Guatemala (Eurostat – International trade; Lamers et al., 2011a).

Table 5: EU bioethanol trade balance (PJ)

Year	2005	2006	2007	2008	2009	2010	2011
Production	19.6	30.9	42.2	60.1	74.8	83.0	73.3
Imports*	4.7	7.6	14.7	27.7	39.3	53.8	66.8
Exports*	1.2	1.3	6.1	10.2	16.9	17.1	17.5
Stock change	0.0	-0.1	-1.0	-0.1	-0.4	-0.1	-0.9
Consumption in transport	23.4	35.8	49.6	76.3	96.6	118.7	121.1

Source: Eurostat-Energy. *Includes intra-EU trade.

According to ePURE (an organisation representing the European renewable ethanol industry at EU level), EU bioethanol production was 93.5 PJ in 2011. ePURE data are considered to be more accurate than Eurostat data because they are provided by the industry itself (Lamers et al., 2011a). However, ePURE statistics do not include consumption and trade data, which is why the Eurostat figures have been used in Table 5.

The US bioethanol trade balance for the period 2005-2011 is presented in Table 6. In 2011, the majority of US bioethanol exports went to Canada (27.8 PJ) and to EU countries (6.0 PJ to the UK and 5.5 PJ to the Netherlands). Imports were predominately from Brazil (36.1 PJ). Additionally, some Brazilian bioethanol came via Caribbean countries owing to the Caribbean free trade agreement with the USA (EIA).

Table 6: US bioethanol trade balance (PJ)

Year	2005	2006	2007	2008	2009	2010	2011
Production	314.5	393.5	525.3	749.9	881.1	1071.2	1122.0
Net trade	10.9	58.9	35.4	42.7	16.0	-30.8	-82.4
Stock change	-1.5	10.8	6.0	12.5	8.0	4.6	1.0
Consumption in transport	310.7	420.0	529.3	746.9	849.5	989.2	993.0

Source: EIA, 2013.

Brazil's bioethanol exports are presented in Table 7. In 2012, most Brazilian exports went to the USA (37.8 PJ) and to countries in the Caribbean Basin Initiative (CBI: 6.9 PJ). Furthermore, some exports went to the EU (1.6 PJ), South Korea (2.8 PJ) and Japan (2.2 PJ).

Table 7: Brazil bioethanol exports (PJ)

Year	2007	2008	2009	2010	2011	2012
US	13.5	31.9	5.7	6.5	13.8	37.8
CBI	15.4	27.6	16.3	3.1	6.9	6.9
EU27	18.0	30.9	18.4	8.8	2.4	1.6
South Korea	1.2	3.9	6.6	8.0	6.4	2.8
Japan	5.6	5.5	5.9	5.5	5.9	2.2
India	0.0	1.4	7.8	1.2	0.6	0.0
Nigeria	1.8	2.1	2.5	1.7	1.6	1.1
Total	58.0	107.5	69.5	40.0	41.3	55.4

Source: UNICA.

1.5.3 Other liquid biofuels

Use of other liquid biofuels (predominately pure vegetable oils) in transport has been decreasing in the EU since 2006, reaching 17.7 PJ in 2011

EU data for 'other liquid biofuels' are presented in Table 8. In 2011, production reached 66.7 PJ and consumption in transport 17.7 PJ. The category includes liquid biofuels used directly as fuel, not included in Eurostat's biopetrol or biodiesel categories (mainly pure vegetable oils).

Table 8: EU other liquid biofuels (PJ)

Year	2005	2006	2007	2008	2009	2010	2011
Production	69.1	124.0	118.2	99.4	87.6	117.0	66.7
Imports*	11.5	13.3	1.8	4.5	7.1	7.7	9.5
Exports*	0.0	0.0	0.0	0.0	0.0	0.2	1.2
Stock change	0.0	0.0	0.0	0.0	0.0	-0.1	0.1
Consumption in transport	49.3	97.8	54.8	37.6	21.0	22.4	17.7

Source: Eurostat-Energy *Includes intra-EU trade.

1.5.4 Biomethane

Biomethane capacities have increased in recent years, reaching 292 926 normal cubic metres per hour (Nm^3/h) in 2013. However, use of biomethane in transport is still limited, mainly to Sweden and Germany.

A growing number of large-scale operations exist to purify biogas and create biomethane, which can subsequently be added to the natural gas grid or used in transport. Global installed capacity for biomethane in 2013 was 292 926 Nm^3/h[26]. The EU had the largest share (69 %), led by Germany with 51 % of global capacities (Table 9) (IEA Bioenergy, Task 37).

Production is estimated at 50 % of installed capacities, which amounts to 146 463 Nm^3/h. The use of biomethane as a transport fuel is still marginal in most countries, with the exception of Sweden and Germany. The reported consumption of biomethane in transport, based on data from the Natural & bio Gas Vehicle Association (NGVA Europe), is presented in Table 10.

[26] Normal cubic metres per hour is a measure of flow rate. It is equal to one cubic metre under ''normal'' conditions, defined as 0°C and 1 atmosphere (101.3 kPa).

Table 9: Biomethane capacities

Country	No of plants	Installed capacity (Nm^3/h)
Germany	117	148 186
USA	14	81 600
Sweden	56	28 025
The Netherlands	21	16 720
Spain	1	4 000
Japan	6	2 400
Switzerland	15	2 225
Austria	10	2 210
South Korea	4	1 710
Canada	3	1 600
France	3	1 300
Norway	3	1 250
Iceland	1	700
UK	3	650
Denmark	1	300
Finland	3	50
Total	261	292 926

Table 10: Biomethane consumption in transport (PJ)

Country	Year	Consumption
Sweden	2013	2.911
Germany	2013	1.908
Switzerland	2011	0.156
France	2011	0.075
Iceland	2012	0.071
Norway	2012	0.067
Finland	2013	0.033
Hungary	2013	0.001

1.5.5 Biofuels in the EU

Biodiesel represents the major part of EU biofuel consumption (76 %) followed by bioethanol (20 %)

Production of biodiesel and bioethanol expanded rapidly in the EU between 2005 and 2010. However, the rate of expansion is expected to slow or, in the case of biodiesel production, reverse. Data on biofuels in the EU for 2011 are presented in Table 11. Final energy consumption in road transport in the EU 28 in 2011 was 12 421 PJ (Eurostat, 2013).

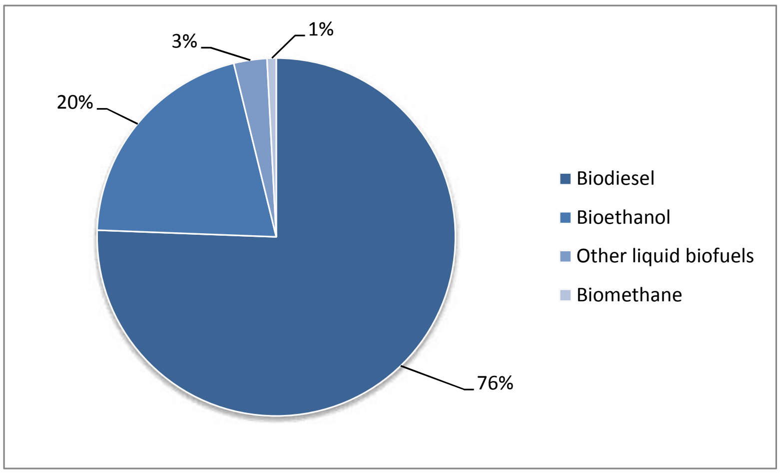
Table 11: Biofuels in the EU in 2011

	No of plants	Capacity (PJ)	Production (PJ)	Consumption (PJ)
Biodiesel[1,2, 3]	256	822.8	339.6	445.6
Bioethanol[1,3]	68	165.1	73.3	121.1
Other liquid biofuels[3]			66.7	17.7
Biomethane[*4,5]	215	61.0	30.5[**]	4.9

([1]USDA; [2]EBB; [3]Eurostat; [4]IEA; [5]NGVA Europe) [*]Based on the data from 2011 to 2013; [**]Estimated as 50 % of total capacity).

Biodiesel accounted for 76 % of the biofuels consumed in the EU transport sector in 2011, while bioethanol accounted for 20 % (Figure 6).

Figure 6: Share of each type of biofuel consumed in the EU transport sector in 2011



1.6 Biofuel projections

Projection studies for biofuels project the future by referring to models, frameworks and expert opinions based on historical trends, patterns of resource use and known technologies. Such projections are useful for informing short- and intermediate-term food security, agricultural development, land use and energy policy decisions. They also contribute to estimates of GHG emissions. In addition, changes to the relevant European rules would automatically shape the future development strategy for the use of biofuels in transport, including the rate at which advanced biofuels penetrate the market. It is still unclear how quickly this will happen, so different projection estimates are being generated.
According to the 2012-2021 Agricultural Outlook of the Organisation for Economic Cooperation and Development and the United Nations Food and Agricultural Organisation (OECD-FAO), global biodiesel production is expected to increase to almost 1 400 PJ by 2021. The EU will remain the largest producer and user of biodiesel. Other significant players are projected to be Argentina, the USA, Brazil, Thailand and Indonesia. Biodiesel trade is projected to increase only slightly, with Argentina remaining the major exporter (OECD-FAO, 2012).

Global bioethanol production is projected to increase to over 3 800 PJ in 2021. The three major producers are expected to remain the USA, Brazil and the EU, followed by China and

India. Brazil will remain the major bioethanol exporter, while global trade will increase from about 4 % to about 7 % of global production by 2021 (OECD-FAO 2012).

According to OECD-FAO 2012, the share of biodiesel produced from vegetable oil in global biodiesel production is expected to decrease by 10 % over the projection period, down to 70 % in 2021. 16 % of global vegetable oil production should be used to produce biodiesel by 2021. Second-generation biodiesel production is projected to increase slightly, mainly coming from the EU. Coarse grain will remain the dominating ethanol feedstock (44 %), followed by sugar cane (34 %). Cellulosic ethanol is projected to reach a global share of almost 9.5 % and will be produced predominately in the USA (OECD-FAO, 2012).

The IEA analyses suggest that biofuels may have to play an important role if the world is to make meaningful reductions in carbon dioxide emissions, and reduce reliance on crude oil at costs similar to those of petrol and diesel in the medium term. According to the IEA, it will be vital to create internationally aligned sustainability certification schemes for biofuels to ensure a positive environmental and social impact, and create an international market for sustainable biofuels. The IEA emphasises the importance of continuing to support advanced biofuels research, development and demonstration, and provide sound support mechanisms to ensure that the new technologies reach full market deployment. Under this scenario, demand for biofuels would increase rapidly, reaching approximately 760 million tonnes of oil equivalent (Mtoe) or 32 exajoules[27] (EJ) in 2050 – a share of 27 % of total transport fuel. This roadmap identifies major barriers, opportunities and policy measures for policymakers, industry and financial partners to accelerate research, development, deployment and demonstration (RDD&D) efforts for sustainable biofuel technologies and ensure sustainable feedstock provision on both national and international scales.

At the European level, growth in consumption of biofuels was steady in the European Union in 2012, rising to almost 14.4 Mtoe (million tonnes of oil equivalent) despite the uncertain political context (EurObserv'ER, 2013). However, according to the same source, the growth in the biofuels market was uneven across the European Union in 2012: consumption increased in 14 countries but decreased in 10. Likely causes were the economic crisis, which prompted some countries to reduce their imports, and uncertainties associated with forthcoming European legislation. These findings indicate that all biofuel projections depend on the political and economic status of each Member State, so the level of uncertainty can be quite high.

According to declarations by the Member States in the NREAPs, only 2.7 Mtoe – about 1 % of the target of the RED – will come from advanced biofuels in 2020[28].

[27] 1 EJ (exajoule) = 10^{18} joule.

[28] Policymakers are discussing how to further incentivise the development and market penetration of advanced biofuels, for example by introducing sub-targets specifically for these biofuels within the existing 10 % target of the RED (see discussions about the ''ILUC policy proposal'' COM(2012)0595 in Box 3).

2. IMPACT OF BIOFUELS ON AGRICULTURE

KEY FINDINGS

- The increase in European biodiesel production has had a significant impact on world vegetable oil markets, and biodiesel is responsible for most of the increase in European vegetable oil demand from 2001 to 2011.
- Cereals used for ethanol in the EU are only a small part of the total market. Most feedstock used by EU ethanol factories is domestically produced.
- The overall effect of biofuels on the EU livestock industry is roughly neutral.
- Throughout the past decades, more than half of the increased world crop production has come from yield increase; however, long-term data suggests a slowdown in yield growth rates in recent decades, especially in developed countries.
- Land-use change induced by the increase in biofuel feedstocks demand is one of the main concerns of the impact of conventional biofuels. Land-use change can be direct (when crops for biofuel are grown on uncultivated land) or indirect (when the use of agricultural land for biofuel pushes other agricultural production into natural ecosystems).
- There is significant land-use change owing to the marginal extra biofuels demand in the EU, and most of this land-use change will take place outside Europe.
- It is estimated that indirect land-use change (ILUC) emissions due to EU biofuel policy are higher for biodiesel oilseed crops than for ethanol feedstocks.
- Biofuels may have a role in the shift towards higher agricultural commodity prices. Forward-looking studies suggest that the EU biofuel policy will have a relevant impact on world prices of oilseeds and vegetable oils and a marginal impact on ethanol feedstocks prices.
- The impact of biofuel production on biodiversity depends on the feedstock used, changes in land use, and the management practices applied. In the future, increased land use and unsustainable consumption of resources could have a negative impact on biodiversity.
- Increased biofuels demand will increase the use of freshwater resources. Water used in biofuel production will increase competition for water resources, which could pose a problem in regions that already experience high levels of water stress.
- The main technology options for waste/residues (agricultural or forest residues, municipal or industrial wastes) are: combustion (heat, power and electricity), fermentation to bioethanol, anaerobic digestion for biogas.
- Agricultural residues account for more than 25 % of the technical potential of biomass in the EU, while forestry residues account for another 23 %.
- The potential of straw and primary forest residues is forecasted to more than double between 2010 and 2020.
- Resource efficiency and the need for robust GHG savings incentivise the use of biomass residues such as manure, straws and logging residues.

2.1 Overall effects of biofuels on crop markets

In order to understand the effects of biofuels on agriculture, it is necessary to know which feedstocks go into which biofuels, and to track trade and commodity prices. This knowledge will be needed later to assess economic consequences and indirect land-use change.

The effects depend not only on the crops that go directly to the EU biofuel factories, but also on the impact on the overall crop markets. For example, when a product such as rapeseed oil is diverted from food use to biofuel, this affects the imports and production of all vegetable oils, and even of other crops. Economic models are needed to understand these processes properly. Analysis of historical data also gives some robust indications[29].

2.1.1 The effect of biodiesel on the markets for oilseed and vegetable oil

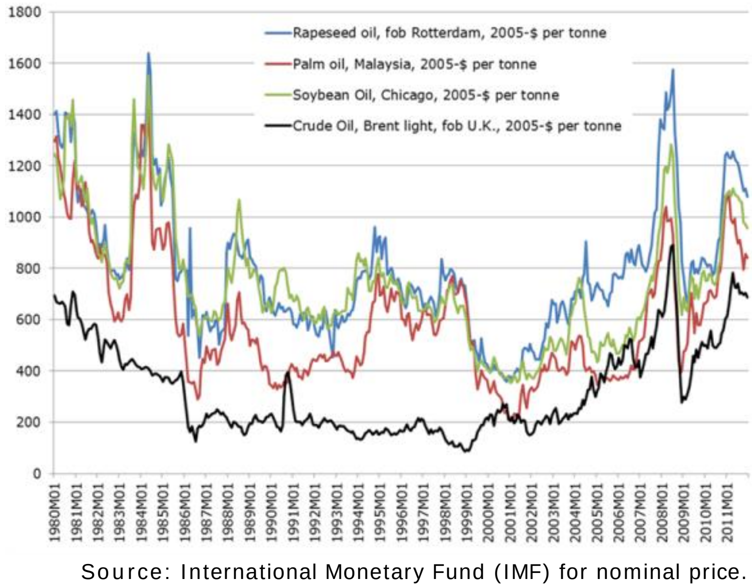
In 2011 EU biodiesel required 20 % of the world's traded vegetable oil

Biodiesel currently represents roughly 76 % of the biofuels used in EU transport. Almost all of this is made from vegetable oil, and in 2011, European biodiesel consumption required about 12 million tonnes of feedstock. That equals the total vegetable oil produced from EU crops, for all uses, or 20 % of the world's traded vegetable oil[30]. It follows, therefore, that EU biodiesel use has an impact on world markets for oilseed and vegetable oil, in particular in the EU.

Real vegetable oil prices rose against trend when extra demand from EU biodiesel appeared

Like other major agricultural commodities, the historical trend of inflation-corrected vegetable oil prices has been downward since records began, with only temporary spikes owing to bad harvests and wars. Agriculture has been able to increase supply fast enough to satisfy the steady increase in demand owing to growth in population and prosperity. However, as shown in Figure 7, there has been a strong rise in world vegetable oil prices since 2002, against the historical trend. This time period corresponds to the relatively sudden rise in demand from EU biofuels. In Section 2.3 we discuss to what extent this was a causal relation.

Figure 7: Inflation-adjusted world prices of vegetable oils and crude oil (normalised to the purchasing value of the US dollar in 2005)



Source: International Monetary Fund (IMF) for nominal price.

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29 The main European biofuels organisations (such as the European Biodiesel Board (EBB) or the European Ethanol Association (ePURE)) do not provide specific statistics on the quantity of feedstocks used to produce the corresponding amount of biofuels. The main sources of data available on the feedstocks used for biofuel production in the EU are the Foreign Agricultural Service of the US Department of Agriculture (USDA) in its annual report on EU biofuels (USDA, 2012), and 2010 consumption data from a study carried out by a consortium of institutes headed by Ecofys for the European Commission (Ecofys, 2012).

30 Traded vegetable oil has been calculated by summing world vegetable oil exports according to USDA-FAS statistics.

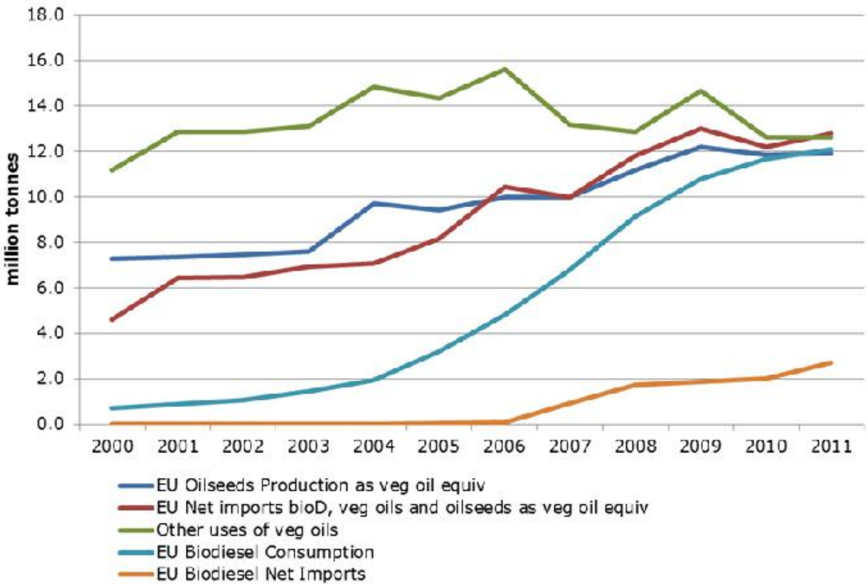
Vegetable oil prices are strongly connected to each other and, since 2005, to the price of crude oil

Vegetable oil prices are very closely correlated to each other (Fry, 2009; Malins, 2013). This reflects the fact that one vegetable oil can easily substitute another in many applications. Consequently, it is necessary to examine the effect of biodiesel production on the vegetable oil market as a whole, not just on the immediate feedstocks supplying the biodiesel factories.

Furthermore, the authors have confirmed the observation of others: until 2005 there was a weak and mainly supply-driven link between agricultural commodity and the energy market (Serra and Zilberman, 2013), while since 2005 this correlation has been strongly positive. A lot of research has been carried out on the impact of biofuels on food prices and fossil fuel prices (see Section 2.3).

The use of biodiesel led to the largest share of increase in EU vegetable oil demand between 2001 and 2011

Figure 8: Historical rise in demand for vegetable oils for EU biofuel, compared with the rise in supply from EU crops and from imports[31]



Source: FAOstat for oilseeds and vegetable oils production and trade; US Department of Agriculture (USDA) 2012 and European Biodiesel Board (EBB) for biodiesel production and consumption; oilseeds converted to vegetable oils using JRC data used in RED calculations).

Figure 8 shows the rise in demand for vegetable oils for EU biofuels. It shows that imports and domestic vegetable oil production increased together, while demand for other uses continued to rise slightly until about 2006 and then declined.

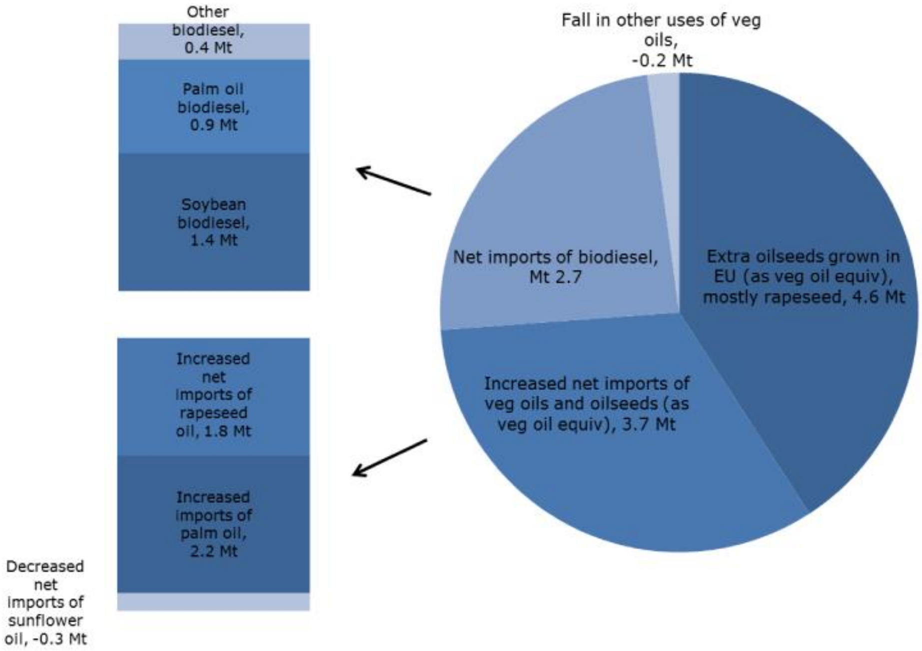
57 % of the increase in EU vegetable oil demand was supplied by imports

Figure 9 shows a breakdown of the sources contributing to the extra vegetable oil that supplied the increase in EU demand between 2001 and 2011. This chart shows the change

[31] In this graph we have converted EU oilseeds production to veg. oil-equivalents, and (for the red line) summed imports in the form of oilseeds (as veg. oil-equivalent), vegetable oils and finished biodiesel. In existing literature, vegetable oils and oilseeds are shown separately, which confuses interpretation. The orange line shows imports of finished biodiesel, which is also included in the total net imports shown by the red line.

in total EU net imports related to vegetable oils, whether in the form of oilseeds, vegetable oil or biodiesel. The tonnes of biodiesel and vegetable oil can simply be added. However, to make the oilseed quantity addable, we have converted the tonnes of oilseeds to 'veg. oil equivalents' by multiplying by the fraction of vegetable oil each oilseed produces when crushed in the oil mill.

Figure 9: Sources of extra vegetable oil that supplied the increase in demand in the EU between 2001 and 2011



Note: All figures are in vegetable oil equivalents[32]. The top bar chart shows a breakdown by crop of the imports of biodiesel, and the lower one of imports as vegetable oil and oilseeds. 'Other biodiesel' includes biodiesel of unclear origin, which may also include some palm and soya bean biodiesel. There was almost no change in net imports of soya-bean-equivalent oil apart from biofuel.

Source: FAOstat for oilseeds and vegetable oils production and trade; USDA 2012 and EBB for biodiesel production and consumption; Lamers (2011b) for biodiesel imports from different feedstocks; oilseeds converted to vegetable oils using JRC data used in RED calculations.

57 % of the extra vegetable oil demand from 2001 to 2011 was met by increased net imports, and 41 % by increased EU oilseeds production. This result was roughly predicted by economic models, including modelling of the European Simulation Model (ESIM) of biofuels proposals by the European Commission (DG AGRI) (as analysed in Appendix 3 of JRC, 2008).

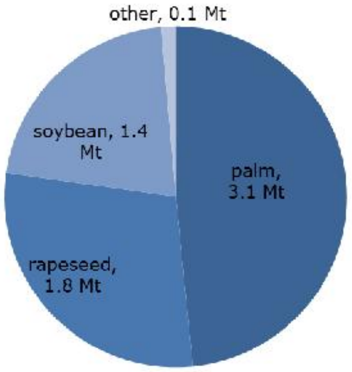
Almost half the increase in net EU vegetable oil-related imports came from palm oil

The following figure shows an alternative breakdown of the total change in net EU imports, this time by crop. The vegetable-oil-equivalent contributions of different crops have been added, for all forms of imports (biodiesel, vegetable oil or oilseed). About half came from palm oil. The change in soya bean oil imports was negligible. In 2001, the EU was a net exporter of rapeseed oil and rapeseed, but by 2011 it had become a large net importer.

[32] Vegetable oil equivalents for oilseeds have been calculated by multiplying the tonnes of oilseeds by the fraction of vegetable oil each produces when crushed in the oil mill.

The elimination of these initial net exports contributes about 30 % to the rise in net imports of vegetable-oil-related products until 2011.

Figure 10: The contribution of different crops to the rise in net imports of EU vegetable-oil-related products, from 2001 to 2011, in the form of biodiesel, oil, or oilseed-as-vegoil-equivalent (million tonnes)

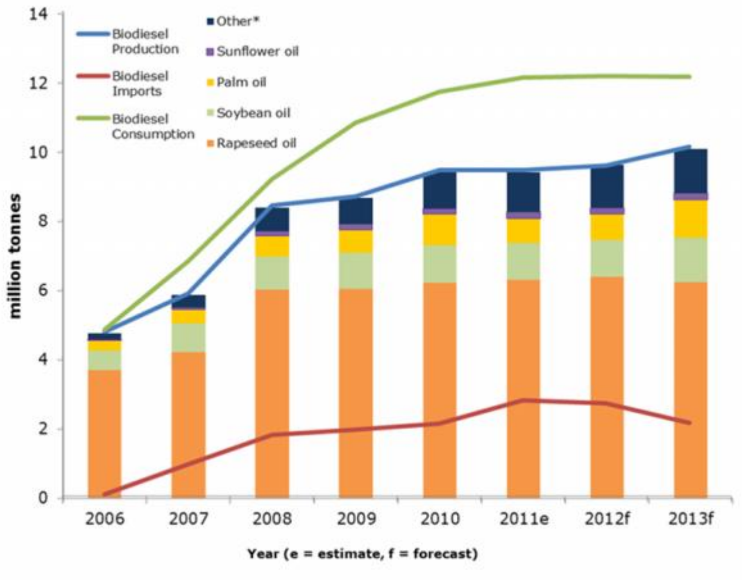


Source: FAOstat for oilseeds and vegetable oils production and trade; USDA 2012 and EBB for biodiesel production and consumption; Lamers (2011b) for biodiesel imports from different feedstocks; oilseeds converted to vegetable oils using JRC data used in RED calculations.

In non-biofuel uses, palm oil increased as rapeseed oil fell

The increase in EU palm oil use came about in spite of rapeseed oil making up most of the direct feedstock consumed by EU biodiesel factories (see Figure 11). About 1.6 million tonnes of palm oil biodiesel were consumed in the EU in 2011[33].

Figure 11: Direct feedstock mix for EU biodiesel production in EU27 (thousands of tonnes)



* Recycled vegetable oils, animal fats and other.
See Figure 8 and Figure 9 for the agricultural and trade impact of biodiesel.
Sources: USDA, 2012, which uses data from Foreign Agricultural Service (FAS) posts; Global Trade Atlas (GTA); European Biodiesel Board (EBB). Note: data for feedstock use are not available and the figures above are estimates by EU FAS posts.

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33 EU palm oil imports (including as finished biodiesel) rose by 3.1 Mt (Figure 10), but in 2011 only about 0.7 Mt of this was used for biodiesel (Figure 11), and another 0.9 Mt was imported as finished palm biodiesel (Figure 11).

From the three figures above it appears that:

- EU palm oil for non-biofuel uses increased by 1.5 Mt from 2001 to 2011.
- Rapeseed oil used directly for biodiesel (Figure 11) increased more than the net imports of rapeseed oil (in all forms: Figure 10). Therefore, all the increase in net imports of rapeseed oil can be ascribed to biodiesel demand, while its other uses declined by 0.5 Mt.
- All the increase in net soya bean oil imports from 2001 to 2011 was in the form of finished biodiesel (Figure 9), so this was also not for other uses.
- The effects of other types of vegetable oil are small (Figure 10).

Therefore, the increase in EU net vegetable oil imports for uses other than biodiesel between 2001 and 2011 was mostly made up of palm oil. This is an important consideration, because the expansion of oil palm plantations has been associated with major releases of greenhouse gas (from drained tropical peatland: see also Box 4 in this chapter) and loss of biodiversity.

Palm oil is the cheapest major vegetable oil. It sells at a discount to other major oils because of its high saturated fat content and the extra costs of handling an oil that solidifies at room temperature. Its share of the non-biofuels market in the EU would probably have increased to some extent even without the competition from biodiesel, which increased EU rapeseed oil prices. However, the share of palm oil in non-biodiesel vegetable oil consumption has expanded much more in the EU than in developed countries which do not make much biodiesel[34].

Therefore, it seems likely that part of the rise in palm oil use in the EU, for non-biodiesel use, has been to replace rapeseed oil diverted from other uses to biofuel.

The direct use of palm oil for biodiesel is currently limited by fuel quality standards

Although palm oil is the cheapest vegetable oil, its direct use for conventional biodiesel production is implicitly limited by EU biodiesel standard EN 14214:2012 (biodiesel from animal fats and tall oil from Scandinavian wood-pulp mills is similar). In practice, palm oil-based biodiesel does not meet winter EN14214 cold-flow standards selected by countries in northern Europe: this constrains the use of 'conventional' biodiesel from palm oil[35]. It is, however, possible to meet this standard by using a feedstock mix of rapeseed oil, soya bean oil and palm oil, and this mostly determines the present feedstock mix[36]. Palm oil and soya bean oil constituted 12 % and 10 % of the total EU biodiesel production respectively in 2010.

[34] Between 2001 and 2011, the share of palm oil in non-biodiesel consumption rose from 23.5 to 40 % in the EU, from 2.1 to 8.6 % in the USA and from 13 to 18 % in Russia (data from USDA). Thus the share rose by 16.5 % in the EU, 6.5 % in the USA and 5 % in Russia.

[35] A similar constraint applies to soya-bean-based biodiesel which does not comply with the iodine value prescribed by the standard.

[36] The actual situation is complex as Member States can define their own cold flow limits, thus allowing flexibility in the amount of palm oil which can be blended.

HVO/HEFA biodiesel could increase the use of palm oil

'Conventional' biodiesel refers to fatty acid methyl esters (FAME) produced by simple transesterification of vegetable oil. However, there is a growing production of deep-hydrogenated vegetable oil (HVO/HEFA), including from factories in South-East Asia. The deep hydrogenation process is slightly more expensive, but can make high-quality biodiesel from almost any vegetable or animal oil.

HVO/HEFA biodiesel is not subject to the blending limitations of conventional FAME (except density parameters that apply to EU diesel standards). Increasing world hydrogenation capacity is therefore likely to increase the amount of biodiesel made directly from palm oil, a cheap resource, if that is allowed by sustainability standards.

'Other' feedstocks of biodiesel are limited by supply

Compared to rapeseed oil or palm oil, animal fats and used cooking oil (and cottonseed oil) are limited by supply, and certainly there is not enough animal fat available for biodiesel production to be seriously limited by fuel cold flow requirements applied in some Member States. A number of them[37] allow biodiesel from used cooking oil and category 1 animal fats[38] to count double against the mandates of the RED. This has the effect of significantly increasing the use and hence the price of used cooking oil. There are instances of certified UCO exceeding the price of rapeseed oil. This has led to fast-increasing imports and the suspicion of fraud in some cases.

The effect on the price of animal fat has been less significant, because factories need hygiene licences to handle it. Member States have the prerogative to incentivise the use of animal fats (also of higher category) for biodiesel. However, most of them do not make this choice as these fats could then be diverted from other high-value uses in the oleochemicals and feed industry, or be replaced with palm oil.

The effects of expanded vegetable oil demand on other crops

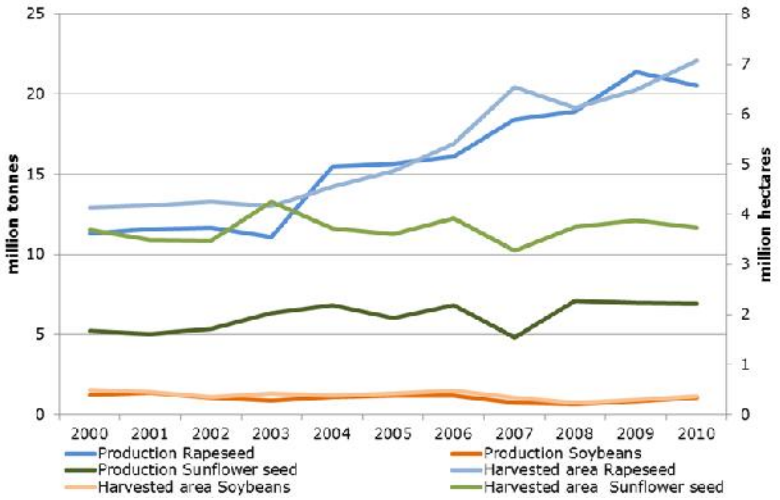
Figure 12 shows that the increase in EU production of rapeseed since 2001 has been achieved by expanding the harvest area: there has been no significant increase in yield[39]. As the total European harvested area has slightly fallen since 2001, rapeseed must have replaced other crops. There are no statistics available to indicate which crops have been directly replaced, but cereals (80 % of the EU harvested area) are likely to have been impacted and, as a result, European cereals exports have probably been reduced.

[37] Austria, Denmark, Finland, France, Germany, Ireland, the Netherlands and the UK.

[38] Category 1 animal fats are the lowest grade which cannot be used for feed or food.

[39] It is possible that improvements in farming technology have been countered by the negative effects on yield of growing rapeseed more frequently in a crop rotation.

Figure 12: Production and harvested area of oilseeds in EU-27



Source: FAOstat.

Figures from EC-DG AGRI 2013 confirm that over the past 20 years land use has increased significantly only for oilseeds. This is notably due to the increasing use of rapeseed oil to produce biodiesel (see paragraph 2.2.1 for more details on land use development in the EU).

2.1.2 Effect of bioethanol on cereals and sugar markets

Cereals used for ethanol in the EU are only a small part of the total market; the impact is therefore difficult to assess

By 2012, ethanol production had grown to consume 37 % of the US coarse grain[40] crop (FAO 2012). However, ethanol production in the EU only uses about 3.6 % of the total cereals produced. This is because EU ethanol production is much smaller than EU biodiesel production, while EU (and world) cereals production is much greater than vegetable oil production.

This means the effects of EU cereal ethanol production on the cereals market are much smaller than the effects of annual yield variations and agricultural policy changes. As a result, they cannot be distinguished by simple historical analysis, but only by applying agro-economic models. These generally predict that part of the extra cereals for ethanol (compared to a baseline without ethanol) come from imports (or reduced exports), part from increased domestic production and part from reduced consumption for food and animal feed. This point is examined further in the section on indirect land-use change modelling.

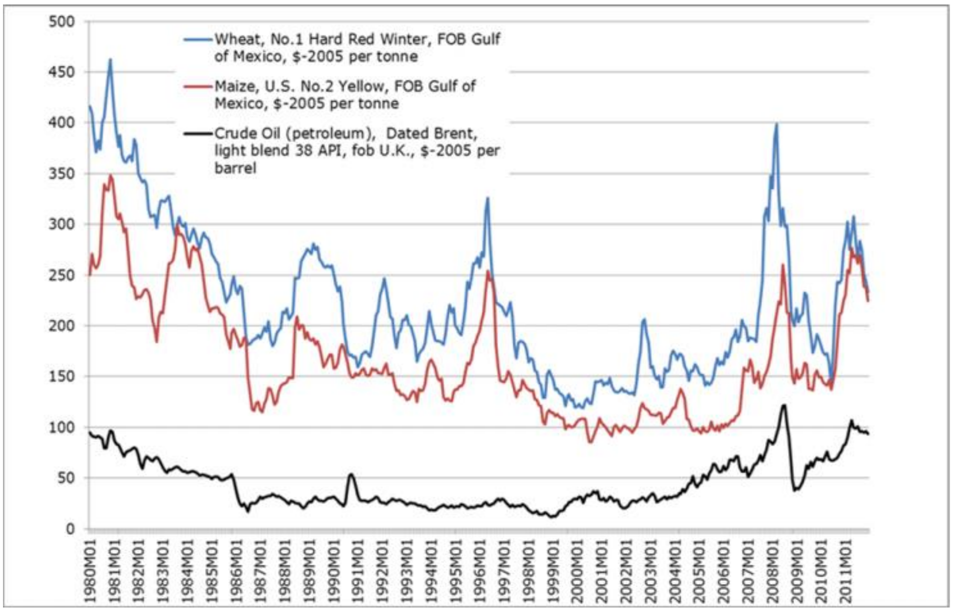
Cereal prices are strongly connected to each other and, since 2005, to the crude oil price, with US maize ethanol providing the link

Cereals can easily replace one another in many applications, in particular animal feed and ethanol manufacture. As a result, global cereals prices are closely linked. Real cereals prices have been generally falling since the agricultural revolution, but started rising again in about 2002, when US ethanol production started to absorb significant quantities of maize (now reaching about 40 % of US production). There was weak correlation with oil prices until about 2005, but since then the observed correlation is strong, particularly when the oil

[40] Coarse grains: all cereals except wheat, in the context of biofuels.

price is high. This is consistent with the ability of the US maize ethanol industry to pay for maize feedstock (Tyner, 2009; Baffes and Haniotis 2010).

Figure 13: Inflation-adjusted world prices of wheat, maize and crude oil (normalised by JRC to the purchasing value of the dollar in 2005)



Source: International Monetary Fund (IMF) for nominal prices.

The effect of ethanol on the EU sugar market is masked by changes in support policy

Ethanol production uses about 10 % of the EU sugar beet crop, in contrast to typically more than 50 % of Brazilian sugar cane. However, the reform of the EU sugar regime has been so profound that it is impossible to see the effects of sugar beet ethanol solely by applying historical analysis. The area under cultivation for sugar beet fell by 40 % from 2000 to 2010, but production decreased by only half this figure[41].

EU sugar producers are assigned a quota of production at guaranteed minimum prices. However, in order to ensure that all the subsidies are used, farmers usually grow too much. Ethanol production is from the out-of-quota ('C' sugar) sugar beet, which is sold at a lower world market price.

Ethanol can be co-produced with sugar

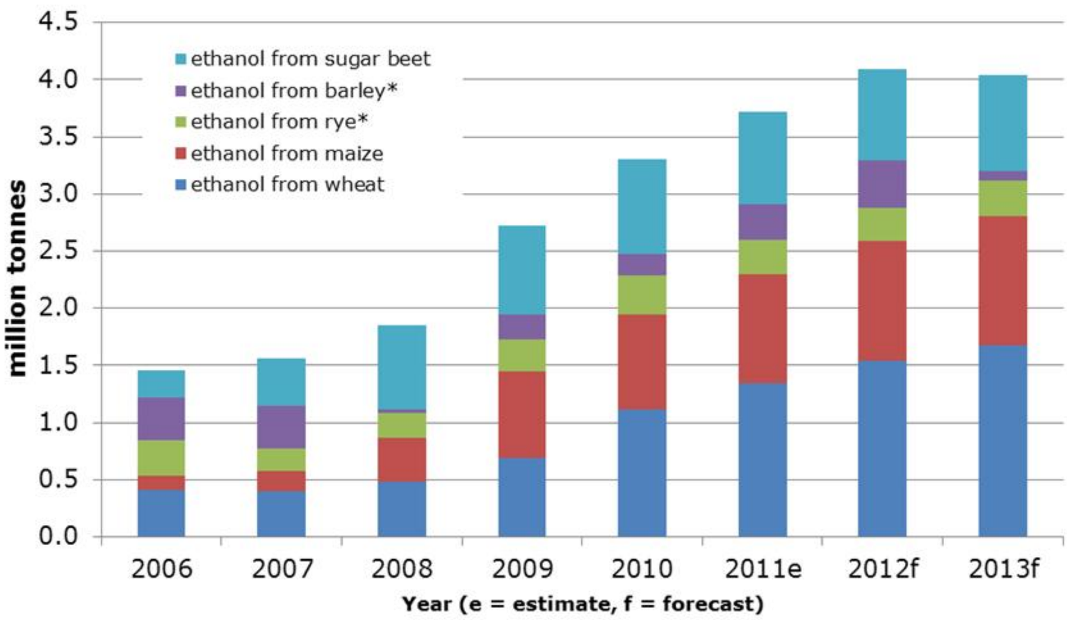
The whole of a sugar beet can be used for making ethanol (including the tops, which contain a substance that interferes with crystallisation of sugar). It is also possible to make ethanol from the low-quality grade of molasses left as a by-product after three stages of sugar crystallisation. Another possibility that offers some process synergies is to co-produce sugar and ethanol, by making ethanol from the residue left after a single sugar crystallisation stage. Sugar beet pulp is a minor by-product of all sugar beet processing.

[41] ''The EU provided a minimum price to growers of sugar beet for a specified quota until 2006. The EU price levels were three times higher than world market prices in 2006 and the Union lost a case in the World Trade Organisation Appellant Body, which forced the EU to alter their regime. The new system brought into force on 1 July 2006 was designed to reduce quotas, not through compulsory quota cuts, but hoping the weaker, less competitive producers would fall away by accepting the incentives to restructure. Thus, less productive areas were taken out of cultivation without decreasing the overall production at the same level'' (Practical Law Publishing Limited, 2013).

Most feedstock of EU ethanol factories is domestically produced

About 20 % of EU ethanol was imported in 2010, including almost 10 % from Brazil (Ecofys 2012). According to the European ethanol association (ePURE), almost 100 % of EU-produced ethanol came from domestically produced feedstock, although Ecofys (2012) reports small shares of imported wheat and maize from the US, Ukraine and Switzerland. ePURE says that about two thirds of EU-made ethanol comes from cereals, although USDA (2012) estimates that the figure is now 79 %. Practically all the rest of EU-made ethanol comes from EU-produced sugar beet or its by-products. The ratio of cereals to sugar beet varies in response to the price of cereals and the yield of sugar beet.

Figure 14: Feedstock used for bioethanol production in EU-27



* assuming yield of ethanol from barley and rye is the same as for wheat
Source: USDA 2012 converted to ethanol on the basis of JRC data used in RED calculations.

Among cereals, wheat is mainly used in north-western Europe and maize in central Europe and Spain. Rye is used as feedstock for bioethanol production in Poland, the Baltic region and Germany, while barley is mainly used in Germany and Spain. In north-western Europe and in the Czech Republic, sugar beet is the main source for bioethanol production (USDA 2012).

2.1.3 Effect of by-products on the animal feed market

The overall effect of biofuels on the EU livestock industry is probably roughly neutral

It is not the quantity of animal feed coming out of biofuel factories that is significant, but the overall effect on the feed market. The by-products of biofuels add to the EU's supply of food for animals. However, a lot of biofuels are made from feedstock that otherwise would all have been used for feed (see Appendix 2 for an estimate of the total animal feed by-product produced by EU biofuels factories).

Feedstock demand for ethanol production competes with animal feed in the cereals market

The most suitable cereals for ethanol production, such as feed-wheat and maize, have high starch and low protein contents. These are also the preferred cereals for animal feed, since higher-quality proteins are available more cheaply in soya bean meal than through higher-protein cereals. The starch (and tiny sugar) component of the cereals is converted to ethanol. The rest, including all the protein, is returned to the animal feed market as dried distiller's grains with solubles (DDGS).

Use of cereals for ethanol could either increase or decrease animal feed supply

In the EU, the conversion of cereals to ethanol creates competing effects:

1. If feed cereals are diverted to ethanol use, their starch content (digestible energy) is removed from the feed market but the total protein going into feed remains unchanged[42].

2. If additional cereals for ethanol are grown on land otherwise occupied by other crops, the DDGS by-product from the ethanol factory is added to the feed market, but the feed from crops that are replaced is lost.

Two other possibilities exist, which have not yet occurred significantly in the EU:

3. Additional EU cereal grown for ethanol on former pasture land would add DDGS to the feed supply. However, some feed from the pasture would be lost, and soil carbon emissions would result from the land-use change.

4. Additional EU cereal grown on natural land, such as forest land, would add DDGS to the feed supply with no compensating loss of feed. However, a large emission of soil carbon would occur.

Making biodiesel from oilseeds could also either increase or decrease animal feed supply

Similar arguments apply to oilseeds for biodiesel, which sends the oilseed meal by-product to the feed supply. Again, imported vegetable oil for biodiesel has no direct effect on the animal feed market, whereas production in the EU has different possible effects:

1. Diverting EU-produced vegetable oil from food to biodiesel use would create no extra feed because the oilseed would in any case have been crushed.

2. Replacing other EU crops with oilseeds would create extra oilseed meals for the feed market, but the feed-value of the replaced crop would be lost.

The other two possibilities (which do not seem so important, historically) correspond to points 3 and 4 above (cereals for ethanol).

If biofuels come from the existing crop area, they generally reduce EU animal feed supplies

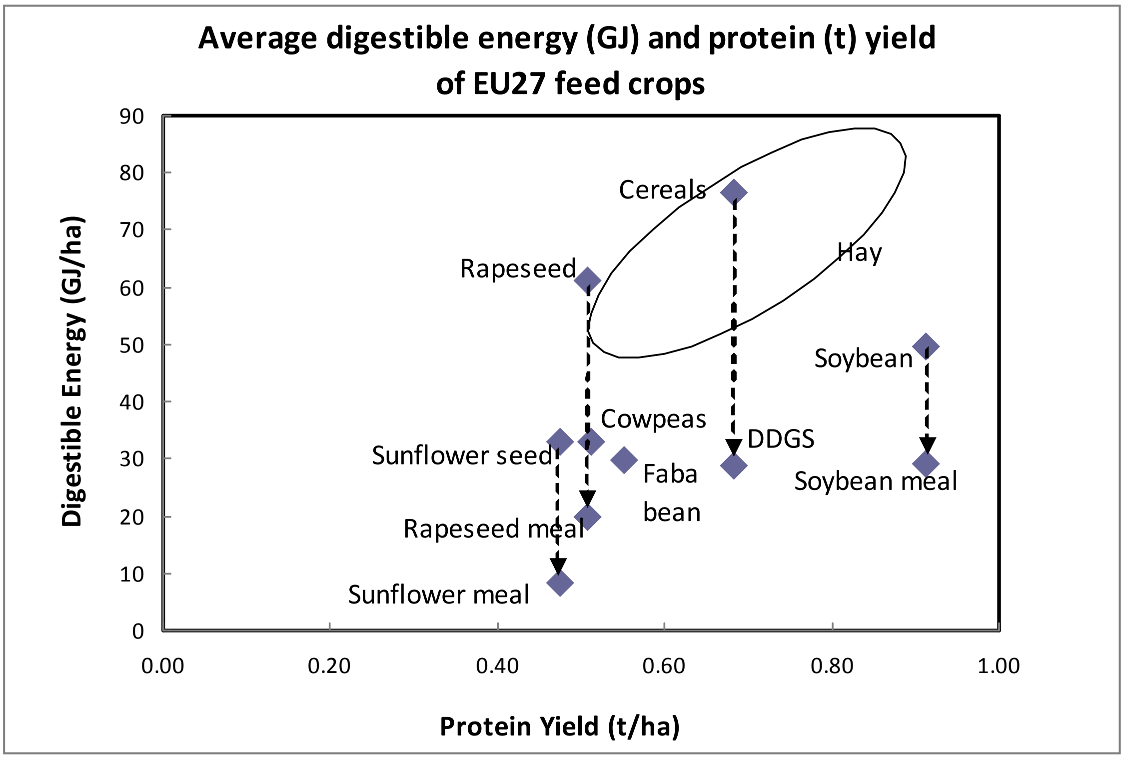
In Figure 15 the arrows show the reduction in digestible energy per hectare when the oil or carbohydrate content of the crop is diverted for making biodiesel or bioethanol. Protein supplies are not affected by the use of the crop.

[42] The DDGS inherits the protein content of the wheat and roughly the same amino acid profile, even though this is modified by yeast and degradation in processing (Noblet et al., 2012).

However, if rapeseed or sunflower replaces other crops in Figure 15 because of extra demand from biodiesel, both digestible energy and protein supplies are reduced (soya bean biodiesel is an exception; it would increase protein per hectare but it barely contributed to EU crops for biodiesel). We conclude that the part of EU biodiesel which displaced other crops in the EU[43] exacerbated the 'protein deficit' (EP, 2011) in EU livestock feed.

Cereals-for-ethanol (DDGS on the chart) give less digestible energy than hay or the same cereals used for feed. However, they have higher protein yield than some 'break-crops' (typically used to renew land that has been farmed with a single crop over a long period), although the chart does not take into account the benefit of break-crops to future yields in the crop rotation. Therefore, the effect of cereal ethanol production on EU animal-feed protein supply is unclear.

Figure 15: Average yields per hectare in terms of digestible energy and crude protein



Using crops for biofuels (indicated by the arrows) removes the starch or oil content of the crop, reducing the digestible energy, but leaving the protein in animal feed by-products[44].
Source: JRC calculations.

Economic models agree that EU biofuels have only a small net effect on the EU livestock sector

Various economic models have been used to analyse the impact of EU biofuels on agricultural markets. All the results published in recent years include the effects of by-products, but do not always report the specific effects on the EU animal-feed market and hence the livestock sector. The models that do report it seem to agree that there is little

[43] See Section 2.1.1: the effect of expanded vegetable oil demand on other crops.

[44] JRC estimates based on EU27 yields from FAO 2011 and feed composition tables from National Research Council 2000. We found no average hay yield, and this depends a lot on the quality of the land. For cropland, we would expect yields at the high end of the range shown. Ethanol is made from feed-cereals which have lower protein, higher starch and higher yields than average cereals. However, FAO does not differentiate feed from bread-quality cereals.

net impact[45]. This implies that the removal from the animal feed market of feedstock for biofuel is roughly compensated for by the return of by-products from the additional production of crops for biofuel.

According to the IFPRI-MIRAGE model[46] (Laborde, 2011), the national plans for EU biofuel will cause a moderate shift away from beef towards poultry and pork production.

What do the by-products replace?

As explained in more detail in Section 4.1.3, consequential life-cycle analysis assigns credits to by-products on the basis of what emissions they avoid by replacing other feeds[47]. To carry out life-cycle assessments (LCAs), as well as economic models of agriculture, one therefore needs to know which other feeds are replaced by biofuel by-products.

Economic models consider feed quality as well as quantity

Agro-economic models that look at the effect of biofuels on agriculture need to make assumptions about which crops are replaced by the by-products of biofuels. Practically all models known to this study[48] have a specific model of the livestock feed sector (which usually distinguishes between livestock species) which balances protein as well as digestible energy. The Global Trade Analysis Project (GTAP), before 2010, and its derivatives IFPRI-MIRAGE and LEITAP (now MAGNET) calculate the replacement of one animal feed by another on the basis of economic value. In other words, they use the value of animal feeds as a proxy for their useful nutritive content (feeds rich in high-quality protein cost more). GLOBIOM is the only model known to this study which only considers digestible energy balance (only for DDGS, not for oilseed meals). The International Institute for Applied Systems Analysis (IIASA) is currently re-examining this.

But there are many complications...

Detailed commercial models of the animal feed industry can predict which feeds would be replaced by DDGS and oilseed meals in a particular country. However, many of the feeds replaced are themselves by-products of other processes, mostly in food processing. That means that their production is practically fixed on a global scale, and will not vary much with feed prices. Models therefore often simplify the calculation by assuming that the marginal animal feeds that are replaced are confined to soya bean meal (to balance crude protein) and feed-wheat or maize (to balance digestible energy).

This simplification ignores differences in protein quality and fibre. Fibre in animal feeds is generally undesirable as it reduces feed efficiency. Protein quality is determined by how well the amino acid mix corresponds to the needs of the animal. Soya bean meal is regarded as the best protein feed because of its favourable amino acid balance and low-fibre content. In particular, it supplies the amino acids that are deficient in cereals-based diets.

Furthermore, extracting the energy component of crops for biofuels makes the remaining combined protein/fibre component available as stand-alone feedstuff which is no longer tied

[45] ESIM model (EC DG-AGRI 2007), (Blanco Fonseca et al., 2010), AGLINK model (JRC-IPTS, 2013), IFPRI-MIRAGE model (Laborde, 2011), FAPRI (Fabiosa, 2010).

[46] Modeling International Relationships in Applied General Equilibrium (MIRAGE) – a model of the International Food Policy Research Institute (IFPRI).

[47] However, the LCA calculations in the Renewable Energy Directive use an alternative, attributional, approach (see Section 4.1.3).

[48] Such as AGLINK (OECD and JRC-IPTS), ESIM (EC DG-AGRI and JRC-IPTS), CAPRI (University of Bonn and JRC-IPTS), FAPRI-CARD and GTAP-post 2010.

to feed energy in a fixed proportion. This constitutes a value added from the perspective of the livestock farmer who is able to optimise the diet.
DDGS inherits the protein content of the wheat and roughly the same amino acid profile, even though this is modified by yeast and degradation in processing. In particular, wheat-DDGS has low and very variable lysine content (Noblet, 2012). Ignoring protein quality may therefore cause the amount of soya bean meal which is substituted to be overestimated.

Rapeseed meal also contains a toxin, erucic acid, which can limit its maximum incorporation into pig and poultry diets.

2.2 Growth in EU crop production

Production = harvested area x yield

Economic models derive extra feedstock for biofuels from four main sources:

- Land area expansion
- Increasing cropping intensity (the frequency with which land area is cropped)
- Boosting yields
- Reduction in food consumption and food quality (see following chapter).

2.2.1 Harvested area

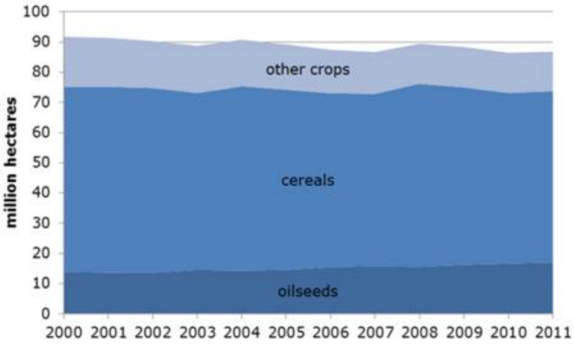
CAP rules stabilised the EU crop area

Economic models take CAP rules into account either explicitly or by using an observed ratio of crop-area-change to price-change. The models are calibrated using historical changes in area and yield as a function of price, typically over the last couple of decades.

Between 1992 and 2005, the CAP gave farmers a subsidy per hectare of cereal land provided they continued to crop it. That stabilised the crop area because: (1) it was less profitable to expand crops on to new land and (2) reductions in the crop area resulted in the loss of subsidies. As a result, most historical gains in EU crop production have inevitably been due to increases in yield and (to a lesser extent) cropping intensity. Even though EU farmers no longer have a policy disincentive to change cereals area, EU production is more constrained by land availability than that in developing countries. ILUC models therefore reasonably find that most indirect land-use change due to EU biofuels policy occurs outside the EU (see Section 2.4 and JRC-IET, 2010).

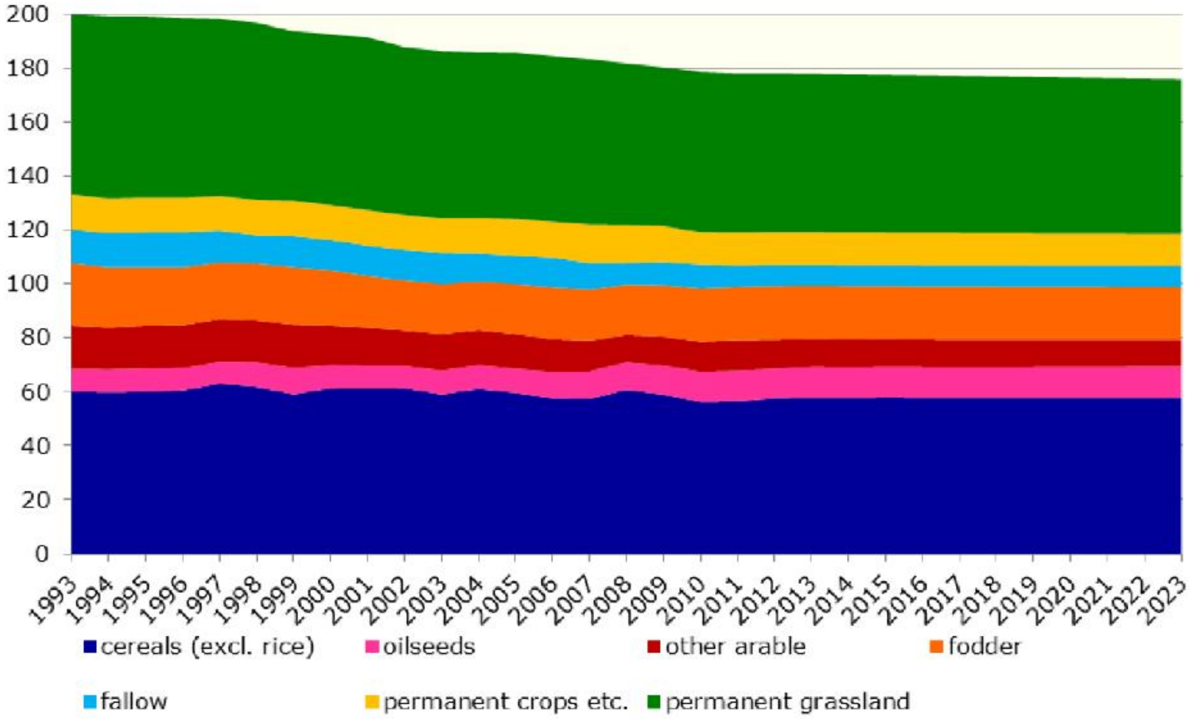
Both crop area and production declined in former communist European countries from the 1990s, following the withdrawal of state targets and subsidies, restitution of land to previous owners and increased job mobility for agricultural workers. In the mid-2000s, these areas were referred to as ‘the land reserve in eastern Europe’, and studies of crop availability for biofuels proposed that increased crop prices would provide an incentive for farmers to use them to grow more feedstock for biofuels. In practice, although crop prices have increased, most of the land has not returned to use. This is due to complex issues of fragmented and unclear land ownership, and loss of agricultural workers, which affect these areas. It was optimistic to expect biofuels to solve these issues, which are addressed by national structural initiatives (Hartvigsen, 2006).

Figure 16: Recent evolution of harvested area of EU-27 crops



Source: FAOstat.

Agricultural land-use developments in the EU (million ha)



Source: Prospects for Agricultural Markets and Income in the EU 2013-2023, December 2013, DG Agriculture and Rural Development, European Commission.

The above figure (DG AGRI, 2013) shows that the area of fallow land (including set-aside) has declined noticeably due to the end of compulsory set-aside in 2008; the area for ‘other arable crops’ has decreased because of a concentration of arable production in the most profitable crops. The inclusion of ‘ecological focus areas’ under CAP greening measures may result in an increase in fallow and set-aside land.

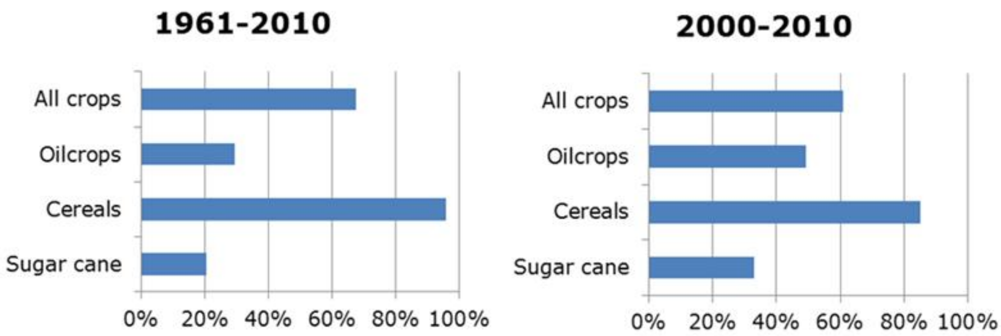
Land-use for most fodder crops (e.g. lucerne, temporary grassland) is declining but that for green maize is on the up, which means that overall land use for this category should stay relatively stable over the longer term. The recent expansion of green maize is due partly to its use as a feedstock in the production of biogas, mainly in Germany, where it has spread to one million additional hectares in the past ten years (though growth has now come to a halt following a change in the support arrangements for biogas production).

Cereal land-use has dropped slightly in the past 20 years, but yields (and overall production) have increased. These trends are expected to continue in the the coming decade.

2.2.2 Yields

Since 1961, more than half of increased world crop production has come from yield increases

Figure 17: Fraction of increased world crop production coming from increased yield



('all crops' category is weighted by the fraction of the crops in the overall expansion in tonnes of production, with sugar as sugar-equivalent; it does not include fodder crops).

Source: FAOstat.

On average, more than half the increase in crop production since 1961 has come from increases in yield rather than harvested area. The contribution of yield increases was 95 % in the case of cereals, but only 21 % for sugar cane and 30 % for oil crops (predominantly soya bean and palm oil).

The more recent data show that the fraction from yield has decreased with time for cereals and 'all crops', which is consistent with the slowdown in yield growth. The opposite is true for sugar cane and oil crops[49].

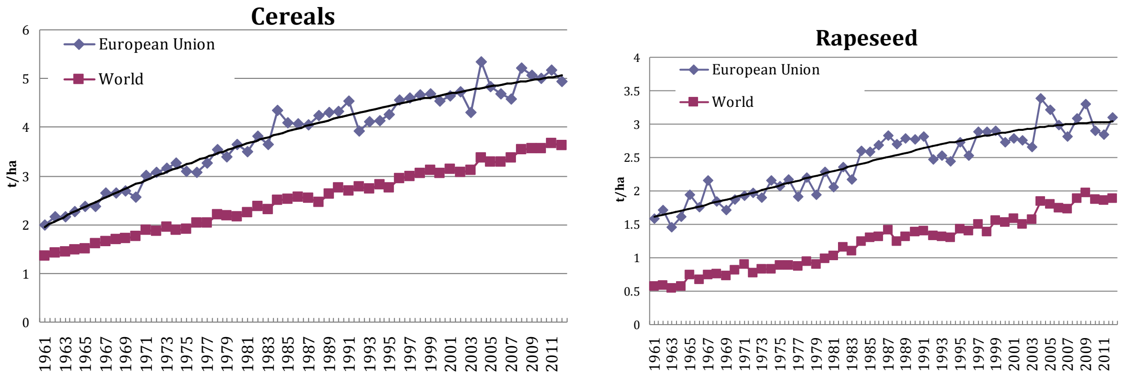
Yield increases are slowing down in developed countries

Long-term data suggests a slowdown in yield growth rates in recent decades at world level, so that there are concerns about the future ability of world crop production to keep up with demand from increased population and prosperity (FAO, 2012; World Bank, 2007). This slowdown is more marked in developed countries, including in the EU.

Another analysis for the World Bank (2011) concluded that there was little potential for expanding production, based on either yield or agricultural area, in countries such as China and Vietnam or in western Europe. However, there is significant potential for yield increases in countries such as Kenya, Malawi and Ukraine, and in Central America.

[49] However, Brazilian sugarcane yields have fallen significantly since 2010.

Figure 18: Trend of cereal and rapeseed yields from 1961 to 2012

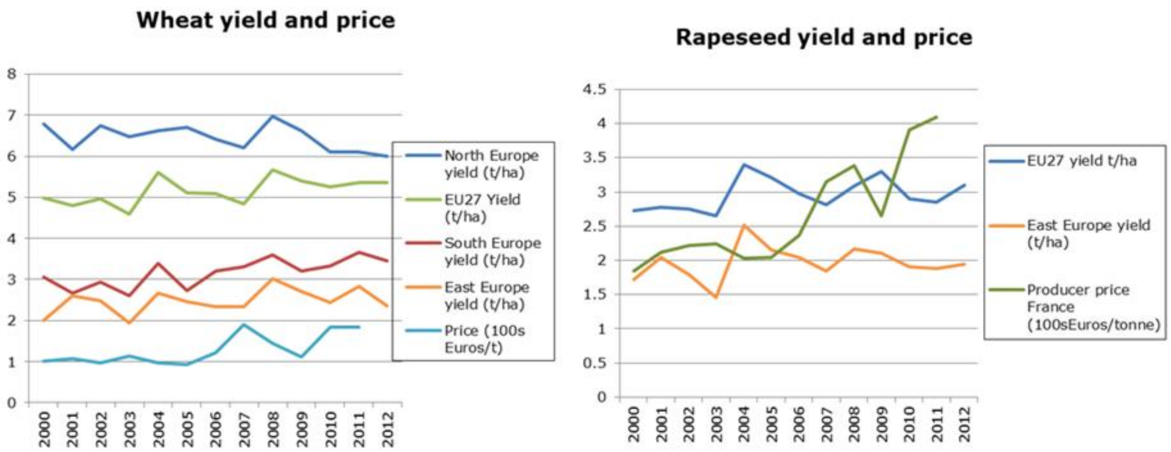


Yields have stagnated in north-western Europe in spite of large crop price increases

The average rates of EU yield increases between 2000 and 2012 were 0.9 % per year for wheat and 0.75 % for rapeseed. DG AGRI figures (EC DG AGRI, 2013) show that over the periods 1997-2001 and 2009-13 the common wheat yield grew by only 0.5 % a year on average; it is expected that this trend will fall to 0.2 % p.a. between 2013 and 2023. As regards rapeseed, the historical trend was 0.6 % p.a.; it is projected to increase to 1 %.

Figure 19 also shows that the stagnation in the yield is not uniform across the continent. It is more marked in the advanced agricultural countries of north-western Europe, which grow most of EU-produced feedstock for biofuels. The doubling of the rapeseed price appears to be connected to demand for biofuels.

Figure 19: Recent evolution of European yields (tonnes/ha)



Price refers to producer prices in France, according to FAOSTAT.

The effect of crop prices on yield is critical in estimates of indirect land-use change

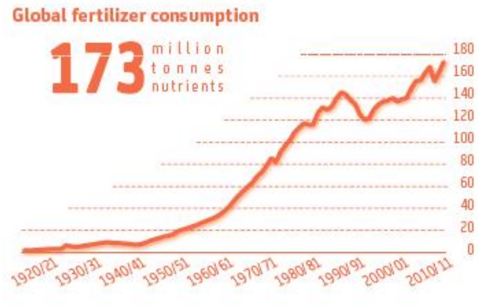
The increase in yield with time is only of secondary importance to models of indirect land-use change (see Section 2.4). What is really important is how yields respond to crop price changes, in comparison with how crop area responds. That is because farmers around the world experience the additional crop demand from biofuels as an increase in crop price. Therefore, if biofuels did not affect crop price, there would be no additional crop production. There is a detailed discussion of how much yields respond to price in Section 2.4.

2.2.3 Fertiliser use and direct farming emissions

Nitrogen (N) is the most important fertiliser: its world use is still increasing

Since its invention, the real cost of synthetic nitrogen fertiliser has fallen even faster than crop prices and its use has grown almost continuously[50]. It has been the major factor in increased food production (International Fertiliser Industry Association (IFA) 2013).

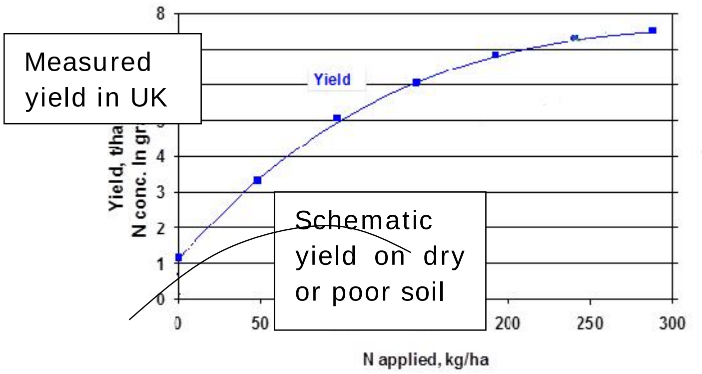
Figure 20: World fertiliser consumption



Source: IFA, 2013.

The efficiency of nitrogen use is calculated on the basis of the number of tonnes of crop per tonne of applied nitrogen. In the world as a whole, it has been almost static in recent years, but since about 1990 it has shown a marked improvement in OECD countries, especially in the EU and the US. This is due to improved technology and possibly the effect of the Nitrates Directive[51]. In the EU, the main reasons for reduced nitrogen fertiliser use are the shift from price intervention to direct income payments, the lowering of guaranteed prices and the decoupling of support from actual crop production in the series of reforms of the CAP since 1992. Conversely, nitrogen use efficiency is still falling in developing countries. This is an inevitable result of the welcome improvement in yields through the increased use of nitrogen fertiliser: farmers are on a curve of diminishing yield returns (see Figure 21).

Figure 21: Experimental data on wheat yield response (blue line) to nitrogen fertiliser application



These experimental data, shown by Williams (2006), come from averaged multi-annual measurements at the UK's Rothamsted research station. This avoids uncertainties in single-year experiments owing to weather variations and changes in the store of nitrogen in the soil carried over to the following season.
Source: Williams (2006), with schematic curve by JRC.

[50] With the exception of the early 1990s and the ending of effective fertiliser subsidies in former Warsaw Pact countries.

[51] With relatively stable crop production, total EU fertiliser use has thus fallen in recent years. The Nitrates Directive (Council Directive 91/676/EEC of 12 December 1991) effectively limits the amount of manure which can be applied per hectare in some areas. This leads to a wider distribution of manure and hence a greater saving of mineral fertiliser.

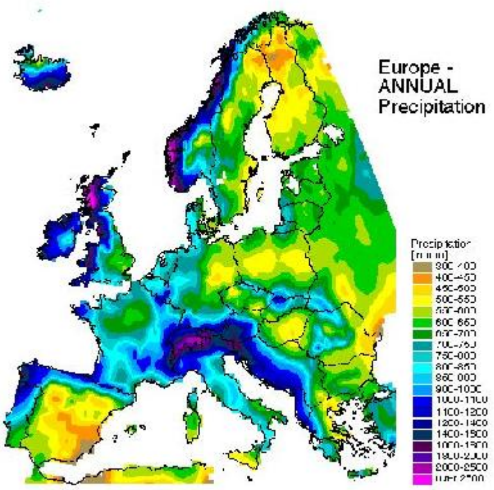
As biofuels will stimulate more crop production, they will surely increase total fertiliser use compared with a policy of no biofuels. Production theory would suggest that a diminishing marginal rate of return for any additional unit of fertiliser would lead to increased average factor intensity.

Water as well as fertiliser is required for high yields, so a 'yield gap' will often remain

However, increasing nitrogen use will not increase the yield of any field in the world to the high levels shown in the above figure: the yield on less fertile and drier fields peaks at lower rates of applied nitrogen. Therefore, the 'yield gap' between developing and developed countries cannot be eliminated if there is not enough water.

In the absence of irrigation, the same argument applies to the yield gap between new Member States and the EU15: although agricultural technology could catch up, thus reducing the 'yield gap', the cereal production areas of new Member States generally get less rain.

Figure 22: Average precipitation in the EU



Source: Jaymans.wordpress.com.

Excluding mountainous areas and the Baltic States (where yield is limited by the short growing season), most of the new Member States are in the yellow or light green areas. By contrast, the main grain-producing areas of the EU15 are mostly blue-green on the map.

Wheat for ethanol uses less fertiliser per tonne than average wheat

The best type of wheat for ethanol production is feed wheat, which is high in starch and low in protein. Dedicated feed wheat varieties, suitable for conditions in north-western Europe, give more tonnes of wheat per tonne of nitrogen fertiliser than bread wheat varieties. Also, in other parts of Europe, wheat intended for ethanol production is given less final fertiliser, as high protein is not required. The effect of this on average fertiliser use per tonne of wheat is taken into account in the calculation of default emissions savings from wheat bioethanol for the Renewable Energy Directive. Maize is even more nitrogen-efficient, where water can be delivered in the right season.

2.3 Effects of EU biofuel policies on commodities prices

The biofuels sector has proved to be a relevant source of new demand for agricultural production in the past decade and represents a new 'market fundamental' that is affecting commodity prices (FAO, 2012).

Biofuels may have an impact on agricultural commodity prices

According to the FAO, the impact of biofuels on food prices, economic growth, energy security, deforestation, land use and climate change is complex and multi-faceted. This impact varies widely depending on the feedstocks, the production methods and the location. In addition, consumers and producers are affected differently.

The shift towards higher and more volatile agricultural commodity prices can be explained by many factors, including population growth and higher per capita incomes; urban migration and associated changing diets in developing countries; weather-related production shocks; and rising demand for biofuel feedstocks. The causes of food price volatility of a structural nature are continued under-funding of agriculture and agriculture research; distorted agriculture and trade policies; increased global trade of agriculture products; and the negative impact of the global energy market shocks on food prices.

The impact of biofuel policies on feedstock prices could be considered as an extra cost for consumers of food, because of their possible impact on prices of agricultural commodities and the increased market volatility of these prices (Charles et al., 2013).

Price increases have a relevant impact on the EU economy, considering that Europe is the world's largest agricultural importer

The increase in prices is particularly important for the European economy, considering that Europe is the world's largest agricultural importer (excluding intra-EU trade). The total net imports of agricultural commodities of the EU27 amounted to EUR 9 billion in 2012 (EC, DG AGRI 2013). A 5 % increase in prices, for example, would translate as an additional EUR 0.45 billion to be paid to import agricultural commodities.

There are a lot of literature studies on the impact of biofuels on commodity prices at global or European level; the estimates vary and are still controversial

The potential impact of the emergence of biofuels on food commodity prices and production has generated considerable interest in economic literature. A lot of research has been undertaken using different methodologies (economic models; research on specific factors; estimates of economic impact; and statistical methods and analysis of statistical relationship) in order to understand the implications for agricultural markets, at both country-specific and international levels (Mitchell, 2008; Lipsky, 2008; Rosegrant, 2008; Baffes and Haniotis, 2010; Timilsina and Shrestha, 2010; Gilbert, 2010; Swinnen and Squicciarini, 2012; Baffes and Dannis, 2013).

Biofuels are one of the many factors that play a role in the food-price system. It is difficult to delineate and isolate findings from literature owing to the different answers found to very different questions using very different methods and approaches (HLPE, 2013).

As explained, the impact of biofuels on crop prices is not always clear when looking at historical data since this impact is mixed with other historical changes. Economic models are needed to isolate the effect of biofuels policy. The main studies can be divided into those that are backward-looking, on the basis of time-series analysis or models of historical data, and those that are forward-looking (Zhang et al., 2013).

Ex-post estimates are difficult to compare because they differ widely owing to the different time periods, price series and types of food products considered (Zhang et al., 2013).

At world level, Mitchell (2008), a researcher at the World Bank, estimated that 70 % of the 2007-2008 spike in food commodity prices was due to biofuels. This report was widely misinterpreted: Mitchell did not state that this was a direct effect through increased crop demand; he stated that this was mostly an indirect effect, speculators assuming a link between crude oil and food prices. He also noted that the crop price movements were exacerbated by export bans and historically low grain stocks.

However, other studies challenged the perception of biofuel policies having such a big impact on agricultural market balances and prices (Gilbert, 2010, Baffes and Haniotis 2010, etc.).

In a 2010 study for the World Bank, Baffes and Haniotis concluded that numerous factors have contributed to the commodity price boom, and that biofuels have played a role, but less than initially thought.

Baffes and Dannis (2013) found that the effect of grain stocks (more precisely, the stock-to-use ratio[52]) could only explain a small part of the increase in crop prices. The major part of the price increase (62 % for maize and 64 % for wheat) was statistically explained by crude oil price increases, but the mechanism for this was not explained. According to JRC analysis, it is too strong an effect to be explained by the increase in the costs of agricultural inputs such as fertiliser. It is possible to speculate that biofuels established a link between crop price and crude oil price in the minds of market-traders, as proposed in Mitchell, 2008.

An extensive review of time-series literature addressing the impact of biofuels on food and/or fuel prices carried out by Serra and Zilberman (2013) concluded that most of the studies reviewed provide evidence that biofuel and/or crude oil prices affect agricultural price levels in the long-run, and that biofuels do not have a long-lasting impact on fossil energy prices.

Ecofys (2012) used a back-casting model analysis using the FAO/IIASA agro-ecological zone (AEZ) model and the IIASA world food system model to quantify the impact of the increase in demand for biofuel feedstocks on prices between 2000 and 2010. It shows that an increase in EU biofuels, reaching 2.95 % of biodiesel and 0.86 % of ethanol for transport fuel in 2010, increased world wheat prices by 2.4 % and 'other food' prices by 3.5 %; the latter includes vegetable oil. No figure was reported for the increase in vegetable oil price.

Forward-looking studies on the impact of EU biofuel policies on prices show a wide range of estimates which depend on the model assumptions

Forward-looking economic models were originally developed to help agricultural policy and trade negotiations. They compare the crop prices in a 'reference scenario' with low biofuel production, and in a 'biofuel scenario' with higher biofuel production. That increase in biofuel production may be explicitly imposed on the model, or worked out inside the model, owing to a specific change in policy or crude oil price.

[52] The stocks-to-use ratio (S/U ratio) is the ratio of end-of-season stocks to total consumption. For maize and wheat, this gives a 22 % and 9 % increase in prices respectively. The increase in biofuels production leads to a lower stocks-to-use ratio, increasing the consumption of food commodities and reducing stocks.

While the consensus within the literature is that biofuels growth is likely to have at least some impact on future commodity prices, the estimates vary considerably.

A recent study conducted by Zhang et al. (2013) reports that the impact of US or world biofuels policies on crop prices is very sensitive to model assumptions which assess the changes in biofuel production according to various scenarios. For example, higher crude oil price will often increase the biofuel production in the 'biofuel' scenario and hence result in greater increases in crop price. Many of the differences between model results could be explained by the differences in biofuel production volume.
Kretschmer et al. (2012) compared the results from various agricultural models as regards the impact of EU biofuels policy on the price of some crop groups. There was a wide range of results, largely due, again, to different increments in biofuel production.
Consequently, it makes sense to assume that the impact of biofuels on crop price depends on the volume of biofuels available. The crop price results should therefore be compared taking into account biofuel demand in the 'biofuel' scenario, which exceeds the demand in the reference scenario.

Table 12 and Figure 23 show the increase in biofuel demand along with the impact on crop price according to studies on EU biofuels policy.
The summary table includes: the analysis by the JRC (JRC, 2008), which uses an ad hoc approach to calculating price effects; a JRC-IPTS analysis (JRC-IPTS, 2010) based on three partial equilibrium models (AGLINK-COSIMO[53], ESIM and CAPRI); data from Laborde (2011) as shown in Kretschmer et al. (2012), based on the IFPRI-MIRAGE model; and a recent study from the JRC Institute for Prospective Technological Studies (IPTS) (JRC-IPTS, 2013) based on the AG-LINK COSIMO model.

Table 12: Results from different economic models of the impact of the EU biofuel policy on commodity prices in 2020

Forward-looking studies	Model	Change in first-generation biofuels share in EU road fuel consumption*	Impact on EU or world prices of different feedstocks (% change)
JRC (2008)*	No model, ad hoc calculation	EU 10 % first-generation mandate compared to no biofuel use: increase in biofuels share =10 %	Cereals: 4 % Vegetable oils: 24 %
JRC-IPTS (2010)	ESIM	7 % share of first-generation biofuels in total transport fuels in the EU compared to 3.7 % share without biofuels policy: increase in first-generation biofuels share =3.3 % of which: increase in biodiesel share in road fuel =0.9 % increase in bioethanol share in road fuel =2.4 %	Cereals (EU): Soft wheat: 8.3 % Maize: 22.2 % Oilseeds (EU): Rapeseed price: 9.7 % Sunflower seed price: 11.2 % Soya bean: 0.5 Vegetable oils (EU) 32.2 % (weighted average based on EU vegetable oil production): Soya bean oil: 17.4 % Rapeseed oil: 34.9 % Sunflower oil: 35.8 % Palm oil: 1.3 % Sugar: 21 %

[53] Results of the AG-LINK COSIMO model by JRC-IPTS, 2010, are not reported because the result of the same model (AG-LINK COSIMO) is included in the other report considered (JRC-IPTS, 2013).

Forward-looking studies	Model	Change in first-generation biofuels share in EU road fuel consumption*	Impact on EU or world prices of different feedstocks (% change)
JRC-IPTS (2010)	CAPRI	First-generation biofuel share of 7 % in total transport energy compared to 1.5 % share without EU biofuel policy: increase in biofuels share = 5.5 % of which: increase in biodiesel share in road fuel = 3.8 % increase in bioethanol share in road fuel = 1.7 %	Cereals (EU): 10.2 % Oilseeds (EU): 19.5 % Vegetable oils (EU): 27.1 % Sugar beet: 2 %
Laborde 2011 (as reported in Kretschmer et al., 2012)	MIRAGE	Policy scenario of 8.6 % first-generation mandate compared to constant 2008 blending of 3.3 %: increase in biofuels share = 5.3 % of which: increase in biodiesel share in road fuel = 3.5 % increase in bioethanol share in road fuel = 1.8 %	Cereals: Wheat: 1.01 % Maize: 0.74 % Oilseeds: Sunflower: 4.8 % Rapeseed: 11.3 % Vegetable oils: 6.4 % (weighted av. based on world vegetable oil production) Palm oil: 4.5 % Rapeseed oil: 9.2 % Soya bean oil: 7.3 % Sugar: Sugar cane/beet: 0.9 % Soya beans: 2.5 %
JRC-IPTS (2013)	AG-LINK COSIMO	First-generation biofuel share of 8.5 % in total fuel use compared to 1.9 % share without EU biofuel policy: increase in first-generation biofuels share = 6.6 % of which: increase in biodiesel share in road fuel = 3.9 % increase in bioethanol share in road fuel = 2.7 %	Cereals: 3.5 % Oilseeds: 5 % Vegetable oil: 14 % Sugar: 2.5 %

* The studies usually report the increase in biodiesel and ethanol shares in diesel and petrol consumption respectively. We estimate the corresponding shares of total road fuel consumption, considering that 2/3 of EU road fuel is diesel and 1/3 is petrol.

** The estimates provided by JRC, 2008, are different because the calculations have not been run simultaneously but one at a time.

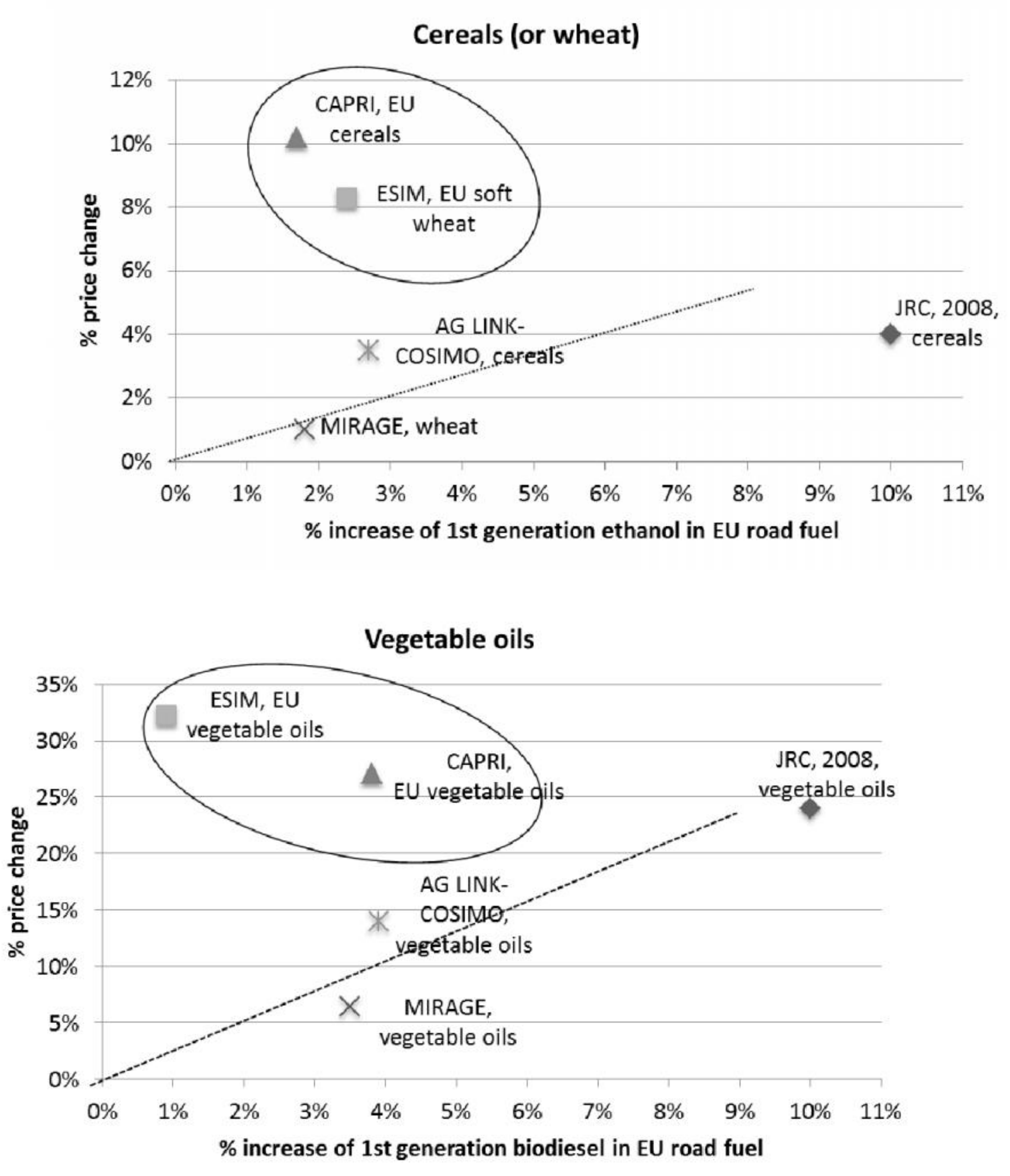
The following figure shows the link between the estimated price changes (for cereals (or wheat) in the first graph and for vegetable oils in the second one) and the increase in bioethanol or biodiesel share respectively. These are the difference between the ethanol or biodiesel share of the total fuel use in the policy scenario and the ethanol or biodiesel share in the scenario without biofuel policy.

All studies show that EU biofuel policies have the biggest impact on world prices of oilseeds (increase in the range of 5 % to 11 % in 2020) and vegetable oils (price increase of 6 % to 14 %) because the EU is a leading producer of biodiesel. This situation could change if the EU were to adopt a policy to mitigate ILUC, which would shift the EU biofuel demand in favour of ethanol rather than biodiesel. The price of crops in the EU rises more, as shown by the ESIM and CAPRI models (JRC-IPTS, 2010).

The price changes found in the studies are all positive and none are negligible. The range of estimates can be explained by the assumptions made in the different models about the

baseline and policy scenario (they do not project the same achievement of the EU mandate) and by the different assumptions made regarding changes in bioethanol and biodiesel use.

Figure 23: Results from different economic models of the impact of the EU biofuel policy on cereal and vegetable oil prices in 2020



On the markets for wheat, maize, sugar cane and sugar beet (ethanol feedstocks), the effect on prices is low (cereals: 1 % to 4 % and sugar: 1 % to 2 %). This is because the cereals market is much larger. On the other hand, cereal prices have a much greater effect on food security.

The changes in first-generation biofuel consumption reported by the studies added up to 10 % of EU road transport fuel. By adding a trendline to the model results for changes in

world prices, we estimate that replacing 7 % of 2020 EU road fuel with first-generation biodiesel and a further 3 % with first-generation bioethanol would increase world vegetable oil prices by roughly 18 % and world cereal prices by roughly 2 % (see Figure 23).
The effects on commodities prices could be higher, in particular for bioethanol, if the biofuel support and other relevant policies in all world regions were taken into account in the estimates provided by the economic models. This could increase the pressure on agricultural markets.

2.4 Land use and land-use change

About 5.7 million hectares (Mha) of land was used to produce feedstocks for EU biofuel consumption in 2010

The total land use worldwide to produce the feedstock for EU-consumed biofuels (which represents 4.27 % of EU transport fuel) in 2010 is estimated at about 5.7 Mha[54] (approximately 5 % of total EU arable land). Of this, 3.2 Mha (57 %) is within the EU and 2.4 Mha (43 %) is outside the EU (Ecofys, 2012).

The rapid growth in the consumption of biofuels that has occurred in the EU in recent years has raised concerns relating to the environmental, ecological and social impact of their production. The sustainability of biofuels has been the subject of debate worldwide.

Many of these effects are related to land-use change (LUC) induced by feedstock cultivation, such as deforestation and the associated increase in GHG emissions, loss of biodiversity and competition with food production.

2.4.1 DLUC and ILUC

Land-use change can be ’direct’ if biofuel crops are grown on uncultivated land, or ’indirect’ if biofuel crops are grown on existing land and are diverted from food production

Land-use change can be ’direct’ (DLUC) or ’indirect’ (ILUC). If the crops needed to make a particular batch of biofuels are grown on uncultivated land, such as pasture or forest, this will cause direct land-use change. If crops grown on existing arable land are used to make biofuels and are diverted from food production, then the gap in the food supply will be partly filled by the expansion of cropland, because of the necessity to replace the food production (JRC-IET, 2010). This is referred to as indirect land-use change (ILUC).

LUC and ILUC could potentially release enough GHG emissions to outweigh the savings from conventional EU biofuels.

Agro-economic models are generally used to estimate ILUC. The extent of ILUC and its potential inclusion in the EU regulatory framework are still under discussion

These discussions arise mainly from the difficulties in monitoring ILUC and the large range of outcomes from models that determine the extent of ILUC (Wicke et al., 2012). Discussions regarding ILUC and its potential inclusion in a regulatory framework are still ongoing in the EU (see Box 3 below).

[54] The estimate takes into account the different origins of feedstock (EU and other countries) and subtracts the co-products share.

ILUC cannot be measured directly, even in retrospect, because of the impossibility of measuring what would have happened without biofuels. A global agro-economic model would be needed in order to estimate that. Then the ILUC emissions associated with EU biofuels policy would be shown by the difference in world land use between a 'policy' scenario which promotes biofuels, and a 'baseline' scenario which does not.

The models do not distinguish which feedstock is grown on 'new' or 'old' land: they simply look at the consequences of crop demand changes on land area; accordingly, the effect could simply be called 'land-use change' (JRC-IET, 2010).

Box 3: ILUC Policy proposal and amendments

In October 2012, the European Commission tabled a proposal[55] to minimise indirect land-use change emissions from biofuels (COM(2012)0595). This proposal is aimed at incentivising the 'transition to biofuels that deliver substantial GHG savings when also estimated indirect land-use change emissions are reported', mainly by: limiting the contribution of biofuels produced from food crops; improving the efficiency of biofuel production processes by raising the GHG savings threshold for new installations; fostering the market penetration of advanced biofuels; and protecting existing investments. The main features of the Commission's proposal are:

- Limiting to 5 % the contribution of food crops (cereals and other starch-rich crops, sugars and oil crops) to biofuels and bioliquids that count towards the RED target of 10 % renewable energy in transport.
- Introducing ILUC emissions values per crop group (cereals and other starch-rich crops, sugars and oil crops) as a reporting obligation (i.e. the emission factors are not inserted in the sustainability criteria of the directives and do not have to be added to direct GHG emissions):
  - Cereals:12 gCO_2/Megajoule
  - Sugar crops: 13 gCO_2/Megajoule
  - Oilseeds: 55 gCO_2/Megajoule.
- An increase from 35 % to 60 % in the minimum GHG savings threshold for biofuels and bioliquids produced in installations built after 1 July 2014.
- Biofuels not requiring cropland for their production are assigned zero ILUC emissions and are incentivised by applying multiplying factors (double or quadruple counting) for their contribution to the 10 % RED target in transport.

In September 2013, pursuant to the co-decision procedure to which this act is subject[56], the European Parliament in its first reading voted on amendments to the Renewable Energy Directive (RED) and the Fuel Quality Directive (FQD). The table below highlights the main differences between the Commission's proposal and the Parliamentary text issued following the vote at first reading:

[55] Proposal for a 'directive of the European Parliament and of the Council amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources' (COM(2012)0595).
[56] 2012/0288 (COD) of 17 October 2012.

EC proposal (COM(2012) 595)	EP text – first reading (11 September 2013)
• 5 % cap on cereal, starch-rich crops, sugar and oil crops to count for the RED target	• 6 % cap for biofuels from cereals and other starch-rich crops, sugars, oil crops and dedicated energy crops, to be included also in FQD target and to be complied with to be granted support.
	• 2.5 % minimum share of advanced biofuels
• Double counting for used cooking oil (UCO), animal fats, non-food cellulosic and lignocellulosic materials etc. (only for the RED target) • Quadruple counting for algae, agricultural and forestry residues (straw), municipal solid waste, industrial waste, bagasse, manure etc. (only for the RED target) • No ILUC emissions for biofuels from waste and residues • By the end of 2017, revision and if necessary proposal on ILUC	• Combinations with multiple counting: - 1x counting (and counted toward 2.5% target advanced biofuels): e.g. straw, manure - 2x counting (and not counted towards the 2.5% target): UCO, tallow - 4x counting (and counted towards the 2.5% target): algae, bacteria
	• 6% GHG emissions reduction in transport fuels (FQD target), including aviation (maritime excluded)
• ILUC emissions to be included in RED and FQD for reporting purposes (FQD: fuel suppliers to report emissions to Member State authorities; RED: Member State authorities to report to the EC)	• ILUC emissions included in the calculations from 2020 onwards (proposed values under revision in 2016)

2.4.2 How economic models are used to estimate ILUC

Complex economic models are generally used to estimate ILUC. These are computable general equilibrium (CGE) models[57] or partial equilibrium (PE) models[58], as well as less complex but more transparent causal-descriptive and deterministic models.

Several models of the world agro-economic system have been used to evaluate the ILUC effects of biofuels (e.g. GTAP – various versions –[59] in the USA and MIRAGE[60] for the EC

[57] Computable general equilibrium (CGE) models are economic models that use actual economic data to estimate how an economy might react to changes in policy, technology or other external factors. CGE models take into account the links among all sectors of the economy and provide results relevant in the short- and medium-term periods. They offer a comprehensive understanding of the impact of biofuels on the global economy, taking into account the feedback mechanisms between biofuels and all the other markets.

[58] Partial equilibrium models do not include all the sectors of the economy, but they cover one sector of the economy considering that the situation in the rest of the economy is unchanged.

[59] The Global Trade Analysis Project (GTAP model) is a general equilibrium model developed by Purdue University.

analysis). The models contain many parameters that are determined by econometric fitting to historical statistical data. However, this is challenging because of the scatter in statistical agricultural data (owing to weather variations), and because many parameters vary simultaneously with time. Therefore, different groups of modellers deduce different values for the same parameters. Also, as models differ in their approach and structure, many of the parameters in one model cannot be compared with those in another.

Agro-economic models view biofuels as an increase in crop demand

Agro-economic models view biofuels as an increase in crop demand, which is partly compensated by the return of by-products from fermentation and oilseed crushing to the animal feed sector. This increased crop demand results in higher prices for crops, which cause the supply to increase and the competing demand in other sectors to decrease.

The competing crop demand is predominantly for food and animal feed. The use of biofuel by-products as animal feed often roughly cancels out the effects on that sector, but the models derive a significant part of the crops for biofuel from a reduction in human food consumption. That contribution to biofuel feedstock is free of ILUC emissions, so the more food consumption is reduced in a model, the lower the calculated ILUC emissions tend to be.

In agro-economic models, the increase in crop supply is only partly satisfied by the expansion of crop area

Only part of the increase in supply is due to the expansion of crop area: models assume that the increased price will also cause crop yields to increase above the baseline[61]. While this is conceptually accepted, this is another area where there are significant differences between models.

The change in yield resulting from biofuels demand, driven by an increase in crop price, is most significant when calculating indirect land-use change

If yield increase depended only on time, extra demand from biofuels would not cause any extra crop supply through yield increase, so it would all have to come from increasing the area under cultivation or from reductions in other uses.

Farmers around the world experience additional crop demand as an increase in crop price. Therefore, if biofuels did not affect crop price, there would be no additional crop production. A critical question is to what extent yields respond to crop price increases, compared with crop area.

Yield might be expected to be sensitive to price, but the response is very difficult to detect

In principle, yields can respond to higher crop prices by various means:

- in the short term, farmers can use more nitrogen fertiliser and pesticides, or increase planting density;
- in the medium term (two to five years), farmers can increase investment in irrigation and drainage, and other farm infrastructure;

[60] The Modeling International Relationships in Applied General Equilibrium (MIRAGE) model is a general equilibrium model developed by the International Food Policy Research Institute (IFPRI).

[61] Improvements in crop yield that depend only on time occur in both the policy scenario and the baseline, and therefore roughly cancel out when the difference is taken into account.

- in the long term, investment in agricultural research can be incentivised, but it takes at least 15 years between laboratory and field.

In the short term there is no obvious response of yields to price. In fact, the JRC and others have found it impossible to detect any of these effects statistically by simply correlating historical data on yields and prices. In the short term there is too much noise from harvest variations, owing to annual weather. The long-term yield response should be greater, but in the long term it is impossible to separate crop price effects from historical trends.

Recent research suggests that yields may respond less to price than is assumed in economic models

Houck and Gallagher (1976) found evidence to support yield-price elasticities[62] for US maize as high as 0.3. Subsequently, Menz and Pardey (1983) and Choi and Helmberger (1993) found that it was not significantly different from zero, even if the margin of error was too high to rule out such a value. Tyner et al. (2010) assumed a yield-price elasticity of 0.25 for the GTAP model used to calculate ILUC effects for the US Environmental Protection Agency (EPA). However, a committee of experts set up by the Californian Air Resources Board (CARB, 2011) agreed that there was no strong empirical evidence to fix a yield-price elasticity. Berry and Schlenker (2011) then developed a more sensitive econometric method. Their estimated elasticity was still not significantly different from zero, but the maximum limit was reduced to 0.1.

The IFPRI-MIRAGE model (Laborde, 2011) uses a range of yield elasticities between 0.1 for developed countries and 0.3 for developing countries, with the explanation that this takes into account any possible contribution from double-cropping.

The yield response must reach a limit for large shocks

Another important point is that although a sustained 10 % increase in crop price might in a few years increase yields by, for example, 3 % above the historical trend, a 100% increase in price would be unlikely to produce an additional 30 % yield increase in the same time. That is because of diminishing returns to increases in farm spending.

Some economic models, for example FAPRI-CARD[63], consider both a low short-term yield response together with an elasticity that describes how the rate of yield increase depends on crop price. However, the rate of yield increase is unlikely to be fully proportional to price (which in any case would only have a moderate effect on the overall yield response in the timeframe of the model projection) (JRC-IET, 2010).

Another way models differ is the way they treat crop displacements. Some have a single yield per crop per region: then if, for example, the maize area grows at the expense of rye, there is a jump in cereals production with no change in overall crop area. Other models assume one crop replaces another at constant value ($/ha), eliminating this effect. However, this introduces another source of 'ILUC-free' production, when low-value crops expand at the expense of expensive specialty crops in the model (e.g. maize instead of

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62 (% change in yield)/(% change in crop price).

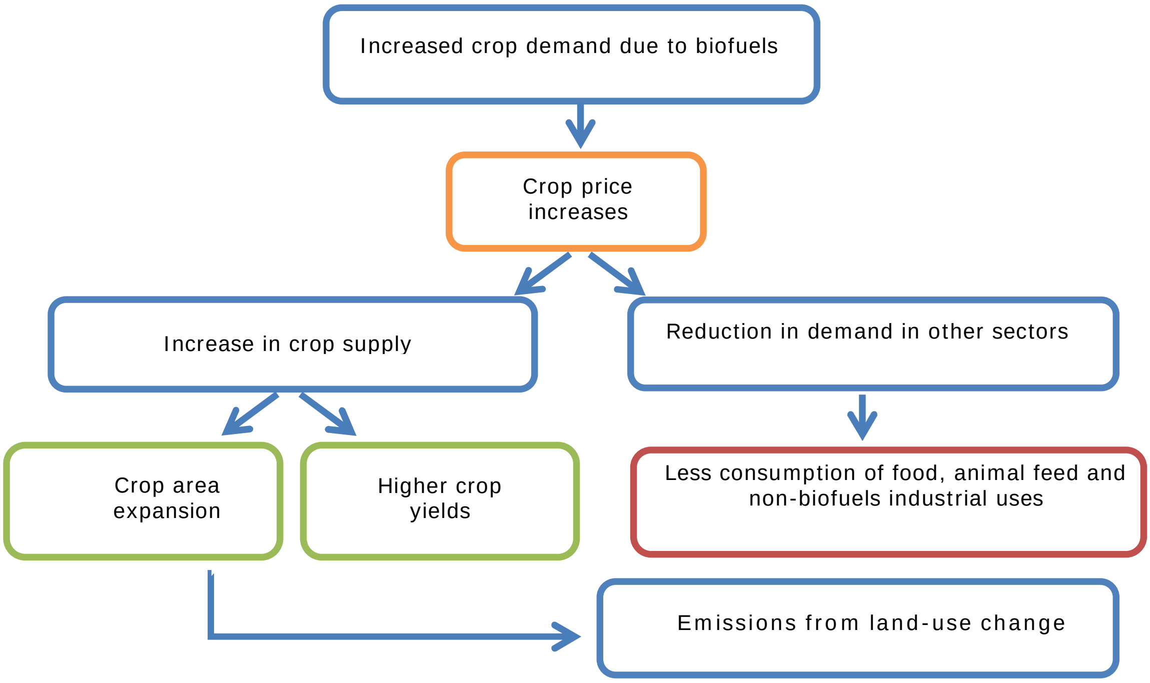
63 The FAPRI/CARD (Food and Agricultural Policy Research Institute / Center for Agricultural and Rural Development) international grains model is a non-spatial, multi-market model that covers several countries/regions and includes a rest-of-the world aggregate.

olives or fruit, as reported in the IFPRI-MIRAGE model for example). This might be characterised as land diverted to biofuels at the expense of food quality.

Finally, models treat 'marginal yield' differently. Models that have a fixed (or practically fixed) yield of a given crop in a given region are assuming that the land at the frontier of cultivation is just as fertile as average land, and capable of growing high-yield crops. This might apply to some developing regions where good land is still uncultivated because of limited transport access, but in general new cropland is likely to have lower yields and to grow more robust, less intensive crops. Other models attempt to estimate this spread of yields. However, the tendency is to underestimate the spread, because statistics are only available at a coarse level, whereas there are considerable yield variations even between different fields on a single farm.

Figure 24 summarises how land-use change derives from the increased biofuels demand (as explained above) in economic models.

Figure 24: Economic models and ILUC



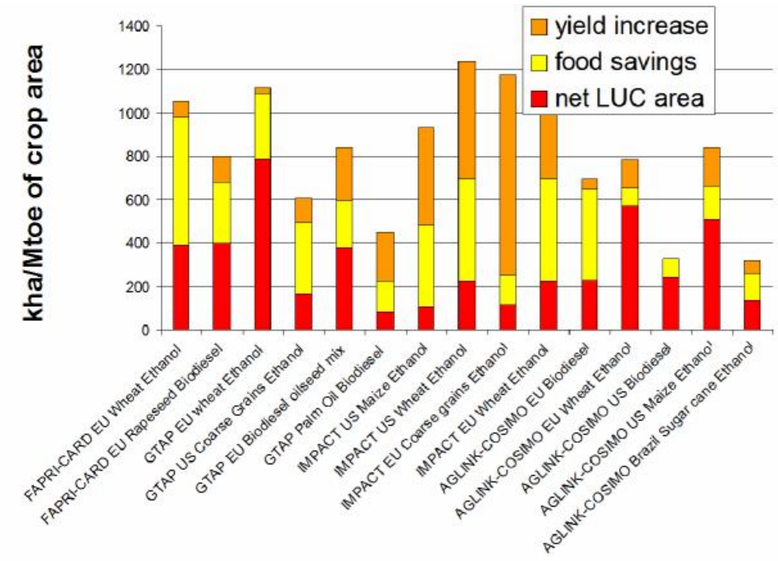
A model comparison carried out by JRC in 2010 shows that the net land-use change area reported by models is only part of the total area change that would occur if no yield increase and no reduction of food consumption were assumed

A model comparison study carried out by the JRC in 2010 (JRC-IET, 2010) compared the crop area changes for a marginal change in demand for particular biofuels in particular regions produced by different economic models. The work involved some of the best-known models[64] worldwide.

One of the results of the model comparison is that the net land-use change area reported by models is only part of the total area change that would occur if no yield increase and no reduction of food consumption are assumed.

64 The partial and full equilibrium models compared in this study are: AGLINK-COSIMO (from OECD); CARD (from FAPRI-ISU); IMPACT (from IFPRI); GTAP (from Purdue University); LEITAP (from LEI); CAPRI (from LEI).

Figure 25: Food-reduction credit and yield increases effects from various economic models



2.4.3 ILUC area and emissions

Agro-economic models in general provide the output of how much extra crop would be produced in different countries/world regions as a result of biofuels policy. Some models also predict the area of lands converted to cropping from pasture, forest or natural land in each region.

The IFPRI-MIRAGE model is the reference study for the impact of the EU biofuels policy

The International Food Policy Research Institute (IFPRI) MIRAGE model is the most suitable model to assess the impact of EU biofuels policy. Laborde (2011) is the European Commission's reference modelling assessment used for the Impact Assessment released in 2012 together with COM(2012)595. In this study, the impact of the EU mandate as described in the NREAPs of the EU27 Member States has been estimated. According to the declarations in the NREAPs, the blending rate of first-generation biofuels in 2020 will be 8.46 % of the total transport fuel consumed in the EU.

The increase in global cropland area resulting from biofuel mandate will be 1.73 million hectares in 2020, according to IFPRI-MIRAGE

Results of the IFPRI-MIRAGE model show that the biofuel mandate will globally lead to an increase in cropland area by 1.73 Mha in 2020 compared to a scenario without the mandate (with an additional amount of biofuels consumed in the EU of 15.5 Mtoe compared to a scenario without the mandate). As a comparison, that number corresponds to an area equivalent to one-tenth of the total amount of arable land in France. The most affected regions in terms of cropland expansion will be outside the EU (Brazil, Latin America, Commonwealth of Independent States (CIS), and Sub Saharan Africa (SSA)). According to the study, pasture and managed forest will represent the two major sources of cropland expansion (accounting for, respectively, 42 % and 39 % of total land expansion), followed by savannah and grasslands (16 %) and primary forest (3 %).

The model comparison study shows that there will be significant land-use change as a result of extra biofuels demand in the EU, according to all models, and that most of the land-use change will take place outside the EU

The model comparison study by the JRC (JRC-IET, 2010) compares the results of the best-known models that run scenarios corresponding to the marginal extra ethanol demand in the EU and the USA, and the marginal extra biodiesel demand in the EU. All models show significant land-use change in all biofuels scenarios (Figure 26).

In the EU ethanol scenarios, the total estimated ILUC (in the world) ranges from about 200 to 750 kilohectares (Kha) per million tonnes of oil equivalent (Mtoe). For most of the EU ethanol scenarios the models project that the largest share of ILUC would occur outside the EU.

In the EU biodiesel scenarios, total ILUC ranges from about 250 to 1900 Kha per Mtoe. In all of the EU biodiesel scenarios, the models project that the largest share of land-use change would also take place outside the EU.

Figure 26: Overall results of the land-use change from different models and scenarios (in hectares per tonne of oil equivalent)

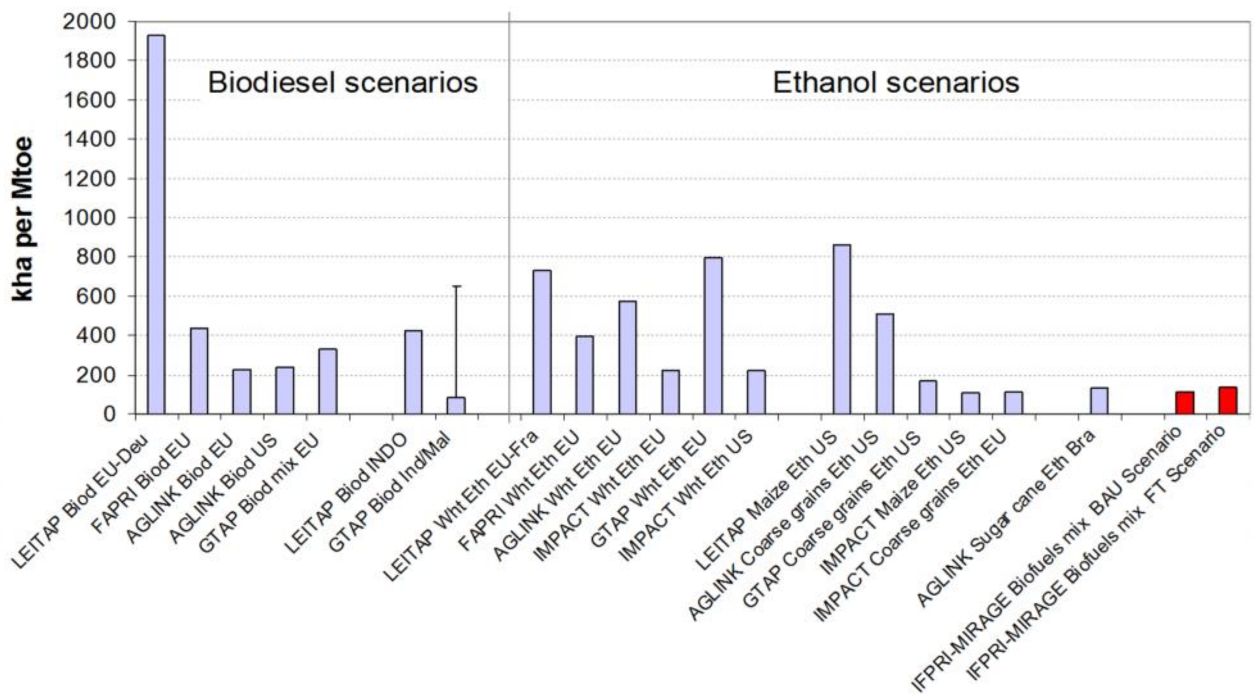
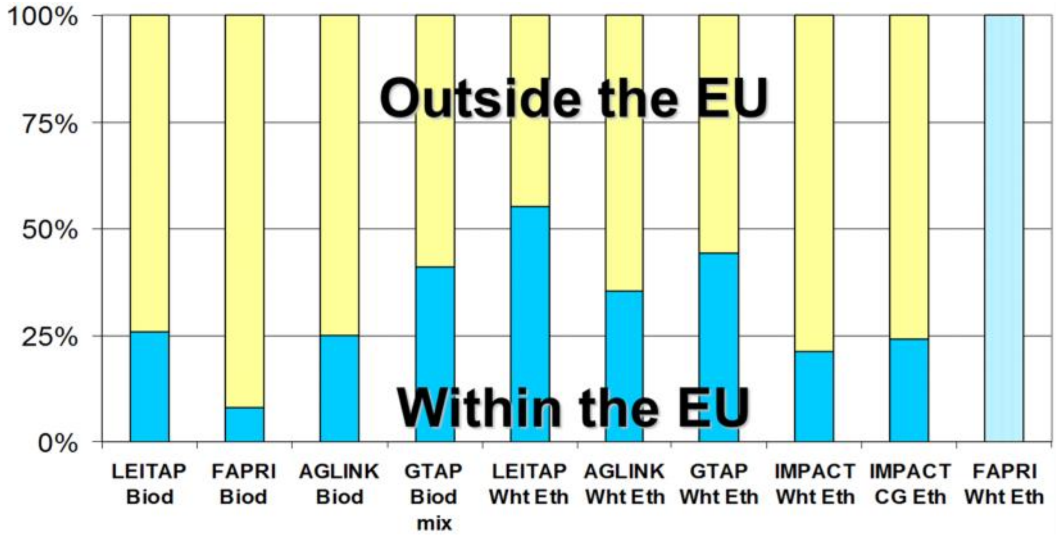


Figure 27: For EU biofuels most land-use change is outside EU



The conversion of land-cover types will result in loss of carbon stocks, which have to be estimated

Converting land-cover types that have high biomass and soil carbon stocks (e.g. forests) into cropland usually results in an immediate loss of carbon stored in above- and below-ground biomass (vegetation), and a more gradual decline of carbon in the soil organic matter (SOM)[65]. Land-use change may also cause an increase in soil carbon stock over the existing level (e.g. through changes in crop management) or in biomass (e.g. if grassland is replaced by permanent woody crops or sugar cane).

The carbon released from biomass is emitted into the atmosphere as CO_2. SOM contains both carbon and nitrogen, and a decline of SOM releases both CO_2 and N_2O (nitrous oxide), a potent GHG.

Biophysical or other land-use models are used to calculate the carbon stock changes resulting from land-use change

As explained above, agro-economic models provide estimates of the total change in crop area in different world regions. To calculate carbon stock changes resulting from this land conversion, economic models must be combined with biophysical or other land use models. One crucial issue is to identify those areas within a certain economic region where the expansion of biofuels production is most likely to occur, and how the additional (marginal) cropland required in different bioenergy policy scenarios can be spatially distributed. Since GHG emissions from land-use change locally vary depending on soil, climate, management factors, the status of converted land etc., the level of spatial disaggregation used is important to capture the pattern of agricultural expansion and related GHG emissions within an economic region.

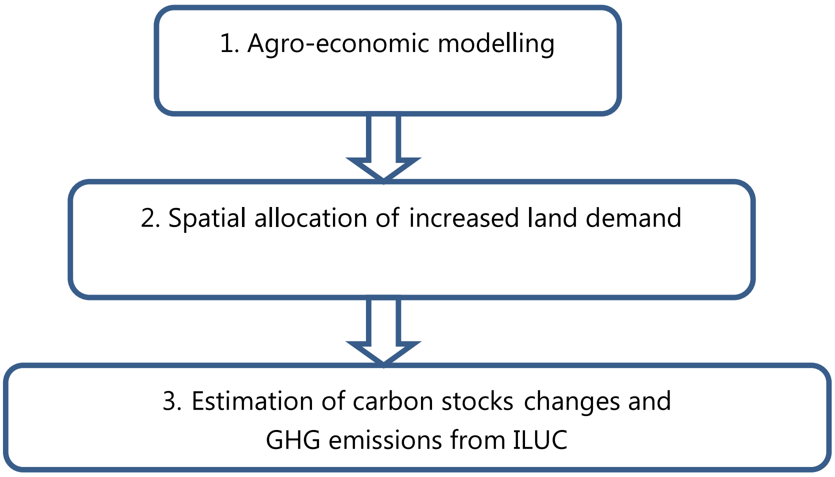
JRC has developed the Cropland Spatial Allocation Model in order to calculate the GHG emissions associated with land-use change

For this purpose, the JRC has developed a 'spatially resolved' model, CSAM (Cropland Spatial Allocation Model) (JRC-IES-IET, 2010). This is capable of distributing regional

[65] Soil organic matter (SOM) is a mixture of materials, including particulate organics, humus and charcoal along with living microbial biomass and fine plant roots.

changes in land use, taken from the results of agro-economic models, on a high-resolution map. It also calculates GHG emissions and CO_2 removals due to changes in soil organic matter (CO_2 from carbon stock changes and N_2O from mineralisation of organic matter in soils) and above- and below-ground biomass carbon stocks. Another advantage of such a method is that it can potentially be applied to the outcome of any economic models, easing the comparability of ILUC estimated from different models. The CSAM currently accepts results from the economic regions and biofuels feedstock of four of the best-known models worldwide: AGLINK-COSIMO, FAPRI-CARD, GTAP and IFPRI-MIRAGE.

Figure 28: Spatial allocation model and ILUC emissions



The JRC-CSAM model has been applied to the outcomes of the IFPRI-MIRAGE model, run in 2011 for the EC (Laborde, 2011), to calculate the geographical distribution of land-use changes and the corresponding GHG emissions, and to compare the results with the GHG emissions estimated by IFPRI (which used a different land-use model).

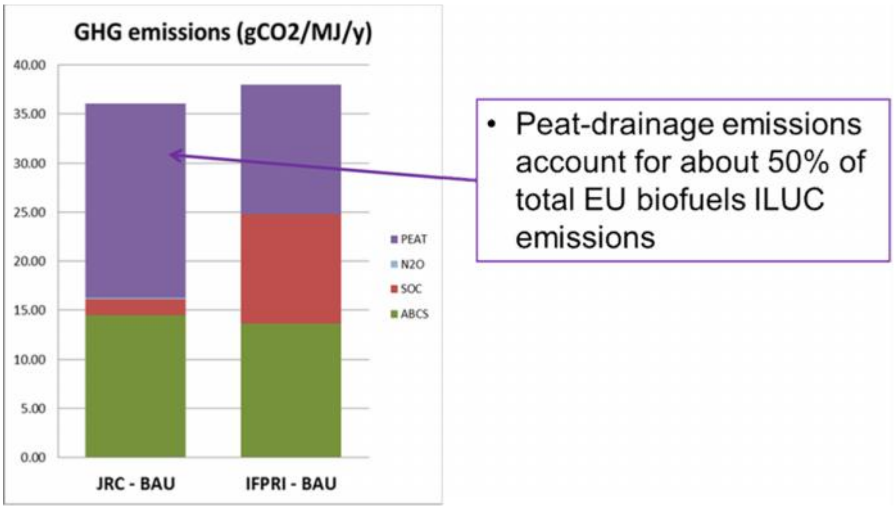
The scenario considered by IFPRI, based on estimates from NREAPs, assumed a total blend of first-generation biofuels of 8.4 %, with a spread bioethanol/biodiesel of 28 %-72 % (NREAP 'full mandate').

JRC-CSAM estimates that the increased biofuel demand will cause ILUC emissions of about 36 grams CO_2 equivalent per megajoule of biofuels

For this scenario, the JRC estimated that the increased biofuels demand will cause ILUC emissions of about 36 grams of CO_2 equivalent per megajoule (gCO_2eq/MJ) of biofuels computed over a period of 20 years[66] (JRC-IES-IET, 2011). This includes emissions from peatland drainage for palm oil plantations (see Box 4), which amount to about 55 % of total GHG emissions. These JRC results are in line with the emissions calculated by IFPRI using their land emissions model (38.4 gCO_2eq/MJ of biofuels - see following Figure).

[66] The 20 year period is chosen to be consistent with the RED.

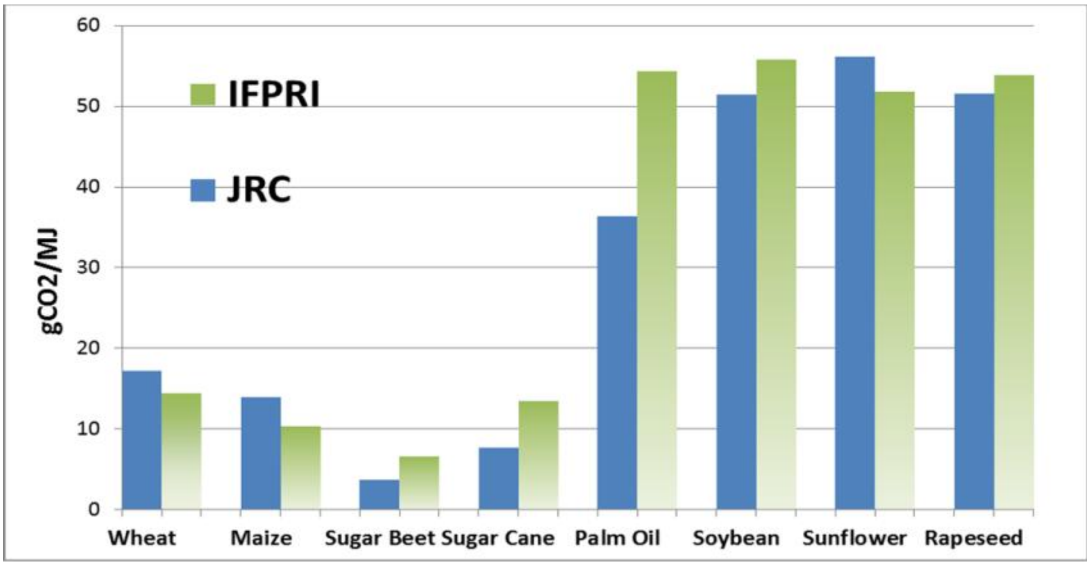
Figure 29: Comparison of GHG emissions calculated with JRC-CSAM land-use model and with IFPRI land-use model, taking as input data land-use changes from IFPRI-MIRAGE economic model



ILUC emissions are higher for biodiesel oilseeds crops than for ethanol feedstocks

The MIRAGE model also gave results for biofuels from individual feedstocks (four for ethanol and four for biodiesel). The JRC calculations applying the CSAM model confirmed IFPRI's conclusion that, in general, ethanol crops have lower ILUC impact (4 to 20 gCO_2eq/MJ) than oilseeds/biodiesel crops (36 to 60 gCO_2eq/MJ), as shown in Figure 30.

Figure 30: ILUC GHG emissions for eight crops resulting from MIRAGE model runs and calculated by IFPRI and the JRC, using two different methodologies



Results show that ILUC GHG emissions are higher for biodiesel oilseed crops (palm, soya bean, sunflower and rapeseed) than those for ethanol cereals. Ethanol sugar crops have the lowest GHG impact.

The differences between biodiesel and ethanol results are mainly due to how much of the additional demand is met by additional production and the role of by-products (as explained

in Laborde, 2011). The increase in demand for cereals feedstocks (maize, wheat), for example, is to a large extent met by displacement of other uses and do not need to be completely replaced, while the additional demand for vegetable oils has to be produced. Vegetable oils do not lead to demand replacement by their own kind but by other vegetable oils due to the integration of the vegetable oils market. Therefore, the effect on vegetable oil will be linked to palm oil and to peatland emissions which are responsible for the high level of LUC emissions (see Box 4).

Box 4: Emissions from peatland drainage for oil palms are very high

There is about twice as much carbon stored in peat as in the above-ground biomass of the world's forests[67], and about 14 % of the peat-C-pool is concentrated in the tropical peat forests of Indonesia and Malaysia [Page 2011]. So losing only a small part of this can give very large consequences in terms of greenhouse gas emissions.

Only plantations need deep drainage

Trees have long been extracted from accessible areas of peatforest, which reduces the standing carbon lost when it is converted to oil palm plantation. However, this does not necessitate drainage: although some may result accidentally from digging ditches to transport out the logs, these rapidly silt up again. Systematic deep and irreversible drainage of peatland is only done to establish a plantation.

Peat-loss CO_2 emissions cover the whole lifetime of the oil palm plantation

If not drained, peat forest continues to sequester carbon as peat, at a rate of roughly 1 tonne per hectare per year. Once drained, the accumulated peat starts to oxidize to form CO_2.

The level of the peat goes down year by year as the carbon is lost. When the soil level approaches the water table, the plantation will die unless the drainage is deepened (then oxidation re-starts). Therefore the loss of soil carbon continues for the entire lifetime of the plantation, or until there is no peat left.

Peat-loss emissions are very high and could be considered as a direct annual emission

This means the peat oxidation emissions are in fact an annual emission which could be added in to the direct emissions calculation. However, traditionally they have been treated along with land-use-change emissions. Estimates of the average annual CO_2 emissions from drained peat have converged in recent years, to around an average figure of 100 tonnes CO_2 per ha per year over the 25 year lifetime of a plantation (Page et al., 2011). That corresponds to about 680 gCO_2/MJ of palm oil from peat-land (at 4 tonnes/ha palm oil yield) and a similar addition to the emissions per MJ of palm biodiesel. If peat-drainage emissions are used as part of an ILUC emissions calculation, they would correspond to about 850 gCO_2/MJ of palm oil from peatland if annualized over the usual 20 years.

Expansion of oil palm onto peatland is accelerating

Oil palm is the most profitable of the few crops which grow well on peat. Although the cost of establishing and maintaining the network of drainage canals means that the plantations on peat are less profitable than those on more traditional plantation soils, an ever

[67] 480 Gtonnes C [Page 2011] compared with 200 Gtonnes [FAO Forest Resources Assessment 2010].

increasing proportion of new plantations are on peat. That is driven by a high vegetable oil price, the lack of alternative land in some areas and the lack of clear existing ownership of peatland.

The RED sustainability criteria only exclude some palm oil on peatland

The sustainability criteria in the Renewable Energy Directive stipulate that no palm oil for EU biofuel may come from land converted from peatland after 2008. However, much peatland was already converted in 2008. Using historical data in (Miettinen et al., 2012), JRC estimated that 16 % of the RED-eligible palm oil from Indonesia and Malaysia (which together account for 85 % of world palm oil production) is grown on peat. So to account for annual CO_2 emissions from this peatland, it would be necessary to add of the order of 100gCO_2/MJ to the average emissions of palm-oil biodiesel satisfying the RED sustainability criteria.

About 30-40 % of new palm oil plantations are on peatland

In estimating ILUC, the important number is the fraction of new oil palm plantations which are established on peat. Comparing the expansion of oil palm onto peatland according to the Malaysian Palm Oil Board (Omar et al., 2010) with the total area of oil-palm expansion given on the same MPOB website, it is found that between 2003 and 2009, 29.6 % of the expansion of Malaysian oil palm area occurred onto peatland. By comparison, combining the area of peatland-to-oil-palm conversion between 2007 and 2010 (Miettinen et al., 2012) with FAO data on total oil-palm expansion shows 40 % of this expansion in Malaysia was onto peatland, and 30 % in Indonesia.

National commitments

Malaysia is a federal republic, and responsibility for land-use planning rests with state governments. The state government of Sarawak, where almost all the peat drainage is occurring, has a programme for actively increasing use of peatland. Indonesia is in negotiations to restrict deforestation in general, but control of provincial land use is reported to be less than completely effective.

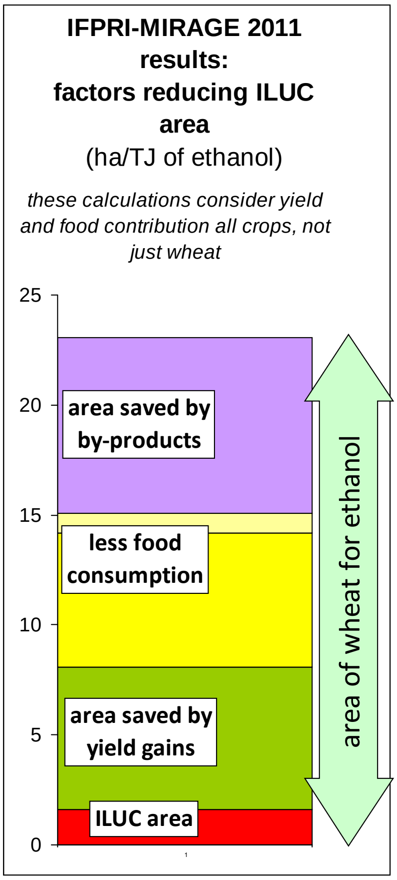
Additional sensitivity analyses have been carried out by IFPRI on the reduction in food consumption, yield and crop replacement

Subsequent analysis by the authors of the IFPRI 2011 work evidenced the need to carry out additional sensitivity analyses on some parameters used in the model, and to investigate some assumptions. These included:

- Yield increase: IFPRI 2011 projections of EU wheat yield were higher than any values reported by other agricultural outlooks.
- Cereals replacing 'other oilseeds' in the EU: the IFPRI 2011 work assumed that cereals could replace the crop category 'other oilseeds' as easily as any other arable crop. However, the JRC discovered that in the EU 'other oilseeds' consisted principally of olives, which are less easily displaced by cereals.
- Reduction in food consumption: all models for ILUC emissions assume a reduction in food consumption as a consequence of increased biofuels demand. The authors considered it was particularly important to show clearly the magnitude of this effect in the model, to understand the GHG benefits attributed to biofuels from food reduction.

Author's analysis of IFPRI 2011 results found that the ILUC area is a small part of the total area needed to grow more crops for biofuels

The JRC decomposition analysis of IFPRI 2011 evidenced that the ILUC area is only a small part of the total area needed to grow more crops for biofuels. In the MIRAGE model, the areas saved by by-products, by reduction in food consumption, and by yield increases are each considerably greater than the residual crop area increase that causes ILUC.



The author's decomposition of the results for the IFPRI-MIRAGE 2011 scenario of ethanol from EU wheat (the principles apply to all scenarios) is shown on the left. The total height of the column represents the increased area of wheat devoted to ethanol production reported in the model results, compared to the baseline scenario.

Apart from expansion of cropland (ILUC) the model derives land for wheat ethanol from three other sources:

- Substitution of animal-feed crops by biofuel by-products.
- Reduction in crop consumption for competing uses (mostly food).
- Land freed up by additional yield gains induced by the higher crop prices caused by biofuel demand.

The area saved by yield gains in the biofuel scenario (compared to the baseline scenario) was calculated by multiplying the total area of each crop by its fractional yield increase, and then summing for all crops.

The remaining area savings must come from by-products and reduced food consumption. The authors calculated the areas saved by by-products and reduced food consumption (calories) independently of each other, on the basis of IFPRI's output tables[68].

The modifications of the MIRAGE model by IFPRI in response to the suggestions of the JRC raise the ILUC emissions compared with 2011 values

In order to assess the relevance of some model assumptions and parameters, the JRC-IET started a collaboration with IFPRI in 2012 to gain a better understanding of the issues referred to above. The aim was also to carry out more work to reduce uncertainties in the evaluation of GHG emissions from crop groups (JRC-IET, 2014c).

IFPRI modified the MIRAGE model in response to the suggestions of the JRC-IET. The

[68] There remains a small area that is ascribed to a reduction in the quality of food consumed by humans (replacement of vegetables and fruit by cereals, for example), an effect which is also reported qualitatively by IFPRI. This happens because the IFPRI model, like other general equilibrium models, considers two market-driven effects. Firstly, increased demand for oilseeds results in farmers switching from other crops (including vegetables) to oilseeds. Secondly, when oil and grain prices increase, families redistribute spending to cheaper sources of calories (cereals) and away from more expensive foods such as oils and vegetables. IFPRI reports very little net effect of biofuels on animal feed use, indicating that the use of by-products practically compensates for the reduction in crops fed to animals.

results suggest an increase in ILUC emissions compared to 2011 values, especially for EU ethanol (Table 13):

(a) If the modelled EU 2020 wheat yield is brought into line with FAO-OECD projections, ILUC emissions for wheat ethanol increase by 15 %, but for other crops they are unaffected or even reduced.

(b) From 0 % to 29 % if the assumption that the crop category 'other oilseeds' including olives in the EU can be replaced by cereals is changed.

(c) Up to +30 %, depending on the crop, if food consumption is kept constant. ILUC coefficients for vegetable oils remain larger in magnitude than those for ethanol crops under all scenarios.

The combined effects bring higher LUC emissions (as expected) compared to the individual changes.

Correcting the two assumptions on yield and on the expansion into other oilseeds (Step 1, Table 13), LUC emissions will increase to a range of 9-14 gCO_2eq/MJ for sugar crops, 12-19 gCO_2eq/MJ for cereals crops and 52-56 gCO_2eq/MJ for vegetable oils.

Adding the food consumption effect, the increases are even higher (see second last row of Table 13). The range of LUC emissions for the crop groups becomes: 7-16 gCO_2eq/MJ for sugar crops, 13-23 gCO_2eq/MJ for cereals and 56-72 gCO_2eq/MJ for vegetable oils.

Table 13: Effect of IFPRI model corrections on ILUC emissions

Annual ILUC emissions (gCO_2eq/MJ of EU consumption, spread over 20 years)								
Crop group (best estimate)	Sugar crops		Cereals		Vegetable oils			
	Ethanol S. Beet	Ethanol S. Cane	Ethanol Maize	Ethanol Wheat	BioD PalmOil	BioD Rape	BioD Soya	BioD Sunf
IFPRI report 2011	7	13	10	14	54	54	56	52
(a) 2020 yields corrected	6	14	10	17	54	53	55	50
(b) No 'other oilseeds' to arable in EU	9	13	11	16	54	56	57	54
(c) No reduction in food consumption	5	15	12	18	63	54	72	62
STEP 1 - Combining (a) 2020 yields corrected and (b) No 'other oilseeds' to arable in EU	9	14	12	19	55	55	56	52
STEP 2 - Combining STEP 1 and (c) Freeze food consumption	7	16	13	23	63	56	72	62
For the record: ILUC emissions according to COM(2012)0595	13		12		55			

Box 5: Cropping intensity and buffer land

Fallow land is overstated as a potential source of ILUC-free crop area

Recently, attention has been drawn to the fact that the total of the harvested area of all crops in the FAOSTAT crop-list is considerably less than the area of arable and permanent cropland. This 'unharvested cropland' has been presented as a reserve of fallow land, where agriculture can expand with minimal land-use change emissions. However, as explained in Appendix 3, this is not the case:

- Fallow land is just one (probably small) part of the unharvested cropland.

- Most of it is in dry areas (e.g. central Asia) where yields are typically very low.

- Increasing use of this land would not increase crop production in proportion, because of the loss of existing unlisted crops (including hay) or of fertilisation benefits, and low yields.

- FAO cropland area data are uncertain.

The category of 'unharvested cropland' or fallow land does not specifically occur in most economic models of ILUC. However, it is accounted for in the models: 'fallow' is divided between other categories such as hay, pasture, cropland-pasture or grassland. There is no historical indication that expansion of crop area due to increased prices occurs preferentially in regions of the world that have recently reduced their crop areas.

The existence of buffer land does not eliminate ILUC

In parts of India and other areas of the world, marginally-suitable cropland creates a 'buffer', which is either not planted due to low expected crop price, or not harvested due to a failed crop. This accounts for most of the considerable variation in world harvested area from year to year across an area roughly the size of Hungary.

It is sometimes stated that ILUC area due to some change in biofuel policy is less than this annual variation, and can therefore be ignored. This implies that the buffer land can be permanently appropriated for extra crop production at the higher sustained crop price. However, variations in crop price would continue with or without biofuels; more uncropped land would be converted to cropland at the next price-peak, and variation in crop area would continue at a higher average value.

Increased double-cropping or use of fallow land could contribute to increased crop production

The fraction of cropland harvested does appear to be increasing with time (see Appendix 3). This is consistent with reports of increased use of double or multiple cropping in China, Brazil, Argentina and the central US. There could also be a contribution from increased harvesting of fallow land, although there are other technical explanations such as the occasional addition of more crops in the FAO crop list, and other historical improvements in the collection of FAO data on harvested area.

In the FAO data the fraction of cropland harvested appears to be increasing by about 0.18 % per year since 1970. However, as explained in Appendix 3, the resulting fractional increase in crop production is probably considerably less, due to low yields etc.. But even if it is assumed that the fractional increase in crop production is the same, this is 10 times less than the rate of yield increase, which averaged 1.8 % per year over the same time (data for world cereals in Figure 18). This means that even if ILUC models ignore the increase in cropping intensity, they will not overestimate ILUC by more than about 10 %.

The more sophisticated economic models, including the IFPRI-MIRAGE model, include variations in double cropping as part of their consideration of yield increase.

2.4.4 Alternative approaches to estimating the ILUC area

Economic models are the correct approach to estimating the ILUC area

The use of economic models is the correct scientific approach to an inherently complex problem which has to rely on hundreds of assumptions and parameters contributing to the model's result. In a drive to clarify the approach, attempts have been made to make simplified calculations using spreadsheets. One approach is to choose a simplified chain of consequences of biofuels production (for example, which crops are substituted by by-products, and where they are produced). However, in reality many consequences occur simultaneously, so selecting particular chains will yield very different results.

An alternative approach, developed in a recent JRC report, estimates ILUC emissions from different crops, starting from reported historical data on crops yield and area changes

Another approach is to estimate what the ILUC effect would be if a certain quantity of biofuel had been produced in the past, using some historical data and some transparent averaging. That is the approach used in a new JRC study (JRC-IET, 2014a).

The JRC, in collaboration with the Netherlands Environment Assessment Agency (PBL) and an independent expert (Koen Overmars) has developed a method to estimate ILUC emissions from different crops. This started from reported historical data (e.g. in FAOSTAT) on crops yield and area changes in the 2004-2012 period. The purpose of the method is not to estimate the impact of the EU biofuels policy in 2020, but to understand what happened in the past (2004-2012) in terms of crop yield increases and area expansion if 1 MJ[69] of biofuels was produced. The method's main assumption is that an increase in crop demand resulting from biofuels would drive increased yield and crop area in the same proportions as they have increased over time in the past. Thus, historical data are used to assess what proportion of all increases in production historically came from yield growth and what proportion from area growth. The results of this analysis can be used to 'back-cast' values predicted by the models (but cannot be directly compared with 'ILUC emissions' estimated by models such as IFPRI-MIRAGE).

The results of this analysis are shown in Table 14. The data are still unpublished and are being discussed by a group of experts. The final report is expected to be published in 2015.

Table 14: Weighted ILUC emissions from 'historical' analysis (gCO_2/MJ)

Feedstock	ILUC emissions in gCO_2/MJ over 20 years	
	CSAM (Cropland Spatial Allocation Model)	
	By RED method*	By value method**
EU wheat	21	21
EU sugar beet	9	7
US maize	13	13
Brazil sugar cane	5	5
EU rapeseed	170	215

69 1 MJ = 10^6 joules.

Feedstock	ILUC emissions in gCO_2/MJ over 20 years	
	CSAM (Cropland Spatial Allocation Model)	
	By RED method*	By value method**
US soya bean	187	230
Other Latin American countries soya bean	199	246
Indonesia palm oil	207	214
Malaysia palm oil	171	176
EU sunflower	171	217
EU wheat straw	0	3
Jatropha (Africa)	63	130
EU willow or poplar	2	2
EU switchgrass or miscanthus	1	1

* This refers to the allocation methods used to allocate by-products. The RED method follows the allocation rules specified in the Renewable Energy Directive (Annex V) for direct emissions, which allocate the emissions from cultivating a crop to biofuels and by-products according to their energy content (lower heating value), except in the case of straw and other low-value residues, which are not given an allocation.

** In the allocation of by-products by value method, the economic value of the biofuel component and the by-product component are taken into consideration in order to determine the share of land that can be attributed to biofuels.

The JRC has developed another independent estimate which starts from the historical deforestation area (and estimated emissions) attributed to the expansion of different crops, and then calculates how that relates to the production increase for each crop

All the approaches mentioned above start with a demand for biofuel and work out the associated ILUC.

The JRC recently used another alternative methodology to provide an independent estimate of the general magnitude of ILUC area and emissions. This method starts from the reported historical deforestation area (and estimated emissions) attributed to the expansion of different crops, and then works out how that relates to the historical production increase for each crop. To determine deforestation per MJ biofuel, we divide the related area by the MJ of biofuel which could be made from the crop. There is no geographical differentiation as to where the extra demand occurs or where that would cause deforestation. The source of the historical deforestation data used for the analysis is a recent report published by the European Commission Directorate-General for Environment (DG-ENV) (EC, 2103). This report estimates which areas of forest were lost to different crops and to other land uses (grazing, logged forest, urban and others) between 1990 and 2008. It uses historical deforestation data from FAO's Forest Resource Assessment 2010, interpreted in conjunction with other FAO data (JRC-IET, 2014b). The results of this JRC work are shown in Table 15.

Table 15: Land-use-change emissions aggregated for different crop groups, only from deforestation and peat forest drainage, attributed to each MJ biofuel

	Emissions from deforestation (gCO_2/MJ)
Oilseeds biodiesel without peat emissions	63
Oilseeds biodiesel with peat emissions	123
Cereals ethanol	15
Sugar cane ethanol	39

In general, the results of the two JRC studies described above show that cereals/sugar crops have lower ILUC emissions than oilseeds. They show somewhat higher ILUC emissions than those estimated for 2020 by most economic models.

This is especially true for biodiesels, mostly because some models do not account for, or underestimate, emissions from drainage of tropical peat. This could also be due to several shortcomings in the models, which cannot easily be separated:

- too much yield increase compared with area, in response to crop price increases;
- not taking sufficient account of the lower yields on marginal land;
- overestimating the ILUC credit from by-products (but we do not believe this to be an important cause).

More details of our analyses, including limitations and uncertainties, can be found in the reports (JRC-IET, 2014a and JRC-IET, 2014b).

2.5 Impact on biodiversity

The impact of biofuel production on biodiversity depends on the feedstock used, changes in land use and the management practices applied

If GHG savings are achieved, the use of biofuels will have a positive effect on biodiversity in the longer term by reducing climate change. Kram et al. (2012) concluded that, up to 2050, biodiversity gains associated with climate change mitigation per se tend to be offset by increased pressure on biodiversity owing to increased bio-energy production. This occurs through land-use change (e.g. deforestation in South-East Asia as a result of palm oil production, and the utilisation of set-aside land in the EU) or off-site effects caused by nutrient leaching and run-off, soil erosion, water use, etc. However, depending on site-specific characteristics biofuel production can have positive or negative effects on biodiversity, depending predominantly on the biofuel feedstock, previous land use, the management practices applied and the location of biofuel production (Table 16).

In the future, biodiversity will continue to be negatively impacted by biofuel production

Increased demand for palm oil has contributed to extensive deforestation in South-East Asia, with a highly negative impact on biodiversity. The expansion of palm oil plantations in South-East Asia is the most cited example of forest loss for biofuel production. In Latin America, for example, it has been reported that soya bean and sugar cane are encroaching into the Brazilian Cerrado. Palm oil production has also been linked to large-scale deforestation in countries such as Colombia, Ecuador, Brazil, Uganda and Cameroon, and in Central America. In the USA and the EU, biofuel plantations are expanding the agricultural

frontier, particularly into set-aside land (Campbell and Doswald, 2009; Sawyer, 2008). Moreover, ILUC effects are considered to be significant. Sugar cane and soya bean cultivation do not result directly in the large-scale loss of tropical forest but may replace pastures, forcing expansion of livestock production into the Legal Amazon (Campbell and Doswald, 2009; Sá et al., 2013; Barona et al., 2010; Martinelli and Filoso 2008). Similarly, the increasing production of maize for ethanol in the USA at the expense of domestic soya bean production has had the reported consequence of increasing deforestation in the Amazon (Laurance, 2007). Studies suggest that biodiversity will continue to be negatively impacted under future scenarios of biofuels production, largely as a result of habitat loss and fragmentation (Campbell and Doswald, 2009; Kram et al., 2012; Ferreira Filho and Horridge, 2014). Biofuel feedstocks that may have a significant impact on biodiversity (excluding the effect of GHG savings) are presented in the following table.

Table 16: Potential impact of different biofuel feedstocks

Feedstock	Positive impact	Negative impact
Annual crops (sugar, starch and oil crops)		• Direct and indirect land-use change • Use of agrochemicals • Water use
Perennial grasses, short-rotation coppices (SRC)	• Utilisation and enhancement of degraded and waste land • Cultivated as vegetation buffers which reduce nutrient and sediment loads in water bodies • Provide ecological corridors for species distribution In comparison with annual crops: • Lower use of agrochemicals • Less land disturbances • Reduction of nutrient leaching and run-off, and of soil erosion • Habitat improvement results in increased diversity of soil fauna, insects, birds, mammals, etc. • Greater landscape diversity	• Negative impact on biodiversity if replacing natural and semi-natural habitats (e.g. forests, scrubs) • Use of herbicides during the establishment phase • Change in water use • Introduction of invasive species • ILUC (if grown on productive land)
Residues from arable land	• Reduction of environmentally unfriendly practices such as residue burning	• Reduction of organic matter input affecting biological activity and biodiversity of soil organisms, with a potential cascading effect • Negative impact on species that depend on agricultural habitats, e.g. farmland birds • Increased use of mineral fertilisers • Increased soil erosion

Feedstock	Positive impact	Negative impact
Forest residues		• Negative impact on species that depend on forest residues (e.g. fungi, bryophytes, lichens, arthropods, birds) • Reduction of carbon stocks
Residues from grasslands	• Prevention of natural succession to a possibly less important habitat • Decreasing nutrient inputs, which is important for maintaining plant diversity	• Indirect effects if previously used for other purposes, e.g. grazing

Sources: Biemans et al., 2008; Riffell et al., 2011; Bunnell and Houde, 2010; Kretschmer et al., 2012; Dale et al., 2010.

The trade-off between reducing management intensity and minimising land-use requirements should be considered in relation to preserving biodiversity

Land demand pressure as a result of biofuel production could be reduced by the use of feedstocks with specific characteristics. Examples are feedstocks that: do not require additional land, e.g. wastes and residues; can be grown on degraded or marginal land, e.g. perennial grasses and short-rotation coppices; or can have high yields within low-input, semi-natural systems that are biodiversity-friendly e.g. semi-natural grasslands (Tilman et al., 2006; Tilman et al., 2009).

However, some studies have suggested that energy crops for advanced biofuels which use these kinds of feedstock may require a larger land area than conventional biofuels. This is largely because advanced biofuels do not produce beneficial co-products such as animal fodder, which would need to be grown separately (RFA, 2008).

Use of degraded and marginal land for the production of advanced biofuels may have positive effects on biodiversity

It is often suggested that advanced biofuels could utilise degraded and marginal land, with positive effects on biodiversity. However, the issue is not straightforward, as there is no clear definition of degraded or marginal land, and this land can have high biodiversity value (Wicke, 2011). Additional factors to take into account are the competition for degraded land for other uses – in particular food, forestry and urbanisation – and the possibility of restoring degraded land (e.g. through afforestation). Biofuels production on degraded and marginal land is usually economically less attractive than production on higher-quality agricultural land, so additional economic incentives may be needed (Campbell and Doswald, 2009; IPCC, 2011).

Impact of biofuels production on biodiversity could be significant, especially as a result of ILUC

The use of agricultural land for biofuels production pushes other agricultural production into natural ecosystems, causing ILUC. The impact of ILUC on biodiversity has so far been addressed by only a few studies. Bertzky et al. (2011) review ILUC with regard to biodiversity impact, concluding that the direct effects of the EU Renewable Energy Directive (RED) on land use will be small, but that the indirect effects may be considerable, with most impact occurring outside the EU. The complexities of ILUC make the assessment of its impact extremely difficult, and have impeded the development of safeguards that could

limit that impact. Nevertheless, ILUC is increasingly recognised, and efforts are being made to mitigate it (Webb and Coates, 2012).

Different measures should be implemented to make biofuels more 'biodiversity-friendly'

As noted, conventional and advanced biofuel can have a positive or a negative impact on biodiversity, depending on different factors. Given that biofuels production will increase in the future, a comprehensive assessment is needed in order to identify its environmental impact and the measures required to reduce it. Site-specific approaches are needed, and sustainability standards should be implemented and improved in order to reduce adverse impact on biodiversity.

2.6 Impact on water use

Increased biofuels demand will increase use of freshwater resources

Agricultural production of biomass for food and fibre accounts for 86 % of freshwater use worldwide, and 70 % of all water withdrawals (up to 90 % or more in some less developed countries) are used for irrigation in agriculture (Diaz-Chavez et al., 2013; Hoogeveen et al., 2009). In many parts of the world, competition is already occurring between different water usages, e.g. households, industry and agriculture. As biofuels require more water than fossil fuels, increased demand for biofuels in combination with an increase in demand for food will put additional pressure on freshwater resources.

The majority of water use in bioenergy systems occurs in feedstock production

Water use in bioenergy systems occurs predominantly in feedstock production, but also in feedstock preparation and transport, and in feedstock conversion in the biorefinery. In accounting for different types of water consumption, the concepts of green, blue and grey water are frequently used. Green water refers to rainwater and soil moisture that evapotranspire during crop production. Blue water is surface and groundwater that is consumed through human intervention, e.g. irrigation. Grey water is the volume of water that becomes polluted during production (e.g. through the use of fertilisers and pesticides) and is defined as the amount of water required dilute the total pollutant load to below a defined ambient water quality standard.

The impact on water resources of increasing biofuel production depends on:

- the feedstock used;
- climate conditions;
- site characteristics;
- agricultural practices; and
- the vegetation replaced by energy crops (Benders, 2002; Gerbens-Leenes et al., 2009).

The water footprint (WF) of biofuels shows wide variation depending on the feedstock used and site-specific characteristics

The water footprint (WF) is defined as direct and indirect water use over the entire supply chain. It is a useful tool for analysing the effects of different human activities on water use. However, estimation of the WF of biofuels shows wide variations in results owing to the different assumptions and methodologies used, which makes them difficult to compare. The

majority of the studies focus on blue irrigation water or consumptive irrigation water, which excludes the portion of irrigation water that is returned to the resource. However, green and grey water are also valuable. If not devoted to biofuel feedstock production, this water could be allocated to other crops, to environmental services, or to reservoir and groundwater recharge.

Water evapotranspired during energy crop production for different biofuels is presented in Table 17 (Berndes, 2002). WFs show wide variation depending on site-specific characteristics.

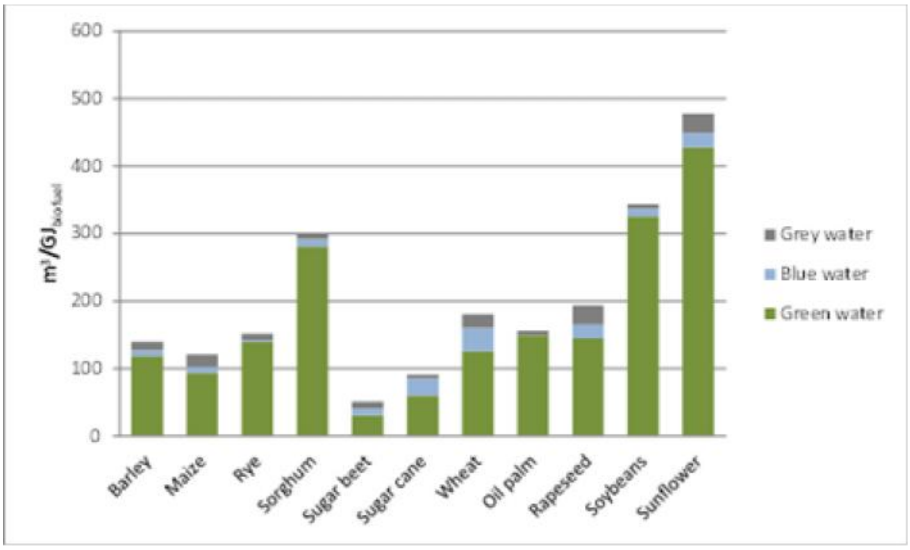
Table 17: Evapotranspiration (ET) of energy crops

Biofuel	Feedstock	ET (m^3 water/GJ)	
		Low	High
Biodiesel	Rapeseed	100	175
Ethanol	Sugar cane	37	155
	Sugar beet	71	188
	Maize	73	346
	Wheat	40	351
	Lignocellulosic crops	11	171

Water footprints for bioethanol tend to be smaller than for biodiesel

Mekonnen and Hoekstra (2011) estimated the global average water footprints (WFs) of biofuel for several crops providing bioethanol and biodiesel. WFs of bioethanol tend to be smaller than for biodiesel (Figure 31). The EU average WF for biodiesel from rapeseed is estimated at 99±15 m^3/GJ (green water 99±15 m^3/GJ; blue water 0 m^3/GJ) and for sugar beet ethanol at 36±11 m^3/GJ (green water 36±11 m^3/GJ; blue water 2±2 m^3/GJ) (Gerbens-Leenes and Hoekstra, 2011).

Figure 31: Total weighted-global average water footprint of bioenergy crops



WFs of biofuels produced from residues are highly dependent on the water allocation method used

Only a few studies considered the WFs of advanced biofuels produced from agricultural residues, e.g. for maize stover and cobs (Wu et al., 2012; King and Webber, 2008; Mishra and Yeh, 2011). As water consumption is mainly associated with feedstock production, the results are highly dependent on the water allocation method between grain and residues.

In 2030, biofuels are expected to account for over 2 % of evapotranspired water and around 5 % of water withdrawals

Biofuel crops globally account for 1 % of evapotranspired water and 2 % of irrigation water (De Fraiture et al., 2008). Several authors estimated the WFs of the future biofuel demand and associated water stress, defined as the ratio of agricultural water demand over the total available water resources. Based on these estimates, it is expected that in 2030 biofuels will account for over 2 % of evapotranspired water and around 5 % of blue water (Gerbens-Leenes et al., 2012; De Fraiture et al., 2008). Although global shares are modest, the impact for some countries could be significant. There is reason for concern in countries with fast-developing economies such as India, China, Thailand and South Africa, where the growing demand for food and energy causes an increased competition for already scarce water resources.

Water used in biofuel production will increase competition for water resources, which could pose a problem in regions that already experience high levels of water stress

Although biofuels currently account for a small share of water use, the share is expected to increase in the future owing to the foreseen increase in demand for biofuels. The problem is aggravated by the large variation of water availability and variable WF of biofuels, caused by differing climate conditions and agricultural practices. Water issues will have to be incorporated in the development of future bioenergy policies. While some countries such as Brazil, Russia or Canada have enough available water to produce and export biofuels, emerging economies such as China, India, Thailand and South Africa already face regional and seasonal water shortages. Therefore, some will have to rely on feedstock/biofuel imports – an outcome that counteracts some of the primary reasons for producing biofuels, especially in developing countries.

Estimated impact would be more severe if seasonal and spatial variability were considered, as well as future climate change

The majority of studies consider annual and country average data on water supply and demand. However, both water demand and availability vary strongly throughout the year, with demands often greatest when availability is smallest, exacerbating the water scarcity problem. Spatial variability is also high, so estimates of available water quantities would be needed at the catchment level so as not to affect the ecosystem adversely. Changes in the hydrological cycle and future global and regional water situations due to climate change will also need to be addressed.

2.7 Waste/residues availability and sustainability

Almost all the current commercial production of biofuels derives from cultivated crops. However, high expectations and investments are placed on advanced biofuels based on organic wastes and residues.

This section deals with the potential availability of these residual materials. Chapter 5 explores in more detail the potential environmental impact that may be associated with an increased production of bioenergy from residues. Chapter 6 assesses technological challenges to convert these feedstocks into suitable transport fuels.

Two recent European projects have provided a clear classification of biomass wastes and residues (Elbersen et al., 2012; Rettenmaier et al., 2010), which is also used in this report.

Among such sources, the wastes and residues are classified as shown in Table 18.
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Table 18: Classification of various biomass wastes and residues, as used in this report

Sector	Biomass Category	Biomass type details	General definition	Specific definition
Biomass from agriculture	Agricultural Primary residues	Dry manure		Poultry, sheep and goat manure
	Agricultural primary residues	Wet manure		Pig and cattle manure
	Agricultural primary residues	Solid agricultural residues	Biomass from agricultural cultivation and harvesting activities	Straw/stubbles (cereals, sunflower, rape)
	Agricultural primary residues	Solid agricultural residues	Biomass from agricultural cultivation, harvesting and maintenance activities	Prunings, orchard residues etc.
	Agricultural primary residues	Solid agricultural residues	Biomass from permanent (semi-natural) grasslands	Grass
Biomass from forestry	Primary forestry residues	Woody biomass	Cultivation and harvesting / logging activities in forests and other wooded land. Biomass from trees / hedges outside forests incl. landscape elements	Available volume of felling residues (branches and roots) and woody residues from landscape maintenance activities outside forests
	Secondary forestry residues	Woody biomass	Biomass coming from wood processing, e.g. industrial production	Bioenergy potential of wood processing residues (e.g. woodchips, sawdust, black liquor)

Sector	Biomass Category	Biomass type details	General definition	Specific definition
Biomass from waste	Primary residues	Biodegradable waste	Biomass from roadside verges	Biomass residues/solid biomass resulting from maintenance activities (e.g. from grass and woody cuttings from roadside verges)
	Secondary residues	Solid and wet agricultural residues	Processing of agricultural products, e.g. for food and feed	Processing residues (e.g. pits from olive pitting, shells/husks from seed/nut shelling and slaughter waste)
	Tertiary residues	Biodegradable waste	Biomass coming from private households and/or private residential gardens	Organic household waste incl. woody fractions, e.g. food leftovers, waste paper, discarded furniture
	Tertiary residues	Organic waste from industry and trade	Biomass from industry and trade, excl. forest industry	Organic waste from industry and trade incl. woody fractions, e.g. bulk transport packaging, recovered demolition wood (excluding wood that goes to non-energy uses)
	Waste biomass	Biodegradable waste	From industry and private households	Sewage sludge

When analysing biomass availability potentials, theoretical maximum potentials have little practical use and should not be mistaken for technical, economical and sustainably achievable quantities

It is important to distinguish between the various types of analyses and biomass potentials that can be obtained and that are reported in various documents:

- Theoretical potential: the overall maximum amount of terrestrial biomass that can be considered theoretically available for bioenergy production within fundamental biophysical limits.

  This type of analysis is not helpful in practical terms. It can actually give a distorted idea of the potential available for bioenergy.

- Technical potential: the fraction of the theoretical potential that is available within a techno-structural framework with the current technological possibilities (such as harvesting techniques, infrastructure and accessibility, processing techniques).

  This analysis provides a more realistic result, but cannot yet be compared with any demand curve, as it does not consider any economic constraints. These analyses are generally based on the primary energy of the biomass feedstocks, disregarding the end-use conversion efficiencies. A type of technical potential analysis is reported in Elbersen et al. (2012), although some sustainability constraints are applied to those predictions.

  The geographic distribution of potential is not essential at this level of analysis, but it becomes an important parameter in the economic analysis, especially for bulky materials such as biomass.

- Economic potential: the share of the technical potential that meets the criteria of economic profitability within the given framework conditions.

  This type of analysis generally employs cost-supply curves in order to model the actual supply of feedstocks in a specific policy context. The analysis presented in the latest EEA report (EEA, 2013a) contains economic potential analysis mixed with demand projections from the NREAPs to obtain a complete supply-demand study. Additional comments on the economic assumptions are added in Section 2.7.4.

- Implementation potential: the fraction of the economic potential that can be implemented within a certain timeframe and under fixed socio-political framework conditions, including economic, institutional and social constraints and policy incentives.

  This is generally implemented by applying a sub-set of constraints to the modelled calculation of economic supply.

- Sustainable potential: integration of environmental, economic and social sustainability criteria into biomass resource assessments.

Some studies apply environmental constraints at higher levels of potential, e.g. to the existing technical potential, ignoring economic constraints (see EEA, (2006) and Elbersen et al., (2012)). Newer studies (EEA, 2013a) employ more refined sustainability criteria as constraints in the modelling of future supply potentials by, for example, excluding feedstocks from high-carbon stock lands or excluding conversion pathways that do not reach a certain GHG saving threshold.

2.7.1 Technology options

Each material has a different set of technology options to be optimally converted to bioenergy and biofuels

It is important to define the specific and possible conversion pathways and end-use efficiencies suitable for each feedstock. The most common conversion pathways are presented in Table 19 for some of the primary and secondary residues. The list of possible conversions is not exhaustive and only provides an indication of what is technically feasible in the short and longer term. Conversion efficiencies are an important parameter as, for example, analysis based on resource efficiency would privilege pathways with higher efficiencies (e.g. combustion for heat production over combustion for power generation).

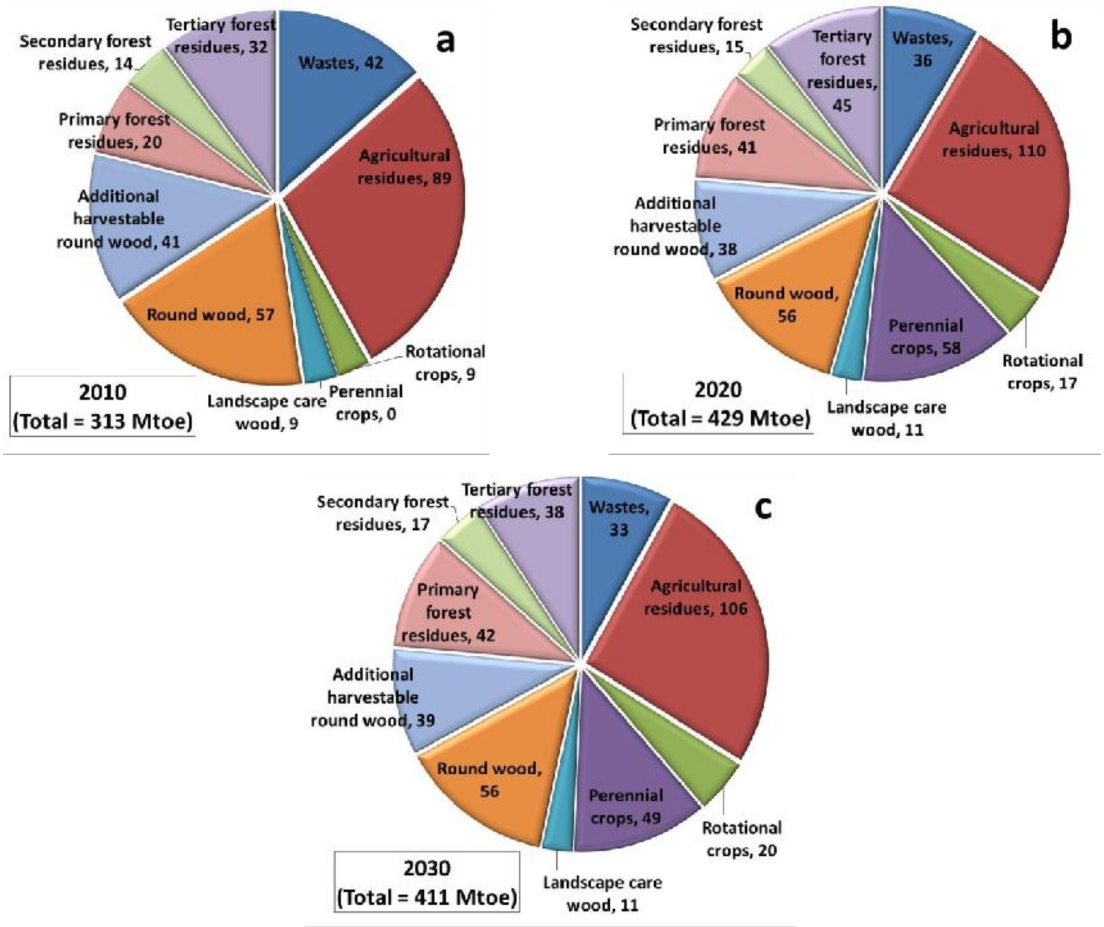
Table 19: Technological options for various biomass wastes and residues

Sector	Biomass type	Technology option 1	Technology option 2	Technology option 3
Biomass from agriculture	Dry manure	Combustion	Anaerobic digestion to biogas	
	Wet manure	Anaerobic digestion to biogas	Supercritical gasification to syngas and biogas	
	Straw/stubbles (cereals, sunflower, rape)	Hydrolysis + fermentation to bioethanol	Combustion for power and heat (stand-alone or co-firing)	Pre-treatment + anaerobic digestion to biogas
	Prunings, orchard residues etc.	Hydrolysis + fermentation to bioethanol	Combustion for power and heat (stand-alone or co-firing)	
	Grass	Hydrolysis + fermentation to bioethanol	Combustion for power and heat (stand-alone or co-firing)	Anaerobic digestion to biogas
Biomass from forestry	Available volume of felling residues (branches and roots) and woody residues from landscape maintenance activities outside forests	Combustion	Hydrolysis + fermentation to bioethanol	Biomass to liquid (BtL) via gasification
	Bioenergy potential of wood processing residues (e.g. woodchips, sawdust)	Combustion	Hydrolysis + fermentation to bioethanol	BtL via gasification
Biomass from waste	Biomass residues/solid biomass resulting from maintenance activities (e.g. from grass and woody cuttings from roadside verges)	Combustion	Hydrolysis + fermentation to bioethanol	BtL via gasification
	Processing residues (e.g. pits from olive pitting, shells/husks from seed/nut shelling and slaughter waste)	Combustion for the solid wastes	Anaerobic digestion for slaughter waste	
	Organic household waste incl. woody fractions (e.g. food leftovers, waste paper, discarded furniture)	Anaerobic digestion to biogas		
	Organic waste from industry and trade incl. woody fractions, (e.g. bulk transport packaging, recovered demolition wood; excluding wood which goes to non-energy uses)	Combustion	BtL	
	Sewage sludge	Anaerobic digestion to Biogas	Supercritical gasification to syngas and biogas	

2.7.2 Availability analysis

Figure 32 illustrates the technical potential available in Europe, as calculated in a recent study (Elbersen et al., 2012). Although the numbers calculated refer to a technical potential, those shown in
Figure 32 take into account the limitations generated by the RED sustainability criteria. Furthermore, other limitations are taken into account in order to exclude alternative, non-energy uses of these materials.[70] Consequently, no displacement effects are accounted for (an analysis of possible substitution impact for a few relevant materials can be found in section 5.3). In addition, this analysis includes no economic constraints (they are introduced in section 2.7.3 where the resulting supply analysis is presented).

Figure 32: Shares of various biomass feedstocks in EU27, technical potential at different time horizons (Elbersen et al., 2012). Values are in million tonnes of oil equivalent (Mtoe) and represent primary energy.



Agricultural residues account for more than 25 % of the technical potential of biomass in the EU while forestry residues account for another 23 %. The potential of straw and primary forest residues is forecast to more than double between 2010 and 2020

[70] A detailed description of assumptions and modelling techniques can be found in Elbersen et al., 2012.

From the analysis it appears that wastes and residual biomass materials actually accounted for more than 65 % of the technical potential of biomass available in the EU in 2010. Agricultural residues contribute with the largest share, increasing from 89 million tonnes of oil equivalent (Mtoe) in 2010 to 110 Mtoe in 2020. It is interesting to see that the forecasts indicate that the potential of available straw could more than double, from 23 Mtoe in 2010 to 49 Mtoe in 2020. This forecast is based on an estimated increase in cereal production, combined with a decline of livestock numbers and the associated straw demand. Manures have also a large potential (57 Mtoe in 2010), but this will remain constant or even decrease in coming years, reflecting a forecasted decrease in livestock numbers. Residues from forestry and wood industries account for 66 Mtoe in 2010 and could potentially increase to 102 Mtoe in 2020. The potential for secondary forest residues (namely sawdust and other sawmill residues) remains essentially the same as at it was in 2010, since the wood industry is expected to grow little if at all in the period up to 2020. However, the potential for primary forest residues (e.g. branches, additional thinnings and stumps) could double, from 20 Mtoe in 2010 to 41 Mtoe in 2020.

It is important to note that while these numbers were obtained by applying certain sustainability conditions, not all of the issues listed in Section 5.3 have actually been accounted for. These values should thus be considered as representing a technical potential.

2.7.3 Supply analysis

The availability analysis presented in section 2.7.2 provides a maximum constraint for the potential bioenergy supply. Furthermore, cost-supply curves can be modelled on the basis of these figures. Combining this information with estimates on bioenergy demand (usually NREAPs up to 2020) and on the additional sustainability constraints defined in various storylines[71], a final picture is drawn on final bioenergy domestic supply in Europe.

A recent study (EEA, 2013a; ETC/SIA, 2013) combines the availability analysis explained above with a modelling based on various sustainability hypotheses.

Stricter sustainability criteria would not mean a lower overall supply of domestic bioenergy

The result provides a potential supply of bioenergy by 2020 that can be directly compared to the demand indicated in the National Renewable Energy Action Plans (NREAPs) provided by every Member State within the framework of the Renewable Energy Directive (ECN, 2011).

Resource efficiency and sustainability criteria strongly incentivise the use of biomass residues such as manures, straws and logging residues, but the inclusion of full sustainability impact of the use of these materials is still missing from the analysis

Figure 3 illustrates the results obtained. It is evident that the policies applied have an influence on the potential supply of different types of biomass feedstocks. In a 'resource

[71] The 'Market First' scenario leaves the bioenergy development to market forces. Policy intervention is limited to the 2020 targets and other sustainability issues (e.g. ILUC) are not addressed.
The 'Climate Focus' scenario assumes more policy intervention. A 50 % GHG savings threshold is introduced (including ILUC factors) and land-use criteria are included.
The 'Resource efficiency' scenario applies all conditions in the climate focus scenario to biofuels and it extends them to bio-heat and bio-electricity. Furthermore, the NREAPs targets are relaxed so that technologies with higher end-use efficiency are promoted (more heat and less electricity is produced from bioenergy).

efficiency' perspective, in fact, wastes are minimised and recycled, and are thus not available for bioenergy (Figure 3c). However, climate-based incentives would favour, and allow the intensification of, the removal of primary forestry residues which would contribute significantly to the supply of available biomass (Figure 3b) (See also Section 5.2 for further discussion on carbon accounting of forest bioenergy).

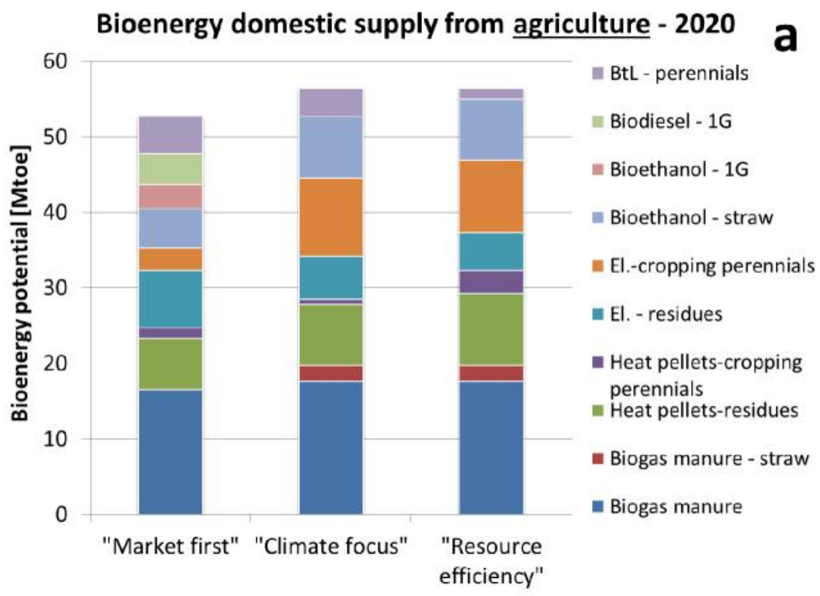
Figure 3a highlights the major contribution that biogas could provide to electricity production, even though biogas from energy crops is excluded from the analysis, partly because it would not be economically competitive without incentives (Scenario 'Market First') and partly because it would not comply with sustainability criteria in the other two scenarios (see also Section 5.4 for further discussion on the issue of biogas/biomethane sustainability).

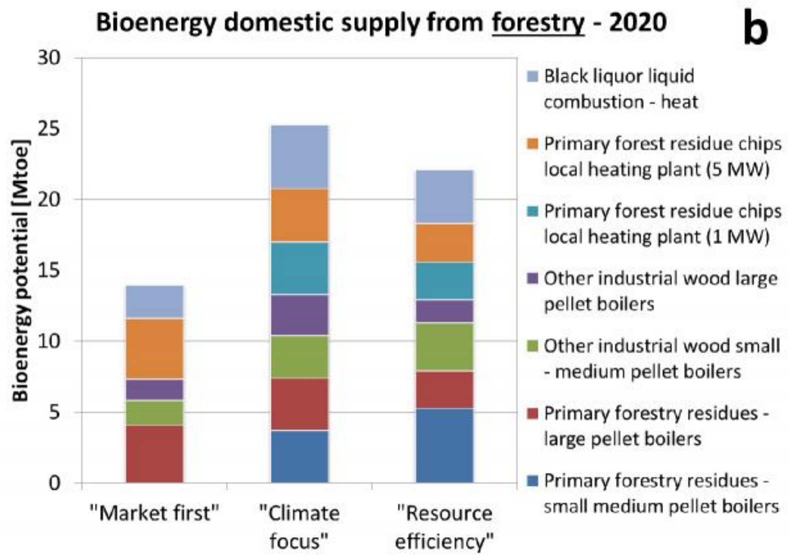
Finally, the model also indicates that applying strong environmental constraints would shift supply from first-generation biofuels, mostly excluded from the mix because of ILUC GHG emissions, towards advanced bioethanol from straw, and synthetic fuels from perennial crops. Besides, the supply in general would shift from biofuels to more resource-efficient pathways such as electricity and heat production.

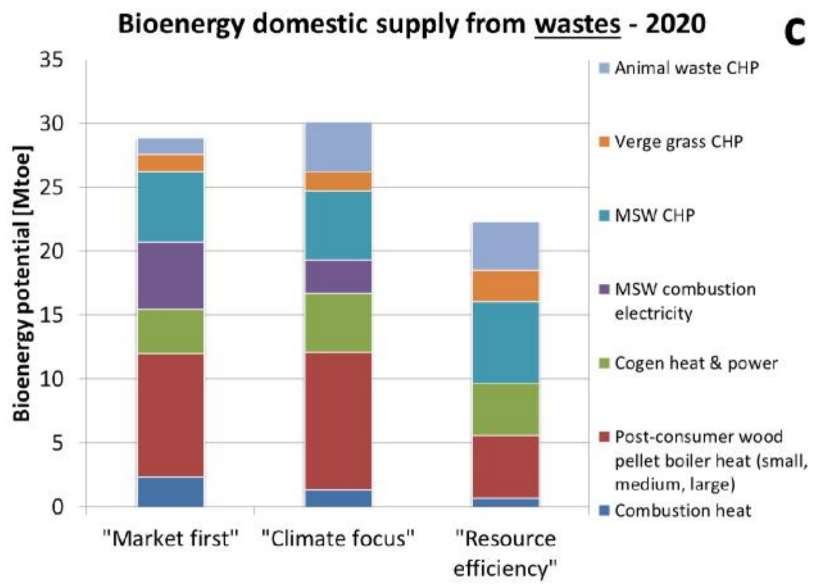
Forestry residues are generally available at higher prices than agricultural resources but are considered able to deliver larger GHG savings. Consequently, in scenarios with stronger constraints on environmental impact and resource efficiency, there is a significant increase of residual forestry resources being utilised for power and heat production.

Finally, the waste potential supply decreases with the stronger constraints associated with assumed increasing efforts to lower waste production and increase recycling and reutilisation.

Figure 33: Domestic bioenergy supply potential in the EU-27 in 2020, from different feedstocks (agriculture, forestry and wastes) and according to three different sustainability scenarios (EEA, 2013a)



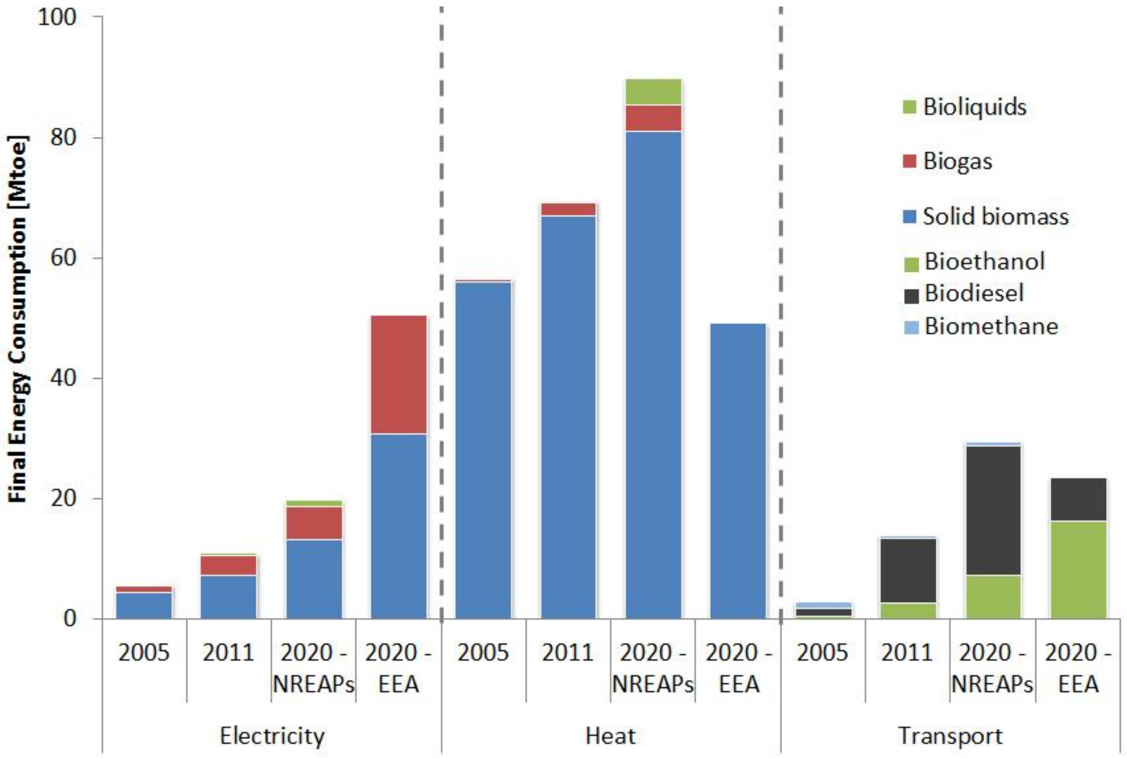




As modelled, a biomass supply based on strict sustainability criteria would be able to satisfy almost 90 % of the forecast demand, but would cause an imbalance between electricity, heat and transport fuels that would need to be managed

The figure below shows the current and forecast contribution of each biomass feedstock to the EU-27 energy mix. It is noteworthy that the forecasted domestic supply of biomass based on stricter climate criteria would be able to satisfy around 88% of the total demand. However, there would be serious imbalance in the different sectors: electricity surplus could be re-directed toward the transport sector to partially cover the deficit, and part of the biogas production could be redirected towards heat production (CHP) and could also be used to provide transport fuel. The climate sustainability criteria affect in particular biodiesel production, causing a serious mismatch between demand and supply that should be balanced via exports and imports.

Figure 34: Contribution of specific bioenergy pathways to the EU-27 targets for renewable energy consumption



Values for 2005 and 2011 represent statistical data (EEA, 2013b). NREAP data for 2020 represent the target curve indicated by each Member State towards the RED targets. EEA data for 2020 represent an estimate (EEA, 2013a) of the bioenergy domestic supply potential by 2020 applying strict climate sustainability criteria ('Climate Focus' scenario).

2.7.4 Assumptions about the supply costs of biomass feedstocks

The analysis reported in EEA (2013a) presents lower estimates of EU 2020 bioenergy availability than those presented in a previous study (EEA, 2006), in part because it takes economics into account.[72] It assumes a biomass price of 3 Euros/GJ[73] in its 'market first' storyline, or EUR 6/GJ in its 'climate focus' and 'resource efficiency' storylines.
Crucially, these are supposed to be prices 'delivered to the processing plant'. However, these prices are considerably lower than current market prices. This is a frequent problem in theoretical bioenergy studies, and is possibly due to the confusion between delivered prices at processing plant and 'stumpage' or farm-gate prices.

- Finland has a developed market in energy-wood, and offers some of the lowest prices in the EU owing to its large and developed forest sector. Nevertheless the present delivered price of energy-wood to Finnish power plants is about EUR 6.0/GJ (METLA, 2013)[74], having risen slightly in recent years. It is therefore optimistic to suppose that much additional wood for energy could be delivered at EUR 6/GJ, or any at all at EUR 3/GJ.

[72] Along with further environmental constraints (e.g. RED criteria, iLUC, etc.).
[73] Per GJ, not per tonne: there is a typing error in EEA 2013 table 4.1.
[74] 21.50 Euros/MWh.

- The world's largest straw-burning power station is situated in what is probably the world's most intensive wheat-growing area, at Ely in England. After nine years of optimising the supply chain, the cost of supplying straw to this power station is now GBP 40 per tonne, at 15% moisture, equivalent to EUR 3.3/GJ[75]. As the cost of straw depends on the transport distance, this could be considered the lower bound for delivered straw price in the EU. However, EEA (2013a) considers that most of the EU's straw-for-energy supply is already available at EUR 3/GJ on delivery.
- The current UK miscanthus price (delivered to power stations under fixed contract) is GBP 70 per tonne, at 16% moisture[76], which corresponds to EUR 5.6/GJ[77]. It would therefore be optimistic to assume that much of the energy crop could be delivered at only EUR 3/GJ, even if technical advances are assumed to have been made by 2020.

Another issue to keep in mind is that EEA (2013a) estimates the total biomass-energy available in EU, including existing biomass use for energy. For example, black liquor is an intermediate product in pulp mills that is burnt to heat the pulping process, meaning that it cannot be used for additional bioenergy elsewhere (unless replaced by another fuel).

75 UK straw: 85 % dry matter, LHV of dry matter 17.1 GJ/tonne, GBP 1 = GBP 1.20.
76 Farmers' Weekly 2013; last accessed on 9 December 2013.
77 Miscanthus: 84% dry matter, LHV of dry matter 17.8 GJ/tonne, GBP 1 = GBP 1.20.

3. EFFICIENCY AND PERFORMANCES OF BIOFUELS

KEY FINDINGS

- The regulatory landscape with regard to biofuel blending limits is not homogeneous and varies across the Member states.
- A variety of standards exists across the Member States, and a variety of mandatory targets exists across world regions.
- The efficiency of fuel alternatives is normally based on their energy content, which is typically lower for biofuels than for conventional fossil fuels.
- The use of biodiesel leads to a reduction of tailpipe emissions of particulate matter (PM), carbon monoxide (CO) and unburned hydrocarbons (HCs). On the other hand, most studies point to an increase in fuel consumption (FC) and in nitrogen oxide (NOx) emissions.
- The impact of biodiesel fuels on regulated pollutants increases as the concentration of the biodiesel in the fuel increases, reaching the maximum impact with the use of neat biodiesel.
- The use of biodiesel leads to the formation of certain carbonyl compounds not identified with diesel, such as hexanaldehyde and valeraldehyde, which have been associated with impact on human health.
- Biodiesel is differentiated from conventional diesel by certain factors that over time may have an effect on vehicle engine performance, including, under certain circumstances, fuelling system malfunctions.
- When blended with petrol for use as a vehicle fuel, ethanol can offer some exhaust emissions benefits over petrol, depending on vehicle type, engine calibration and blend level. Non-regulated pollutants seem either to increase or decrease, depending on the ethanol blending ratio.
- One of the major concerns pertaining to the use of petrol/ethanol blends is the possible increase in evaporative emissions.
- Alcohol/ethanol fuels degrade certain types of rubber and accelerate the corrosion of several metals and, as a consequence, some engine components that come in contact with ethanol may need to be replaced with new components made of a non-degradable material.

3.1 Energy balance and energy content of different biofuels

3.1.1 An overview of blending

Fuel blends are mixtures of traditional and alternative fuels in varying percentages.

Several technologies are used to blend biobased components in transport fuels from fossil sources. Such technologies vary depending on the biobased component used, e.g. biodiesel or bioethanol. The choice of technology used is determined mainly by the physical characteristics and subsequent behaviour of the biofuel components.

The physical characteristics of biofuel components determine both blending technologies and blending grades

Low-concentration blends are treated as fungible fuels[78] in the EU and other markets, but higher blends may cause problems in fuel pipelines and affect fuel efficiency and performance in vehicles. For biodiesel, four boundary factors currently limit the blending percentages, or grades, in fossil fuels:

- Biodiesel has a more limited storage life than conventional fossil diesel. It must be stored carefully to avoid degradation when blended with fossil diesel.
- Biofuels are usually mixed just prior to transfer to the service station. They need to be used/consumed within a limited time.
- Like fossil diesel, biodiesel clouds in cold weather, gelling and becoming full of wax crystals that can clog a fuel filter, affecting vehicle performance and reliability.
- Original equipment manufacturers (OEMs) have expressed concern over deposit formation when biodiesel is used in the high-pressure fuel injection systems used in diesel passenger vehicles. They have also expressed concern over the use of sub-standard biodiesel, or biodiesel which is improperly blended with fossil diesel, causing fuel filters to block.

Health, safety, security and environmental concerns determine how biofuels are transported, distributed and eventually blended with fossil fuels

In the case of bioethanol blending, it should be noted that ethanol has a corrosive effect and has also a bearing on performance issues, such as fuel economy.

The amount of ethanol blended in the pool is restricted by the maximum quantity of oxygenates permitted by weight percent. As ethanol cannot be moved through petrol product pipelines, a segregated distribution network is needed to transfer it before it is blended in terminals. The pre-blended petrol component, without ethanol, is normally shipped via pipeline, while the ethanol is transported separately by road, train or barge.

Health, safety, security and environmental (HSSE) standards are a concern with ethanol transport, particularly when blending to its maximum level in the E85[79] grade, as there are issues concerning the safety certification of dispensers, given that the fuel has a high-blend vapour pressure.

However, the case of ethanol as a blend component differs from biodiesel as it is not solely used to meet regulatory mandates. Ethanol is also used as an octane booster[80], replacing other octane booster components[81].

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[78] Fungible fuels are fuels with equivalent physical and chemical properties, distributed in a co-mingled manner and subject to sufficient specifications and quality control to allow that they, within a given type, can be substituted for each other. Fuel specifications are adopted by regulatory bodies for control purposes in the trade/distribution/use of fuels. Fungible fuel specifications vary by fuel type, fuel grade and season (temperature).

[79] Ethanol fuel blends have ‘E’ numbers that describe the percentage of ethanol fuel in the mixture by volume. For example, E85 is 85 % anhydrous ethanol and 15 % petrol. Similarly, biodiesel fuel blends have ‘B’ numbers that describe the percentage of biodiesel in the mixture by volume. For example, B7 is 7 % fatty acid methyl esters (FAME) and 93 % fossil diesel fuel.

[80] Octane is a measure of how slowly petrol burns. The higher the octane number, the slower the flame burns. Therefore, octane boosters deliver increases in petrol octane levels resulting in better fuel efficiency for the petrol vehicle.

[81] The most popular include methyl tertiary butyl ether (MTBE) and ethyl tertiary butyl ether (ETBE).

3.1.2 Current European CEN fuel specifications

For the reasons briefly discussed above, the Comité Européen de Normalisation (CEN)[82] determines specifications for fuel and biofuel blending[83].

Table 20: Standards (current European CEN fuel specifications)

Type of specification	CEN Identification	Brief description
Per biocomponent	EN 15376	For ethanol (up to 10% in regular petrol)
	EN 14214	Fatty acid methyl esters (FAME)
Per fuel type	EN 228	Petrol: up to 5% (E5), or 10% (E10) ethanol and 2.7% or 3.7% oxygen respectively
	EN 590	Diesel fuel: up to 7 % v/v FAME
	EN 228	Petrol: up to 5% (E5), or 10% (E10) ethanol and 2.7% or 3.7% oxygen respectively
Technical specifications in process of 'upgrading' into European standards	CEN/TS 15293	For E85 (85% of ethanol blend)
	CEN/TS 15940	For paraffinic diesel fuel or HVO

There are usually no limits on the addition of second-generation renewable diesel (apart from the density parameter for the diesel fuel standard for HVO). These are known as 'drop-in' fuels and typically include:

- Hydrogenated vegetable oils (HVO) and animal fats
- Biomass-to-liquids (BTL).

The jet fuel standards for the US and the EU are coordinated (and identical): ASTM D1655 and (UK/ Europe) Def Stan 91-91, which include requirements for semi-synthetic jet fuel, including biofuel.

Fuel specifications and blending grades differ per transport mode

As of 1 July 2011, the revised American Society for Testing and Materials (ASTM)[84] standard D7566-11 for aviation turbine fuel allows up to 50 % v/v of blending components to be manufactured from hydroprocessed esters and fatty acids (HEFA) from a variety of renewable sources, in particular jatropha, camelina and animal fats.

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82 The Comité Européen de Normalisation is a non-profit organisation for the development, maintenance and distribution of coherent sets of standards and specifications. CEN members are all Member States of the EU, plus three members of the European Free Trade Association (Iceland, Norway and Switzerland) and Macedonia and Turkey.

83 As noted, blends are mixtures of traditional and alternative fuels in varying percentages. Blends can be thought of as transitional fuels: the lowest percentage blends have been introduced, are being marketed, to work with current engine and powertrain technologies, while paving the way for future integration. For example, B7 (having about 7 % of biobased content mixed in diesel fuel of fossil origin) can be pumped directly into the tank of any diesel car or truck. Ethanol is also blended (E5, having about 5 % of biobased content) with the standard petrol dispensed in the EU.

84 Established in 1898, today's ASTM International is one of the largest voluntary standards-developing organisations in the world. ASTM standards are voluntary in that their use is not mandated by ASTM. However, government regulators often give voluntary standards the force of law by citing them in laws, regulations and codes. D7566-11 is the standard adopted in 2011 providing specifications for aviation turbine fuel containing synthesised hydrocarbons.

The EU and the USA have developed different approaches to regulating (and standardising) renewable fuels

The US Renewable Fuel Standard 2 (RFS2) is a volumetric standard aimed at increasing the production and use of renewable fuel in the US. The RFS2 applies to producers and importers of petrol and diesel in the US; it does not regulate fossil fuels. On the contrary, it mandates the use of 36 billion US gallons[85] (136.3 billion litres) of renewable fuel by 2022. The RFS2 classifies renewable fuel into four categories: cellulosic biofuel, biomass-based diesel, advanced biofuel and renewable biofuel. It specifies a minimum GHG reduction threshold for each type of renewable fuel. To determine whether a biofuel can qualify as renewable fuel, and in which of the four categories it is to be classified, its carbon intensity is compared to that of baseline petrol and diesel. The baseline reference is petrol or diesel produced in the crude mix in the US in 2003. Life-cycle analysis has been used to estimate carbon intensity for various fuels (life-cycle assessment methodologies are detailed in Section 4.1.3). For biofuels, emissions from indirect land-use changes are included.

The US Renewable Fuel Standard 2 has some negative effects

According to the US Environmental Protection Agency (EPA), the effects of the RFS2 standard are mixed: lower GHG emissions, as well as impact on air and water quality, are likely to be counter-balanced by increased nitrogen and fertiliser loading of river basins. These changes are to an extent due to reduced exhaust emissions and petrol use but also to reduced livestock populations. This sheds light on the interconnections between biofuel production and the food and animal-feed sectors.[86]

The US approach (of mandating the total volume of biofuels to be consumed by 2022) results in fuels with higher blending grades than in the EU

With respect to biofuel blending into fossil-based fuels, 10 % ethanol and 20 % biodiesel blending are now widespread in the US. The volumes mandated by RFS2 require that these blending grades are increased, in particular for ethanol blending into petrol. For this reason, the EPA has approved a 15 % ethanol blending for vehicle model years 2001 and newer.

The regulatory landscape in the USA is not homogeneous

Other measures at state level exist in the USA. The California Low-Carbon Fuel Standard (LCFS) is possibly the most renowned. It is a fuel-neutral GHG performance standard aimed at reducing GHG emissions from the transport sector by 10 % by 2020 relative to a 2010 baseline. Such reductions could be achieved by means of not only biofuels but also other low-carbon fuels, such as compressed natural gas (CNG), hydrogen and electricity. To achieve the required reduction, biofuel blending is one option. Other options are the selling of other alternative fuels such as electricity, CNG derived from North-American sources and biogas. Such fuels can also be included in the programme to generate credits. The standard does not apply to fuels that have been identified as having so-called 'niche' uses, such as fuels for aircrafts, military vehicles and equipment, and ships. Similar programmes also exist in other part of the USA[87] and Canada[88].

[85] 1 US gallon = 3.785 litres.

[86] US-EPA – Assessment and Standard Division Office of Transport and Air Quality 'Regulatory Impact Analysis' (EPA-420-R-10-006), 2010.

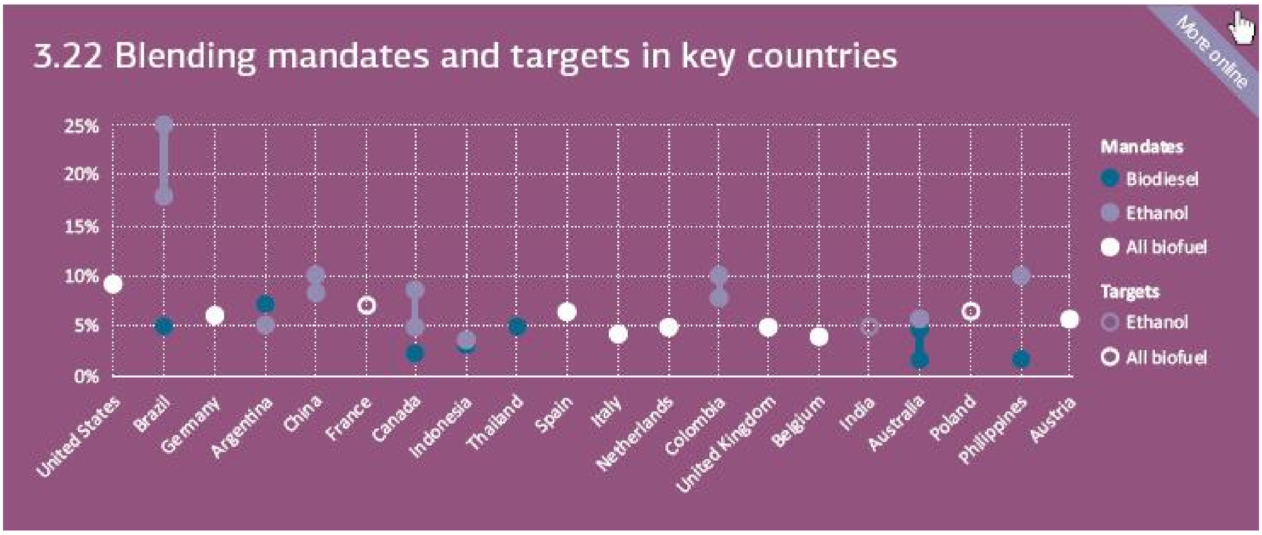
[87] The Oregon Clean Fuels Program, the Washington Low-Carbon Fuel Standard, the Northeast and Mid-Atlantic States Clean Fuels Standard, to name a few examples.

[88] The British Columbia Renewable and Low Carbon Fuel Requirement Regulation (RLCFRR).

Future biofuel supplies will partly be determined by the approaches taken by, and the implementation of, relevant regulation in fast-growing countries

In 2012, liquid biofuels accounted for approximately 3.4 % of global road transport fuels, with a small but increasing use in aviation and marine sectors. Global production of fuel ethanol was down by roughly 1.3% by volume from 2011 (because of high feedstock prices), while biodiesel production increased slightly. Global production of fuel ethanol reached 83.1 billion litres of ethanol, while biodiesel production reached 22.5 billion litres (1/4 of ethanol production)

Blending mandates and targets exist in over 50 countries around the world, including important producing countries in Latin America, South East Asia and Africa. Beyond the EU and the US, major players can be identified in fast-growing countries such as China (10 % biofuels mandate in place for 2020, with a current overall target for renewable energy of 15% for 2020), India (20% ethanol mandate in place for 2017) and Brazil (where the target has already been reached, with an expected level of 15-20 % demand for petrol supplied by ethanol by 2020-2022). These countries are expected to exert significant pressure on the global availability and prices of biofuels through the next decade.



Source: IEA Tracking Clean Energy Progress 2013.

However, only a few regions, such as the EU and the USA, have dedicated policies in place to support advanced biofuels.

3.1.3 Initiatives by EU Member States

The regulatory landscape in the EU is also varied

Initiatives at Member States level vary widely: France, Germany and Finland have approved of E10; France and Germany approved B7 in 2008 when it was still not approved at European level; France has approved of B30 in for captive fleets (i.e. urban busses, taxis etc.); and Germany approved B100 in 2008 for specially adapted vehicles.

Examples from other countries range from the approval of B20 in Poland and of B30 in the Czech Republic for captive fleets to the approval of E85 in Austria, France and Germany and of ED95 in Sweden.

The latest versions of the petrol (EN228) and diesel fuel standards (EN590) used in the EU allow blending up to E10 and B7, respectively.

Table 21: EU Member State initiatives – some examples

Blending grade	EU Member State	Brief description
E10	France, Germany, Finland	Up to 10% v/v ethanol blending in petrol
E85	Austria, Germany, France, Italy, the Netherlands, Sweden, UK	Up to 85% v/v ethanol blending in petrol for so-called flexi-fuel vehicles (FFV)
B7	France	Up to 7% v/v FAME blending in diesel fuel
	Germany	Plus 3% of renewable diesel
B20	Poland	For captive fleets
B30	France	For captive fleets
	Czech Republic	For captive fleets
B100	Germany	For specially adapted vehicles

Heterogeneous initiatives put the single market at stake

Standardisation of high-quality fuels containing sustainable biocomponents is essential, not only to ensure trouble-free engine performance in current and future European road vehicles, but also to ensure the effective working of the internal market.

3.1.4 Blending protection grades

Biofuel blend grades in standard vehicles are limited to low grades to avoid degradation of the engine and the fuelling system. As briefly explained above, the primary causes of this are incompatibility with certain diesel exhaust systems and engine oil dilution, filter clogging, erosion or compression, depending on biofuel type(s).

Fuel diversification through blending requires accurate consumer information and shall not exclude non-adapted fleet segments or geographic areas because of regulatory differences

Conversely, car engines and powertrains may be modified to run smoothly with higher blends. However, this option requires that lower blends remain available to satisfy fuel demand generated by the older part of the circulating fleet. Vehicles and re-fuelling points also need to be equipped, and must clearly display straightforward labels to allow the driver to refuel his or her car with the suitable fuel blend.

The introduction of increasingly higher blending grades may be reflected by provisions for ‘protection grades’ on the side of the vehicle. These provisions would indicate the start year for models and engines that are compatible with higher blends or – conversely – indicate at the pump which older vehicles require lower blending grades.

3.1.5 Efficiency of transport fuels

GHG emissions reductions and energy efficiency do not proceed in parallel

In general terms and with given exceptions, alternative motor fuels, including biofuels, may allow for a reduction of GHG emissions. However, they tend to have lower energy content than fossil fuels. This aspect can be explained using the concept of heat content.

Energy density and heat content

Net fossil fuel energy savings when using alternative fuels, including biofuels, need to be made on the basis of energy content/density

Heat content is defined as the amount of energy in a system capable of doing work. It can be measured in different ways and refer to different parameters, but it is broadly accepted that the lower heating value is considered and that this is measured in megajoules (MJ) per weight or capacity. As an example from the table below shows, ethanol is characterised by lower heat content than petrol (21.3 MJ/l vs 32.2 MJ/l): as a result, the net fossil fuel energy savings when using alternative fuels, including biofuels, need to be made on the basis of energy content/density and not on the volumetric bases. Results tend to demonstrate that although biomass-based transport fuels may result in lower CO_2 emission levels along the entire pathway, there are no net energy savings owing to the comparatively lower energy density of biofuels compared to fossil fuels.

Table 22: Fuel properties

Fuel	Density	LHV	CO_2 emission factor	
	kg/m^3	(MJ/kg)	g CO_2/MJ	kg CO_2/kg
Liquid hydrocarbons				
Petrol 2000	0.75	42.9	74.4	3.19
Petrol 2010	0.745	43.2	73.4	3.17
Diesel 2000	0.835	43	73.5	3.16
Diesel 2010	0.832	43.1	73.2	3.16
Naphtha (HT)	0.72	43.7	71.2	3.11
FT Naphtha	0.7	44.5	69.2	3.08
FT Diesel	0.78	44	70.8	3.12
Oxygenates				
Methanol	0.793	19.9	69.1	1.38
Ethanol	0.794	26.8	71.4	1.91
MTBE	0.745	35.1	71.2	2.5
ETBE	0.75	36.3	71.3	2.59
DME	0.67	28.4	67.3	1.91
FAME	0.89	36.8	76.2	2.81
Gases				
Comp. Hydrogen		120.1	0	0
Liquid Hydrogen		120.1	0	0
CNG (EU mix)		45.1	56.2	2.54
HVO (Nesté)	0.78	44		
LPG			65.7	3.02

Source: CONCAWE.

For practical purposes, and to allow direct comparisons of fuel alternatives, it is useful to convert the energy content of each fuel alternative into one comparable unit, either multiples of joules or tonnes of oil equivalent. This facilitates benchmarking and comparing across alternatives.

Table 23: Conversion factors

Conversion Table	
1 toe* 41.85 GJ	1 Mtoe 41.85 PJ
1 t Diesel 43.1 GJ	1Mt Diesel 43.10 PJ 1.032 Mtoe
1 t Petrol 43.2 GJ	1 Mt Petrol 43.2 PJ 1.032 Mtoe
1 t CNG 45.1 GJ	1 Mt CNG 45.1 PJ 1.100 Mtoe
1 t LPG 46.0 GJ	1 Mt LPG 46.03 PJ 1.100 Mtoe
1 t FAME 36.8 GJ	1 Mt FAME 26.80 PJ 0.679 Mtoe
1 t HVO 44.0 GJ	1 Mt HVO 44.00 PJ 1.051 Mtoe
1 t BTL 44.0 GJ	1 Mt BTL 44.00 PJ 1.051 Mtoe
1 t Ethanol 26.8 GJ	1 Mt Ethanol 26.80 PJ 0.640 Mtoe
	1 Mt DME 28.4 PJ 0.679 Mtoe
1 t E85 29.9 GJ	1 Mt E85 29.90 PJ 0.715 Mtoe

*toe: tonne of oil equivalent

All conventional or alternative fuels are the result of production/distribution processes consuming energy and causing emissions. It is therefore also necessary to consider the steps and processes required to produce conventional and alternative fuels, and their respective energy efficiency and GHG emission values per energy unit. Regarding the effect of blends or pure biofuels on engine efficiency, very interesting results have been demonstrated, for both petrol and diesel engines, regarding whether there is a possibility to recalibrate the engine or when the engine can be redesigned.

According to a recent study from TNO (2013), for petrol engines the efficiency improvement is primarily linked to specific fuel properties such as the higher octane number of the biofuels. With high blends (>50 %) an efficiency improvement of 15 % or more seems possible, but even more interesting is a possible efficiency gain of up to 10 % with a 20 % ethanol blend. This means that the actual fossil fuel reduction could be larger than the biofuel share. According to the same study, for diesel engines the efficiency improvement is related to improvements of the NOx-particulates and NOx-fuel consumption trade-offs. With relatively simple recalibrations, it is possible to achieve a 4-5 % efficiency

improvement with pure HVO or biodiesel (FAME), or a 1-2 % efficiency improvement with 20 % ethanol or butanol in diesel. Especially with diesel engines, it is expected that further improvements will be possible through more extensive recalibration or design optimisation.

3.2 Impact of biofuel use in different transport modes on EU/UN goals for GHG emission reduction and renewable energy use

This section provides data on the impact on tailpipe (exhaust) emissions from the use of biofuels. Emphasis is given to both regulated and non-regulated pollutants from the use of the most commonly used biofuels for transport.

3.2.1 Emissions from biodiesel

The investigation of exhaust emissions from the use of biofuels is extremely important for the evaluation of their overall impact on human health and the environment

Biodiesel is a mixture of various fatty acid methyl esters; the exact composition depends on the feedstock. This is a distinctly different composition than the hydrocarbon content of fossil diesel. These differences in chemical character affect a number of physical properties which can in turn affect tailpipe emissions in ways distinct from those of conventional fuels. When used as a vehicle fuel, biodiesel offers some tailpipe and GHG emissions benefits over conventional petrol and diesel.

Particulate matter, carbon monoxide and unburned hydrocarbons seem to decrease with the use of biodiesel. However, fuel consumption and nitrogen oxides increase in most studies

The GHG emission benefits of biodiesel are especially significant, because carbon dioxide (CO_2) released during fuel combustion is offset by the CO_2 captured by the plants from which biodiesel is produced. In addition, as a result of the different physicochemical characteristics, biodiesel has been found to affect emissions of diesel engines (EPA, 2002; Tat, 2003; Knothe et al., 2005; Sze, 2007; Szybist et al., 2007; Kousoulidou et al., 2010). In general, particulate matter (PM), carbon monoxide (CO) and unburned hydrocarbons (HCs) seem to decrease with the use of biodiesel. However, fuel consumption (FC) and nitrogen oxides (NOx) increase in most studies. The variation in PM and NOx emissions has been attributed both to the difference in chemical character, which affects combustion kinetics, but also to the effect of the different physical properties on fuel-spray characteristics.

Most of the literature on biodiesel effects is based on emissions measurements of heavy-duty vehicles and engines. Only recently have a few studies on diesel passenger cars begun to appear (Karavalakis et al., 2007; Fontaras et al., 2009; Karavalakis et al., 2009; Kousoulidou et al., 2009; Kousoulidou et al., 2012). Since diesel cars are widespread in Europe, it is important to study the effects of biodiesel on emissions, given the potential implications for air quality and fuel efficiency. In this respect, two key biodiesel parameters need to be explored: the effects of feedstock type and blending ratio on emissions and consumption.

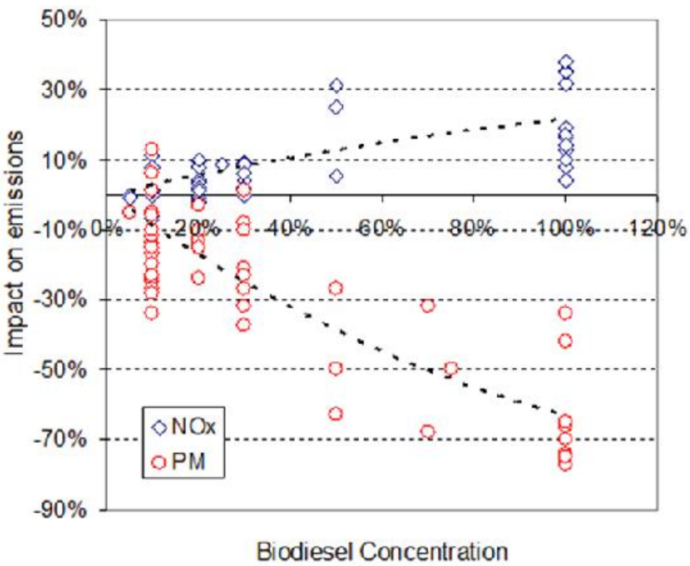
The impact of biodiesel on regulated pollutants is not straightforward as it seems to depend mainly on the blending ratio, the physical properties of the biodiesel, the vehicle/engine technology and the driving conditions

Results from various studies indicate that the effect of biodiesel on regulated pollutants is not straightforward. It seems to depend mainly on the blending ratio, but also on the physical properties of the biodiesel, the vehicle/engine technology and the driving conditions. More specifically, it can be concluded that the impact of biodiesel fuels on regulated pollutants increases as the concentration of the biodiesel in the fuel increases, reaching the maximum impact with the use of neat biodiesel.

The studies data collected from the literature for this report suggest that, for passenger cars and light duty trucks, NOx emissions increase by up to 16 % with straight biodiesel, while PM decreases by about 70 %. This is an important observation that should be considered when calculating the impact of high-concentration biodiesel application on diesel vehicles. If multi-fuel compatible engines are developed, engine manufacturers may benefit from such trade-offs to reduce emissions through proper engine calibration.

These observations suggest that the use of biodiesel in blends of up to 10 % will not contravene the NOx emission standard and could even be used in areas suffering from photochemical pollution, providing benefits from the significant reduction of PM. The key factor in this mandatory transition would be the replacement, by up to 10 %, of conventional diesel fuels with biodiesel fuels with favourable properties in order to establish a fair NOx-PM trade-off.

Figure 35: Evolution of NOx and PM emissions with increasing biodiesel concentration (based on numerous studies)



The use of biodiesel leads to the formation of certain compounds not identified with diesel, such as hexanaldehyde and valeraldehyde, which have been associated with impact on human health

Analysis of results from various studies indicates that the impact of biodiesel on carbonyl emissions varies with the fuels tested. Overall, biodiesel appears to have a minor effect on these contaminants. However, the use of some biodiesels results in significant increases, whereas the use of others leads to decreases. Biodiesels derived from rapeseed and palm oil (two feedstocks extensively used in Europe) are among those that systematically lead to

increases. The compounds formaldehyde and acroleine, which are associated with significant health risks, present the highest average increases when biodiesel is employed. In addition, the use of biodiesel leads to the formation of certain compounds not identified with diesel, such as hexanaldehyde and valeraldehyde, which have been associated with impact on human health (Kousoulidou, 2011).

Figure 36: Total average carbonyl compound emissions for conventional diesel and various types of biodiesel tested over all driving cycles, expressed in mg/km

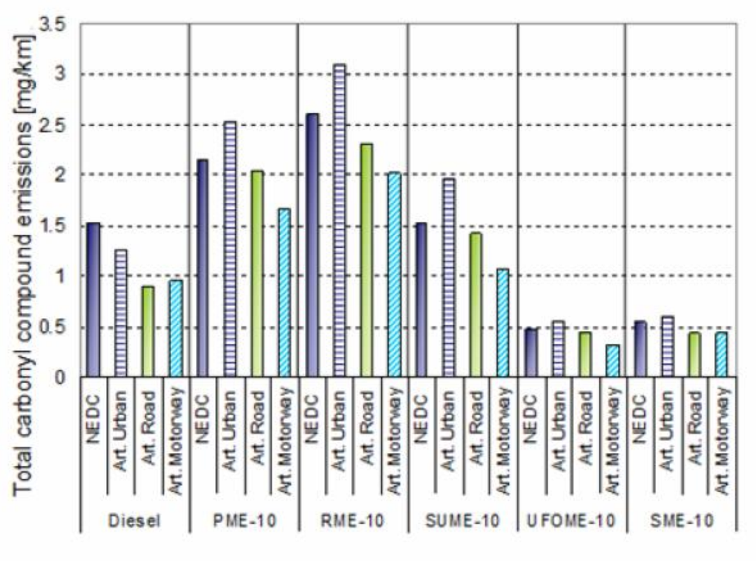
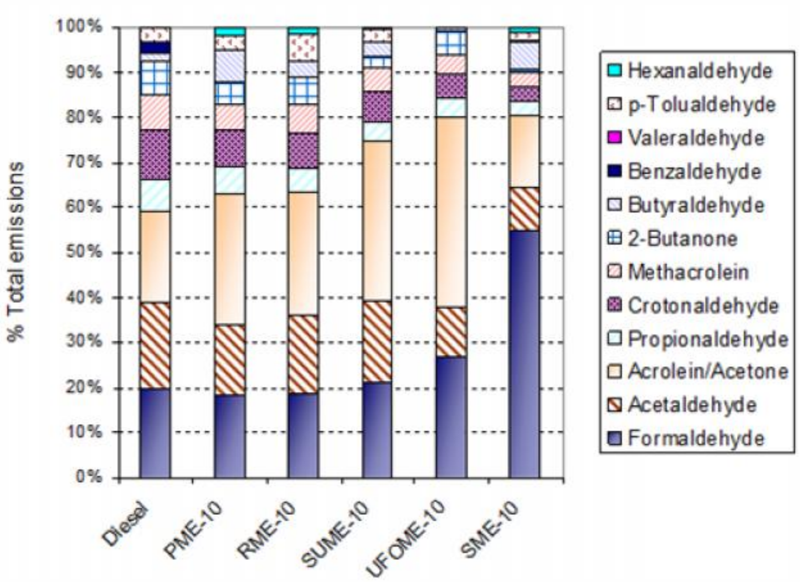


Figure 37: Percentage of each individual compound on total emissions for each fuel tested



3.2.2 Emissions from bioethanol

According to numerous studies (EIA, UNICA, ePURE, USDA) the use of bioethanol in Europe as a blend in petrol is increasing. Both France and Spain have established fuel ethanol industries that do not use ethanol directly but transform it into ETBE (ethyl tert-butyl ether). ETBE is produced by mixing ethanol and isobutylene and reacting them with heat

over a catalyst. The benefit of ETBE is that it eliminates many of the historical impediments to a more extensive use of ethanol, such as its effect of increasing the volatility of petrol and its incompatibility with petrol pipelines. As already discussed, bioethanol can be used as a fuel in a number of different ways:

- As a blend with petrol (from 5 % to 85 %). As a 5 % blend it can be used in all petrol engines. As a low-percentage alcohol-petrol blend (E10 is 10 % ethanol, also known as 'gasohol'), ethanol can also be used with little or no engine modification. However, higher E85 blends require several modifications.
- As a direct substitute for petrol in cars with appropriately modified engines.
- As a blend with diesel in diesel engines, also known as 'E-diesel' fuel blends.
- As a blend with biodiesel in diesel engines, also known as 'BE-diesel' fuel blends.

The following sections include a brief analysis of the vehicle types that can operate on ethanol blends, and of the associated values for tailpipe emissions and performance. Emphasis is given to NOx and PM emissions since these pollutants have been associated with major impact on human health. Investigation of the impact of specific fuels on NOx emissions is particularly relevant for areas where photochemical pollution occurs.

3.2.3 'Flexible-fuel' vehicles

Flexible-fuel vehicles have an internal combustion engine designed to run on more than one fuel, usually petrol blended with either ethanol or methanol

In Europe, flexible-fuel vehicles (FFVs) can run on any percentage of petrol-ethanol blend (up to E85) or on neat petrol. The engine-management system automatically detects what type of fuel is being used and accordingly adjusts the timing. With 27.1 million FFV automobiles, motorcycles and light-duty trucks sold worldwide by December 2011 (with sales concentrated in four markets: Brazil (16.3 million), the US (10 million), Canada (more than 600 000) and Europe, led by Sweden (228 522)), it is clear that FFVs are a strong parameter in the automotive sector.

Some modifications are required to allow petrol cars to run on bioethanol (for blends higher than E5). Usually some engine components that come in contact with ethanol may need to be replaced with new components made of a non-degradable material.

One of the primary arguments advanced by advocates of ethanol enrichment is the claimed reduction in air pollutant emissions relative to petrol fuel. Since ethanol is an 'oxygenate', and introduces a greater oxygen-to-fuel mixture, an improvement of combustion efficiency is expected. However, the true picture is far more complex than this argument might suggest. The following sections discuss the main results from a considerable number of studies of vehicle tailpipe emissions in the peer-reviewed and technical literature.

All studies report a very high variation in NOx emissions in the use of bioethanol blends, ranging from significant improvements (with emission reductions of up to 67 %) to equally significant aggravations (with emission increases of up to 79 %)

The main conclusion after comparing all studies on the use of E10 blends is that no consistent change can be seen regarding NOx emissions. Some studies indicate that E10 blends generally cause higher NOx emissions compared to neat petrol (Reuter et al., 1992; CARB, 1998; Koshland et al., 1998; NRC 1999 and Hsieh et al. 2002), some studies indicate mixed results (Knapp et al., 1998; He et al., 2003), while other show no change or

marginally lower emissions (Reading et al., 2002; Egeback et al., 2005). The average increase of NOx emissions is in the order of 1 %, with a range from -10 % to +7 %, as shown from various experiments conducted on passenger cars (Reading et al., 2002; TNO 2004; Karlsson, 2006).

The average increase of NOx emissions is in the order of 25 % with the use of E20 blends in passenger cars, with results ranging from -17 % to +79 % (Zervas et al., 2003; Egeback et al., 2005; Karlsson, 2006).

All studies report a very high variation in NOx emissions with the use of bioethanol blends, ranging from significant improvements (with emission reductions of up to 67 %) to equally significant aggravations (with emission increases of up to 79 %). The variations in the published results are not directly associated with ethanol content or vehicle class. However, in contrast to what applies for diesel engines, petrol engine emission performance is dominated by the operation of a three-way catalyst. Small variations of the combustion stoichiometry may have important effects on catalyst efficiency. In particular for NOx, if the ethanol oxygen content in the fuel is not properly compensated for by the engine, this will lead to a lean exhaust which completely inhibits the reducing efficiency of the catalyst, resulting in higher NOx emissions. Over-compensation will have the opposite result. In addition, the use of an additive package to change certain properties of the blend may influence the emission performance of the vehicle. According to Gautam et al. (2000), longer-chain alcohol additives result in an increase in NOx emissions.

Exhaust PM emissions from petrol passenger cars are only a fraction of those for diesel cars (1-3 mg/km, as compared with 25-50 mg/km). Measurements made to evaluate the impact of ethanol-petrol blends on PM emissions show that E10 leads to reductions of 50 %, with a range of -33% to -59% (Reading et al., 2002), as compared to results for neat petrol.

As already mentioned, all fuels on the market that are used for transport purposes must contain a certain proportion of renewable energy sources, and ethanol in petrol is a promising solution for reaching this goal. In addition to decreasing dependence on fossil fuel, ethanol contributes to reducing air pollutant emissions during combustion (carbon monoxide and total hydrocarbons), and has a positive effect on greenhouse gas emissions. These considerations rely on numerous emission studies performed in standard conditions (20-30 ^{o}C). However, very few emission data are available for the cold ambient temperatures that prevail in winter. The results of one study showed higher unregulated emissions at -7 ^{o}C than at 22 ^{o}C, regardless of the ethanol content in the fuel blend (Clairotte et al., 2012). These results lead to the conclusion that the implementation and adjustment of new technical devices, such as after-treatment systems and block-heaters, are needed to adapt vehicles to alternative fuel characteristics.

Most studies that assess non-regulated emissions indicate that emissions of benzene, toluene, ethyl benzene and aldehydes either increase or decrease according to the ethanol blending ratio and are not proportionally dependant on the blending ratio. For example, in a study in which ethanol blends were used at various blending ratios, the analysis suggests that the use of E10 results in statistically significant increases in emissions of NMHC (9 %), NMOG (14 %), acetaldehyde (108 %), 1,3-butadiene (16 %) and benzene (15 %), and no statistically significant changes in NOX, CO_2, CH_4, N_2O or formaldehyde emissions (Graham et al.,2008). The same analysis suggests that the use of E85 results in statistically significant decreases in emissions of NOX (45 %), NMHC (48 %), 1,3-butadiene (77 %), and benzene (76 %), statistically significant increases in emissions of formaldehyde (73 %) and acetaldehyde (2540 %), and no statistically significant change in CO, CO_2 or NMOG emissions.

The blending of ethanol into petrol influences evaporative emissions via different mechanisms

The blending of ethanol into petrol at up to approximately 40-50% (E40-E50) results in an increase in vapour pressure. This may lead to increases of evaporative emissions (see 3.2.5 for more details). The results of a major test programme designed specifically to investigate the influence of petrol vapour pressure and ethanol content on evaporative emissions from modern European passenger cars confirm that vapour pressure is a key fuel variable for evaporative emissions (Martini et al., 2007). In general, increasing fuel vapour pressure above a specific limit can lead to increased evaporative emissions owing to the enhanced fuel-vapour generation mode. Limiting the vapour pressure of petrol/ethanol blends to the same value as pure hydrocarbon petrols (e.g. 60 kPa for summer-grade petrol), as required by the current Fuel Quality Directive, does not guarantee that this value is not exceeded when petrols with and without ethanol are available within a given refuelling radius. Known as the commingling effect, the mixing of two different petrol qualities in the tanks of a vehicle results in a general increase in petrol vapour pressure.

As an illustration of the commingling effect, consider a motorist who brings his car to a service station for refuelling when the tank is half full. If one assumes that the original fuel in the tank contains a 10 % ethanol-blend at a given vapour pressure and that the fuel added to the tank at the station is a non-ethanol blend of the same vapour pressure, the overall effect will be to turn the non-ethanol petrol into a 5 % ethanol blend by volume causing an increase of its vapour pressure.

Ethanol might also influence evaporative emissions via different mechanisms than the increased vapour pressure of ethanol/petrol blends (CARB, 1999). Ethanol is known to increase the fuel permeation rate through elastomeric materials (rubber and plastic parts) that make up a vehicle's fuel and fuel vapour systems. Results from a large-scale study on fuel permeation showed that non-ethanol hydrocarbon permeation emissions generally increased when ethanol-containing fuels were tested (CRC, 2004).

3.2.4 Emissions from fuel combination (E-diesel, HVOs-diesel and BE-diesel)

'E-diesel'

There is a clear trend of increased NOx emissions and reduced PM emissions when E-diesel is used

Ethanol is a widely available oxygenate with a long history of use in petrol blends, so it has also been considered as a potential oxygenate for diesel fuel blending. However, when considering an alternative fuel for use in diesel engines, it is important to take a number of issues into account. These include supply and distribution, integrity of the fuel being delivered to the engine, emissions and engine durability.

Numerous techniques have been examined in order to evaluate whether it is possible to use blends of diesel and ethanol in compression-ignition engines. Some of these techniques include alcohol fumigation, dual injection, alcohol-diesel fuel emulsions and alcohol-diesel fuel blends. Among these techniques, blends are the most promising since they are stable and can be used in engines with relatively no modifications. Blends of ethanol with diesel fuel are often referred to as 'E-diesel'.
The addition of ethanol to diesel fuel simultaneously decreases cetane number, heating value, aromatics fractions and kinematic viscosity, and changes distillation temperatures

(He et al., 2003). Most importantly, E-diesel blends have a much lower flash point[89], and higher vapour formation potential in confined spaces, than diesel fuel (Peckham, 2001).

The solubility of ethanol in diesel is affected mainly by the temperature, hydrocarbon composition of the diesel and the water content in the blend (Ecklund et al., 1984). In order to keep the blends homogenous and stable, an additive and an ignition improver are used. This can enhance the cetane number of the blends and favourably affect the physicochemical properties related to ignition and combustion (He et al., 2003). In addition, additives can prevent the ethanol and diesel from separating at very low temperatures or if water contamination occurs.

Viscosity and lubricity play significant roles in the lubrication of fuel-injection systems, particularly those incorporating rotary distributor injection pumps that rely fully on the fuel for lubrication within the high-pressure pumping mechanism. The addition of ethanol to diesel lowers fuel viscosity and lubricity, and this may lead to greater pump and injector leakage, reducing maximum fuel delivery and ultimately power output (Hansen et al., 2005).

The comparison of emissions from E-diesel and diesel fuel is complicated. Results vary widely according to the conditions under which the fuel is used (speed, load, test cycle, engine size, engine design, etc.). Since the blending of ethanol and diesel fuels results in a decrease of the cetane number and an alteration of the physiochemical properties, an additive package is usually used to compensate for the deterioration of fuel characteristics. The variation of cetane number and physiochemical properties of each individual blend can also influence the emissions.

Experiments have tested NOx emissions with the use of E-diesel (Reuter et al., 1992; Corkwell et al., 2003) in different passenger cars under various operation conditions with E10 blends. The results show an average increase in NOx emissions in the order of 12 %, ranging from a 2 % decrease to a 25 % increase compared to neat diesel (Reuter et al., 1992). The addition of ethanol in diesel fuel results in significant reductions of PM emissions. The average reduction from all measurements collected on the use of E10 on passenger cars is in the order of -5 %, ranging from -67 % to +65 %.

<u>HVO-diesel (diesel from hydrotreated vegetable oils or hydrotreated used cooking oils)</u>

Most studies report reductions of regulated pollutants with the use of HVOs. However, some studies report increases in NOx and PM emissions which need to be investigated further

In general, the good fuel characteristics that HVOs present lead to exhaust emissions benefits and good engine performance (Alleman et al., 2003). Substantial reductions in NOx, PM, CO and HC emissions are reported with the use of HVOs on heavy-duty engines (Kitano et al., 2007; Kuronen et al., 2007; Aatola et al., 2008), although NOx increases have also been observed (Murtonen et al. 2009). Moreover, the use of such fuels leads to alterations of exhaust emissions of light-duty engines, where it seems that the actual effect

[89] The flash point of a volatile material is the lowest temperature at which it can vaporise to form an ignitable mixture in air. At the flash point, the vapour may cease to burn when the source of ignition is removed. The flash point is often used as a descriptive characteristic of liquid fuel, and it is also used to help characterise the fire hazards of liquids.

of the HVO-diesel blends is much dependent on the operation mode (Kitano et al., 2007). Different engine operating conditions may lead to opposite conclusions regarding the effect on NOx, PM and smoke (Happonen et al., 2013). Most of the studies available in the literature were conducted on heavy-duty engines, and the picture seems to be altered when it comes to light-duty engines. For example, in a study in which HVOs were tested on light-duty vehicles with exhaust gas recirculation (EGR), it was not possible to detect clear trends in NOx emissions (Rantanen, 2005). Another survey found that for light-duty vehicles the effect of paraffinic fuels on NOx and PM results may vary (Clark, 2002). One EGR-equipped vehicle resulted in low PM emissions but a slight NOx increase, while another vehicle optimised for low NOx showed significant NOx reduction with the paraffinic fuel, but poor PM performance.

In one study, a number of experiments with neat hydrotreated waste HVO were performed on a light-duty common-rail Euro 5 diesel engine (Kousoulidou, Dimaratos et al., 2013). The measurements included in-cylinder pressure, pollutants emissions and fuel consumption. Combustion effects were limited. However, emission effects included both higher and lower NOx and smoke, depending on the operation point. In another study, the results on the engine bench were compared against a Euro 4 common-rail light-duty vehicle driven on the chassis dynamometer, using 50%v/v HVO - 50% v/v diesel blends, in order to include the effects of emission-control systems (EGR and oxidation catalyst) (Kousoulidou, Amanatidis et al., 2013). The measurements included regulated pollutants emissions (including particle size and size distribution) and fuel consumption. The results indicate that the tested fuel is a very promising fuel, with a high cetane number and zero polyaromatics, oxygen, etc. It led to lower emission levels except for NOx and PM, perhaps owing to the different properties of the fuel (higher viscosity etc.), which may cause combustion variations and have possible effects on fuel injection and spray pattern, compared to petroleum diesel. However, the optimisation and adjusting of the engine may provide a different picture regarding NOx and PM emission levels. This needs to be further investigated in order to completely evaluate the impact of this alternative fuel on vehicles' tailpipe emissions.

BE-diesel (biodiesel-ethanol-diesel)

Ethanol-blend and biodiesel-blend would substantially reduce PM emissions but produce higher levels of NOx concentrations compared with fossil diesel

The main disadvantage of E–diesel fuel blends is that ethanol will not mix with diesel over a wide range of temperatures (Gerdes et al., 2001). Studies have revealed that biodiesel can be used successfully to stabilise ethanol in diesel, and the biodiesel–ethanol–diesel (BE-diesel) blend fuel can be stable well below the freezing point of water (Fernando et al., 2004). It has therefore been suggested that the biodiesel and ethanol blends can be an optimised oxygenated agent for diesel fuels (McCormick et al., 2001). According to Cardone et al. (2002), the disadvantages of BE-diesel compared to fossil diesel is the lower heating value of BE–diesel, which may account for the lower engine power, exhaust temperature and torque, and higher BSFC[90] (brake specific fuel consumption), relative to fossil diesel (Cardone et al., 2002).

[90] BSFC is a measure of the fuel efficiency of a shaft-reciprocating engine. It is the rate of fuel consumption divided by the power produced. It may also be thought of as power-specific fuel consumption, for this reason. BSFC allows the fuel efficiency of different reciprocating engines to be directly compared.

Some studies have found that ethanol-blend and biodiesel-blend would substantially reduce PM emissions, but produce higher levels of NOx concentrations compared with fossil diesel (Ali et al., 1995; Starr, 1997). In the studies by Pang et al. (2006), Shi et al. (2005) and Ali et al. (1995), results showed that PM emissions were substantially reduced for BE–diesel compared to neat diesel.

3.2.5 Evaporative emissions

Evaporative emissions from a vehicle can be defined as all the volatile organic compounds (VOCs) emitted by the vehicle itself and not deriving from fuel combustion

One of the major concerns related to the use of petrol/ethanol blends is the possible increase in evaporative emissions from vehicles. These can be defined generically as all the volatile organic compounds (VOCs) emitted by the vehicle itself and not deriving from fuel combustion. For petrol vehicles, most of the evaporative emissions are due to a loss of hydrocarbons from the fuel system. More specifically, the major contributions to evaporative emissions come from fuel evaporation from the tank and fuel permeation through fuel hoses, fuel tank, connectors etc. (Martini et al., 2012). VOC compounds may also come from materials used for vehicle construction, such as plastics and interior trim, or from other system fluids (e.g. windshield detergent). However, these emissions are usually very low in modern cars, and in any case do not depend on fuel quality.

Ethanol has a significant influence on both the exhaust and evaporative emissions of petrol passenger cars when added to the fuel, even at low levels (5 %). Due to the oxygen content of ethanol, some exhaust emissions may be slightly reduced, but some other non-regulated pollutants (e.g. acetaldehyde) may increase. The increase of evaporative emissions due to ethanol is due to a combination of factors:

- increased vapour pressure of the petrol/ethanol blends;
- increased fuel permeation through plastic and rubber components of fuel system;
- commingling effect;
- increased refuelling emissions.

The issues related to the impact of the presence of ethanol in the fuel on evaporative emissions have been addressed extensively in a large number of studies conducted in the US. In response to this, the US-EPA (United States Environmental Protection Agency) and CARB (California Air Resources Board, or 'Clean Air Agency') have developed specific measures to reduce or eliminate the negative effects of ethanol on the evaporative emissions of vehicles. As a result, current US legislation on evaporative emissions is much stricter than that of the EU and consists of different test procedures for, and specific requirements on, components that thoroughly cover all the factors influencing the process. In order to improve the capability of European petrol cars to control evaporative emissions in real-world driving conditions, especially in view of a wider introduction of ethanol in the fuel market, it is considered necessary that EU legislation regarding these emissions be revised.

Current EU legislation on evaporative emissions dates back to Directive 98/69/EC (Euro 3-4 standards). Since then, neither the emissions limits nor the test procedure have changed. However, pursuant to current law, the European Commission has the obligation to review the evaporative emissions test procedure in order to improve control of these emissions. According to the rules in force, the technical measures taken by the manufacturer must be

such as to ensure that the tailpipe and evaporative emissions are effectively limited throughout the normal life of the vehicles under normal conditions of use. Due to the wider introduction of biofuels, the Commission intends to review test procedures for evaporative emissions. This review should consider whether greater global harmonisation is desirable through the alignment of EU test procedure with those of the US. In doing so, consideration may be given to introducing in-service conformity or durability requirements to control the effects on evaporative emissions of long-term use of fuels containing ethanol.

Evaporative emissions have been associated with severe impact on human health and the environment

To date, the following effects from evaporative emissions have been reported or associated with them:

- human exposure to ozone (acute effects on mortality and morbidity);
- exposure of crops to ozone (yield loss);
- impact associated with long-term exposure to ozone;
- direct effects of VOCs;
- effects of VOCs through the formation of secondary organic aerosol;
- effects on biodiversity.

According to Martini et al. (2012), three different aspects have to be addressed:

1. A more effective control of evaporative emissions throughout the normal life of the vehicles under normal conditions of use

A first implication is that the evaporative emissions should be controlled more effectively in real-world driving conditions and not just in laboratory conditions. There is evidence that in many cases the evaporative emissions control systems are designed just to pass the type-approval test according to the legislative procedure.[91] In particular, as described in this report, the purging strategy adopted in some models is such that the canister is not purged efficiently when the vehicle is driven at low speeds in urban areas. This can easily lead to saturated canisters that may result in uncontrolled evaporative emissions, especially in hot climates. In addition, in the current type-approval test the vehicle is driven over three whole NEDCs (new European driving cycles) after the loading of the canister and before the evaporative emissions diurnal test is started. This means that the vehicle is driven for a total of 33 km, during which the canister is purged. Real-world activity data shows that the typical trip length is much shorter, especially in urban areas.

2. A more effective control throughout the useful life of the vehicles also implies an improved durability of the control system for evaporative emissions

EU legislation currently provides no procedure to ensure the durability of the evaporative control system over the useful life of the vehicle. In the US, in addition to specific durability requirements, the performance of the evaporative control system is also checked regularly by means of an in-use verification programme.

[91] The new European driving cycle or ‘type-approval driving cycle’ is a driving cycle designed to assess the emission levels of car engines and fuel economy in passenger cars (excluding light trucks and commercial vehicles). The NEDC is supposed to represent the typical usage of a car in Europe. It consists of four repeated ECE-15 Urban Driving Cycles (UDC) and an Extra-Urban driving cycle (EUDC).

3. The impact of ethanol on evaporative emissions

Ethanol has a significant influence on both the exhaust and evaporative emissions of petrol passenger cars when added to the fuel, even at low levels (5 %). As already mentioned, due to the oxygen content of ethanol, some exhaust emissions may be slightly reduced while other, non-regulated pollutants (e.g. acetaldehyde) may increase. According to the literature, the blending of ethanol up to E30 into petrol results in an increase in vapour pressure, and thus increases evaporative emissions. Results from a major test programme, specifically designed to investigate the influence of petrol vapour pressure and ethanol content on evaporative emissions from modern European passenger cars, confirmed that vapour pressure is a key fuel variable for evaporative emissions (Martini et al., 2007b). In addition, ethanol may also influence evaporative emissions via other mechanisms than the increased vapour pressure of ethanol/petrol blends (CARB, 1999). Ethanol is known to increase the fuel permeation rate through the elastomeric materials (rubber and plastic parts) that make up the vehicle's fuel and fuel vapour systems. Results from a large-scale study on fuel permeation showed that non-ethanol hydrocarbon permeation emissions generally increased when the ethanol-containing fuels were tested (CRC, 2004).

In addition, one of the potential issues associated with the use of ethanol/petrol blends is the effect of ethanol on canister efficiency (Grisanti et al., 1995). The working capacity of a canister is typically around 50 % of its total equilibrium adsorption capacity, and is heavily dependent on several parameters, such as canister design and purge conditions. During normal operation, a 'heel' of material that cannot be easily desorbed builds up within the carbon bed, reducing the working capacity of the canister. The magnitude of the heel depends also on the carbon properties. Larger hydrocarbon molecules are less easily desorbed than smaller ones, so the average molecular weight of the heel increases over time. Ethanol is a polar molecule and is known to be less easily desorbed from activated carbon. Therefore, the use of a fuel containing ethanol could significantly increase the heel and reduce the working capacity of the canister. This would result in an increase in evaporative emissions.

3.2.6 Biofuels compatibility and durability issues

Some European manufacturers have specifically modified their engines to allow them to run on higher blends of biofuels, but many have not. There is a shift towards making engines compatible, which generally involves the use of appropriate synthetic rubbers for seals, fuel hoses, etc.

Modern diesel engines are quite sensitive to fuel quality and characteristics. In particular the fuelling system of common rail engines can be affected by various factors, such as cold flow properties, concentration of unsaturated compounds, acidity and viscosity. Biodiesel is differentiated from conventional diesel in certain factors that may in time have an effect on a vehicle's engine. According to the literature, vegetable-oil-derived fuels can under certain circumstances lead to malfunctions of the fuelling system. This is due to their reduced cold flow properties and higher viscosity, their ability to form polymers (Giannelos et al., 2005) and the fact that their application may result in injector coking formation (Pundir et al., 1994). For this reason, the application of additives (cetane improvers, cold flow improvers, oxidation stability improvers) in biodiesel is a common practice (Bauer et al., 2004).

Some modifications are required to enable petrol cars to run on bioethanol (for blends higher than E5, as is the case for all cars produced since 2008/2010). Alcohol fuels degrade certain types of rubber and accelerate the corrosion of several metals. Therefore, some engine components that come into contact with ethanol may need to be replaced with new

components made of a non-degradable material. Compared with petrol, bioethanol has a higher natural octane number that allows it to be used at high compression ratios, thus increasing engine efficiency. However, it also has a lower energy density than petrol, this requiring an adjustment of the ignition timing in a conventional petrol engine and the fitting of a larger tank to achieve the same useful distance. Pure bioethanol is difficult to vaporise at low temperatures. Use of E95-E100 may lead to difficulties in starting vehicles in cold weather. For this reason, the fuel is usually blended with a small amount of petrol to improve ignition (E85 is a common high-percentage blend).

3.2.7 Criticalities in reaching RED and FQD targets

EU rules prioritise the environmental performance of transport fuels

As outlined in previous sections (see boxes 1 and 3), transport-specific mandatory targets are included in EU legislation in pursuit of the overall objective of lowering the carbon emissions of the transport system.

Multiplying factors and sustainability criteria are used as incentives to achieve environmental mandatory targets. Electricity generated from renewable sources counts 2.5 times towards the 10 % target. According to the RED, similar minimum sustainability criteria, as well as minimum GHG savings per unit of energy, must apply to biofuels.

Member States are in charge of delivering the RED mandate

The RED mandates the establishment of a national renewable energy action plan (NREAP) for each Member State, including information on targets for different transport and non-transport sectors.[92] Member States are also expected to implement measures to achieve these targets, assessing the contribution of measures for energy efficiency and energy saving. The RED therefore places the responsibility for fulfilling the RED targets on the Member States.

Fuel suppliers are in charge of delivering the FQD mandate

As described in Box 1, the FQD sets environmental requirements for fossil fuels. It provides technical specifications for fuel quality parameters, as well as binding targets to reduce life-cycle GHG emissions from fuel or energy in transport by 6 % by 2020, relative to the 2010 fossil fuel GHG emissions baseline. This is expected to be achieved by increased efficiencies in refinery and biofuel blending. The FQD target takes into account the impact of renewable fuels on life-cycle GHG emission savings of fuels supplied for on-road vehicles, non-road mobile machinery (including rail and inland water transport), agricultural and forestry tractors and recreational craft.

The RED and FQD do not include exactly the same set of variables

With respect to transport activities, the main difference between the RED and the FQD is that the FQD excludes fuel consumed by air transport while the RED includes it. The FQD calculation also includes off-road fuel consumption, which is excluded from the RED calculation. From 2011, fuel suppliers must report annually to the Member States on the

[92] JRC reference report 'Review of Technical Assessment of National Renewable Energy Action Plans 2012' (EUR 25757 EN), 2013. The main goals of the report are: to verify the achievement of an overall EU-28 target of 20 % and of the Member States' targets; to compare the proposed renewable resources with resource estimates; and to make a comparative analysis between the data reported and the technically and environmentally available, and economically competitive resources in order to identify the possible risks (such as capital, resources and technology risks) of the introduction and development of renewable energy technologies.

life-cycle GHG emissions per unit of fuel supplied. The FQD places the burden for fulfilling the FQD targets on fuel suppliers and not on the Member States.

Table 24: Schematic overview of the transport sector as outlined in the RED and FQD

	Numerator /		Denominator		
	Renewable energy		Total energy		
	Type	RED	Type	RED	FQD
Road					
Passenger cars	All	✓	G,D,Bio,Elec	✓	✓
Light-duty vehicles	All	✓	G,D,Bio,Elec	✓	✓
Heavy-duty vehicles	All	✓	G,D,Bio,Elec	✓	✓
Buses and coaches	All	✓	G,D,Bio,Elec	✓	✓
Motorcycles	All	✓	G,D,Bio,Elec	✓	✓
Off-road vehicles	All	✓	G,D,Bio	✓	✓
Non-road					
Inland-navigation	All	✓	D	✓	✓
Aviation	All	✓	G	✓	✗
Rail	All	✓	G,D,Bio,Elec	✓	✓
Pipeline Transport	All	✓		✗	✗
Non-road mobile machinery		✗		✗	✓
Electricity in transport		✓		✓	✓

Notes: G=petrol; D=diesel; B=biofuel; Elec=electricity

Availability to the EU of sustainable, cost- and energy-efficient biofuels is essential

Most of the EU biofuel feedstock necessary to reach the 10 % biofuels target will come from EU production diverted from exports and indirect imports, mostly to replace vegetable oils otherwise used for food, and direct imports (JRC, 2008).

The economic interplay at global level also determines whether or not environmental/climate externalities may be shifted from the EU to other world regions

The increased demand for biofuels induced by the mandatory targets of the RED and the FQD must be met by increased supply. The questions, therefore, are: whether sufficient and sustainably-produced volumes of biofuels will be available in Europe by 2020; whether they may be partially diverted from today's production pathways; whether this diversion may shock interlinked markets; whether Europe will prime in its quest for fuel alternatives, including biofuels, compared to other world regions; and how much of European demand for biofuels will be satisfied from domestic production and how much from imports.

Although there are many uncertainties, in general it can be stated that:[93]

- Ethanol is likely to be available in volumes needed to cover EU demand, given lower petrol volumes and the availability of imported ethanol.
- Despite growing global supply of advanced ethanol, uncertainties remain about EU production through 2020 and availability to the EU transport sector.
- Conventional biodiesel (FAME) is expected to be available in the volumes needed. However, questions remain regarding domestic production, global demand and competition over waste oils and vegetable oils, which are sought in the production of both other types of biofuels (hydrogenated vegetable oils, HVO) and of foodstuffs and animal feed.

[93] JRC Scientific and Technical Report 'EU renewable energy targets in 2020: Revised analysis of scenarios for transport fuels' (EUR 26581 EN), 2014.

4. COST-BENEFIT ANALYSIS

KEY FINDINGS

- EU biofuels policy aims at achieving GHG savings, a secure energy supply and economic and employment benefits.
- Ethanol produced from sugar crops and straw show the highest GHG savings (50 % to 90% savings with respect to the fossil fuel replaced), and their ILUC emissions are also thought to be relatively low. Bioethanol from cereals (wheat and maize) save less emissions in general.
- ILUC emissions aside, GHG savings on the main biodiesel fuels are in the range of 35% to 50% relative to the fossil fuel replaced.
- ILUC emissions aside, biodiesel-fuelled cars show overall 'well-to-wheel' (WTW) emissions in the same order of magnitude as emissions from electric cars (80-100 gCO_2eq/km).
- If ILUC emission estimates are included in the analysis, however, GHG savings for bioethanol fall by approximately 15 %, while biodiesels show negative GHG savings (i.e. they emit more greenhouse gas than fossil fuels).
- Since biodiesel dominates the mix of biofuels in EU, the ILUC emissions, as estimated for the Commission by IFPRI, are sufficient to negate the emissions savings achieved by the EU biofuels policy.

Costs

- Even when ILUC emissions are not taken into account, the extra production cost of biodiesels, as compared to that of fossil fuels, means that the cost of saving greenhouse gas emissions is EUR 100-330/tCO_2.
- Not counting ILUC emissions, bioethanol fuels from sugars and straw yield the lowest cost for emissions savings (EUR 100-200/tCO_2 avoided), while bioethanol from wheat yield higher costs.
- 2011 estimates of the cost of EU biofuel policy vary from EUR 7 billion to EUR 8.4 billion, corresponding to EUR 14-17 per person, or EUR 26-32 per vehicle.

Benefits

- Not counting ILUC emissions, the EU biofuel policy saved 24 thousand tonnes of CO_2-equivalent GHG emissions in 2011. If the IFPRI estimates of ILUC emissions are included, there were no GHG emission savings.
- Studies that include calculations for assumed increases in taxation to pay for biofuel subsidies conclude in general that the overall EU employment effects of biofuel policy are neutral or even negative (and that they have as well a negative net welfare benefit).
- Biofuels replaced 5.1 % of EU road-fuels and up to 2.2 % of EU crude oil use in 2011.
- In 2020 the biofuels for road transport should save about 10 billion litres of petrol and 20 billion litres of road diesel.
- This notwithstanding, the impact of biofuels on refining economics will remain low in the 2010-2020 timeframe.

Biofuel policies in the EU are promoted to pursue three main objectives: 1) environmental benefits, mainly considered in terms of reduced GHG emissions; 2) employment benefits; and 3) security of supply.

The following paragraphs provide an analysis of each of these objectives, taking into account the amount and cost of GHG saved; the production costs and the subsidies; and the effects on employment and oil supply.

4.1 Environmental impact: GHG emissions

This section provides an analysis of the environmental performance of biofuels. It quantifies GHG emission savings achieved through the use of biofuel in place of fossil fuel, and compares GHG savings from different biofuels. The comparisons are based either on a single biofuel or on the combined efficiency of different biofuels in different vehicles.

4.1.1 'Direct' GHG emissions

Sustainability criteria in EU legislation require minimum GHG savings

Mandatory environmental sustainability criteria for biofuels consumed in the EU are listed in the RED and FQD (see box 1). These criteria include a 35 % reduction of life-cycle GHG emissions compared to those of the fossil fuel in use (a 50 % reduction from 2017 and a 60 % reduction from 2018)[94].

The methodology to calculate life-cycle GHG emissions is set by the directives

The RED and the FQD set the rules[95] and methodology[96] for calculating the GHG impact of biofuels. According to these, GHG emissions from the production and use of biofuels and bioliquids should be calculated by adding up all the emissions deriving from the cultivation of raw materials, processing, transport and distribution. Emissions from carbon stock changes caused by direct land-use change (if they occurred) should also be taken into account. These 'life-cycle' GHG emissions are referred to as 'direct emissions'.

Figure 38: Processes included in the GHG direct emissions calculation

Economic operators must declare actual GHG emission savings from their biofuel, or alternatively may use default values listed in the directives

Economic operators must prove that their biofuels comply with the GHG-savings requirements of the directives, and must therefore declare the direct GHG emissions from their biofuels. However, calculating life-cycle GHG emission from a biofuel pathway is a complicated issue and may be problematic for some producers. Therefore, to help economic operators to calculate their GHG emission savings and reduce their administrative burden, the two directives include a list of default GHG emission values for the main liquid and solid

[94] These GHG savings thresholds are currently under discussion, and may be reviewed following the Commission's proposal on ILUC (COM(2012)0595).
[95] Article 19.1 of RED and Article 7d.1 of FQD.
[96] Part C of Annex V to RED and Annex IV to FQD.

biomass pathways. Economic operators may decide whether to calculate and declare their own actual emissions, or to use the default values.

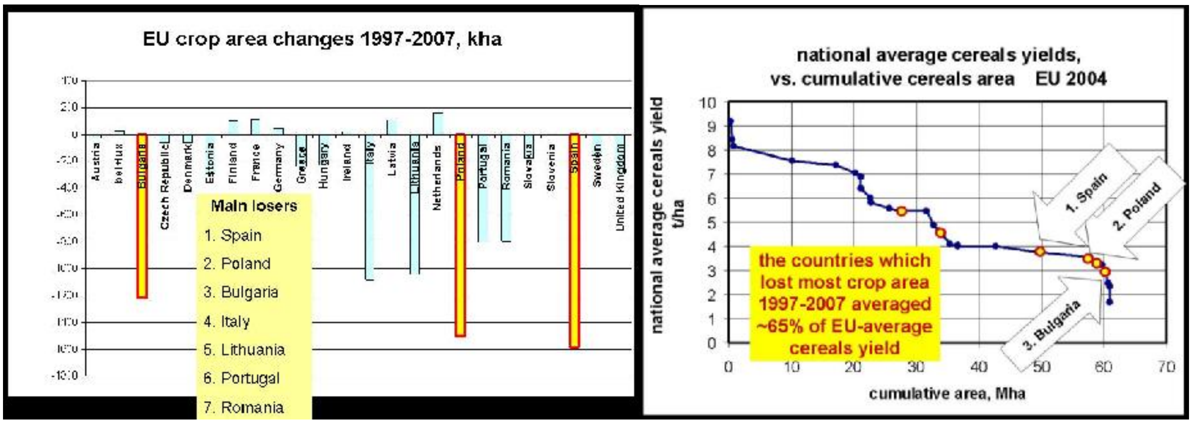
Operators have the option of choosing default values for some processes (such as cultivation) and declaring actual values for others (such as processing). This gives rise to the possibility of 'cherry-picking' default values for the processes with above-average emissions. The default values for processing emissions are derived from JRC's best-estimate of the average processing emissions (listed in Annex V of RED as 'typical' emissions), by adding a 40 % 'safety factor'. However, there is no conservatism factor on the emissions of the other processes in the chain. This means that about half the operators can reduce their emissions by selective use of process-default-values. According to Article 19.7 of the RED and Article 7d.7 of the FQD, the Commission may adapt the default values in line with technical and scientific progress by updating the existing values and by adding additional pathways.

Cultivation emissions are affected by the large range of yield within the EU

Kraenzlein (2009) used the University of Bonn's detailed model of EU agriculture (CAPRI) to estimate the spread of energy used to make a tonne of crop by different EU districts. He reported that the spread was due almost entirely to differences in yield. When he ranked different regions of the EU in terms of farming energy efficiency, he found that the lowest quartile use double the energy per tonne of the most efficient wheat producers to grow a tonne of wheat (or 150 % of the EU energy-use average). GHG emissions increase with energy use.

Cropland abandoned recently in the EU typically had low yields

Figure 39: The national average cereals yields of countries that lost crop area in the EU averaged only 65 % of the EU average (average was weighted according to the area lost per country)



It is sometimes claimed that biofuels could reverse or at least decelerate the historical loss of EU crop area. As noted in Section 2.2.1, the gradual loss of harvested area in the EU in recent years has mainly occurred in the dry regions of southern Europe (partly due to voluntary set-aside) and in new Member States. Any reversal of this loss due to extra crop demand from biofuels would almost certainly result in lower than EU-average yield and, thus, in higher emissions per tonne for the crops from the reclaimed land, if one assumes that the loss (and the reclaim) is mainly driven by crop prices (which may not be the case). If the loss of cropland is mainly driven by factors other than price, then it is questionable

whether additional demand would bring those lands with below-average productivity back into production.

Additional production from extra area gives lower yields and higher farming emissions per extra tonne of crop

Crops are generally located on the best available farmland, especially in the EU and other 'old-world' countries like India and China. An exception to the general rule would be in some parts of South America where there may be areas of high potential fertility that have not yet been cropped owing to the lack of transport access. Where crop prices can be assumed to be the main driver for land abandonment and reclaim, it follows that: 1) expansion in most of the world would occur on land with less than average yield; and 2) more crop area would be required than indicated by average yield. These factors have to some extent been taken into account in some ILUC models (GTAP, LEITAP, IFPRI-MIRAGE) but not in others (AGLINK, IFPRI-IMAGE).

No life-cycle analysis known to this study has calculated the marginal direct cultivation emissions for the expansion of crop production. However, it follows from the reasoning above that if biofuels induce extra crop production by expanding crop area, the extra 'direct' cultivation emissions could be considerably higher than the average emissions calculated in the 'typical' values in annex V to the Renewable Energy Directive or the JEC-WTW study.

Default values can be used only if there is no direct land-use change

Economic operators can use default values only if biofuels are produced without direct land-use change. If direct land-use change occurs, default values cannot be used and actual GHG emissions (including land-use change emissions) must be calculated using the methodology specified in the directives.

Land-use change can release CO_2 and N_2O stored in soils and biomass

Converting land cover types with high biomass and soil carbon stocks (e.g. forests) into cropland usually results in an immediate loss of carbon stored in above- and below-ground biomass (vegetation), and a more gradual decline of carbon in the soil organic matter (SOM).

The carbon released from biomass is emitted into the atmosphere as CO_2, while other non-CO_2 gases may be emitted under particular circumstances (i.e. if biomass burning is involved in land clearing). SOM contains both nitrogen and carbon, and a decline of SOM releases both CO_2 and nitrous oxide N_2O.

Land-use change may also cause an increase in soil carbon stock over the existing level (e.g. through changes in crop management) or in biomass (e.g. if grassland is replaced by permanent woody crops or sugar cane).

Guidelines to calculate land-use change emissions are provided by the Commission

Annualised emissions from carbon-stock changes caused by direct land-use change are to be calculated according to the rule provided in Annex V.7 to the RED and Annex IV.7 to the FQD. They result from the difference between the carbon stock associated with the land use in January 2008 and the actual land use. Guidelines for the calculation of land carbon

stocks for a set of soil, land cover and climate conditions are established by Commission Decision 2010/335, which draws on JRC methodology (JRC-IES, 2010). The emissions are calculated according to changes in land use, management practices and inputs, which form a management system. Explicit data on cropland categories and a breakdown on crop types (e.g. perennial or annual) are also included in the guidelines.

4.1.2 Indirect emissions

ILUC emissions are not accounted for in the methodology of the directives

The GHG emissions associated with changes in the carbon stock of land resulting from indirect changes in land use (ILUC) are not subject to reporting requirements under the current legislation, nor do the sustainability criteria provided in the EU directives consider any ILUC effect.

The two directives (RED and FQD, see Box 1) require the Commission to explore the issue further, in order to develop a methodology to minimise GHG emissions caused by ILUC.

Several studies have been commissioned or carried out by the EC since 2008 (e.g. Al-Riffai et al., 2010; Laborde, 2011; JRC-IET, 2010; JRC-IPTS, 2010).

Although uncertainties remain, it is now recognised that ILUC can have an impact on GHG emissions savings

The Commission has summarised the consultations and analytical work conducted on this topic (COM(2010)0811). It acknowledges that indirect land-use change can reduce GHG emissions savings associated with biofuels and bioliquids. The communication also identifies a number of uncertainties and limitations associated with the available numerical models used to quantify indirect land-use change.

The debate is still ongoing regarding the extent of ILUC and on whether and, if so, how to include ILUC in a regulatory framework. The discussions derive mainly from the difficulties in estimating ILUC and the large range of outcomes from models that estimate the extent of ILUC.

A legislative proposal from the Commission (COM(2012)0595) lays down that ILUC emissions per crop group (cereals and other starch-rich crops, sugars, oil crops) should be introduced in the RED as a reporting requirement, but not inserted in the sustainability criteria (see box 3 in section 2.4). This proposal is based on the results of IFPRI modelling (Laborde, 2011). The main element of the proposal with regard to containing ILUC is to limit the contribution of conventional biofuels towards the 10 % target for renewable energy in transport to 5 %, as the remaining renewable energy options in transport can be assumed to cause less ILUC (advanced biofuels) or even no ILUC (wind and PV power in electric vehicles).

More information on the methods to estimate ILUC GHG emissions is presented in section 2.4.

Other indirect emissions besides ILUC emissions can be also relevant

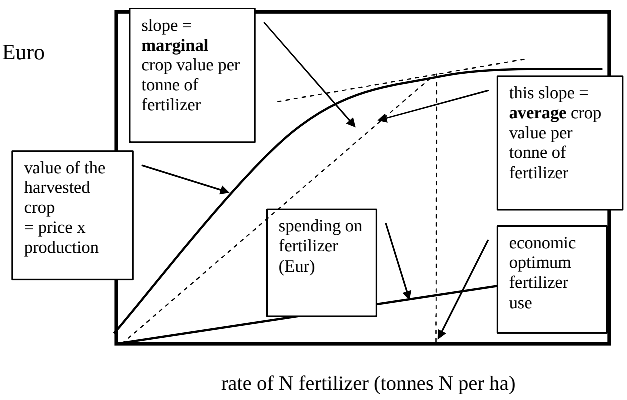
ILUC emissions are just one of the indirect emissions caused by biofuels production. When crop prices, and hence production, increase as a result of biofuels, emissions also arise

from other sources, such as intensified farming for higher yields[97] and annual emissions from farming of newly planted areas[98].

Even if yields were to increase significantly in response to biofuels-driven crop-price rises, marginal GHG emissions would probably still be high

As explained above, increasing fertiliser application is only one way farmers can increase yields. However, in this case, diminishing rates of return per additional unit fertiliser employed would lead to marginal emissions per marginal tonne of crop that are much higher than the average cultivation emissions.

Figure 40: Schematic shape of a nitrogen fertiliser response curve for a given field, in terms of value of the harvest



Note: The slope of the cost-of-fertiliser line is the farm-gate price of the fertiliser.

A farmer will increase spending on nitrogen fertiliser until the value of the marginal crop production falls to equal the marginal cost of fertiliser, making the marginal tonnes of crop/marginal tonnes of fertiliser applied equal to the per-tonne price ratio of crop/fertiliser.

Recently, this price ratio for UK wheat farmers was about 0.2, which means marginal fertiliser use per marginal tonne of crop is also about 0.2. By comparison, the average fertiliser use per tonne was about 0.025 tonnes wheat/tonne fertiliser, so the marginal use of extra fertiliser per tonne of extra crop was roughly eight times higher than the average fertiliser per tonne.

Emissions for production of nitrogen fertiliser and its use in the field (soil N_2O emissions) account for about 40 % of typical wheat ethanol emissions in RED calculations. There are other ways to increase yield, as explained in section 2.4. Many of these (e.g. more use of herbicides and pesticides, distributed using diesel fuel) also increment emissions. However, even if extra emissions from other means of yield increase are not counted, the high marginal fertiliser use means that even a small contribution of fertiliser to yield increase[99]

97 As crop prices increase, the economically optimum spending on all crop inputs (such as fertilisers) also increases, in order to increase yields. In general, this can be expected to mean higher emissions per tonne of crop.

98 The expanded part of the crop area has, in general, poorer yields, because in most of the world the best land is farmed first. This is likely to cause higher annual farming emissions per tonne of crop (when compared to growing the same crop on more fertile land).

99 A significant statistical correlation between fertiliser use and expected crop price was the only reason to propose a significant price-on-yield effect, even though no statistically significant direct correlation of yield on expected price could be found. As argued by Choi and Helmberger (1993), 'why else would farmers use more fertiliser?'.

will make the marginal emissions per tonne of crop from extra yield higher than the average GHG emissions per tonne of crop.

Therefore, the direct GHG emissions associated with ethanol from crops provided by price-induced yield increase could be much higher than the average emissions in RED annex V. No life-cycle assessment (LCA) or ILUC work known to this study has taken this into account.

The variability and uncertainty in direct cultivation emissions is high

About a quarter of average wheat ethanol emissions and half of rapeseed-biodiesel emissions come from N_2O soil emissions during cultivation. Measured N_2O emissions have been found to vary by a factor of five within one field, at least a factor of two between years, and by more than 100 between individual fields. It follows that not every batch of biofuel will save GHG emissions; savings can only occur across an average of biofuel production.

The JRC estimates per-crop average N_2O emissions by a method that, on a large scale, tends toward correspondence with the commonly used Intergovernmental Panel on Climate Change (IPCC) tier 1 method. The IPCC method was developed estimating national average soil-N_2O emissions for Kyoto reporting. It only claims a precision of the national average emissions at a factor of three, higher or lower, which may be too pessimistic.

4.1.3 'Well-to-wheel' (WTW) and RED approaches to estimate GHG savings

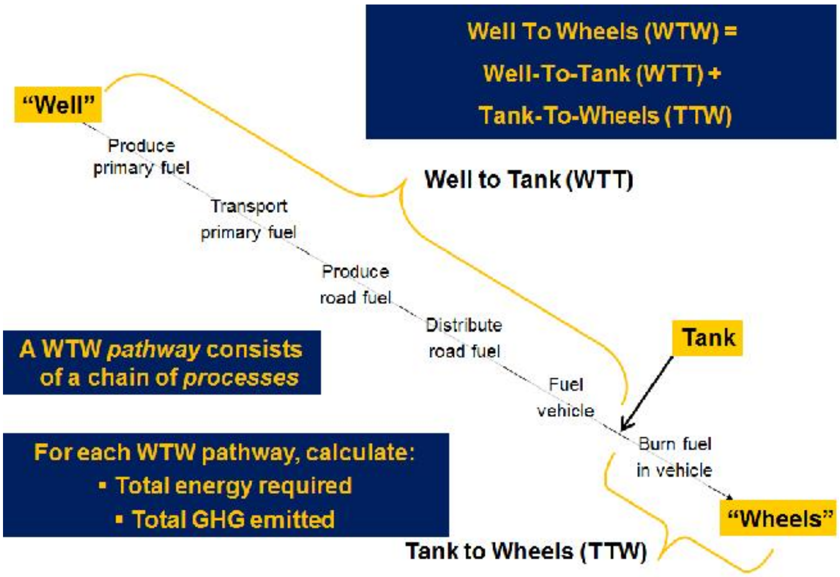
Life-cycle assessment methodologies are used in policy to assess environmental impact

Life-cycle assessment (LCA) is considered a useful way to determine the environmental impact of a product and is now being used in large-scale decision processes. Two main types of LCA are used. 'Attributional' LCA focuses on describing the environmentally relevant physical flows to and from a product or process, useful when comparing two or more systems delivering the same functional unit (e.g. 1 MJ of fuel). 'Consequential' assessment describes how relevant environmental flows will change in response to possible decisions, by modelling a hypothetical, generic supply-chain that is forecast according to market-mechanisms, and potentially includes political interactions and consumer behaviour changes (ILCD, 2010). A 'consequential' approach is needed when assessing the consequences of a decision in the foreground system for other processes and systems of the economy.

The 'well-to-wheel' (WTW) approach used by the JEC consortium is a simplified attributional method focused on energy consumption and GHG emissions, alternative to the methodology proposed in the RED and the FQD

An attributional methodology to quantify life-cycle GHG emissions of fuel (including biofuel) pathways is the so-called 'well-to-wheel' (WTW) approach. The WTW is a methodology aimed at assessing the energy consumption, and the GHG emissions, of road transport. In the framework of the JEC (JRC-EUCAR-CONCAWE) research collaboration, the WTW methodology quantifies energy required for, and GHG resulting from, the production, transport, distribution and combustion of conventional and alternative road transport fuels. This methodology allows for easy calculations and comparisons among different fuels.

Figure 41: Processes included in the JEC well-to-wheels methodology



The JEC-WTW method is therefore a simplified type of LCA with system boundaries set to focus exclusively on energy consumption and GHG emissions.

LCA 'normal' approaches include the footprint from more processes than the WTW method and are more complex

Conversely, the LCA 'normal' approach considers not only energy and GHG (as in the WTW) for the production of a conventional or alternative fuel, but also the consumption of all the materials needed for the production process. These include power plants and refineries, as well as the materials needed for manufacturing vehicles and vehicle components. It also considers water requirements and emissions of many kinds of pollutants (liquid, gaseous), etc. Data calculations are more complex because the LCA methodology considers in more detail the footprint of any given process. The results are also very much context-specific, which reduces comparability across alternatives.

The JEC-WTW method uses a 'substitution' approach to attribute GHG emissions to by-products

Generally, a fuel production process simultaneously produces some by-products. A key issue in estimating life-cycle GHG emissions is to determine how much of these emissions should be ascribed to the biofuel and how much to the by-product.

The JEC-WTW method uses a rigorous approach for accounting benefits from by-products – the so-called 'substitution' approach (or 'system expansion') – whereby the emission credit foreseen for a by-product represents the emissions saved by not producing the product it replaces (marginal approach). This is recommended by the ISO14040 set of standards for LCA.

The methodology set in RED and FQD is a type of attributional LCA

An 'attributional' LCA is the approach adopted for the calculation of the 'typical' and 'default' emissions in accordance with Annex V to the RED legislation. The calculation method used is simpler (compared to the JEC-WTW method) and more convenient for stakeholders to adopt when using their own data.

In the RED and FQD, emissions are divided between biofuels and by-products in proportion to their energy content (allocation by energy)

The methodology adopted in the RED and FQD split the emissions of the biofuel process between biofuel and by-products on the basis of their heat energy contents. This 'allocation' approach generally gives more favourable results for biofuels.

The methodology chosen to calculate GHG emissions strongly affects the results

As highlighted above, methodological choices do have an impact on the results of the analysis. Such choices are therefore intimately connected to the specific purpose of the analysis.

The RED method is suitable for legislation, but for policy analysis the JEC-WTW approach is more appropriate

As mentioned in the Impact Assessment accompanying the 'Package of implementation measures for the EU's objectives on climate change and renewable energy for 2020', many authorities have concluded that the substitution approach is the most appropriate for policy analysis purposes (IA-RED 2008, ISO 14044:2006). The Impact Assessment also acknowledges that the JEC consortium, which has used the substitution approach in its well-to-wheel study, is a reference on the subject. Instead, the RED allocation method is more appropriate for regulatory purposes and as a practical regulatory tool.

The authors of the present study therefore deem it appropriate to use the JEC-WTW method and results (highlighting, whenever necessary, the differences from the RED Annex-V approach).

Figure 42: Different methodology for GHG-saving calculations

JEC Well-to-Wheel:	Annex V to RED:
• Scientifically more robust • GHG emissions attributed to co-products via 'substitution' approach • Suitable for policy analysis	• Easier to perform • GHG emissions attributed to co-products via allocation by energy content • Suitable for regulatory purposes

The following paragraphs summarise and compare GHG savings from the use of liquid biofuels in the road transport sector. The production costs of the corresponding biofuels are also presented.

The data used for this analysis are extracted from the WTW studies carried out in the framework of the JEC collaboration mentioned above. These studies[100] pursue the objectives of estimating the GHG emissions and energy balance of conventional and alternative automotive fuels and power-train options significant for Europe after 2010. The JEC-WTW work evolves by means of periodic updates of reports, incorporating process

[100] The JEC-WTW reports are available at http://iet.jrc.ec.europa.eu/about-jec.

improvements reported by relevant stakeholders, e.g. vehicle manufacturers, original equipment manufacturers (OEMs) and those involved in the production, refining and regulation of fuel, biofuels and power.

All data used to calculate GHG impact (with the exception of ILUC emissions) are extracted from the latest version of the WTT (well-to-tank) report published in July 2013 (WTT v4, EUR 26028 EN).

The JEC-WTW emissions for biofuels used here are not the same as in RED

The GHG emissions savings reported here are not the same as the typical or default GHG savings reported in Annex V to the RED (2008), being derived using improved input data and a different methodology. The JEC-WTW uses substitution methodology for by-products, whereas the RED uses allocations (see the discussion above). In the impact assessment of the RED it is stated that the correct LCA methodology to use for policy assessment purposes is the so-called substitution methodology, whereas the allocation methodology is only used in the RED for the administrative convenience of stakeholders and the Commission. For most biofuels, the allocation method gives slightly more favourable results.

4.1.4 Biofuel pathways considered

The main ethanol pathways considered are ethanol from wheat, straw, maize, sugar beet and sugar cane

In the framework of this study, only the main or commercially viable biofuel pathways (liquid biofuels as bioethanol and biodiesel) that could have a significant impact on the EU biofuel market are taken into account. For technical and economic reasons, biogas is commonly used to produce electricity, not for transport applications, so biogas pathways are not considered in this section. The most common ethanol pathways from crops produced in Europe taken into account are: ethanol from wheat, ethanol from wheat straw, ethanol from maize and ethanol from sugar beet. In addition, the following pathways relevant to the European market are considered: ethanol produced in Brazil from sugar cane, and ethanol from US maize grain.

The main biodiesel pathways considered are biodiesel from rapeseed, sunflower, soya bean and palm oil

Biodiesel in the EU is produced mainly from food crops (rapeseed, soya bean, palm and sunflower), although biodiesel made from recycled oils and fats has increased in recent years. An important part of EU biodiesel production (Flach, 2012) is based on imported vegetable oils; hence the growing demand for imported soya beans, soya bean oil and palm oil. In this section, GHG emissions from food crop based biodiesel pathways are considered.

The production process considered for biodiesel is transesterification

The biodiesel production process considered in the calculations is the transesterification process (see also section 1.1.1). This chemical process uses an alcohol (methanol or ethanol) to transform the raw renewable oil into (methyl or ethyl) esters, and also provides glycerol as a by-product. Methanol is the alcohol commonly used for the transesterification step, hence the generic name of FAME (fatty acid methyl esters). In the pathway taken into account in this study, different options for the disposal of glycerine have been considered.

An alternative industrial process for producing biodiesel from oil crops is the hydrotreatment of vegetable oils (HVO). This chemical process has the advantage of producing biodiesel with virtually the same chemical properties as fossil diesel, but requires higher energy inputs. However, since HVO pathways do not give numerical values significantly different from the equivalent FAME processes (see WTT v4, 2013, section 4.5.4), the quantitative evaluations refer only to FAME processes.

While the straw ethanol process has been considered, second-generation biofuels (including those made from miscanthus or wood) have not been included as, generally speaking, they have not yet contributed any significant biofuel production, and as the available data on these processes are still uncertain. This is also the case for third-generation biofuels (e.g. algae), which are still in the laboratory-research phase.

4.1.5 GHG emission savings of biofuels

This section presents the average GHG saving performances of the main biofuel pathways extracted from the WTT v4 report mentioned above. ILUC GHG emissions are also added to give an estimate of the total environmental impact.

A range of numbers is used to reflect the different process options and by-product uses

It is difficult to present a single number representing GHG emissions for a biofuel from a particular crop because various alternative conversion processes can be used, and there are different uses for the by-products. This has a large influence on the result when substitution methodology is used, as here. Therefore, a range of numbers is shown, which takes into account both the alternative pathways and the uncertainty in the estimate of each.

The range of uncertainty in N_2O emissions is itself uncertain and is not considered

However, in common with other studies, the uncertainty in N_2O emissions from cultivation of soils is not taken into account here. If the full uncertainty range specified by IPCC were used, no biofuel could be shown to save GHG, even considering only direct emissions[101].

ILUC emissions are also uncertain

The data on direct emissions presented in this report are in the range of other literature studies.[102] However, the JEC-WTW data do not include indirect emissions from land-use change. To give an idea of how much this might affect the results, the ILUC emissions proposed in COM(2012)0595 have been added. These are: 12 gCO_2eq/MJ for cereals, 13 gCO_2eq/MJ for sugar crops and 55 gCO_2eq/MJ for oil crops. The use of ILUC data and their value are still subject to strong debate. The ILUC uncertainty ranges have been included in the IFPRI report (Laborde, 2011).

There are no estimates of ILUC emissions for waste and residues in COM(2012)0595. The JRC, in collaboration with IFPRI, recently carried out a preliminary assessment of ILUC emissions for wheat straw using the MIRAGE model (described in 2.4.2), finding a value of 4 gCO_2/MJ.

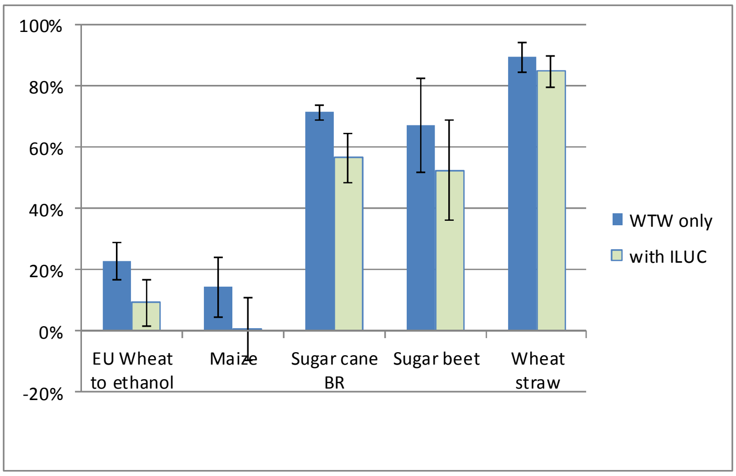
[101] The authors think IPCC is too pessimistic, but have no quantitative estimate of the true uncertainty.
[102] Data compared with a review of 60 LCA studies performed by the OECD-IEA (2011).

For each crop, the main pathways for making biofuel are merged into a single range

Appendix 4 presents the different variants (pathways) considered for this report for making biofuel from different crops; they are taken from the WTT v4 report (2013). The authors selected, for each type of biofuel (e.g. biodiesel from rapeseed), a sub-group of WTW pathways that probably occur in practice (data on the mix of specific pathways actually employed for producing a biofuel from a feedstock are unavailable), but this still left several pathways for each type of biofuel. To simplify the discussion, only the range of results for each crop is shown (including the JEC uncertainty in each result). It should be noted that the merged averages are simple arithmetic averages, which should not disguise the fact that most of the more favourable pathways are at the moment only employed in a minority of production.

The uncertainty range presented is only for 60 % probability, and only the most common pathways for biofuel production were considered. Therefore, some specific exceptions are possible. Furthermore, the soil-N_2O emissions and ILUC factors are both uncertain. Figure 43 and Figure 44 present the standard GHG saving efficiencies of the most relevant bioethanol and biodiesel fuels, while comparing their emissions with GHG emissions from equivalent fossil fuels (petrol and diesel respectively). Tables of the results and more details are in Appendix 4.

Figure 43: Emission savings from different bioethanol fuels



Sugar pathways have lower total (direct+indirect) GHG emissions than cereals

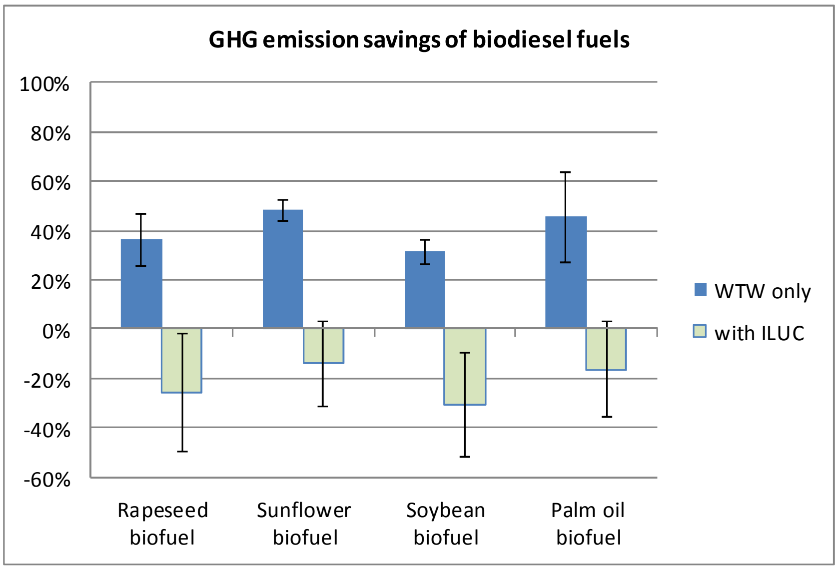
Based on these calculations, both for WTW and for ILUC data, the GHG saving efficiency of bioethanol from cereals (from wheat and from maize) is significantly lower than the GHG saving from sugar ethanol (sugar beet and sugar cane) and wheat-straw ethanol.[103]

For all conventional ethanol feedstocks, ILUC reduces GHG saving by roughly 15 %

For ethanol from cereals and sugars, total GHG savings reduce by about 15 % when ILUC emissions are included (as proposed in COM(2012)0595).

[103] Please note that according to the WTW methodology adopted in this report, GHG saving values can be lower than RED GHG saving values (typically greater than 35 %) because the RED energy allocation method gives higher GHG saving results. Therefore, the emission savings estimated in this study cannot be used for compliance with the RED sustainability criteria of the RED.

Figure 44: Emissions savings from different biodiesel fuels



The direct GHG savings of the main biodiesel pathways from food crops are in the range of 35 %–50 %, but if ILUC emissions are added, negative GHG savings occur

According to the WTW methodology and the hypotheses explained above, the GHG saving of the main biodiesels is, without accounting ILUC factors, in the order of 35 %–50 %. When the ILUC effects are taken into account, however, all the main biodiesel pathways have a negative environmental impact.

4.1.6 GHG emissions for different powertrains

WTW = WTT + TTW

Different automotive powertrains have different efficiencies. The well-to-wheels (WTW) methodology allows the overall efficiency of different fuel pathways and different powertrain configurations to be compared, combining the GHG efficiency of the considered fuel (well-to-tank (WTT) as seen in section 4.1.5) with the efficiency of the specific powertrain type (tank-to-wheel or TTW). This section presents simplified data from the WTW methodology.

For the vehicle calculations in the TTW, a common vehicle platform representing the most widespread European segment of passenger vehicles (C-Class compact 5-seater European sedan) was used, and a number of powertrain options assessed.

Vehicle efficiencies for 2010 cars in the new European driving cycle (NEDC)

The C-segment reference vehicle model year 2010 is equipped with a 1.4L direct injection spark ignition (DISI) internal combustion engine (ICE) for petrol engines, a direct injection compression ignition (DICI) ICE for diesel engines, and a 6 speed Manual Transmission (MT) and Front Wheel Drive (FWD).

Vehicle technologies (referring to the engine, the powertrain and the after-treatment systems) comply with regulated pollutant emission regulations in force. Lastly, fuel consumptions and GHG emissions are evaluated on the basis of the current European type-approval cycle (NEDC).

It is important to note that:

- the model vehicle is simply a comparison tool and is not deemed to represent the European average in terms of fuel consumption; and
- the results relate to compact passenger car applications, and should not be generalised to other segments, such as heavy duty or sport utility vehicles.

The specific emissions reported in Table 25 have been considered under the NEDC test-cycle.

Table 25: Main characteristics of reference passenger vehicles

	Fuel consumption	TTW emissions
2010 DISI petrol car	6.3 l/100 km	150 gCO_2eq/km
2010 DICI diesel car	4.5 l/100 km	120 gCO_2eq/km

WTW emissions of EU diesel vehicles are lower than those of petrol vehicles

While simple distillation of crude oil yields a 'natural' ratio of diesel to petrol, the ratio of diesel/petrol in EU demand is considerably higher than this, and is increasing with the growth in the share of diesel cars. EU refineries devote money, energy and CO_2 emissions to increase the diesel share. Therefore, the emissions saved by replacing one MJ of diesel are greater than those saved by replacing 1MJ petrol.

Nevertheless, diesel vehicles are more efficient. Both effects are taken into account in the WTW calculations: Table 25 shows that WTW emissions from diesel vehicles are around 17% less than those of a similar petrol model. Therefore dieselisation of the EU vehicle fleet has been largely responsible for the reduction in transport emissions in recent years.

We assume biodiesel replaces diesel and bioethanol replaces petrol

If one were to assume that a further increase in the diesel/petrol ratio in EU refining is impossible, one could conclude that biodiesel would, in the long term, allow further dieselisation of the EU vehicle fleet, so that one could attribute the diesel efficiency gains to biodiesel, considerably improving its apparent WTW emissions balance (the opposite would apply to bioethanol replacing petrol). However, the diesel/petrol imbalance is already being relieved in other ways, notably through diesel-petrol swaps with the US and the import of diesel from Russia. Therefore, it is not true that further dieselisation cannot occur without the aid of biodiesel. Accordingly, in the rest of this report, we assume that biofuels do not change the fraction of diesel vehicles in the EU fleet.

Average EU electricity emissions were assumed

For electric energy, the considered emissions for generating and distributing a kWh of electricity at low voltage are 540 gCO_2eq/kWh (WTT v4, 2013). The efficiency (NEDC cycle) of a battery-electric car is considered to be 14.5 kWh/100 km.

Box 6: Electric energy for transport

For the purpose of comparing biofuel GHG impact with competing 'green' technologies, the GHG emission reductions of the battery-electric car are also assessed.

Battery-electric cars have no tailpipe emissions, but cause GHG emissions at the power station where electricity is produced. Consequently, their emissions depend on how the electric energy is generated, or the share of energy sources adopted (e.g. 30 % from nuclear, 25 % from coal, 16 % from renewables, etc.).

The share of different energy sources in the gross electric energy generation is also known as the 'electricity mix'. The electricity mix varies strongly depending on the time and the geographical region considered. Calculations for this report were based on WTT v4 (2013), reporting the average 2009 electric mix of the EU27 Member States.

On the basis of these data, the GHG emissions embedded in one unit of electric energy (kWh) supplied (in EU27 in 2009) at low voltage is 540 gCO_2eq/kWh.

Battery-electric cars can use electric energy with different efficiencies. For the energy efficiency of a battery-electric car in the C-Class of the passenger car market, tank-to-wheel data from TTW v4 (2013) were used, considering an efficiency of 14.5 kWh/100 km.

Combining WTT GHG emissions with the TTW vehicle specifications presented in Table 25 above, gives the following final WTW results.

Bioethanol and biodiesels are normally blended with conventional fuels and are not used neat. The tables below describe the EU mix of feedstocks for bioethanol (E5 and E10) and biodiesel blends on the EU market in 2010.

Table 26: EU bioethanol mix

EU Bioethanol mix 2010 for E5 and E10 market blends	share
Wheat	25%
Maize /Corn	20%
Sugar beet	30%
Sugar cane	14%
other	12%

Share of Ethanol (% energy) in blend		
E5	3.2%	[4.9%vol]
E10	6.5%	[9.9%vol]
E20	13.2%	[19.9%vol]

Source: Ecofys.

Table 27: EU biodiesel mix 2010 for B7 market blend

EU FAME consumption mix 2010	share
Rapeseed	48%
Soya bean	22%
Oil palm fruit	11%
sunflower seed	4%
other	15%

Share of FAME (% energy) in blend		
B7	6.367%	[6.9%vol]

Source: Ecofys.

Notwithstanding this consideration, and solely for comparative purposes, data in the following tables are presented under the 'as if' assumption that biofuels could be used as neat fuel in passenger cars of the 2010 model year sold on the EU market. Data are presented without noting the range of uncertainty. Fuel-engine combinations that emit more GHG than the fossil fuel they replace are presented in red.

Table 28: WTW analysis of the main fuel pathways and powertrain configurations

	Mean WTW emissions (gCO_2eq/km)	mean WTW plus ILUC emissions (gCO_2eq/km)
Ethanol pathways (as neat fuel) vs. fossil petrol:		
2010 DISI petrol car comparator	178	N/A
EU wheat ethanol	137	162
Brazilian sugar cane to ethanol	51	77
EU sugar beet to ethanol	58.6	85
EU wheat straw to ethanol	19	27
Maize ethanol	151	177
Biodiesel pathways (as neat fuel) vs. fossil diesel		
Conventional diesel comparator	145	N/A
Rapeseed biodiesel	93	182
Sunflower biodiesel	76	165
Soya bean biodiesel	91	180
Palm oil biodiesel	79.6	169
Battery-electric car		
EU electric mix + battery-electric car	78	N/A

Battery-electric cars offer better GHG savings than most biofuels if ILUC emissions are included

The full WTW calculations reported in the table above show the results expected from Table 25 and the tables in Appendix 4:

- The best GHG savings are achieved by replacing petrol with ethanol from sugar crops or wheat straw.
- Biodiesels from food crops only save GHG if ILUC is disregarded.

In addition:

- Battery-electric cars save more GHG than conventional biofuels, except for sugars (Brazilian sugar cane and sugar beet) and wheat straw, if ILUC emissions are included.
- The JEC WTW v2 report estimated the cost of GHG savings for different uses of land or biomass. It showed that biofuels used for producing electricity save more GHG per tonne than biofuels used in transport. As electric cars save GHG compared to petrol/diesel even with the present (2009) EU-mix of electricity, emissions must be even more favourable if bioenergy sources (or any other form of renewable electricity) are used to increase the share of RES in the electricity mix.

4.2 Direct cost of biofuels production

Along with GHG savings, biofuel production costs must be considered

The amount of GHG saved is an important variable in assessing the effectiveness of a biofuel. However, it is not sufficient for decision-making since the RED requires that biofuels replacing fossil fuels should be introduced 'in a cost-effective way'. Consequently, the cost of replacing traditional road fuel with biofuels must also be considered by comparing the production costs of biofuels with the commercial cost of equivalent fossil fuels.

Estimates of biofuel production costs are based on a JRC-IET algorithm that considers the cost to the EU as a whole, thus not including taxes and subsidies

The costs of biofuels manufactured in Europe have been estimated by means of a JEC algorithm[104], already used in WTW-2 (2007), and recently comprehensively updated by JRC-IET with 2013 data. The algorithm simulates the biofuel industrial production process both from a technical and an economic point of view. All input data are based on recent published literature, and the results are for the cost to the EU as a whole.

The main hypotheses used to calculate biofuel production costs are the following:

- For biofuel industrial plants, a capital charge of 12 % has been used, representing a return on investment of about 8 % without accounting for a profit tax, which returns to the EU.
- A 20 % uncertainty range on capital investments was applied.
- Operating costs were assumed to be 3 % of capital investment (with 5 % uncertainty).

[104] Originally constructed by J-F Larive, formerly of CONCAWE. This update is not part of the JEC consortium.

- Costs of crops, animal feeds and chemicals required as input materials to the biofuel production processes refer to statistics from their commercial costs in 2013 (average January-May). The EUR/USD exchange rate considered is 1.34. The cost of bioethanol from Brazilian sugar cane is (in Europe) the EU commercial cost (Rotterdam average 2013). The sources used are: FAO, Farming online, Index Mundi, Platts.
- Uncertainty on crop prices and biofuel by-products (as cake and glycerin) in 2013 has been assumed equal to 4 % for all crops and by-products. This has been calculated from the average variability of crop prices from January 2013 to May 2013.
- Uncertainty with respect to diesel, petrol and alcohol prices in 2013 has been assumed to be the same as the variability of the Brent crude oil for 2013 (January-May): 5 %.
- Investment capital costs and operating costs of plants have been considered on a 2013 basis, updating data from WTW-2 (2007) by mean of the CEPCI Index.
- Neither incentives nor taxes have been considered in the calculations.
- Common error theory has been used to propagate uncertainties on the overall biodiesel production cost (see, for example, Taylor, 1997).

The authors calculation shows a range of production costs for bioethanol (from EUR 24.5 euro/GJ for ethanol from EU grown wheat to EUR 30.1/GJ for imported sugar cane ethanol from Brazil) and biodiesel (from EUR 19.6/GJ for palm oil biodiesel to EUR 26.2/GJ for sunflower biodiesel)

The results of the authors' simulations for the industrial production costs of the main[105] bioethanol and biodiesel fuels are reported Table 30 and Table 29. Costs are expressed per unit of energy content (euros per GJ[106]). The 'bottom-up' costs obtained from the authors' calculations are very similar to commercial prices (Platts, 2013), showing that biofuel manufacturers are competing efficiently with each other. This is also consistent with profit from biofuels being passed back to crop prices, reportedly to land prices, and so ultimately to landowners. The costs calculated by the authors are also consistent with the main international studies in this field (IEA, 2006; IEA, 2007; and IEA, 2012).

Table 29: Bioethanol – costs of production and substitution

	2013 production cost (EUR/GJ)	2013 replacement cost (EUR/GJ)
EU wheat to ethanol	26.7 (± 5.9%)	10.7 (± 16%)
Brazilian sugar cane to ethanol	30.1 (± 5%)	14.1 (± 12%)
EU Sugar beet to ethanol	25.7 (± 4.3%)	9.7 (± 14%)
EU wheat straw to ethanol	24.5 (± 12%)	8.5 (± 36%)
2013 reference petrol commercial price:		
Petrol (from crude oil)	16.0 (± 5%)	N/A

105 All the pathways proposed in section 4.1, with the exclusion of ethanol from maize grain (Appendix 4).
106 GJ refers to gigajoule; one billion joules.

Table 30: Biodiesel – costs of production and substitution

	2013 production cost [EUR/GJ]	2013 replacement cost [EUR/GJ]
Rapeseed biodiesel	26.1 (± 5.5%)	11 (± 16%)
Sunflower biodiesel	26.2 (± 5.4%)	11 (± 15%)
Soya bean biodiesel	24.9 (± 7.8%)	9 (± 23%)
Palm oil biodiesel	19.6 (± 5%)	4 (± 26%)
2013 reference diesel commercial price:		
Diesel (from crude oil)	15.6 (± 5%)	N/A

Biofuel production costs compared with diesel and petrol prices are more expensive per GJ of energy

The second columns of the tables above show the cost of replacing fossil fuel with biofuels. This is calculated on the basis of energy content, by subtracting the biofuel cost to the commodity price (without tax) of the equivalent fossil fuel.

It should be noted that biodiesels have different cold-flow characteristics, which have not been economically quantified here. Palm oil biodiesel cannot be blended to 10 % without infringing fuel cold-flow requirements in most countries. However, this problem is managed by fuel distributors who restrict palm oil biodiesel in blending to ensure the final fuel quality reaches the national standard.

4.2.1 Cost of greenhouse gas savings with biofuels

The cost of saving a tonne of CO_2 by using a biofuel can be found by looking at the cost of replacing the fossil fuel with a biofuel, and considering this along with the GHG savings. By including the ILUC factor, the results change significantly

The ratio between the replacement cost and GHG emission savings can be used to assess the cost efficiency of biofuels for GHG reduction. This ratio (expressed in euros per tonne of CO_2 avoided) allows a comparison between different biofuels and other options for saving GHG.

Among bioethanol fuels, wheat ethanol presents a higher cost per tonne of CO_2 saved than sugar and wheat-straw ethanol. Adding the ILUC impact further reduces the cost of CO_2 reduction for wheat bioethanol

The charts below provide an overview of the cost per tonne of CO_2 avoided for bioethanol fuels (Figure 45) and biodiesels (Figure 46). The result has been calculated by excluding taxes and incentives. The GHG savings considered as the denominator of this ratio are the same as the values proposed in Appendix 4.

Figure 45: Cost of GHG savings from different bioethanol fuels

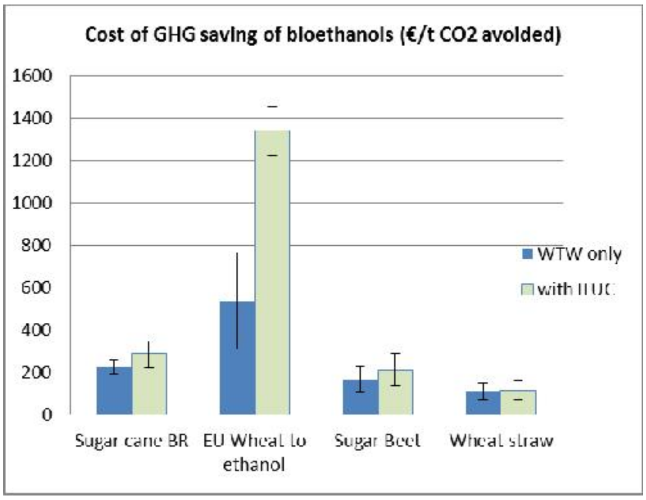


Figure 45 shows that for bioethanol fuels, considering WTW data, using wheat bioethanol to save a tonne of CO_2 costs five times more than using sugars or wheat straw.

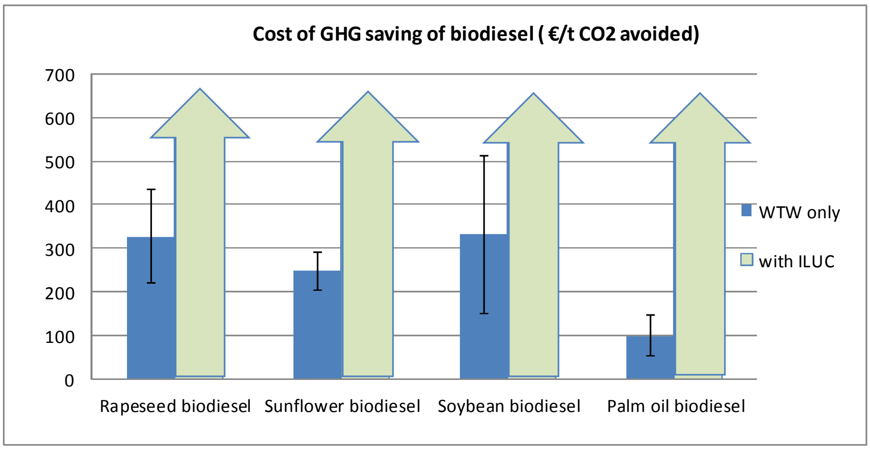
The low performance of wheat bioethanol is confirmed even if the RED methodology is used for the calculation.[107]

Adding the ILUC impact, the performance of wheat bioethanol is even worse (increasing from EUR 550/tCO_2 to EUR 1400tCO_2).

The ILUC impact has much less effect on the costs of GHG savings for sugar cane, sugar beet and wheat straw.

The main biodiesel fuels exhibit different cost of CO_2 reduction, ranging from EUR 100/tCO_2 avoided (for palm oil biodiesel) to EUR 330/tCO_2 avoided (for rapeseed and soya bean biodiesel) without ILUC. Since the GHG savings of biodiesel with ILUC are negative, the emissions-reduction cost could be considered infinite

Figure 46: Cost of GHG savings from different biodiesel fuels



[107] Using the same input data but changing the methodology to that for 'typical' GHG saving values used in the RED show slightly better absolute values for cereal-bioethanol (EUR 260–560/tCO_2) and similar performances for other bioethanol fuels (EUR 100–300/tCO_2).

The main biodiesel fuels exhibit different cost per tonne of CO_2 avoided range, for 'WTW only' data, from 50 to 500 EUR/tCO_2 avoided (including uncertainty). Palm oil biodiesel performs best, as only direct emissions are included, and rapeseed biodiesel performs worst, as shown in Figure 46.

If the RED methodology is adopted, the results are very similar to the WTW data presented here, with only slightly better performances (from 50 to 400 EUR/tCO_2 avoided).

Since the GHG saving of the biodiesels considered is negative with the ILUC impact added, their GHG saving costs can be represented as infinite.

These costs of GHG savings (referring to 2013 data) are higher than those in JRC (2008) which were calculated with the same methodology but using data from 2007. Particularly for ethanol from cereal crops, in 2007 the cost of replacing was estimated at 130 to 330 EUR/tCO_2, while now it is higher (see detail in Figure 45). The cost per tonne of CO_2 avoided has increased for biodiesel; in 2007 it was estimated at 130 EUR/tCO_2, but now the estimates range from 100 to 350 EUR/tCO_2 (see the above Figure). This is not due to a rise in crop prices (which rose but at a slightly lower rate than crude oil prices), but to updated input data for GHG emissions calculations.

It should be noted that the costs considered in this section do not include any evaluation of macroeconomic benefits, such as economic growth following the installation in the EU of new biorefining plants, assessment of the consequent growth of employment in the EU, etc. Moreover, neither taxes nor subsidies have been considered, nor the impact on the EU and on national fiscal systems. These issues will be discussed in the following sections.

4.3 Total policy cost

For biofuel subsidies in the EU, there are two main estimates in the literature: the figures provided by the International Energy Agency (IEA) in its World Energy Outlook (IEA, 2010; IEA, 2012) and the estimates provided by the Global Subsidies Initiative (GSI) of the International Institute for Sustainable Development (IISD) in various reports (Kutas et al., 2007; Jung et al., 2010; Charles et al., 2013).

FIRST ESTIMATE: IEA estimates that EU biofuels subsidies were EUR 8.4 billion in 2011 by comparing biofuels prices and references prices of petroleum-based substitutes

The IEA estimates (IEA, 2012) that in the EU in 2011 biofuel subsidies were USD 11 billion (EUR 8.4 billion). This represents 46 % of the global subsidies to biofuels and 13 % of global subsidies for all forms of renewable energy. The IEA figure is based on the overall level of transport fuel consumption in the EU market, multiplied by the difference between biofuel prices and the reference prices for comparable petroleum-based substitutes (Charles et al., 2013; IEA, 2012). This estimate does not include any additional mark-up by blenders in buying biodiesel on the market and then selling it in blends.

The number from the IEA represents the direct cost to society of replacing fossil fuels with biofuels, which are more expensive. The mechanism by which Member States have sought to achieve the mandatory EU biofuels target may have incurred additional costs due to policy inefficiency (such as over-subsidy by detaxation of biofuels at the pump).

SECOND ESTIMATE: Authors estimate part of the cost of the policy by summing the bottom-up replacement costs for different biofuels

It can be expected that a major part of the cost of the EU biofuels policy is the additional production cost of biofuel compared with that of the fossil fuel it replaces (other policy costs would include the cost of blending, profits and administration). In previous sections, the authors present estimates of the production costs of bioethanol (without taxes or incentives) in 2013, and the replacement costs of petrol with bioethanol (Table 29). These can be used to estimate the total additional production cost of the biofuels compared to the fossil fuel they replaced in EU in 2011.

Table 31: Bioethanol production costs and petrol-bioethanol replacement costs

	2011 Replacement Cost (EUR/GJ)
EU wheat to ethanol	10.3 (± 16%)
Brazilian sugar cane to ethanol	13.5 (± 12%)
EU sugar beet to ethanol	9.3 (± 14%)

In terms of energy content, in 2010 ethanol from wheat made up 25 % of total EU bioethanol consumption; bioethanol from maize grain, 20 %; sugar beet bioethanol, 30 %; and sugar cane bioethanol, 14 % (Ecofys 2012, Table 45). These percentages were used to weight the replacement cost for bioethanol. Considering the similarity in replacement costs of different biofuels, changes in the bioethanol feedstocks mix between 2010 and 2011 would not significantly affect the average.

The additional production cost of ethanol compared with the petrol it replaces is about EUR 0.22 per litre of ethanol (which corresponds to EUR 0.34 per litre of fossil fuel replaced)

The average cost for the replacement of petrol with bioethanol then amounts to 10.5 EUR/GJ (uncertainty of 14% gives a range of 9 to 12 EUR/GJ), equivalent to 0.22 EUR/litre (0.19 to 0.26 EUR/litre) or 0.34 EUR/litre of petrol.[108]

The extra production cost of bioethanol compared with the petrol it replaced was around EUR 1.4 billion in the EU in 2011

In order to estimate the part of the policy cost which was absorbed by the additional production costs of ethanol compared to that of petrol, the authors multiplied the average ethanol replacement cost by the EU bioethanol consumption. Multiplying the total demand of bioethanol in 2011 (6214 million litres[109], according to EurObserv'ER, 2012) by the average replacement cost, the minimum cost of supporting bioethanol in 2011 works out at EUR 1.4 billion (with a 14 % uncertainty).

The same procedure is applied to biodiesel, starting from the production costs in 2013 and the replacement costs of diesel with biodiesel (from Table 30 in the previous section).

[108] The conversion has been made considering: ethanol density = 0.794 kg/l; ethanol LHV = 26.8 MJ/kg; petrol density = 0.745 kg/l; petrol LHV = 43.2 MJ/kg. Data from JEC-WTWv4 2013.
[109] Using WTW conversion factors, it is equal to 13.2*10^7 GJ.

Table 32: Biodiesel production costs and diesel-biodiesel replacement costs

	2011 Replacement Cost (EUR/GJ)
Rapeseed biodiesel	10.1 (± 16%)
Sunflower biodiesel	10.1 (± 15%)
Soya bean biodiesel	8.9 (± 23%)
Palm oil biodiesel	3.8 (± 26%)

The additional production cost from replacing diesel with biodiesel works out at about EUR 0.30/litre of biodiesel (which corresponds to EUR 0.32/litre of fossil fuel replaced)

Again the authors used the data from the Ecofys report (Table 44, Ecofys 2012) on the share of biodiesel consumed in the EU in 2010[110] to find the weighted-average replacement cost of fossil diesel by biodiesel. The result is 9.0 EUR/GJ (with a 18 % uncertainty: 7.4 to 10.6 EUR/GJ), which is equal to 0.30 EUR/litre of biodiesel (0.24 to 0.35 EUR/litre) or 0.32 EUR/litre of diesel.[111]

The additional production cost of biodiesel compared with diesel biodiesel had a cost of around EUR 4.2 billion in the EU in 2011

The authors then multiplied the average diesel replacement cost by the 2011 EU biodiesel demand (total EU demand for biodiesel in 2011 was 14 272 million litres[112], according to EurObserv'ER, 2012). The part of the cost of the policies absorbed by the additional production cost of biodiesel compared to diesels estimated at EUR 4.2 billion (with an uncertainty of 18 %) in 2011.

The authors estimate that the part of policy cost which was absorbed by the additional production cost of biofuels compared to fossil fuel was EUR 5.6 billion in EU in 2011

The authors thus estimate that total additional production cost of the EU biofuels compared to the fossil fuels they replace was EUR 5.6 billion in 2011 (EUR 1.3 billion for bioethanol and EUR 4.2 billion for biodiesel). Wheat ethanol and rapeseed biodiesel are both about 67 % more expensive to produce than the fossil fuel they replace. This does not include profits by biofuel manufacturers, costs and profits by blenders or additional society costs due to policy inefficiency.

[110] Rapeseed biodiesel: 48 %; soya bean biodiesel: 22 %; palm oil biodiesel: 11 %; sunflower biodiesel: 5 %.

[111] Conversion made by considering: FAME density = 0.890 kg/l; FAME; LHV = 37.2 MJ/kg; diesel density = 0.832 kg/l; diesel LHV = 43.1 MJ/kg. Data from JEC-WTWv4 2013.

[112] Using WTW conversion factors, it is equal to: 47*10^7 GJ.

THIRD ESTIMATE: GSI / IISD found that the cost of protecting EU biofuels against imported biofuels was between EUR 5.5 billion to EUR 6.9 billion in the EU in 2011

The estimates provided by the Global Subsidies Initiative and the International Institute of Sustainable Development (GSI/IISD) adopt a different approach. This sums the cost of different biofuel support measures used in the EU (market transfers[113], budgetary support[114], and support for research and development[115]) (Charles et al., 2013).
The GSI/IISD provide a range for the total support estimated in 2011, which amounts to EUR 5.5 billion to EUR 6.9 billion, 85 % of which has been estimated for biodiesel. On a per litre basis, the support amounts to EUR 0.15-0.21 for ethanol and EUR 0.32-0.39 per litre of biodiesel in 2011.

GSI / IISD estimates only the cost of support to the European biofuel industry, not the total cost of the EU biofuels policy

The estimates provided by GSI/IISD (Charles et al., 2013) compare the actual cost of the policy support with the minimum cost for achieving the same biofuel consumption in the EU by buying it on the world market. To estimate the cost of the biofuel consumption mandates introduced by Member States, GSI/IISD start with the difference between biofuel prices in the EU and biofuel prices on the world commodities market.

The authors estimate that, on the basis of the GSI / IISD figures, the cost of the entire EU biofuel policy (compared to using no biofuels) would be about EUR 7 billion in the EU in 2011

To estimate the total cost to the EU of its biofuels policy in 2011, compared with using no biofuels in 2011, it is necessary to consider the difference in price between biofuels and the fossil-based fuels they replace.[116]

The price gap between biodiesel and diesel is given by the difference between the EU biodiesel price in 2011 (which is 90 cents per litre, as provided by GSI/IISD from Platts) and the EU diesel price in the same year (which was 70 cents per litre[117]). Converting these values to EUR/GJ gives a difference of 7.6 EUR/GJ.

Multiplying the price gap with the total biodiesel demand in 2011, the market price support for biodiesel is estimated at EUR 3.6 billion (Table 33).

The same procedure for ethanol starts with the ethanol price in the EU for 2011 (63 cents per litre, as provided by GSI/IISD from OECD/FAO 2011) and the EU petrol price in 2011

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113 The market transfers include an estimate of the most important support instruments used in the EU, which are the mandatory blending rates and border protection through tariffs (import duties). The former establishes mandatory requirements for the share of biofuels in transport fuels sold, whereas the latter aims at protecting European production of biofuels through tariffs on biofuel imports.

114 Budgetary support includes the fuel excise tax, which consists in tax exemptions or reduction for biofuels compared to the fossil fuels. In most countries the system is applied without a quota, while in a few states it is applied with a quota. This means that exemptions and reductions are only granted up to a certain level of production.

115 Support for research and development (R&D) includes the various programmes and projects financed by the EU and Member States to foster R&D activities in the biofuel sector, with a special focus on advanced biofuels made from non-edible feedstocks.

116 Gamba et al. (2013) comment on the methodology used by GSI/IISD to estimate the market price support. The authors agree that the comparison should be made between the biodiesel and diesel price. However, they maintain that the market support already includes the budgetary support measure. As the comparison is made on the basis of pre-taxes prices, the authors think that the budgetary support has to be added to the market price support to estimate the total amount of subsidies.

117 The source is Commission DG Energy's Market Observatory & Statistics website.

(64 cents per litre[118]) and converts them to EUR/GJ. The resulting price gap between ethanol and petrol is 9.6 EUR/GJ.

Multiplying the price gap with the total ethanol demand in 2011, the market support for ethanol is estimated at EUR 1.3 billion (Table 33).

Adding these figures to the EU-industry subsidy estimated by GSI/IISD on budgetary support[119], the overall cost of the biofuel policy in 2011 comes out at EUR 1.9 billion for ethanol and EUR 5.1 billion for biodiesel, amounting to almost EUR 7 billion in total, corresponding to EUR 14 per person or about EUR 26 per vehicle. This includes the cost reduction or exemptions from fuel excise tax and the support for research and development (as shown in Table 33).

On a per litre basis this corresponds to 0.30 EUR/litre for ethanol (or 0.45 EUR/litre of petrol) and 0.35 EUR/litre for biodiesel (0.38 EUR/litre of diesel).

Table 33: Biofuels subsidies estimates

	2011 (EUR million)		
	Ethanol	Biodiesel	Total
Market support	1280	3572	4852
Budgetary support	562	1485	2047
Support for R&D	26	26	52
Total support	1868	5083	6951
Support EUR per litre biofuel consumed	0.30	0.35	

Source: Charles et al., 2013.

CONCLUSION ON THE THREE POLICY COST ESTIMATES

Estimates of the EU biofuel policy total costs in 2011 vary between EUR 7 billion and EUR 8.4 billion, which corresponds to EUR 14 to EUR 17 per person, or about EUR 26 to EUR 32 per vehicle

The estimates of the total costs of the EU biofuel policy in 2011 based on the literature vary between EUR 7 billion and EUR 8.4 billion in 2011, which corresponds to EUR 14 to EUR 17 per person in Europe and about EUR 26 to EUR 32 per vehicle.

The authors estimate that the part of these costs that is absorbed by the extra production costs of biofuels compared to fossil fuels amounted to 5.6 billion euro in 2011. This indicates that roughly 20-33 % of the cost of the policy goes into administration, profits and blending costs.

[118] Commission DG Energy's Market Observatory & Statistics website.

[119] The estimates on budgetary support have been revised by GSI/IISD in 'Addendum to Biofuels-At what Cost? A review of costs and benefits of EU biofuel policies', August 2013. The new estimates are in line with the estimates provided by Gamba, Spottle, Hamelilinck (2013).

Box 7: Fossil fuel subsidies for transport

Subsidies for fossil fuel are outweighed by taxation.

We often hear that 'fossil fuel subsidies are higher than those for renewables'. Usually this statement refers to IMF report 'Energy subsidies reforms: lessons and implication' [IMF 2013]. But we need to understand what this report means by 'subsidies'.

For petroleum products, they estimate two categories of subsidies:

1) The 'pre-tax subsidy' is given by the difference between the international prices adjusted for transport and distribution costs and the price paid by consumers. Some countries subsidise the component petroleum products to relieve poverty, etc. in this way, but there is no such subsidy in the EU.

2) The 'post-tax subsidy' is given by the sum of the pre-tax subsidy and two other components:

- The revenue component: the IMF has calculated the difference between sales tax or VAT on fossil fuels compared to that on other consumer goods. As it happens, the same or lower taxes apply to biofuels in most EU countries.
- Externalities: the IMF has estimated the cost of externalities such as the cost of congestion, accidents, carbon emissions and local pollution. For example, in the United Kingdom the tax associated with such externalities is mainly the cost of congestion (60 %) and accidents (about 20 %), which are the same for biofuels. The carbon component of fossil fuels accounts for only 12 % of the total externalities cost.

Thus a better name for 'post-tax subsidy' would be 'net welfare loss' of fossil fuel use.

In most EU countries, the revenue component was greater than the externalities cost, such that the 'post-tax subsidies' turn out to be negative and are reported as zero. In other words, there was a net welfare gain from fossil fuel. The 'post-tax subsidies' were only positive (corresponding to a net welfare loss) for some EU countries: Austria, Cyprus, Estonia, Ireland, Luxembourg, Malta, Slovenia, Spain, and Sweden.

4.4 Total greenhouse gas savings of the EU biofuel policy

Ethanol saved some greenhouse gas emissions in 2011

In 2011 EU used 6.2 billion litres (132 million GJ) ethanol (EurObserver, 2012), and the authors estimate that the average GHG savings for this mix of ethanols was 45.3 gCO_2e/MJ without considering ILUC emissions, or 32.6 gCO_2e/MJ including the ILUC emissions estimated for the Commission by Laborde, 2011. These figures imply that ethanol use saved about 6 Mt of CO_2e emissions, not considering ILUC emissions. If we include the ILUC emissions, the savings from ethanol fall to 4.3 Mt of CO_2e in 2011.

Biodiesel increased greenhouse gas emissions if ILUC emissions are included

In 2011 the EU used 14.3 billion litres (473 million GJ) biodiesel (EurObserver 2012], and the authors estimate that the average GHG savings for this mix of biodiesels was 38.0 gCO_2e/MJ without considering ILUC emissions, or minus 17.0 gCO_2e/MJ including the ILUC emissions estimated for the Commission by Laborde, 2011. These figures imply that biodiesel use saved about 18 Mt of CO_2e emissions, not considering ILUC emissions. If we include the ILUC emissions, the biodiesel no longer saves emissions, but increases them. The increase in emissions totalled 8 Mt of CO_2e in 2011.

As a whole, biofuels in the EU saved GHG emissions only if ILUC emissions are not taken into account

Adding the effects of bioethanol and biodiesel in in EU 2011, we conclude that

- Without considering ILUC emissions, EU biofuels saved about 24 Mt of CO_2 equivalent greenhouse gas emissions.[120]
- **Taking into account the ILUC emissions calculated for the European Commission by Laborde, 2011, biofuels in the EU increased greenhouse gas emissions by a net 3.7 Mt of CO_2 equivalent in 2011**

4.5 Impact on employment

There are several drivers for the EU to introduce biofuels in the transport sector, including the creation of jobs.

In principle, biofuels can have a positive local economic impact in the regions where they are grown or manufactured. However, since biofuels are still more expensive than fossil fuels, the additional cost or public spending will counter the overall positive impact if taxes increase to keep the budgetary impact neutral.

Job creation is one of the objectives of the biofuels mandate in the EU, but information on the effect on employment is still insufficient

Several studies with a national or EU focus have addressed the additional benefits of renewable energy policies in terms of employment.

However, given the relevance of job creation for supporting biofuels development, the level of information available on employment effects is currently insufficient. More research is required, as highlighted by the Global Subsidies Initiative (GSI) of the International Institute for Sustainable Development (IISD) in their 2013 report (Charles et al., 2013).

Global gross employment in the biofuels sector is estimated at 1.5 million, which is about half the jobs in the renewable energy industry

Data from the International Renewable Energy Agency (IRENA) for 2010 estimate the global gross employment in the biofuels sector[121] at 1.5 million, which is about half of the jobs in the renewable energy industry (IRENA, 2011).

Estimates proposed by Urbanchuk (2012) for the Global Renewable Fuels Association, agree with the above figure. They indicate that global ethanol and biodiesel production supported nearly 1.4 million jobs in all sectors of the global economy in 2010. This figure takes account not only of jobs directly involved in the biofuels production, but also of jobs in agriculture, other supplying industries and other sectors that benefit from the economic market generated by biofuels. The US and Brazil account for the largest share of employment in ethanol production occurs.

[120] This result is in line with the estimate of GHG savings for 2010 reported in the Renewable Energy Progress report [EC, 2013] of 22.6 to 25.5 Mt CO2eq. http://ec.europa.eu/energy/renewables/reports/reports_en.htm.

[121] Refers to the sum of positive employment effects resulting from investments in renewable energy, and does not take into account negative employment effects that may be experienced in other sectors.

Estimates of employment in the biofuels sector point to the creation in the EU of jobs associated with biofuels

At EU level, the same estimates (Urbanchuk, 2012) indicate that the biodiesel and bioethanol sectors supported around 220 000 jobs in 2010. This is higher than the estimates proposed by EurObserv'ER, which reports estimated employment associated with biofuels in the EU27 at over 150 000 jobs within the agricultural supply chain in 2010 (EurObserv'ER, 2011) and at 115 000 jobs for 2012 (EurObserv'ER, 2013).

The EU biofuels sector representatives, such as ePURE, use an approach for assessing direct jobs based on 'employment factors'. This simply consists of surveying a sample of biofuel production plants to identify the number of employees working at the refining site and the plant's installed annual capacity. It estimates the number of onsite jobs per litre of biofuels (Charles et al., 2013).

Based on ePURE and EurObserv'ER 'employment factors', the IISD calculates employment in the biofuels sector in 2011 to include 70 272 jobs in EU ethanol production and 51 639 jobs in the EU biodiesel industry

According to ePURE, there are 16 jobs for every 1 million litres of domestically produced renewable ethanol (Charles et al., 2013). Based on this, GSI/IISD has calculated the number of jobs at 70 272 in EU ethanol production in 2011 (Charles et al., 2013). By contrast, EurObserv'ER estimates that every 1 million litres of biodiesel produced in the EU creates only 5.3 jobs (EurObserv'ER, 2012). Applying this employment factor to 2011 biodiesel production figures, GSI/IISD has calculated the number of jobs in the industry at 51 639 (Charles et al., 2013). In a shared document, various biofuels associations (EBB, ePURE, COCERAL, CIBE, Copa-Cogeca, FEDIOL & EOA, 2012) claim that the EU biofuels industry creates 100 000 direct jobs for European citizens. However, no sources are cited in the document.

According to estimates presented in the Commission's Impact Assessment SWD(2012) 343, the expected employment increase related to biofuels in EU in 2020 is on the order of 400 000 jobs, mostly in agriculture. This estimate is based on the EmployRES report by Ragwitz et al. (2009), which uses an input-output model (MULTIREG) for a scenario in which all existing renewable energy policies will be continued until 2030 in the EU and worldwide. However, this is an estimate of the gross employment effect, which does not take into account adjustments in other parts of the economy. These include, particularly, the depressive effects of increases in transport fuel price, or the increase in taxes to pay for subsidies or detaxation at the pump (see below).

The effect on employment should be evaluated considering the net effects on all sectors of the economy

Due to the wide range of sectors in which jobs are claimed to be created, especially in the agricultural sector, the overall number and quality of jobs created by the biofuels industry is subject to disagreement (Charles et al., 2013).

Many of the farm-related jobs would probably have existed with or without biofuels, especially if the alternative to biofuels is more EU crop exports. The additional jobs created by the biofuels sector are most likely those associated with biofuel processing facilities or transport (Swenson, 2006) and they may be offset by losses in, for example, petroleum processing facilities. More important is the depressive effect of taxation (to make up for tax income lost by detaxation of biofuels at the pump) or, alternatively, increases in the transport fuel price. Therefore, any policy that requires more public spending should be

evaluated by including the effects of the extra taxation needed to balance the extra spending.

In other words, the net effect on employment has to be estimated. This should take into account the interrelations between all sectors of the economy, including the effect on the conventional fuel sectors that compete with the biofuel sector, and the effects of taxation, price changes and ensuing changes in consumers' expenditure, in the context of a balanced budget.

An overall estimate for all renewable energy shows a moderate increase in gross domestic product and employment in the EU27 in 2020 in all renewable energy sectors

The EmployRES report by Ragwitz et al. (2009) also estimates the net impact of all renewable energy policy using two different macroeconomic models (ASTRA and NEMESIS). The conclusion of both models is that GDP would be slightly stimulated by the renewable energy policies (0.11-0.14 % increase), but also that 64-80 % of the gross gain in jobs in the renewables sector would be offset by jobs losses elsewhere in the economy (the net effects of biofuels alone are not calculated).

An analysis based on an input-output model concluded that the net EU employment effects are neutral or close to neutral

An analysis by JRC-IPTS based on an input-output model of EU economy reported in (JRC, 2008) provides an estimate of the total net employment effects. It takes into account the balance between different employment components and considers different penetration scenarios for biofuels (6.9 % biofuel share or 14 % biofuel share in 2020).

In all cases, it was assumed that the additional costs of biofuels compared to fossil transport fuels were compensated by fuel tax reductions, recollected in turn from private consumers through an increase in general taxation (and disposable income) of equal amount to ensure government budget neutrality.

The model calculated the largest absolute employment losses in the service sector, since specific employment gains are absent in the services, and this sector has the largest overall employment base.

The conclusion is that the net EU employment effects, under the technology and market assumptions specified in the scenarios, are neutral or close to neutral (up to 250 000 jobs, 0.125 % of the total jobs in EU, created or destroyed).

Note that the JRC-IPTS analysis only looked at employment impacts in EU. The increase in world crop prices induced by biofuels demand would be expected to benefit employment in the major crop-exporting regions, for example the US, Brazil, Argentina, Indonesia and Malaysia.

A paper based on the GTAP economic model shows a negative impact on employment of the EU biofuel policies in 2015

A negative result on employment is shown in a paper that analyses the employment and welfare consequences of two biofuels programmes (US and EU) using the GTAP model[122]

[122] It is a version of GTAP (Global Trade Analysis Project) developed by Hertel, Tyner and Birur in 2010, in which the usual assumption of full employment is modified to include unemployment and a jobs market in the EU.

(Padella, Finco and Tyner, 2012). The analysis is based on the mandate of 6.25 % of biofuel consumption in the EU in 2015 (compared to no mandate). The aim of the study was to measure the change in welfare due to the mandate.

The results show that employment is created only in the biofuels sector and in oilseed farming, but not in the rest of the economy. The global welfare change is negative, showing a loss in welfare for EU society as a whole. The global welfare loss is caused by a loss in efficiency, which represents a change in welfare owing to the reallocation of existing resources. Most of the welfare loss is in the labour sector. In other words, people get poorer because society has to pay money to substitute fossil fuel with biofuel. Furthermore, the overall fuel sector declines, as there is a loss of fuel demand due to fuel price increases. These losses result in a reduction of overall employment, which declines by 2 % in the EU from 2006 to 2015 as a result of the biofuels mandate. In this model, the biofuels mandate is pushing the economy away from a more efficient allocation of resources.[123]

Most biofuel jobs are not created in ‘convergence regions’

Where jobs are created is also relevant. The Renewable Energy Directive (RED) recognises the importance of ‘providing opportunities for employment and regional development, especially in rural and isolated areas’.

The analysis carried out by IISD (Charles et al., 2013) considers the location of the majority of installed production capacity. It assumes that direct and indirect employees of the biofuels industry are probably clustered around biofuel refining sites. Therefore, the majority of jobs created by the EU biofuels industry (64-69 % of the total created in 2011) are not likely to be in ‘convergence regions’ (areas within the EU where the per capita GDP is less than 75 % of the average of the EU27 countries), with the exception of north-eastern Germany.

CONCLUSION

There are two types of studies on the effects of biofuels on employment. In general, those that account for the increase in taxation to pay for biofuel subsidies conclude that employment effects are neutral or even negative (as well as negative net welfare benefit). Only the studies that consider biofuel subsidies leading to public spending increases that are not compensated with taxation show a significant gain in employment.

4.6 EU reduced dependence on oil import through biofuel use

Biofuels replaced 5.1 % of EU road-fuels and up to 2.2 % of EU crude oil use in 2011

In 2011, biofuels accounted for approximately 5.1 % of EU road fuels, measured by energy content (data from [CONCAWE 2013], interpolated and elaborated by the authors). Taking into account the extra crude oil used in refining (JEC-WTW v4 data), this saved 2.2 % of EU crude oil consumption. However, this calculation does not take into account a small amount of petroleum products used in growing and processing biofuels, nor the fact that some biofuel was imported, or made from imported feedstock. In 2011, 23 % of biodiesel and 24 % of bioethanol were imported directly as finished products (USDA 2012). The fraction of imported feedstock in biofuel production is more difficult to define; section 2.1 shows that considering the EU vegetable oil demand as a whole, about 57 % of the extra demand

[123] The result on employment depends on the assumption that the increase in wages is equal to the increase in the price index for private consumption after the biofuel mandates in the EU.

since 2001 could be attributed to imports, whilst the same calculation cannot be made for cereals. In any case, even if biofuel or feedstock-for-biofuel is imported, it can be said that biofuels have expanded the range of sources of supply of transport fuel.

The Renewable Energy Directive mandates the Member States to replace 10 % of petrol and diesel for road transport by 2020. The projection in OECD/FAO Agricultural Outlook (2012a) indicates that in 2020 the fraction of biofuels imported in the EU as finished product will be 10 % of biodiesel and 19 % of ethanol. Of course, unforeseen changes in market forces, as well as changes to mandates, taxes and duties, can modify the result.

In the following sections the projected impact of biofuels on oil imports is analysed.

4.6.1 Biofuel reference scenario

When considering the future effect of biofuels on oil imports, there are a large number of factors that can affect future scenarios

Energy technologies never work alone, and there is always competition between them. In order to assess the impact that the biofuel used in Europe has on EU oil imports, it is necessary to compare the technical and economic characteristics of biofuels with their competing technologies (such as traditional fuels). This should be done by considering the whole EU energy system, where political targets and technical and economic boundary conditions on biofuels are just some of the factors affecting the results. EU policies in other sectors, macroeconomic trends and other emerging technologies are also part of the picture. In order to examine such scenarios, a large number of variables need to be analysed and forecasted towards 2020: the EU energy demand for road transport; the costs of fuels; the composition and efficiency of the transport fleet and the rate of replacement of new cars; the composition of the EU energy mix etc. Quite complex techno-economic models can be adopted, and different initial hypotheses can lead to different results. Consequently, from a policy-making point of view, it is necessary to rely on scenarios based on a data-set that can be considered ‘shared’ by the largest number of stakeholders and policy-makers.

The OECD/FAO Agricultural Outlook (2012a) has been adopted as the main source for the biofuel market projections in this section

The OECD/FAO Agricultural Outlook (2012a) provides a shared reference point, suitable for ‘baseline’ policy-making considerations and as a main source in this study for biofuel market projections. The OECD/FAO reference scenario considers an amount of biofuel production consistent with the RED strategic targets.

<u>Main scenario hypotheses</u>

Since initial hypotheses strongly affect the results of projections, the main hypotheses adopted in the reference study (OECD/FAO, 2012a) are listed below:

- Along the timeframe considered (2012-2020), ethanol and biodiesel prices are expected to remain supported by high crude oil prices and by the implementation and continuation of EU policies promoting biofuel use.
- Global biofuel trade is anticipated to grow significantly (although to a lesser degree for biodiesel), with a strong cross-trade among global markets. Ethanol markets will remain dominated by the US, Brazil and the EU. Biodiesel markets will likely remain dominated by the EU, followed by the US, Argentina and Brazil.
- The EU is expected to be by far the largest producer and user of biodiesel.

Taking into account the OECD/FAO assumptions, the EU is set to import approximately 2000 million litres of biodiesel and over 3000 million litres of bioethanol in 2020

According to the boundary conditions listed above, the reference study provides, as an output, the biodiesel consumptions requirements and the expected production as shown in the following figure. The difference between consumption and production is the net trade with other countries, such as the US, Brazil and countries in the Far East. The EU will import about 2000 million litres of biodiesel in 2020.

Figure 47: Forecast European biodiesel market

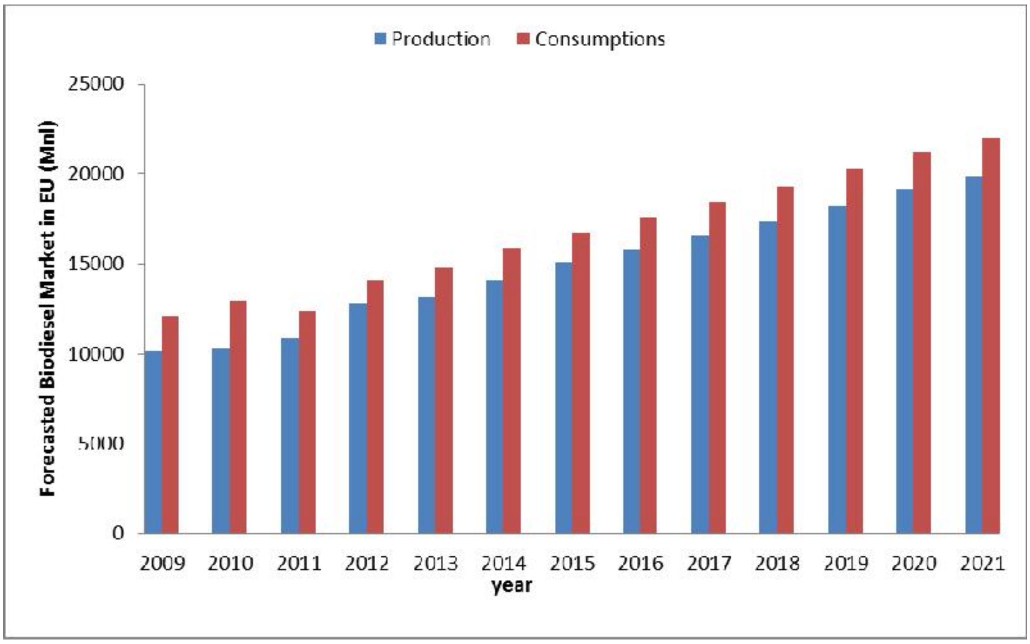
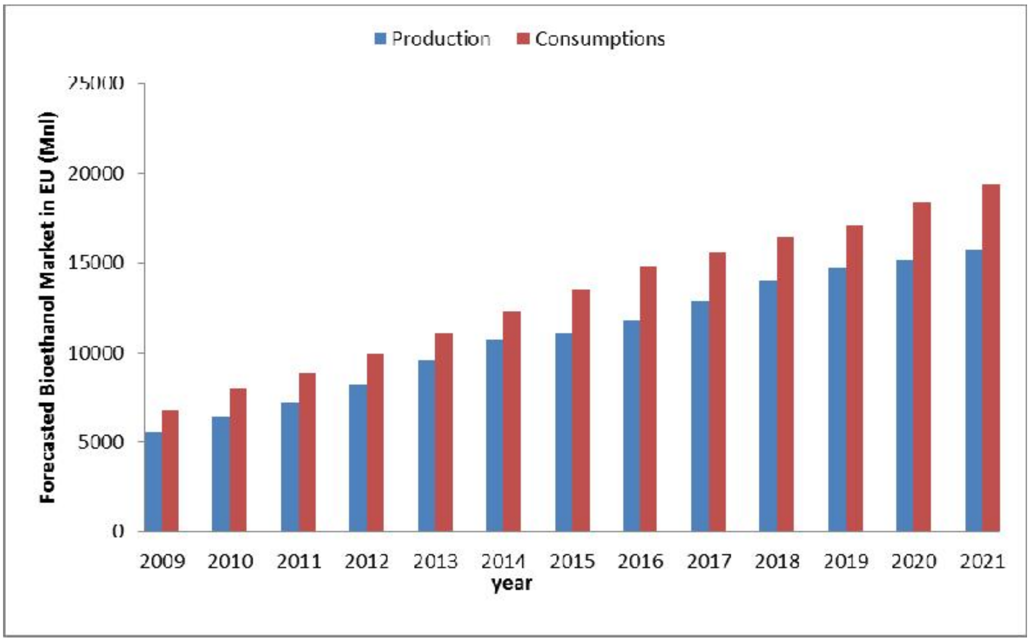


Figure 48: Forecast European bioethanol market



OECD/FAO forecasts for production and consumption for the European bioethanol market are shown in the figure above. They show a negative trade balance for the EU, which is expected to import 3600 million litres of ethanol from outside the EU in 2021.

The increased shares of biofuels in the total road transport fuels predicted for 2020 will displace greater volumes of fossil fuels

To put the forecasts for biofuel markets into perspective (matching the RED targets), it is necessary to compare market data presented in Figures 47 and 48 with projections for road transport fuel needs (OECD, 2012b), as shown in Table 34. The shares of petrol and biodiesel are calculated in terms of energy content, because EU RED targets are expressed as an energy-content ratio.

Table 34: Share of biofuels within the EU's total road transport fuel needs

	2009-2011			2021		
	Total	Of which biofuel	Share of biofuel	Total	Of which biofuel	Share of biofuel
	(Mtoe)	(Mtoe)	(%)	(Mtoe)	(Mtoe)	(%)
Petrol type	103	2.8	2.7%	103	8.6	8.3%
Diesel type	189	9.4	5.1%	200	16.7	8.4%

Converted[124] in terms of volume of fossil fuel saved in 2021, 8.6 Mtoe of bioethanol are equivalent to about 11 billion litres of petrol saved, while the 16.7 Mtoe of biodiesel are equivalent to about 20 billion litres of road diesel saved.

These data are the outcome of just one of the possible scenarios for the 2020 biofuel market. Different studies present the same biofuel total impact but with a different share of ethanol and diesel (e.g. GSI, 2013).

4.6.2 Prospective impact on EU refining industry

The EU oil market and oil refining facilities relevant to the EU have to be considered to put into perspective biofuel demand forecasts

To evaluate the impact of biofuels in the oil supply market, it is necessary to view the forecasts on biofuel demand presented above in perspective with EU oil market and oil refining facilities. The study from CONCAWE (2013) is used here as a reference source for oil supply; it is reasonably[125] consistent with the OECD/FAO (2012a) biofuel scenario used in the section above. The reference scenario considered gives overall[126] results similar to the 2020 figures from Wood-McKenzie (2010).

[124] Considering the conversion factors in Appendix1 of the WTW (2011) v3 report.

[125] The main differences between the OECD/FAO and CONCAWE 2020 projections are that CONCAWE considers: 1) a total fuel demand 10 % lower than OECD; 2) an EU fleet that is more than 30 % 'dieselised'; 3) a biodiesel/bioethanol demand ratio 20 % higher than that of the OECD.

[126] According to the Scenario 1 of Wood Mackenzie (2010), the total biofuel demand in 2020 will be about 30 Mt, while the CONCAWE 2020 scenario forecasts 28 Mt.

Predictions for the EU's crude oil demand indicate an overall reduction of 1.5 % from 2010 to 2020. In regions supplying the EU, oil production will reduce in some areas but grow in others

The reference scenario (CONCAWE, 2013) presents 2020 data on the total EU demand for oil-refined products, not only for road transport but also for heating etc. This demand is forecast to decline, owing mainly to economic trends, but also to the increasing use of alternative fuels and to energy efficiency improvements (not only in the automotive sector). Another aspect to consider is that the European fleet of vehicles is becoming more and more 'dieselised'.

Specific hypotheses apply to the oil-supply scenario: the producing regions more favourable to the EU are, for logistical reasons, the North Sea, North and West Africa and, recently, the Caspian Sea. North Sea production is in decline because of the depletion of resources not compensated by new discoveries, while the Caspian Sea is becoming a major producer. The geographic proximity and favourable logistics makes Europe a natural growing consumer of Caspian resources, compensating for the fall in 'indigenous' North Sea production (ibid, Appendix 5).

In general, the total crude oil supply to the EU is reduced by 1.5 %, from 660 million tonnes in 2010 to 650 million tonnes in 2020.

The EU demand for petrol and diesel is expected to decline by 1.1 % between 2010 and 2020

In the framework of general EU energy policies, the growing biofuels trends deliver a projected decrease in EU demand for petrol and road diesel: the demand for these refinery products is expected to fall from 270.6 million tonnes per annum (Mt/a) in 2010 to 267.6 Mt/a in 2020 (see Table 35 below).

Table 35: EU demand for refinery products in the biofuel scenario

	2010	2020	2010-2020 Variation	2010-2020 Variation
	(Mt/a)	(Mt/a)	(Mt/a)	(%)
Petrol	88.1	72.2	- 15.9	- 18%
Road diesel	182.5	195.4	+ 12.9	+ 7%
Total	270.6	267.6	- 3.0	- 1.1%

These decreasing effects are cumulative, and result from all the boundary conditions considered in the initial hypotheses (as well as from economic trends, energy-efficiency measures etc.), making it difficult to identify the standalone impact of biofuels on this decrease.

The blending of biofuels up to 2020 is not expected to impact refinery economics significantly

The impact of biofuels on refining economics in 2010-2020 is likely to remain low. In particular, the increase in biodiesel production will not eliminate the shortage of 'middle distillate' (diesel and kerosene) in the EU. Even though scenario 1 of Wood Mackenzie (2010, Section 12.3.2) assumes that the RED and FQD requirements will be met with a relatively high share of biodiesel and a low share of bioethanol, it states that 'Europe

remains short of middle distillates with middle distillate pricing movement expected to remain almost unchanged'.

However, the biofuel benefits are more evident over a longer period (2005-2030). The CONCAWE projections for 2030 (against a 2005 baseline) are that biofuels would be responsible for about a fifth of the overall reduction in demand for refined oil products (CONCAWE 2013, Section 3.5).

The progressive dieselisation of the EU fleet requires more biodiesel than bioethanol. Producing more bioethanol than diesel would affect EU refining economics negatively

Comparing different 2020 scenarios (Wood Mackanzie, 2010) with petrol and diesel demand, it is possible to see how the 'natural' ratio of diesel to petrol produced by oil refineries is insufficient to satisfy market requests. The progressive dieselisation of the EU vehicle fleet requires more and more diesel, and EU refineries spend money and energy to increase the diesel fraction. In 2008, 30 % of EU-produced petrol was exported.

The production of a relatively high share of ethanol with respect to biodiesel would exacerbate this trend, making it cheaper to import the extra diesel fuel as a finished product: '[F]or every barrel of biopetrol which enters the petrol pool, European petrol prices will move downwards and so reduce the net cash margin for European refiners. European refiners can be expected to respond to these price signals by reducing their supply. As refineries reduce their production, their carbon emissions will fall in line with the reduction in crude demand' (Wood Mackanzie, 2010, scenario 2). This would have a negative effect on the EU refining economics.

5. SUSTAINABILITY ISSUES OF 'NON-FOOD' BIOFUELS

KEY FINDINGS

- The assumption of biogenic carbon neutrality for forest-derived biofuels is not valid under policy-relevant time horizons (in particular for dedicated harvest of stemwood).
- The use of stemwood from dedicated harvest for biofuels causes an actual increase in GHG emissions compared to those from fossil fuels in the short to medium term (decades). It may start to generate GHG savings only in the long-term (several decades to centuries).
- For residual wood (e.g. forest residues, thinning wood and salvage logging), GHG savings are achievable in the short to medium term. This feedstock is expected to provide most of the additional increment of biomass for biofuels by 2020.
- Market-mediated effects and other climate forcers should be included in the analysis of biofuel policies.
- Bioenergy from the analysed agricultural and forest residues will generally achieve GHG emissions savings compared to fossil fuels, even when all direct and indirect effects are considered.
- Other bioenergy-induced impact presents medium to high potential risks, especially related to biodiversity and the organic matter content of soil.
- Further long-term experimental research is needed for many of the analysed impact and feedstocks.
- Biomethane produced by anaerobic digestion of energy crops can cause GHG emissions higher than natural gas if production occurs without proper technological and management choices.
- The anaerobic digestion of residues using the best practices can guarantee significant GHG savings.

5.1 Introduction

Much of the focus of the previous chapters, and of the current debate, has been on the sustainability issues associated with 'first-generation' biofuels, which are produced from food crops.

Increasing interest in advanced biofuels requires a deeper analysis into possible sustainability risks

However, increasing political and technological interest is being concentrated on advanced biofuels, defined here as biofuels based on non-food materials. For this reason, it is important not to underestimate, or neglect, the potential sustainability issues associated with these materials.

Therefore, this chapter shifts the focus to the issues associated with three groups of feedstocks and technologies, which are forecasted to become (or, in the case of biogas, already are) very relevant to the bioenergy mix in the EU.

Section 5.2 deals with the issues associated to the proper carbon accounting of forest biomass; section 5.3 presents an assessment of possible risks and benefits associated with an increased use of biomass residues and wastes for energy production; section 5.4 analyses the uncertainties and risks associated with GHG emissions in biomethane production.

Before analysing the specific feedstocks, it is important to define some concepts about life-cycle assessment (LCA) and system boundaries, which are essential to a proper understanding of the issues described later on.

5.1.1 System boundaries and bioenergy-induced impact

Life-cycle assessment is the tool recommended by ISO, and is also specified in European legislation (ILCD, 2010) for the analysis of environmental impact of products or services.

There are two main types of LCA: attributional and consequential

The classic type of comparative attributional LCA[127] (ALCA) compares two or more systems delivering the same functional unit (e.g. 1 MJ of fuel, the transport of 1 tonne of products per 1 km, 1 MJ of electricity). The result of the analysis allows the comparison of the different systems in terms of environmental impact and resource depletion.

A consequential approach is needed when assessing the consequences that a decision taken in the foreground system may have on other processes and systems of the economy. This is the case, for example, for the environmental impact of a policy that affects several sectors of the economy. The consequential life-cycle analysis (CLCA) model, therefore, does not reflect the actual (or forecasted) specific, or average, supply-chain. Rather, it models a hypothetical, generic supply-chain that is modelled according to market mechanisms, and potentially includes political interactions and consumer behaviour changes (ILCD, 2010; Plevin et al., 2014).

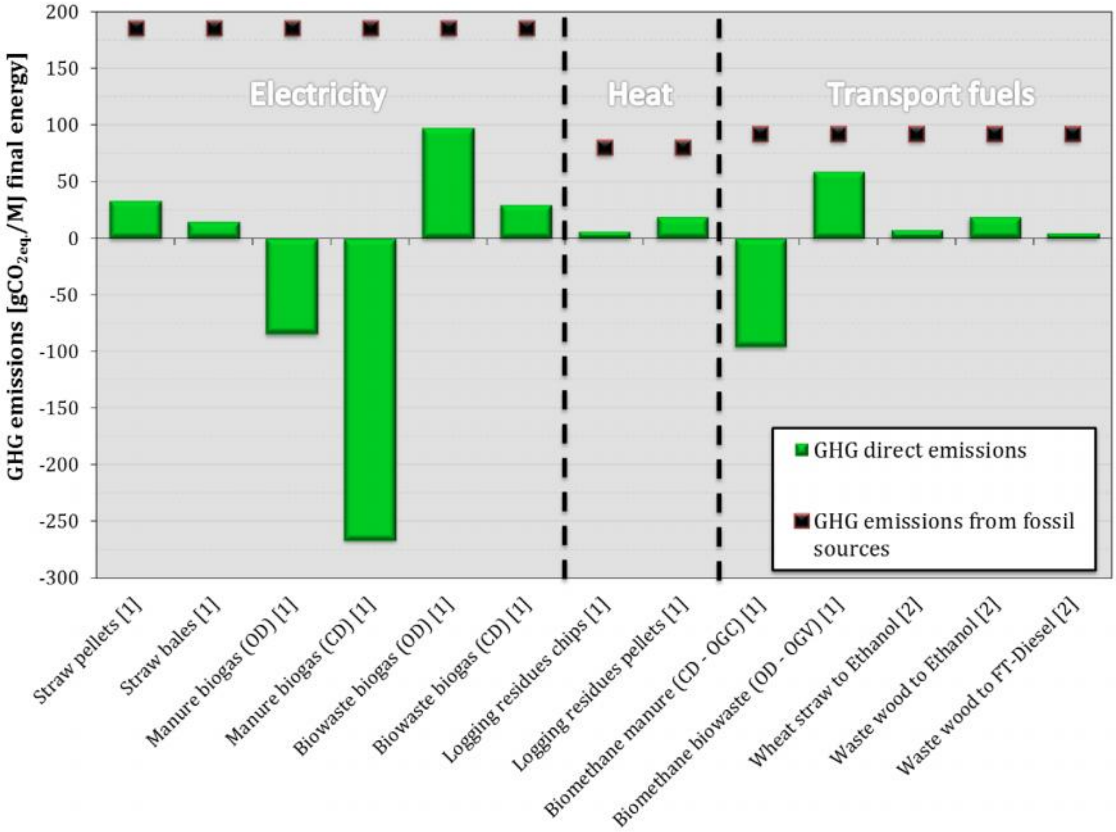
The methodology used in the RED and FQD is a simplified attributional LCA accounting for direct GHG emissions in the bioenergy production

The simplified LCA methodology included in the RED and FQD is relatively detailed for what concerns the calculation of the direct GHG emissions associated with the supply chain of the bioenergy system. These are the typical and default values also indicated in the directives (see also section 4.1.1 for direct emissions related to other biofuels).

Evaluating such direct GHG emissions for the production of bioenergy from residues, wastes and lignocellulosic feedstocks is quite straightforward, and the results generally indicate emissions which are much lower than for the fossil alternatives (see Figure 49).

[127] 'Attributional LCA' depicts the potential environmental impact that can be attributed to a system (e.g. a product) over its life cycle, i.e. upstream along the supply chain and downstream following the system's use and end-of-life value chain. This is opposed to 'consequential LCA', which instead aims at identifying the consequences that a decision in the foreground system has for other processes and systems of the economy, both in the analysed system's background system and on other systems.

Figure 49: GHG emissions associated with the production of bioenergy from residues and wastes[128]



In the RED methodology, however, the effects associated with the fossil system are evaluated only in comparison with the so-called fossil fuel comparator. This number contains the life-cycle (including combustion) GHG emissions associated with the production of the fossil energy.

GHG savings associated with biofuels and bioenergy produced from residues are generally high, well above 60 %

Figure 49 represents a collection of GHG emissions associated to the supply chain of various pathways to produce power, heat and transport fuels from some common biomass residues and woody materials. It is evident that GHG emissions savings well above 60 % can be easily achieved when compared against a fossil fuel comparator.

Expanding the system boundaries and applying more consequential thinking is essential for understanding the actual GHG emissions and environmental impact of advanced biofuels

However, in order to understand the actual GHG emissions and environmental impact of bioenergy and biofuels obtained from these feedstocks, it is necessary to expand the analysis of the fossil system to include what would have happened to that biomass feedstock if it had not been used for energy production. As much as for the ILUC analysis, it is essential to expand the system boundaries and move from a purely attributional methodology to a more consequential one, in order to create an accurate representation of bioenergy sustainability.

[128] Sources: (1) JRC, 2014, EUR26696EN; (2) WTT v4, 2013. OD = open storage of digestate; CD = closed storage of digestate; OGC = off-gas combusted; OGV = off-gas vented.

The methodology and criticalities associated with ILUC calculations (mainly for food crops) are explained in detail in section 2.4. This chapter illustrates the issues associated with biofuels produced from forest biomass and agricultural residues.

5.2 Emissions and carbon accounting from forest biomass

This chapter explains the main and latest literature findings on the issue of forest biomass carbon accounting.

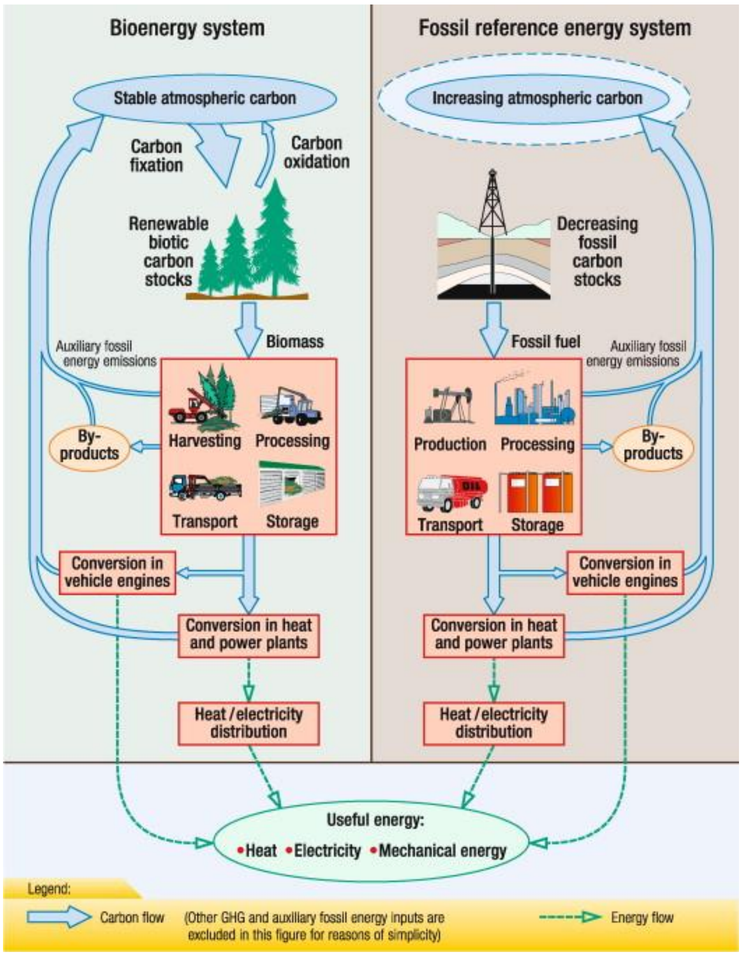
5.2.1 The concepts of 'carbon neutrality' and 'carbon debt'

Bioenergy is often considered carbon-neutral, especially in energy policies

Bioenergy is commonly considered a 'carbon-neutral' source of energy. This assumption derives from the fact that biomass combustion releases the same amount of CO_2 as was captured by the plant during its growth. Fossil fuels combustion releases CO_2 that has been locked up for millions of years and would be removed from the atmosphere only in geological periods, therefore causing the temporary accumulation of CO_2 in the atmosphere. The figure below shows a general scheme of this concept of comparing bioenergy and fossil-energy systems.

In the current European renewable energy policy framework, forest biomass used for energy and transport is considered as a 'carbon-neutral' source. For example, in Annex V to RED and Annex IV to FQD it is stated that emissions from the fuel in use shall be taken to be zero for biofuels and bioliquids.

Figure 50: Comparison of the carbon and energy flows in bioenergy and fossil energy systems (Berndes et al., 2010)



For inventory and accounting purposes, bioenergy is correctly reported as carbon-neutral at the point of combustion when carbon stock changes on forest land are reported in the land use, land-use change and forestry (LULUCF) sector

The 'carbon neutrality' assumption originates from the methodology developed by the Intergovernmental Panel on Climate Change (IPCC)[129] to monitor GHG emissions. According to the IPCC guidelines for national inventories, carbon dioxide emissions and removals from the use of biomass for energy are included in the LULUCF sector at the point and year of harvest, and the 'upstream emissions' are accounted for in other sectors (e.g. the diesel for transport is accounted in the transport sector). In order to avoid double counting, direct CO_2 emissions from biomass combustion used for energy are only recorded as a memo item in the energy sector (i.e. these emissions are not included in the energy sector total).[130]

In forest bioenergy carbon accounting, the assumption of carbon neutrality is not valid unless the carbon stock changes in the forest are fully included in the analysis

However, when calculating the GHG performances of specific bioenergy pathways in order to assess their eligibility for subsidies and targets compliance, the carbon neutrality assumption is not valid, unless all the carbon pools are included in the life-cycle assessment. For example, fossil diesel used for transport of the biomass causes an emission from the fossil carbon pool to the atmosphere. Therefore, it is taken into account as fossil GHG emissions associated with the life cycle of bioenergy. The same should apply to carbon stock changes in the forest: if there is a flow of carbon from the forest to the atmosphere, this has to be included in the LCA and properly allocated to bioenergy, irrespective of whether or not it is accounted for in the LULUCF sector.

There is a temporal imbalance between emissions and absorption of atmospheric CO_2 in the case of forest biomass combustion

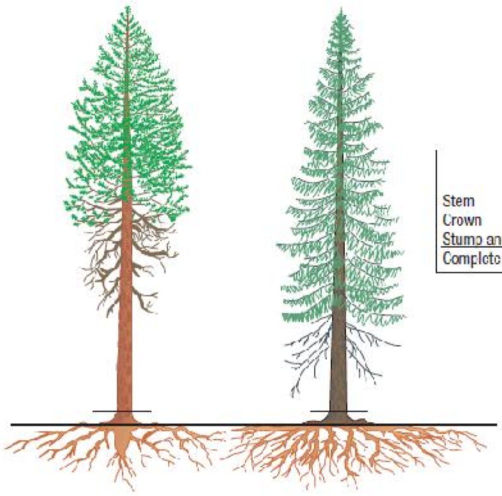
Forests consist of a series of six carbon pools constantly interacting among each other: (a) above-ground biomass; (b) below-ground biomass; (c) dead wood; (d) litter; (e) soil and (f) harvested wood products (HWP) (IPCC, 2006). Harvesting and processing wood leads to changes in the carbon stored in these pools.

Trees consist of different parts. The main part of a tree is called stem; this is the part with the highest commercial value. The part of the tree that remains attached to the root system after the trunk is cut is called stump. Tops, branches, defective stems and other portions of trees produced as a by-product during the normal course of harvesting stemwood are defined as logging residues.

[129] The Intergovernmental Panel on Climate Change (IPCC) is a scientific body under the auspices of the United Nations (UN). It reviews and assesses the most recent scientific, technical and socio-economic information produced worldwide relevant to the understanding of climate change. It publishes the Guidelines for National Greenhouse Gas Inventories.

[130] See Q 2-10 in http://www.ipcc-nggip.iges.or.jp/faq/faq.html.

Figure 51: Distribution of biomass between stem, crown and stump-root system in final fellings



	Scots pine		Norway spruce	
	Proportion, %			
Stem	100	69	100	59
Crown	23	16	45	27
Stump and root	22	15	24	14
Complete tree	145	100	169	100

Source: Hakkila, 2004.

When wood is harvested and removed from the forest, the forest carbon stock inevitably decreases. The forest (if it does indeed remain a forest) may reabsorb an equivalent amount of carbon as it grows over a number of years (in the form of CO_2). If the energy produced from the forest is used to replace fossil fuel, the emissions avoided by substitution contribute to offset the initial CO_2 emissions. However, the time it will take to restore the initial level of forest carbon depends on the growth rate of trees and the management regime of the forest. In boreal forests, for example, 70 to 120 years are necessary before a stand of trees is mature; in temperate or tropical forests this time is normally shorter, depending on the species and site conditions.

In the bioenergy scenario, the decrease of forest carbon stock due to wood harvest for bioenergy can only be repaid in time if forest productivity increases

When a forest is harvested at regular intervals as a mosaic of stands, following a sustainable-management approach, the amount of extracted wood is kept equal or lower in the long term to the amount of woody biomass generated by the forest (called net annual increment: NAI). The carbon stock of such a managed forest is anyway lower than that of an unmanaged forest, or of a forest managed with longer rotation cycles.

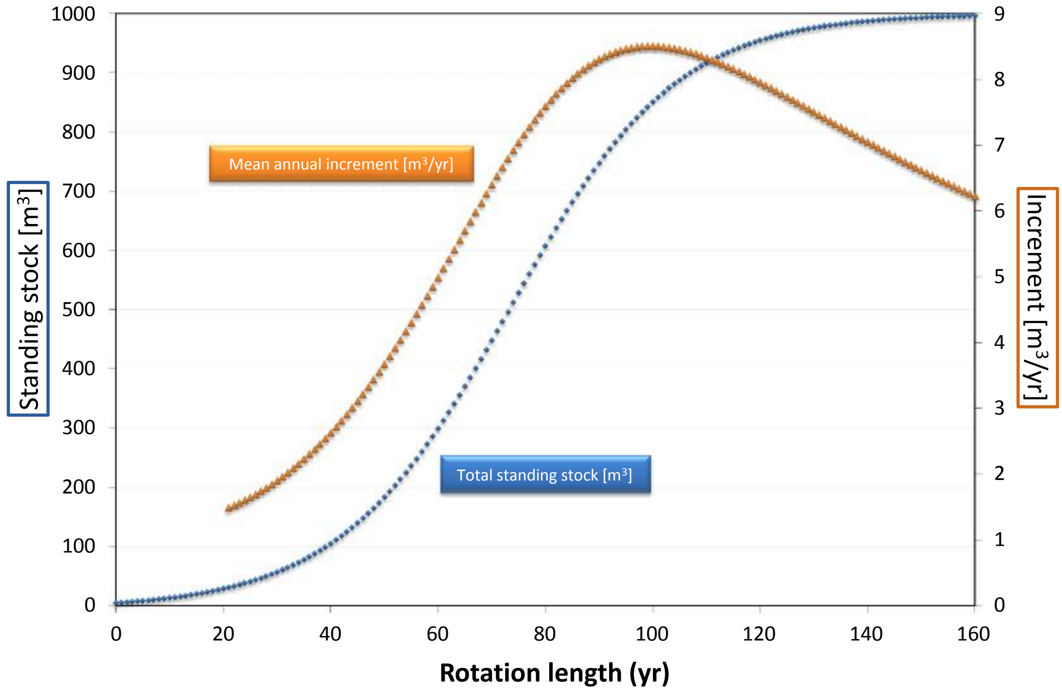
Assuming that the biomass used for biofuels is not diverted from other sectors (e.g. pulp and paper, particle board etc.), it has to come from additional harvest from the forest.[131]

Figure 52 represents a schematic development of carbon stock in a forest landscape. A way of increasing the productivity of a forest is to shorten the rotation period. Shortening the rotation time decreases the amount of carbon stored in the forest to a new, lower, steady level. If the current rotation is longer than that corresponding to the culmination of the harvest rate (e.g. if managed at 120 years rotation), the carbon stock, in this example, is about 950 cubic metres of carbon per hectare (m^3/ha) and the mean annual increment (MAI) is 8 m^3/ha. Shortening the rotation time may increase the average annual harvestable volume (e.g. at 100 years rotation the standing carbon stock is 850 m^3/ha

[131] According to the NREAPs (National Renewable Energy Action Plans), the increase in bioenergy production by 2020 will derive only from wood harvested direct from the forest.

while the MAI is 8.5 m^3/ha). Therefore, the lowering of the carbon stock will be compensated over time by the increased accumulated production volumes, and therefore substitution benefits. If the rotation is shortened to an extent at which the productivity decreases (e.g. at 80 years rotation the standing carbon stock is 575 m^3/ha while the MAI is 7.4 m^3/ha), the initial additional emissions of the bioenergy system can never be paid back because less biomass is produced, and therefore the substitution credits are absent.

Figure 52: Effect of rotation time on mean carbon stock in a forest



Note: A qualitative example of total carbon stock for an entire forest at different steady states for harvesting rotation cycles of different lengths (blue curve). The red curve is the annual volume of timber felled to keep the forest in a steady state; therefore it is also the MAI of the entire forest.

Forest bioenergy is more carbon intensive than fossil fuels

If wood is processed to produce biofuels and then combusted, its carbon content is released in a pulse as CO_2. The quantity of CO_2 released per unit of delivered energy is, in most cases, higher than the one associated to the combustion of the fossil fuel replaced. This is because biomass normally has a higher carbon intensity in comparison with fossil fuels, which means that more CO_2 is emitted per MJ of energy produced at the point of combustion.[132] Moreover, higher energy losses and emissions are usually incurred in collecting, transporting, processing, storing and distributing the biomass fuel compared to traditional fossil fuels. The reasons for these higher emissions are to be found in the lower density of biomass sources. Biomass has to be collected from vast areas with complex processes to avoid undesired environmental impact, resulting in high energetic costs. Fossil fuels are, in comparison, ‘punctual sources’. Furthermore, while fossil fuels have a very high energy density and are virtually dry and ‘easy’ to process, the energy content of biomass is lower, being partially oxidised. Biomass has relatively high water content and is more difficult to process, or at least the technologies are not yet as mature as in the fossil industry. A further cause for the higher emissions of carbon from bioenergy is the fact that not all the biomass can be harvested; leaves, fine roots and small branches are left on the

[132] The carbon intensity of wood is 102 gCO_2/MJ energy, while hard coal has 96 gCO_2/MJ energy and natural gas 56.4 gCO_2/MJ energy (WTT v4, 2013).

ground to rot. Finally, the lost sequestration of carbon has to be considered. When the forest is cut and replanted, the seedlings have a much smaller capacity for fixing atmospheric CO_2 than the forest they have replaced (see also the blue curve in Figure 52).

Biorefinery plants usually have a lower conversion efficiency than fossil fuels refineries. About half of the energy content of the biomass is lost during the intensive processing needed for the production of lignocellulosic ethanol to substitute fossil fuels (WTT v4, 2013).

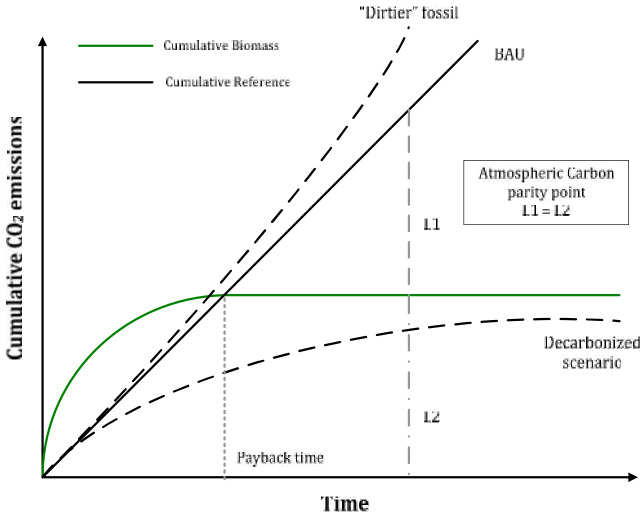
Considered together, the above-mentioned phenomena generate emissions of biogenic CO_2 from forest bioenergy systems that are greater than those from a reference fossil system.

Being renewable, and therefore continuously replacing fossil fuels, biofuels from forest biomass may provide GHG savings in time

However, a growing forest will eventually reabsorb the CO_2 emitted (if the forest productivity increases) and, if the harvested wood is used to replace fossil fuels, in the long term the new bioenergy system will generate less GHG emissions than the current fossil system.

Figure 53 illustrates the general phenomenon qualitatively. The green line represents the difference in carbon stocked in a forest between a ‘business as usual’ extraction rate and an increased extraction rate prompted by biofuels demand. The black lines represent GHG emissions generated through the use of fossil fuels. The first point where the two lines intercept is called ‘payback time’ and represents the point in time when emissions from the fossil system and the biofuels system are equal. The distance between the green and the black line represents the additional emissions over the fossil fuel (the carbon debt) at various time steps. Only after the payback time is reached will the biofuels system start to accrue GHG emissions savings relative to the fossil system. Therefore, the biofuels feedstock cannot be considered to be carbon-neutral until the additional emissions are saved by substitution; and this happens only at the point indicated as ‘atmospheric carbon parity point’. Figure 53 also represents various alternative possibilities for the reference fossil system.

Figure 53: Visual description of payback time and atmospheric carbon parity point with different reference scenarios



Note: Green line: drop in the forest carbon stock due to bioenergy/biofuels production; black lines: accumulated reduction in carbon emissions from substitution of fossil fuels (business as usual case, dirtier fossil fuel and decarbonised scenario).

5.2.2 JRC-IET literature analysis of carbon accounting of forest bioenergy

The efficiency in providing GHG savings with time depends on the type of forest and type of feedstock used

The JRC-IET recently carried out a literature review on the issue of forest carbon accounting (JRC-IET, 2013a). The outcomes of this review are summarised in Table 36.

Table 36: Qualitative evaluation of papers reviewed

Biomass source	CO_2 emissions reduction efficiency					
	Short term (10 years)		Medium term (50 years)		Long term (centuries)	
	coal	natural gas	coal	natural gas	coal	natural gas
Temperate stemwood energy dedicated harvest	---	---	+/-	-	++	+
Boreal stemwood energy dedicated harvest	---	---	-	- -	+	+
Harvest residues*	+/-	+/-	+	+	++	++
Thinning wood*	+/-	+/-	+	+	++	++
Landscape care wood*	+/-	+/-	+	+	++	++
Salvage logging wood*	+/-	+/-	+	+	++	++
New plantation on marginal agricultural land (if not causing ILUC)	+++	+++	+++	+++	+++	+++
Forest substitution with fast growth plantation	-	-	++	+	+++	+++
Indirect wood (industrial residues, waste wood etc.)	+++	+++	+++	+++	+++	+++

Source: JRC-IET, 2013a.

+/-: the GHG emissions of bioenergy and fossil are comparable; which one is lower depends on specific pathways.

-; --; ---: the bioenergy system emits more CO_2eq than the reference fossil system.

+; ++; +++-: the bioenergy system emits less CO_2eq than the reference fossil system.

*For residues, thinning and salvage logging it depends on alternative use (roadside combustion) and decay rate

The results correlate strongly with the following parameters: the fossil fuel replaced; the efficiency of the biomass utilisation; the future growth rate of the forest; the management regime for biomass harvest; and the initial landscape carbon stock.

The effects of the main factors on the payback time of stemwood bioenergy are summarised in Table 37.

Table 37: Impact of various factors on payback times of stemwood bioenergy

Factor	Payback time
Higher carbon intensity of substituted fossil fuel	Shorter
Higher growth rate of the forest	Shorter
Higher biomass conversion efficiency	Shorter
Higher initial carbon stock	Longer
Higher harvest level	Longer

The dedicated harvest of stemwood or whole trees for biofuels purposes only causes an increase of GHG emissions in the short to medium term

The reviewed studies indicate that the use of stemwood from dedicated harvest for biofuels would cause an actual increase in GHG emissions compared to those from fossil fuels in the short and medium term (decades). It may start to generate GHG savings only in the long term (several decades to centuries), provided that the initial assumptions remain valid. The harvest of stemwood for bioenergy purposes is not common today. However, it is becoming a more common practice and is expected to further expand in the future.

Residual wood (harvest residues, salvage logging, thinnings, landscape care wood) may provide GHG savings in the medium to long term

The issue of higher initial CO_2 emissions does not only apply to the clear-cut of forests, but also to thinning practices and logging residues removal. Increased harvest by more frequent or increased thinning causes a reduction of the carbon stock of the forest, but could be mitigated by the faster growing of the remaining stems. Harvest of residues causes a temporary reduction in the respective forest carbon pool.

However, the increase of emissions of the forest bioenergy systems are limited (in size and/or duration) with forest residues, thinnings[133] and salvage logging[134] (if not used for other purposes). If wood is already dead, it decomposes slowly by releasing its carbon content as emission. For these feedstocks, GHG savings are achievable in the short term. The only exception is the case of stumps in boreal climates, because of the very long time required for natural decay. GHG savings could be achieved immediately if, in the counterfactual scenario, the wood were to be burned at roadside, as it happens in Canada. These feedstocks are expected to provide most of the additional increment of biomass for bioenergy by 2020.

The amount of secondary and tertiary wood use for bioenergy is not expected to increase

Waste wood and industrial wood residues, currently the most common feedstocks for pellets production, may provide GHG savings already in the short term. However, there is very little room for increased use of these feedstocks, as practically all are already used. This is confirmed also in the NREAPs, where the planned increase in bioenergy by 2020 is basically only from biomass sourced direct from the forest.

[133] During thinning operations trees are removed in order to reduce stand density and to enhance diameter growth and the volume of the residual stand.

[134] Forest salvage includes the removal of trees that are damaged, dying or dead (as a result of injurious agents such as wind, ice storms, invasive epidemic forest pathogens, insects and diseases) and the removal of wood to reduce fire hazards.

If degraded or marginal agricultural or grazing land is changed into forest (without causing any ILUC), GHG savings can be obtained in the short term, as the land carbon stock increases and the biomass is then used for biofuels.

Fast-growing plantations may provide GHG savings in the short term if on marginal or degraded land. However, they may also increase pressure on forests or cause ILUC

If an existing forest is replaced with a fast-growing plantation of trees (short-rotation forestry – SRF), then the land carbon stock decreases, and there are no emissions savings in the short term. As SRF is expected to expand in developing countries as well as elsewhere, this may directly trigger additional pressure on forests or cause ILUC.

Payback times are longer in the case of intensive processing, such as lignocellulosic ethanol from forest biomass

As far as the reference scenarios are concerned, the fossil fuel replaced plays an important role (as illustrated in Figure 53). The more carbon intensive the fossil fuel replaced is, the shorter the payback time and the carbon parity point. Conversely, the less efficient the bioenergy system is, the longer the payback time. If wood is used in intensive processing, such as for substitution of petrol via lignocellulosic ethanol, the payback times are longer because of the loss of energy in the biofuels production (WTT v4, 2013).

Payback times are calculated by keeping the reference fossil fuel constant, even though it will change with time

The timeframe of the comparison also plays a relevant role in the performance of the reference fossil system chosen for comparison. If the timeframe of the analysis is short, the current emissions from the reference system can be considered appropriate and constant. However, in the case of a long-term analysis, the anticipated changes in the fossil reference system also have to be accounted for. For instance, in practically all of the studies analysed, the fossil reference system (e.g. coal or natural gas) is kept constant and unchanged for the whole of the analysis (even over centuries). However, the energy system will change in the future. It may change in one of two directions: either towards decarbonisation – implying that future savings might be much smaller than current ones, and payback times might extend to infinite – or towards more GHG-intensive fossil energy sources, implying higher GHG savings. This should be reflected in the models in an adequate way.

The appropriate tool to assess the impact of biofuel policies is consequential LCA

However, an attributional approach, such as the calculation of the payback time, is not the correct tool to analyse the impact of a forest bioenergy policy. The policy definitely causes changes in the background system via market-mediated impact, so a consequential approach should be adopted. The consequential analysis should address the effects generated by the bioenergy policy on all of the economic sectors affected, and assess the relative increase/decrease in GHG emissions.

Comparative attributional LCA (the comparison between pathways) does not internalise the market-mediated effects on other sectors of the economy and the consequent GHG impact

The following possible impact of forest bioenergy incentives can be identified:

- Displacement of wood from product industries, or indirect wood-use change (IWUC), e.g. wood used in furniture and buildings or, more likely, in the pulp, paper and panel board industries. This can lead to the use of more carbon-intensive materials, such as concrete and steel.
- Displacement of wood from other energy sectors, or indirect fuel-use change (IFUC), which then may have to replace the raw materials with more GHG-intensive energy sources.
- Competition for land, i.e. indirect land-use change (ILUC).
- Management intensification (increased and improved management, fertilisation, suppression of natural disturbances, etc.). This may cause an increase in productivity, which may shorten payback times.
- Rebound effect: normally the comparison with the fossil system is performed with a substitution factor of 1 (1 MJ bioenergy replaces 1 MJ of fossil energy). However, the introduction of an additional source of energy in the energy market may cause a rebound effect due to the energy price reduction[135], triggering an increase in consumption and reducing the substitution factor (1 unit of bioenergy replaces less than 1 unit of energy from fossil fuels).

Forest bioenergy also has an impact on the climate through short-lived GHG changes and surface albedo

The uncertainty associated with the carbon accounting in the results reported is limited. However, if other climate forcers (e.g. short-lived GHG and surface albedo[136]) are included in the analysis, such uncertainty would increase dramatically, and the impact would become strongly dependent on local conditions. Currently, the large variability in the estimation of these climate forcers still hinders a systematic inclusion of these effects in scientific and policy evaluations.

Impact of natural disturbances on GHG performances of forest bioenergy pathways are difficult to estimate and are uncertain

The results for natural disturbances (e.g. wild fires, pests outbreaks and windthrow) are very scattered, and it is difficult to reach meaningful conclusions about their effects. They are unpredictable events, so it is a complicated matter to factor them into calculations of forest GHG savings and to distinguish the relative impact on the biofuel and reference scenarios.

In conclusion, when assessing the potential for climate change mitigation of forest lignocellulosic biofuels from forest biomass, it is not valid to assume biogenic carbon neutrality within policy-relevant time horizons if carbon stock changes in the forest are not accounted for. This is true in particular for the case of dedicated harvest of stemwood for bioenergy.

135 According to economic laws of supply and demand, a surplus occurs if demand remains unchanged and supply increases, leading to a lower equilibrium price.

136 Definitions may be found in the glossary.

Lignocellulosic biofuels from forest biomass can actually contribute to the reduction of GHG emissions in such a timeframe. However, a differentiation must be made among the different forest feedstocks to avoid a temporary increase in GHG emissions, and competition with other uses of forest biomass.

5.3 Bioenergy-induced environmental impact using residues and wastes

5.3.1 Background

Biomass wastes and residues have an essential role to play in reaching the Europe 2020 targets. They are widely available (see section 2.7), are generally cheaper than energy crops and are regarded as free of environmental burden (such as ILUC)[137].

In the current RED methodology, biofuels from residues and wastes are strongly promoted

In the current versions of the RED and FQD, biofuels produced from residues and wastes are promoted by counting double toward the targets and by assigning zero GHG emissions from upstream operations.

However, the actual environmental impact caused by an additional demand for residues for bioenergy depends largely on the origin and type of the feedstock, and in many cases this impact may be significant. A detailed analysis of the most commonly used residues for bioenergy is therefore necessary in order to promote only the best practices and to minimise negative effects.

In the RED methodology, the alternative uses of biomass residues are excluded from the analysis

As noted above, for a complete picture of the sustainability of bioenergy it is necessary to expand the system boundaries and to analyse the alternative uses for biomass residues. It is also necessary to consider the alternatives (materials or techniques) that would be employed if that material were removed for bioenergy.

The figure below illustrates this concept by depicting what is included within the boundaries of the simplified RED LCA methodology (figures a and b) and what is instead left out (figure c).

[137] Although recent studies, as mentioned in 2.4, show that the ILUC impact of agricultural residues like wheat straw is small, but not negligible.

Figure 54: Illustration of the system boundaries for the example of straw ethanol

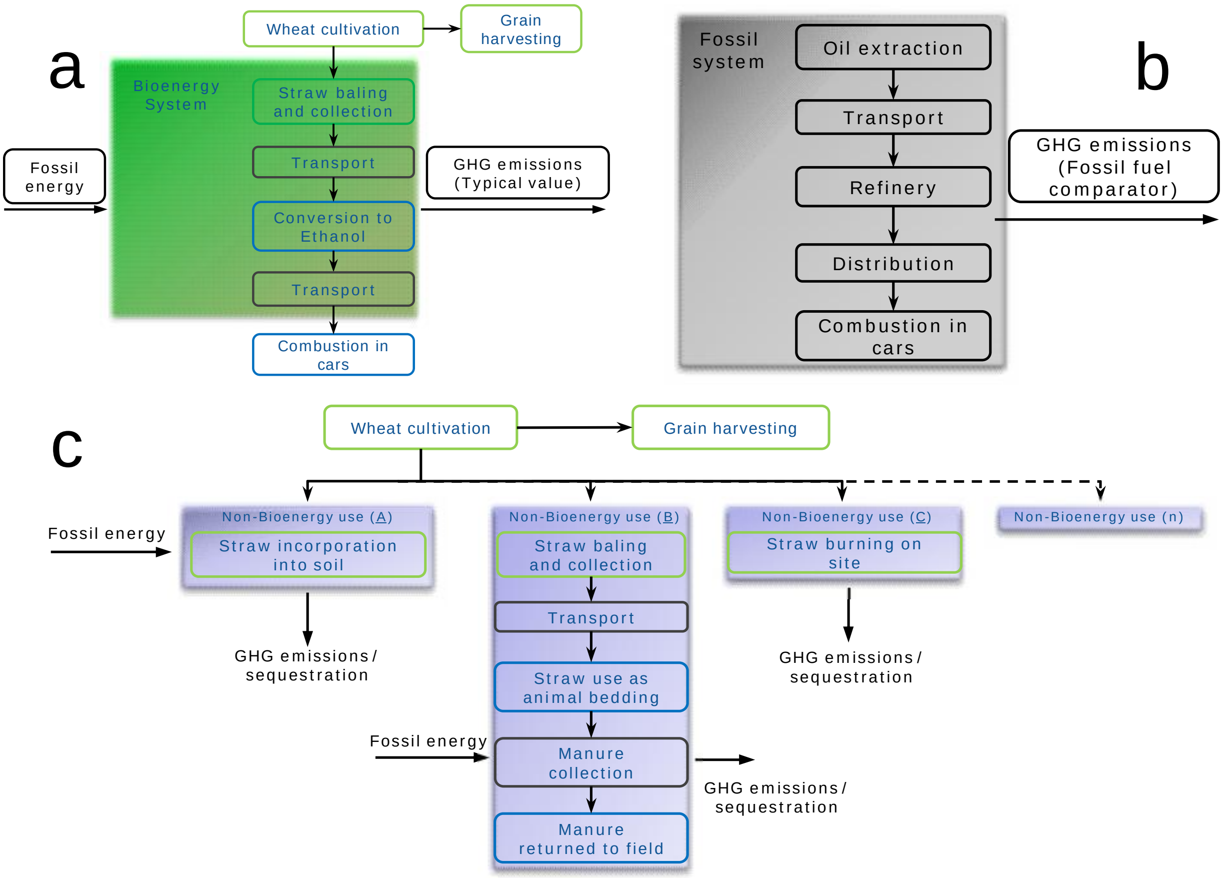


Figure a represents the processes included in the calculation of the typical values in Annex V to the RED. Figure b represents the processes included in the calculation of the fossil fuel comparator. Figure c represents three alternative systems for non-bioenergy use of straw: straw incorporation into soil, straw use as bedding material and straw combustion on site. Removal/displacement effects caused by bioenergy use of the straw are currently not included in the RED and FQD methodology.

When studying the alternative uses of biomass residues three main elements need to be defined: a baseline use, the removal effects and the displacement effects

A full consequential analysis requires the nesting of a mix of complex models, thereby adding many levels of complexity. It involves assumptions on 'what-if?' scenarios and the modelling of market dynamics (to determine whether, and in which amounts, the non-bioenergy use A or B will take place, for example). These factors can add a high level of uncertainty to the results owing to the uncertainty of data, modelling techniques and assumptions. However, compared to other cases in which a consequential analysis of bioenergy impact is required (see for example ILUC and carbon accounting of forest bioenergy), the non-bioenergy uses linked to biomass residues/wastes (e.g. animal bedding) do not have the same global dimension as the food market, and the impact of their removal is generally of a lower magnitude compared to LUC carbon emissions and, finally, the indirect effects on other systems can, in first approximation, be considered to be limited or negligible.

In view of these considerations, it is possible, as a first step towards a more complex, global and dynamic analysis, to provide a static picture of various scenarios. In this work we have divided the analysis into the elements described below, which can then be analysed independently in order to individuate and underline possible environmentally critical points that may otherwise go unnoticed.

The three elements that constitute the analysis are:

1. non-bioenergy uses of biomass wastes and residues considered for bioenergy (baseline use);
2. effects of an increased removal from the original environment (removal effects);
3. effects of subtraction from other industries (displacement effects).

Removal effects are associated with the increased removal (compared to the baseline) of biomass residues from their original environment

Removal effects are associated with a change in management (compared to the baseline considered) caused by bioenergy policies/incentives. For example, a farmer who cultivates wheat may not have a market available to sell the straw produced, and therefore re-incorporates it into the field to maintain soil qualities. By promoting the use of straw for bioenergy, a market opportunity could open up for the farmer to sell the straw, which would then be removed from its original (baseline) use. As described in the following sections, this could have positive and negative effects on the soil and on the environment at large, which should be carefully assessed and quantified in order to create a full picture of sustainability of the bioenergy alternative.

Displacement effects are associated with the diversion of residues from other industries to bioenergy

Displacement effects are caused when an increase in demand from the bioenergy industry causes supply to be diverted from other industries. As a result, these will need either to source the feedstock from a different location or to employ different materials. Recalling the example above of straw, a farmer who cultivates wheat in an area rich in livestock might sell part of the straw to the livestock industry to be used as bedding material for the stables (baseline use). An increased demand in straw for bioenergy could make it more convenient for the farmer to sell the straw to power plants or biofuels producers, leaving the livestock industry in need to substitute the missing supply. For the specific case of straw, there are various alternatives with little or no environmental impact, such as other materials (e.g. sawdust, geotextile etc.) or changes in the management (e.g. no bedding). However, for other industries the alternative materials could cause significant additional GHG emissions.

Due to the complexity of the phenomena, the site-specific nature of many effects and the multitude of scenarios, a qualitative analysis is provided in this chapter for many of the impacts analysed.

The analysis is limited to few of the most relevant residues for the EU situation (see section 2.7): straw, pruning residues, manures and forest-logging residues.

5.3.2 Cereal straw

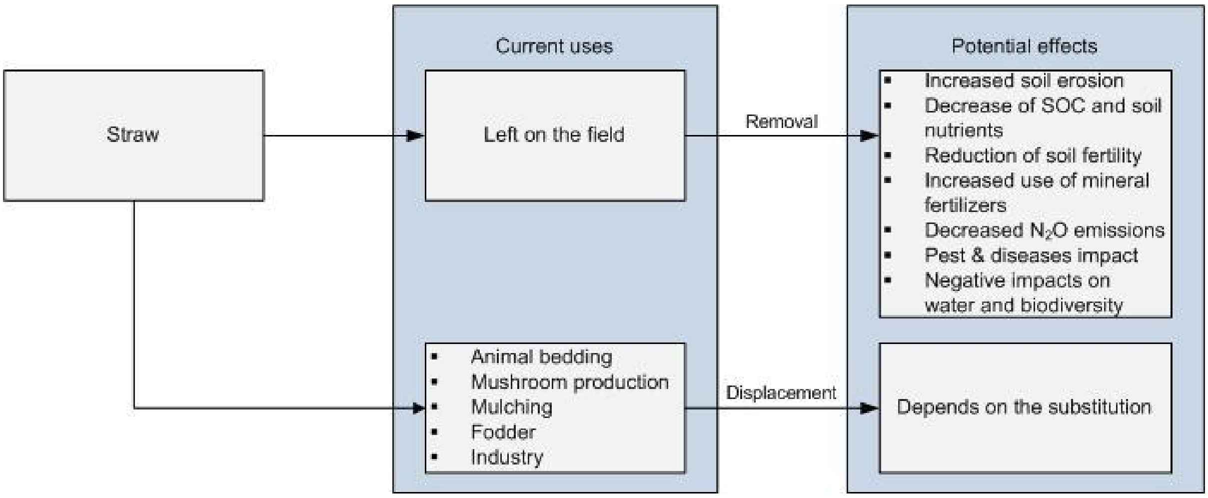
<u>Baseline uses</u>

Currently, straw is predominately used as a soil improver and animal bedding

Straw is an agricultural by-product, the dry stalks of cereal plants, after the grain and chaff have been removed. In the EU, cereal straw is currently used for:

- Soil improvement – straws are first chopped then either left on fields or incorporated into the soil after ploughing with the aim of reducing soil erosion, and of maintaining/improving the organic carbon, nutrients content and physical properties of soil.
- Animal bedding – a major part of the straw collected from agricultural fields is used for this purpose. Part of the straw used will become a constituent of farmyard manure or compost and will be returned to soil (although probably not to the same location from where it was removed).
- Mushroom production, mulching – as a growth substrate and for frost protection.
- Livestock fodder – as supplementary feed.
- Industry – as insulating material, fibreboards, pulp and paper, etc. (Kretschmer et al., 2012) (Figure 55).

Figure 55: Baseline uses of cereal straw and potential effects of its removal for bioenergy



25-30 % of straw in the EU could be available for bioenergy production, but the environmental impact of full and partial removal should be carefully assessed

Information on the availability of straw in the EU is limited, especially on the regional scale. On average, 25-30% of the straw produced could be available for energy production after competing uses are taken into account. However, the share varies significantly owing to site-specific conditions and different practices applied (Kretschmer et al., 2012). It is also worth remembering that straws constitute around 50 % of all the available above-ground residues (AGR) produced in the cultivation of cereals. The remaining part of the AGR is generally left on the field in any case, mitigating in part the removal of the straw.

Removal effects[138,139]

Straw utilisation for bioenergy generates GHG savings even when accounting for all associated phenomena

From the studies analysed it appears that the final GHG balance of straw bioenergy is affected negatively by the decrease in soil organic carbon (SOC)[140] through straw removal and the addition of synthetic fertilisers to compensate for the removal of nutrients. On the other hand, straw removal appears to decrease N_2O emissions from the soil significantly. When fossil fuel substitution is included, it is clear that straw bioenergy can still guarantee GHG savings, even if the actual amount should be calculated on a case-by-case basis.

Straw removal has various potential environmental effects, the most significant being a decrease in SOC, soil nutrients and soil fertility, leading to ILUC emissions for straw bioenergy as well

The removal of straw from agricultural fields may have a negative impact on physical and chemical soil properties that could eventually affect crop productivity. Additional research is needed to quantify these effects properly in the long term, since a decrease in cereal productivity may lead to ILUC emissions associated with straw-bioenergy. Furthermore, in some European regions, especially southern Europe, the SOC content is already low and is decreasing even when agricultural residues are incorporated on a regular basis. As a result, residues removal in such areas would not only mean a lower SOC content but also a faster decrease towards levels of SOC where cultivation is not possible anymore (land degradation). In addition, the impact of climate change is forecasted to speed up the degradation process. Lastly, it should be considered that eventual losses in productivity in low-SOC soils would cause even less residues to be produced and incorporated in the soil, with a subsequent vicious circle that could lead to an irreversible loss of productive land.

The levels of the impact will depend on site-specific characteristics, and mitigation option should be considered (retention levels, management changes and the application of bioenergy by-products)

Site-specific levels of residue retention should therefore be determined, and residue removal should be accompanied by management practices (e.g. covering crops, diverse crop rotations and manure application) that minimise the potentially adverse impact. The application of bioenergy conversion by-products (e.g. ashes or biochars) should also be considered, and should be evaluated carefully as a potential mitigation measure.

Displacement effects

Various bedding materials could displace straw for animal bedding, but in mushroom production there is currently no viable alternative to straw

The most common competitive use of straw, besides its use as a soil improver, is as animal bedding. Cereal straw is typically the bedding material chosen for a majority of farms, but there are numerous other bedding materials available that can be used, alone or mixed with straw, to compensate for its eventual displacement towards bioenergy:

[138] Many of the empirical results are obtained in extreme conditions (complete removal of residues from the soil) in order to amplify the differences between management conditions. Partial retention is thus included in the mitigation option.

[139] Detailed description of the sources and phenomena for each of the analysed effects can be found in Appendix 5.

[140] SOC is the amount of elemental carbon contained in soil organic matter (SOM). It is generally agreed that this amounts to about 58 % of SOM.

- woodchips, shavings and sawdust – materials that currently are primarily used for energy production;
- waste shredded paper, paper crumb and lime ash – waste materials;
- high-yielding grasses – additional land for the production is needed; marginal or degraded land could be used;
- geotextile mattresses – utilisation of fossil fuels and feedstock.

In the case of displacement, therefore, the overall environmental impact will depend on the impact of producing and transporting the alternative material substituting the straw.

Mushroom production could potentially be affected most by straw displacement as there is currently no viable alternative to the use of straw as a principal ingredient to produce growth substrate (Spöttle et al., 2013).

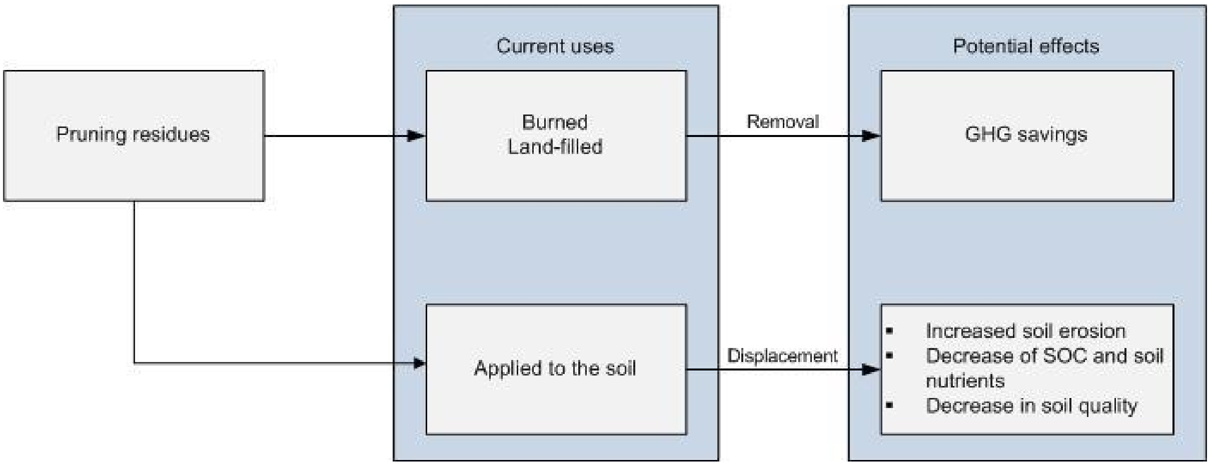
5.3.3 Pruning residues

Baseline uses

In general, pruning residues are being land-filled or burned near fields

Residues generated from the pruning of orchards, olive groves and vineyards consist of small branches and biomass resulting from regular and cleaning operations. Permanent crops are predominately distributed in the Mediterranean and eastern parts of Europe. Pruning residues are usually land-filled or burned near fields. These activities are increasingly controlled by authorities in keeping with safety and environmental constrains. Residues are also used as soil covering around trees to protect the soil and provide nutrients and organic matter as they decompose. Finding a use for pruning residues, either for bioenergy or soil improvement, would eliminate a disposal problem and would potentially bring revenues or reduce management cost (Cavalaglio and Cotana, 2007; Repullo et al., 2012; Faraco and Hadar, 2011) (Figure 56).

Figure 56: Baseline uses of pruning residues and the potential effects of their removal



Removal/displacement effects[141]

Pruning residues could be used for bioenergy production or applied back to the fields, improving current management practices by protecting the soil and providing nutrients

The utilisation of pruning residues for bioenergy production or soil improvement provides an opportunity to improve current management practices. Used for bioenergy, they would replace fossil fuels, guaranteeing GHG savings, while applied to the field, they would improve soil characteristics. The preferred use of pruning residues should be determined at a local level, depending on site-specific characteristics.

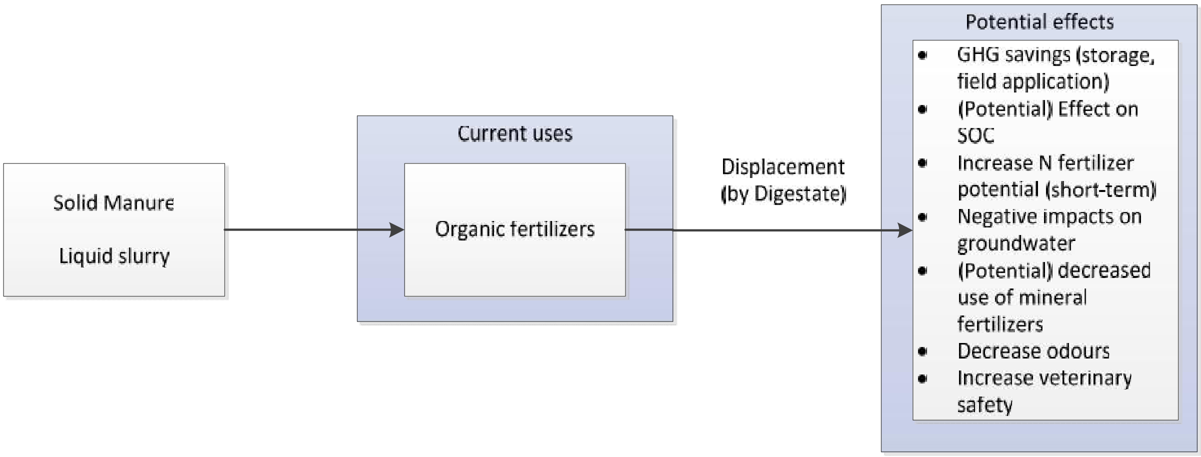
5.3.4 Feedlot manures

Baseline uses

Manure is composed of the faeces and urine of livestock. Most of the large amounts produced in Europe is used as organic fertiliser, while only a small percentage is used for biogas production via anaerobic digestion

Manure is a residue produced in all livestock activities. It is generally composed of faeces and urine from animals, bedding material and food residues. Based on their water content, manures can usually be categorised as farmyard manure (FYM), slurry or deep litter. The estimated livestock manure production in the EU27 amounted to about 1.4 billion tonnes in 2011, of which only about 50.7 million tonnes (3.7 % of total manures, 8.5 % of total slurry production) of liquid slurry were treated by means of anaerobic digestion (Foged et al., 2011).

Figure 57: Baseline uses of manures and potential effects of their removal



The products of anaerobic digestion are biogas and a residue called digestate. This residue is mostly composed of water and the undigested solid part from the original manure feedstock.

Digestate can be used as organic fertiliser to substitute the manure (solid or slurry) used for biogas production (Figure 57). In an ideal scenario, the digestate would work as, or more, efficiently as a fertiliser compared to the original manure. Therefore, the biogas produced would basically be free of any environmental burdens (except those associated

[141] A detailed description of the sources and phenomena for each of the analysed effects can be found in Appendix 5.

with the use of fossil fuels in the construction and operation of the biogas plant and transport of substrate), as it would simply constitute an additional product. Long-term field trials are needed to assess carefully the properties of digestate. Since the interest in this material is still fairly recent, fundamental experimental data are still scarce.

Removal/displacement effects[142]

In order to analyse the actual impact of biogas production, it is important to consider the differences (in terms of fertilising potential and direct emissions) between digestate and FYM, and between digestate and liquid slurry.

Biogas production should be the preferred route when considering GHG emissions reduction

Regarding GHG emissions, it is possible to identify two main drivers, a negative and a positive one. Because of the lower carbon content in the digestate (as a large part of the initial carbon content has been digested and collected as biogas in the anaerobic digester), SOC accumulation on the field could be lower as compared to the use of untreated manure and, consequently, this lost sequestration should be considered as an additional carbon emission attributed to the biogas. Long-term studies, or at least models, to substantiate this are still scarce, and it is therefore difficult to quantify this impact. On the other hand, the management (storage and field application) of untreated manure causes significant emissions of methane and N_2O that are either lower or almost completely avoided when a biogas plant is installed (Battini et al., 2014). These avoided emissions are surely larger than the loss in SOC, making the biogas route always the preferred choice in terms of GHG emissions reduction.

Digestate has higher fertilisation potential than manure in the short term, but the advantage disappears in the longer term

Furthermore, digestate contains a higher share of plant-available nitrogen compared to untreated manure which, depending on the application techniques used, could either lead to increased leaching of nitrates and ammonia volatilisation or to increased savings of synthetic N fertilisers. Currently, available field tests have produced scattered results when analysing the impact of the use digestate on crop productivity. The larger share of plant-available nitrogen in the digestate seems to be responsible for higher yields in the first years after application. However, in the long term the organic nitrogen from untreated manure that was accumulated in the soil will eventually be mineralised, cancelling the differences in fertiliser potential between raw manures and digestate.

Improved agricultural techniques could lead to an optimised use of digestate, but further long-term experimental research is needed

Improved application techniques for digestates are essential in order to use the digestate in an optimal way and to maximise its advantages. This could lead to additional savings of synthetic fertilisers, but further long-term, experimental studies will be fundamental to determine the best practices in the use of digestate.

[142] A detailed description of the sources and phenomena for each of the analysed effects can be found in Appendix 5.

5.3.5 Forest logging residues

Baseline use

Logging residues (such as branches and stumps) constitute a large share of a trees mass and are produced in large quantities during logging operations. They are generally left on the forest floor for economic and environmental reasons

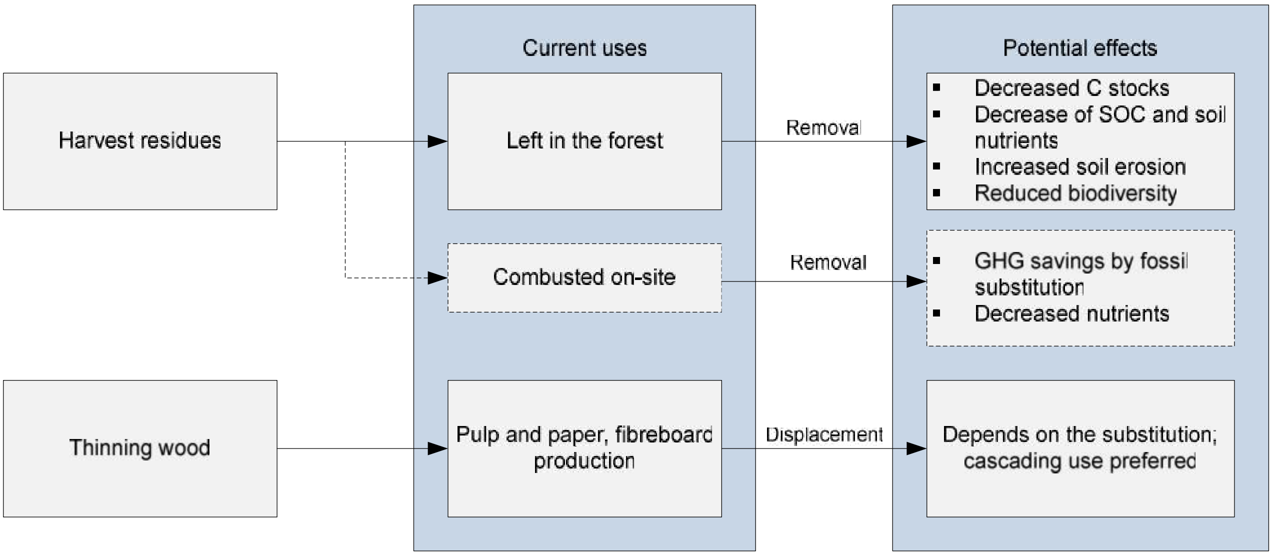
Primary forest residues from forestry operations can be classified as: 'slash' from final fellings (branches, needles, leaves, stumps, roots, low-grade and decayed wood tops); slash and small trees from thinning and clearing operations; and unmerchantable stemwood. They are produced as by-products during the normal course of harvesting stemwood as sawlogs, pulpwood or cordwood. Additional residual wood may be available from salvage logging operations (e.g. trees dying or dead as a result of the spread of pathogens, insects or diseases).

Wood from thinnings may, to some extent, be assimilated to harvest residues (especially pre-commercial thinnings). Alternatively, depending on the wood quality, the use of thinnings wood for bioenergy may compete with other uses, such as pulp and paper and other industrial wood (Figure 58). Additional fellings of stemwood for bioenergy use (including additional thinning operations driven by the bioenergy market) are excluded from this analysis. An in-depth discussion of these feedstocks can be found in Section 5.2.

Figure 51 shows that, depending on the species, a large percentage of the total mass of a tree is actually contained in the crown and stump-roots system, with percentages reaching almost 40 % for Norway Spruce. As shown in section 2.7, a large bioenergy potential from forest residues is estimated to be available in the EU, increasing from 20 Mtoe in 2010 to 41 Mtoe and in 2020.

Forest logging residues are often not economically harvestable, owing to their scattered nature and the consequent high costs for procurement and transport. Furthermore, local guidelines may require that a certain share of residues is left on the forest floor to protect the soil health (Fritsche et al., 2014). Consequently, a large share of these materials is usually left on the forest floor to decay. In some cases, for example in Canada, they may be transported off-site and then left or even combusted at roadside (McKechnie, 2011). There are several advantages to avoiding this practice: the main one being substituting fossil fuels and avoiding the associated GHG emissions. Furthermore, the use of an industrial combustion technology (e.g. industrial boiler or stove) would cause fewer pollutant emissions compared to open-air combustion. One of the few advantages of on-site burning, instead, would be the recirculation of some of the nutrients (mainly phosphorus and partially potassium) to the forest soil.

Figure 58: Baseline uses of logging residues and potential effects of their removal



Removal effects[143]

It is generally considered that environmental risks may increase with the implementation of more intensive forest management (including the removal of forest residues).

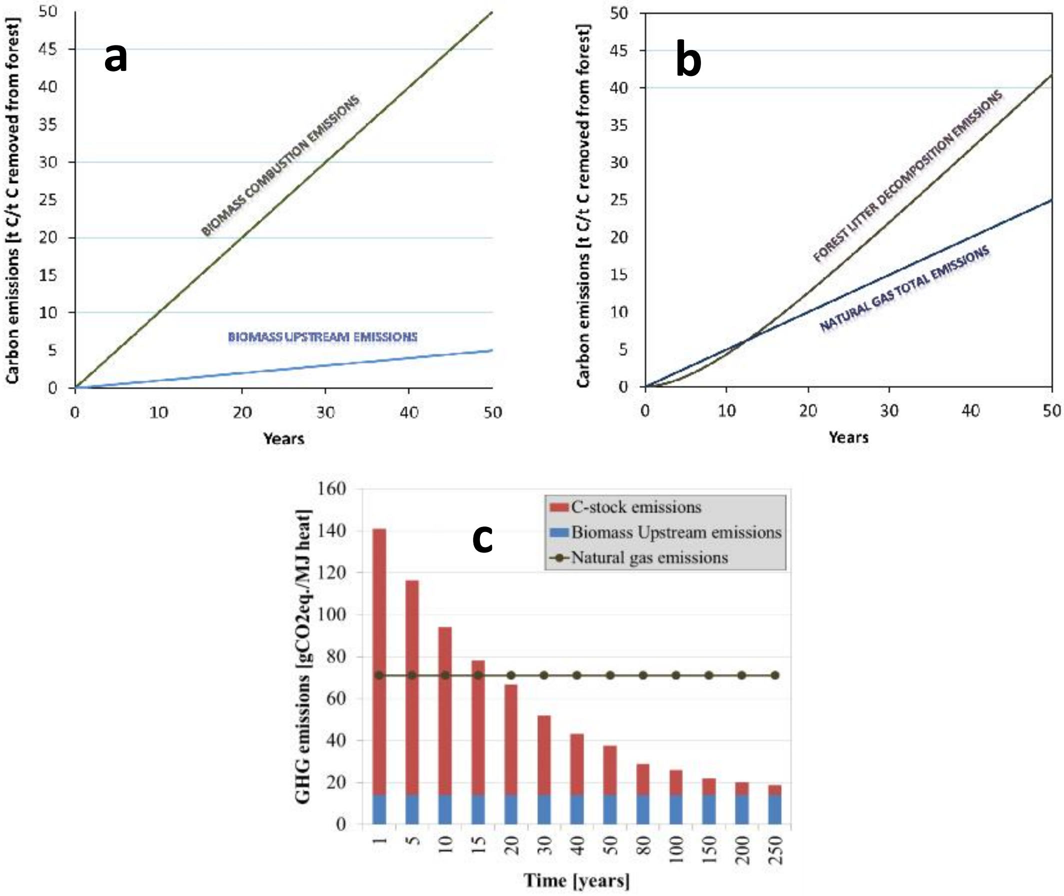
There is still large uncertainty about the long-term effects of increased logging residues removal. These effects are largely site- and feedstock-specific, and should as such be analysed in their environment.

Logging residues achieve GHG savings in the short to medium term (decades)

With regard to GHG emissions, the main issue with logging residues is the time lag between decomposition on the forest floor and combustion for bioenergy. When residues are left on the forest floor, the rate at which they decompose depends on climatic conditions and on the size and type of the wood fragments. However, it is certainly slower than the instantaneous release of emissions that occurs when they are combusted for energy (Figure 59 a and b). The difference in atmospheric carbon associated with the use of bioenergy, when compared to natural decay, causes higher GHG emissions than the fossil system for a period of time that can range from a few years (twigs removed to substitute coal systems) to up to more than 60 years (for stumps removed to substitute natural gas boilers). See Figure 59 c and JRC-IET (2013a) for a comprehensive review.

[143] A detailed description of the sources and phenomena for each of the analysed effects can be found in Appendix 5.

Figure 59: Carbon emissions from the production of heat in a pellet stove for pellets from branches



Data are relative to 1 tonne of carbon (tC) removed from the forest floor. Fossil substitute is considered to be a natural gas domestic boiler. In Figure 1 above: a) = bioenergy system; b) = fossil system with residues left on the forest floor; c) = GHG emissions for 1 MJ of heat produced from wood pellets from branches when the carbon stock change in the forest litter is added to the upstream emissions. Background data are taken from JRC, 2014.

Furthermore, modelling results indicate that significant negative impact on soil health and forest fertility should be expected when residues are completely removed from the forest soil. However, so far these results have not been fully substantiated by field trials. Soil nutrients pools appears to be little affected by the removal of residues, but the effect may be more relevant on low-fertility soils. In addition, physical properties may be affected negatively (increased erosion) but also positively (warmer soil).

Biodiversity is affected, especially the abundance and diversity of bird and invertebrate species. Forest simplification and facilitating invasive species are also possible risks

Increased harvesting of forest residues can have a negative impact on forest biodiversity. This seems to be primarily due to the removal of niche habitats (i.e. dead and downed wood), with a potential cascade effect on the whole ecosystem. Reported data indicate a significant reduction in abundance and diversity of bird species when deadwood is removed from the forest. The main effect was reported for cavity-nesters (e.g. woodpeckers). A possible correlating factor is the decrease in numbers of invertebrates. including insects, in areas where forest residues are extracted. When the residues are harvested and stored in

piles at roadside, they attract insects searching for breeding substance. When the residues are removed and transported to power plants, the larvae and offspring of the insects are trapped and removed from the forest, not only reducing the abundance of insects but also removing an important source of food for birds (Riffell, 2011; Victorsson and Jonsell, 2013). Another important issue is linked to forest simplification and the possible introduction of new invasive species in heavily harvested stands (Fritsche et al., 2014).

Mitigation measures are available to recirculate lost nutrients, but their practical and economic effectiveness is still to be verified

Possible mitigation measures such as reapplying combustion ashes, liming or application of synthetic fertilisers could balance the lost nutrients, but the effects on tree productivity are still uncertain (Demeyer et al., 2001; Aronsson and Ekelund, 2004; Stupak et al., 2007; Saarsalmi et al., 2011).

Local guidelines already exist requiring that a certain proportion of such residues be left on the forest floor in order to protect soil health and biodiversity (Fritsche et al., 2012). These requirements should also be taken into account consistently when promoting removal for bioenergy use.

<u>Displacement effects</u>

Logging residues are rarely used for any product production, so there is no significant risk of displacement effect. Existing thinning wood and stems unsuitable for pulp production could be diverted from particle-board production

Collection of residues such as tops and branches is an expensive operation, and it has only become important recently with the incentives associated with use for bioenergy. Logging residues are not commonly used in traditional wood industries, so any large-scale displacement of current wood markets (e.g. for pulpwood) arising from use of thinning wood for bioenergy is currently unlikely. However, displacement of lower-quality wood products (e.g. particle board) in favour of bioenergy should be monitored.

5.3.6 Qualitative assessment of increased removal of residues for bioenergy purposes

The qualitative assessment presented in the following table indicates the overall performance of different residues in respect to various forms of impact, the aim being to underline critical issues that should not be neglected in the policy process. Risk and benefits were assessed regarding the likelihood, level and reversibility of an impact. The likelihood indicator represents the probability that an impact (risk and benefit) associated with the removal of the material from its non-bioenergy use will occur. Likelihood is assessed with values between 0 and 2, from ‘impact not occurring’ to ‘high probability’. The impact level represents the magnitude and the quality (risk or benefit) of an impact. Impact level is assessed with a value between -2.5 and 2.5, where negative values represent benefits and positive values risks. Reversibility represents the possibility, and the time needed, for natural recovery of the initial status once management is reverted back to its original situation. Reversibility considers that most of the risks and benefits are associated with a change in management; meaning that, as long as the change is maintained, the impact is happening and the recovery time only starts after equilibrium under new management has been reached. Artificial recovery measures are not assessed in the table because they are included as a separate item under mitigation measures. Reversibility is assessed with values between 1 (indicating that natural recovery is possible in the short term) and 2 (indicating either that natural recovery is not possible or that it occurs only in the long term). At the end, scores were multiplied and risk/benefits divided into various categories.

Table 38: Qualitative assessment of various environmental impact caused by the use of biomass residues for energy as compared with their baseline uses

One neutral category(😐), three positive categories (Low ≥-1 (☺); Medium -4<x<-1 (☺☺); High ≤ -6 (☺☺☺)) and three negative categories (Low x≤1 (☹); Medium 1<x<4 (☹☹); High x≤6 (☹☹☹)). The table is colour-coded simply to indicate overall benefit (green), negative impact (red) or marginal effect (orange). Grey cells indicate categories where no significant impact is found. A more comprehensive version of this table can be found in Appendix 5.

	Total GHG emissions compared with fossil fuels	SOM/SOC	Nutrients pool	Soil health and productivity	N_2O, CH_4 emissions	Pests, diseases, odours	Biodiversity	Water	Displacement effects
Straw (Baseline considers straw left on field)	☺☺☺	☹☹☹	☹☹☹	☹☹☹	☺☺	☺☺	☹☹	☹	☹☹
Pruning residues (Baseline is removal from soil)	☺☺☺	☹☹☹	☹☹☹	☹☹☹	☺	☺☺	☹☹	☹☹	☹
Manure (Baseline considers use as organic amendment)	☺☺☺	☹☹☹	☺	☺☺	☺☺☺	☺☺☺	☹☹	☹☹	No alternative use
Forest residues (Baseline considers residues left on forest floor)	Short-term: ☹☹ Long-term: ☺☺☺	☹☹	☹☹	☹☹	😐	☺☺	☹☹☹	😐	No alternative use

5.4 Greenhouse gas emissions of biogas and biomethane pathways

Biogas production via anaerobic digestion has historically been viewed optimistically in terms of GHG emissions savings and overall environmental impact.

Generous incentives for biogas and biomethane have favoured large-scale plants fed with energy crops rather than with agricultural residues

Very advantageous incentives to electricity produced by anaerobic digestion have been provided in some countries (e.g. Germany and Italy) over the last five years.

Only a few installations have been built for the production of biomethane for transport, which is subject to the RED sustainability criteria. The great majority of facilities have been dedicated to the on-site production of power and heat, which is not subject to any mandatory European sustainability criteria (Commission staff working document SWD(2014)0259), e.g. in Germany the ratio of biomethane plants to those burning raw biogas for electricity production was 1:80 in 2012.

Anaerobic digestion is a relatively straightforward technology. As such, it can play an important role in rural development by creating a sustainable market for waste and reducing emissions from agriculture. Therefore, the attention it receives is justified.

The advantages of digesting agri residues, manures, food waste and sludges are many and significant (Boulamanti et al., 2013a; IEA, 2013, Battini et al., 2014). However, the large, unconditional incentives offered have driven the market towards large production facilities which cannot be fed solely with residues. As a result, large shares of energy crops (maize in particular) have been diverted to biogas production. For instance, in 2012 energy crops used for biogas production occupied more than 8 % of all agricultural land in Germany (Table 39).

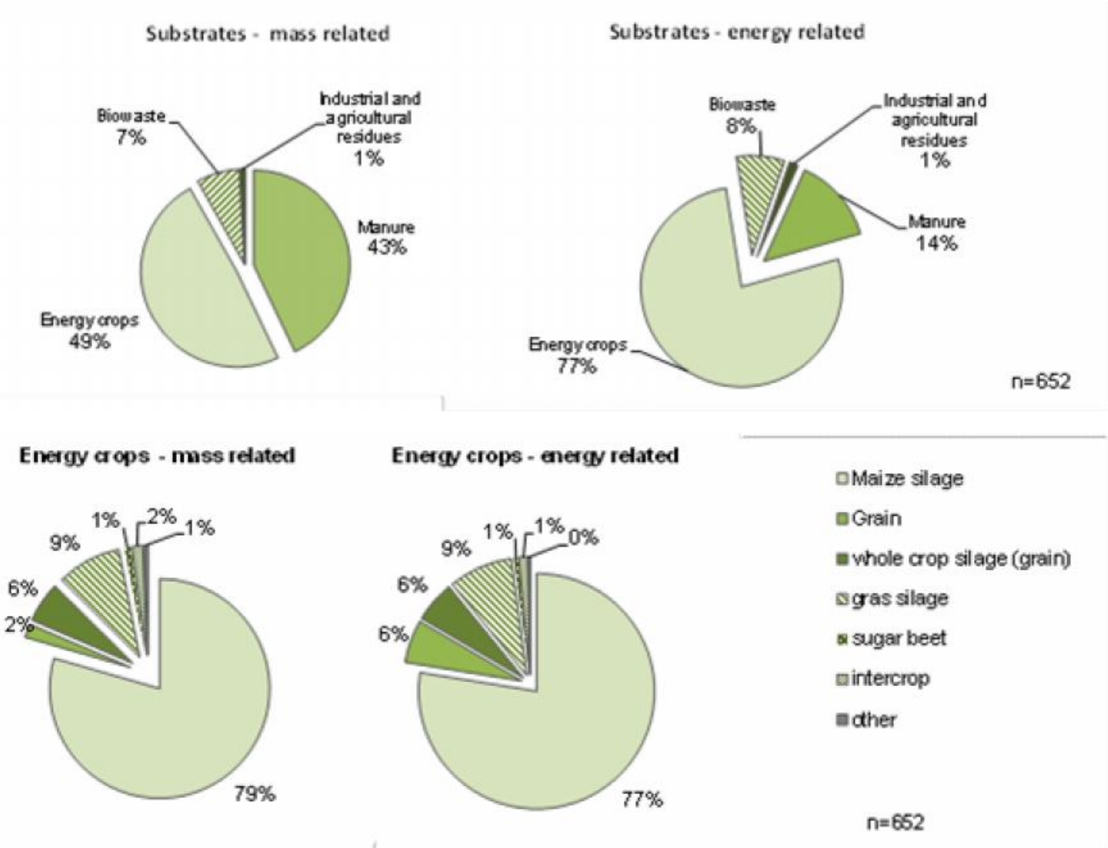
Table 39: Share of agricultural land in Germany cultivated with energy crops used for biogas (both for power and for biomethane production)

Energy crops	2011		2012	
	ha	%*	ha	%*
Rapeseed oil for biodiesel	910 000	7.71	913 000	7.73
Crops for bioethanol	240 000	2.03	243 000	2.06
Crops for biogas	900 000	7.63	962 000	8.15
Solid biomass for combustion	6 000	0.05	6 500	0.06
Total	2 056 000	17.42	2 124 500	18.00

* Based on total crop land: 11 800 000 ha, source: FNR (Agency for Renewable Resources), 2012.

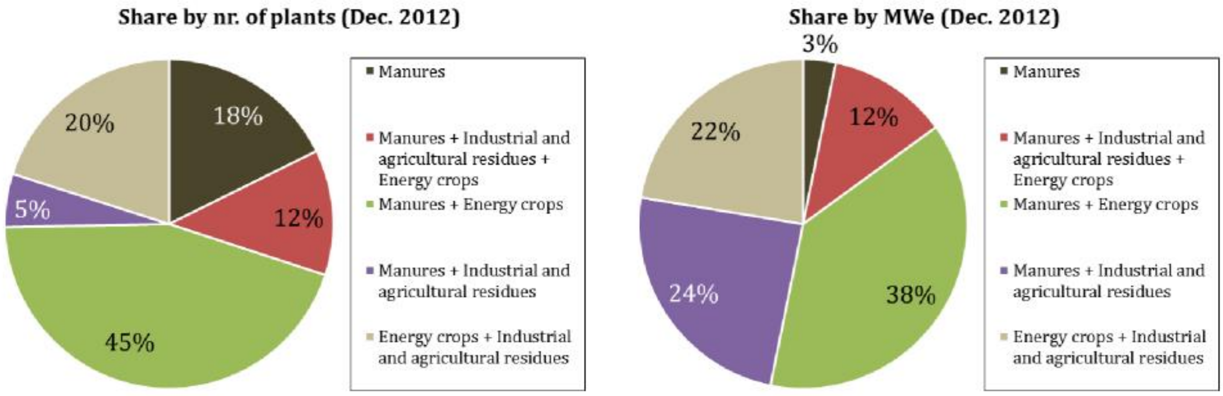
This move towards production based on energy crops (as shown in Figure 60 for Germany and Italy) has been driven by the high methane potential from starch crops (at least double the potential of manure (IEA, 2013)), economies of scale and the advantageous logistics of maize.

Figure 60: Substrates used in biogas production in Germany in 2011



Source: DBFZ Biomethane survey, 2011.

Figure 60b: Share of substrates mix for electricity production by anaerobic digestion in Italy at December 2012



Source: Crpa survey, 2013.

Since 2012, Germany and Italy (the two major agricultural biogas producers in the EU) have been adjusting both the level and the structure of incentives for biogas in order to favour smaller production facilities, the use of agriresidues and best practices, e.g. gas-tight storage of digestate (DM 6 July 2012; EEG, 2011).

Sources of GHG emissions in biogas and biomethane production are still ignored in many analyses; they are difficult to quantify due to lack of empirical measurements

However, there are still open issues concerning the full assessment of GHG emissions from biogas production. This is due in part to the lack of reliable empirical data, but also to the well-rooted conviction that biogas production is an intrinsically sustainable practice.

The following issues have not been properly accounted for in biogas LCAs:

Methane and N_2O emissions from storage of the digestate are significant in the case of open-tank storage and can significantly reduce GHG savings of biomethane produced from energy crops. Use of gas-tight tanks should be strongly promoted

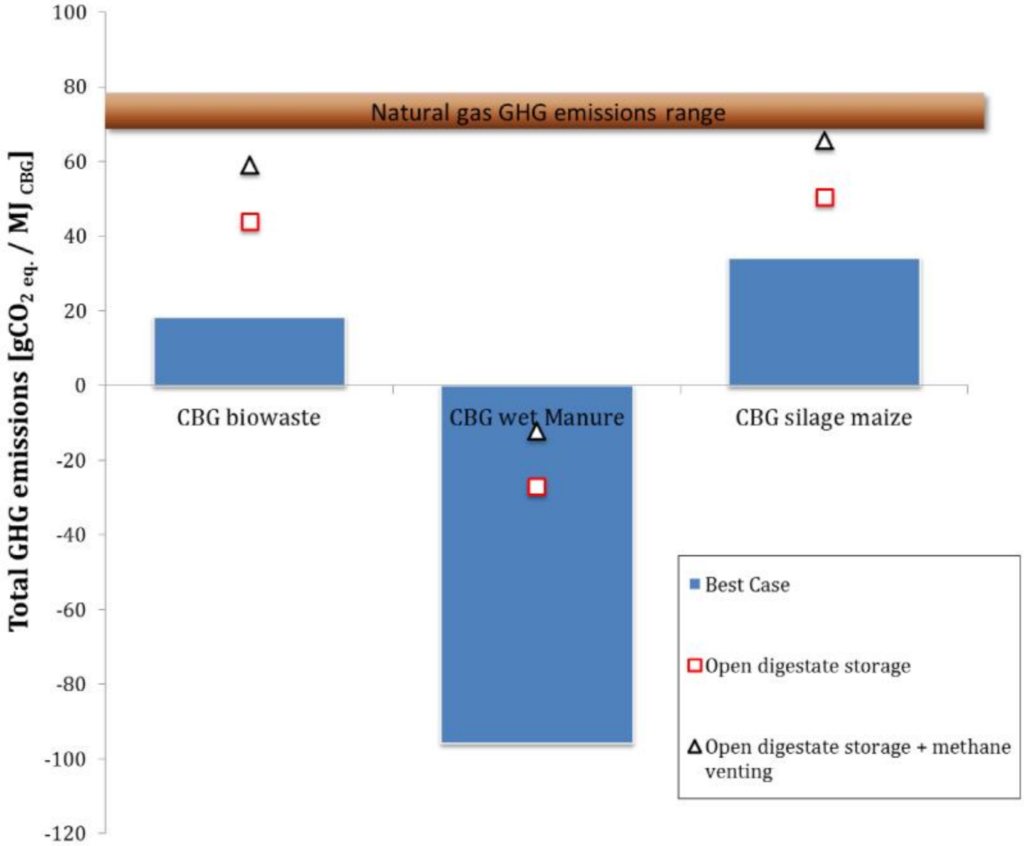
1. The residual digestate from anaerobic digestion should be stored in large tanks until it is needed for field application as soil amendment and organic fertiliser. During this time, the digestate continues to release methane and N_2O: two powerful GHGs.

   Although such emissions would also have happened (and in larger quantities) with the storage of untreated manure/slurry (see Section 5.3.4), it is also important to remember that this would not have been the case for energy crops. Anaerobic digestion of an energy crop and subsequent storage of the digestate in an open tank will generate significant GHG emissions that would not have taken place otherwise.

   The uncertainty over the degree of such emissions is quite large, so further research on the topic is needed (Amon et al., 2006a and 2006b; IPCC, 2006; JRC, 2014).

   If one considers feedlot manures as substrates, the savings due to the lower emissions from digestate storage, as compared to manure storage, are significant. Even the pathways with open storage of digestate from manure achieve savings higher than 100 % compared to fossil electricity and fossil transport fuels (see Figure 61).

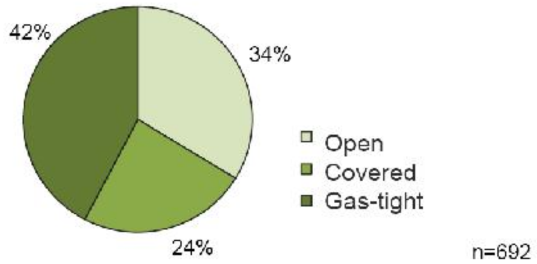
Figure 61: GHG emissions from compressed biomethane (CGB) pathways employing three feedstocks: biowaste, manure and silage maize



The bars represent the emissions obtained in the best configuration (gas-tight storage of digestate and complete flaring of methane stream from the upgrading plant). The square symbols add the emissions due to open-tank storage of the digestate. The triangles represent an even worse case, with open-tank storage and venting without oxidation of the methane from upgrading. Source: JRC, 2014 and WTT v4.0, 2013.

It is possible to argue that these savings are rather due to bad agricultural practices than to the biogas itself: if all farmers were to store their slurry in gas-tight tanks (and flare the collected methane), these ‘credits’ would not be assigned to biogas. However, since this is not the case, it seems appropriate that the merits of the avoided emissions are allocated to biogas production.

Figure 62: Share of digestate management in Germany



Source: DBFZ Biomethane survey, 2011.

In the case of gas-tight storage of the digestate, the savings for compressed biogas from manures would reach values higher than 200 % while the compressed biogas from maize would achieve around 50 % GHG savings. This practice was not incentivised under the first wave of subsidies in Italy and Germany, but it is now

part of the new set of criteria for obtaining a higher subsidy. A recent survey of biogas production facilities in Germany found that less than half had installed a gas-tight tank (Figure 62).

Values of methane emissions for digestate storage from manure-fed plants can account for about 10 % of the methane produced; the range of this value is approximately 1 % to 5 % for maize plants. The emissions avoided from storage of liquid slurry correspond to some 15 to 20 % of the produced methane (depending on the average temperature) and are lower for the storage of solid manure (WTT v4, 2013, JRC, 2014).

To place these values in context, the GHG savings of biomethane produced from maize versus fossil natural gas would be reduced by almost 50 % if the storage of digestate were carried out in open tanks.

Fugitive and flaring emissions can be significant, but can be largely avoided with proper management

2. Biogas production facilities deal with large quantities of methane, which is a GHG 25 times more powerful than CO_2. This means that even small leakages would have a large impact on the overall carbon footprint of the facility. Unfortunately, the accidental nature of fugitive and flaring emissions makes it a very complex matter to obtain reliable general data.

   Fugitive emissions have mostly been measured at pipeline connections and during non-regular functioning of the plant when an overpressure in the digester causes the gases to be vented to the atmosphere. In some plants a flare is installed to make sure that the methane and other organic compounds are oxidised to CO_2 before being released into the atmosphere. However, this mostly happens in newer and larger facilities, while in many other cases the methane is simply released.

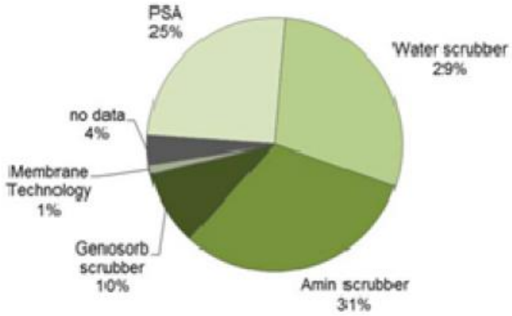
   A few studies of overall methane emissions from biogas facilities report values of some 1 % to 3 % of the methane produced being lost as fugitive emissions in normal conditions, and even up to 20 % in the case of over-pressure and venting (IEA, 2013).

CH_4 emissions from upgrading plants are significant, but can be avoided by flaring the off-gases

3. The biogas in output from the digester is a mix of methane, CO_2 and other trace gases. The CO_2 needs to be removed from the gas stream in order to enhance the methane content to ‘grid quality’ (generally around 97 % vol.) so that the biogas can be used in the natural gas grid, or in natural gas-fuelled cars. This operation is called upgrading of the biogas to biomethane.

   Currently only a few facilities are upgrading biogas to biomethane (see Section 1.5.4), and those that do so use a large variety of technologies, as shown in Figure 63.

Figure 63: Share of upgrading technologies deployed in Germany in 2011



Source: DBFZ Biomethane survey, 2011.

Some of these technologies (e.g. PSA and membranes) are likely to capture significant amounts of methane together with the CO_2 to be removed. If this gas stream is not flared or oxidised, the methane is released into the atmosphere; emissions can reach up to 3-5 % of the methane produced.

Methane slip from biogas combined heat and power (CHP) engines is a significant emissions source in biogas electricity production and is very difficult to avoid, even by technological development

4. Biogas facilities producing power (and heat) generally employ large reciprocating engines (diesel or Otto cycle engines), which combust the biogas with an average content of methane of around 55 $\%_{vol.}$ to 65 $\%_{vol}$. The poor quality of the gas is responsible for an imperfect combustion, which can cause emissions of unburned methane up to 1.7 % of the total methane produced.

   These emissions tend to be overlooked on the principle that emissions of GHG from end-use of biomass and biofuels are usually excluded from the analysis or considered irrelevant because of their biogenic origin (these emissions, though, are included in the methodology suggested in SWD(2014)0259).

Fertiliser efficiency and SOC change when digestate is used as a fertiliser in place of manure/slurry

5. Fertiliser efficiency and SOC change when digestate is used as a fertiliser in place of manure/slurry: See Section 5.3.4, which is specifically dedicated to analysing this issue.

Many of the GHG emissions listed here can be avoided or minimised by promoting the right technologies and management. However, in order to do this, they should be properly accounted for in sustainability analyses and legislation.

6. POTENTIAL FOR TECHNOLOGICAL IMPROVEMENTS

KEY FINDINGS

- First-generation biofuels remain considerably more expensive than fossil fuels, despite steady progress in reducing costs and improving efficiency of processing.
- It is possible to reduce the calculated direct greenhouse gas emissions of the process by using by-products to heat the process instead of, e.g., natural gas. However, this requires more expensive equipment, and the income from sale of animal feed is lost. Furthermore, this would remove the benefit which by-products have on indirect emissions from ILUC.
- The progress of second-generation biofuel production has been much slower than anticipated in RED. The problem is not so much technical as economic. The plants are extremely complex and capital-intensive, and this cost handicap cannot be recovered unless feedstock is very cheap, the plant is built on a vast scale, and/or there are valuable by-products.
- The economics of second-generation biofuel plants depends strongly on scale. The process is thus technically possible, but the economics are still unproven, and depend on how much value is placed on carbon emission reduction.
- Third-generation biofuel usually means biofuel from algae. Many different approaches are being investigated and it is far too early to pick winners. A potential problem is scale-up of processes using pure strains of algae: the whole plant needs to be kept sterile to avoid invasion by natural organisms.

6.1 First-generation biofuels processes

Bioethanol process

The first step in bioethanol production is extraction

The technology for bioethanol production is quite simple. The initial step in the process involves grinding the biomass feedstock (most commonly wheat, barley, maize, sugar cane or sugar beet) to help the plant components (saccharose and the starch) release sugar. The sugar is extracted from the ground material by cooking in water. Enzymes are used as catalysts to enhance sugar extraction. Without the energy-consuming cooking step, the final ethanol yield would be very low.

Followed by fermentation

Fermentation is then carried out on the sugar-containing mixture. Up to this stage the process is very similar to making beer or wine. Microbes from yeast feed on the sugars and produce a mixture of ethanol (C_2H_5OH) and carbon dioxide (CO_2). Fermentation is an energy-efficient but rather slow process, so there is an incentive to increase the rate of ethanol formation in order to reduce both operating and investment costs. Process acceleration can be achieved using a propagation tank to get the yeast into optimum condition before adding it to the fermenter.

And then by distillation and drying

Distillation separates ~96% pure ethanol from the fermented ‘wine’. This can be used as ‘hydrous ethanol’ fuel. However, in the EU the fuel standard for ethanol blended into petrol specifies a very low water content, which necessitates an extra drying step using molecular sieves.

The by-product is sold as animal feed

In Europe, the solids strained from the 'wine' before distillation are usually dried. They are then mixed with the residue from evaporating the solution left after distillation, and sold as DDGS animal feed.

Biodiesel-FAME process

The main type of biofuel in the EU is fatty acid methyl ester (FAME). This is mostly made form rapeseed, soy and sunflower oils, although many other ingredients may be used (e.g. maize oil, jatropha and algae). However, FAME from palm oil, tall-oil and animal fat is rather viscous and therefore cannot be used as a major blend component in cold weather.

For biodiesel production, oil is first recovered from the oilseeds

The production of vegetable oil from oilseeds is conventionally called 'pressing' even though it usually involves cooking and solvent extraction. This generally gives oilseed meals, whose use as livestock feed helps the economics of the process. The exception is palm oil, where empty fruit bunches are in the best case returned to the plantation as mulch.

Next, the oil needs to be partially refined before further processing.

The oil then undergoes chemical reactions (transesterification) to obtain FAME biodiesel

FAME is made from vegetable oil by transesterification: a chemical reaction with an alcohol, normally methanol (CH_3OH), in the presence of a catalyst (commonly sodium hydroxide or potassium hydroxide), to form the methyl ester and 10 % glycerol as by-product. Usually fossil-derived methanol is used because it is cheapest, but it would be possible to improve the emissions savings slightly by using bioethanol.

Glycerine is a co-product of FAME

Glycerine means a commercial product made mostly of the chemical glycerol. It is separated from the biodiesel as an ~80 % solution in water with the catalyst and impurities. In the impure state, it is sometimes used for making biogas, blended in animal feed, or as a feed to specially-built burners or chemical plant, for example steam-reformers for making hydrogen. Alternatively, it is distilled to edible-standard glycerine, which has many disparate uses in chemicals, food and other industries.

Biodiesel: hydrogenated vegetable oil (HVO Process)

This process reacts vegetable oil with hydrogen to form a paraffinic hydrocarbon with similar properties to fossil kerosene (aircraft fuel) or diesel. The cost of the hydrogen and catalysts and the higher temperatures required is thought to make the process slightly more expensive than transesterification, but on the other hand it can make good-quality fuel from any type of vegetable oil or animal fat. That makes it more suitable for processing palm oil and tall oil, which are cheaper than other vegetable oils, as well as animal fats and waste cooking oil.

The calculated GHG savings could be improved by use of renewable hydrogen.

6.2 Second-generation and advanced biofuels

Technologies for second-generation biofuels

Second-generation plants are much more complex and expensive than first-generation ones

Second-generation and advanced biofuels are produced from non-food cellulosic and lignocellulosic biomass such as wood, straw, grass, wastes and process residues. The biggest difference from first-generation processes lies in the complexity needed to convert indigestible components of the lignocellulosic biomass into biofuel. The three components of lignocellulosic biomass that need special treatment to produce biofuels and/or bioenergy are:

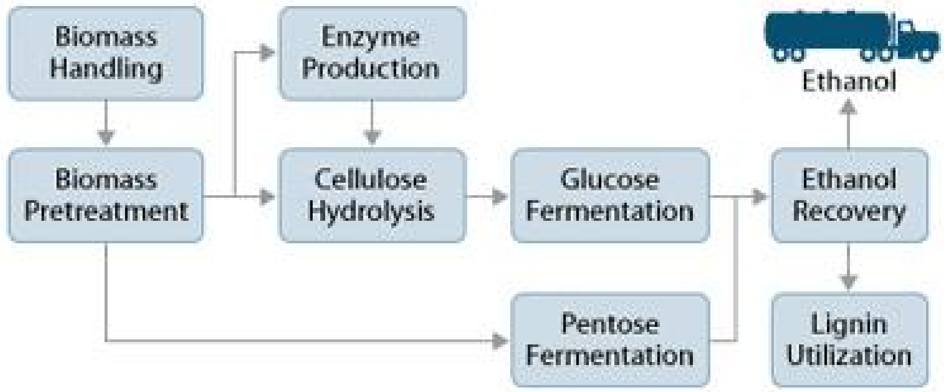
1. Cellulose – the cell-wall material of plants, which is highly resistant to natural degradation but contains a high proportion of simple sugar – glucose – which after release can be readily fermented into ethanol.
2. Hemicellulose – also part of plant cell walls and containing more complex sugars like xylose, arabinose and mannose; these are more abundant in straw and maize residues than in woody biomass.
3. Lignin – the non-sugar component affording strength and protection against biological degradation.

There are two main technologies under development for the production of second-generation and advanced biofuels: thermochemical and biochemical.

Biochemical plants usually convert cellulosic material to ethanol

Biochemical processes generally work by extracting components like sugars or oils. These can be converted to biofuels, biochemicals and biomaterials using processes that are more akin to processing food and feed (Figure 64). In these processes, enzymes and other micro-organisms are used to convert the cellulose and hemicellulose components of the feedstocks to sugars prior to their fermentation to produce ethanol.

Figure 64: Schematic of a biochemical cellulosic ethanol production process



Thermochemical plants convert biomass to various synthetic fuels

Thermochemical processes operate at temperatures high enough to result in rapid decomposition of biomass into basic chemical compounds. Using temperatures over 800°C, gasification is the highest-temperature process, producing a simple mixture of gases which can then be used to synthesise fuels or other chemicals.

Three complete thermochemical biofuel plants have been demonstrated in the EU:

- A BTL (biomass to liquids) process which combines gasification with Fischer-Tropsch (FT) synthesis can produce excellent hydrocarbon diesel and petrol. The drawback is that the synthesis plant is extremely expensive; it is somewhat cheaper to make methanol or Dimethyl Ether, the latter being an excellent diesel fuel which, however, requires modified engines.
- Synthetic natural gas (SNG), which is equivalent to biomethane and is produced from woody biomass. The process has been successfully demonstrated using fluidised-bed technology in Austria; a 20 MW demonstration plant in Sweden was commissioned late in 2013. SNG can be considered a transport biofuel if used as compressed gas.
- (JRC 2008) identified the black-liquor gasification route, integrated into a woodpulp mill, as the most promising second-generation biofuel route. In the Kraft woodpulp process, black liquor contains all the wood components (principally lignin) which did not go into the woodpulp. Traditionally it is burnt to provide the necessary process heat. Instead, it can be diverted to a gasifier. The product gases are then used for fuel synthesis. This reduces the heat available for the pulp process, which is made up for by burning forest residues. Thus overall, the process converts forest residues to biofuel. The process has been demonstrated at medium scale by a European project in Sweden.

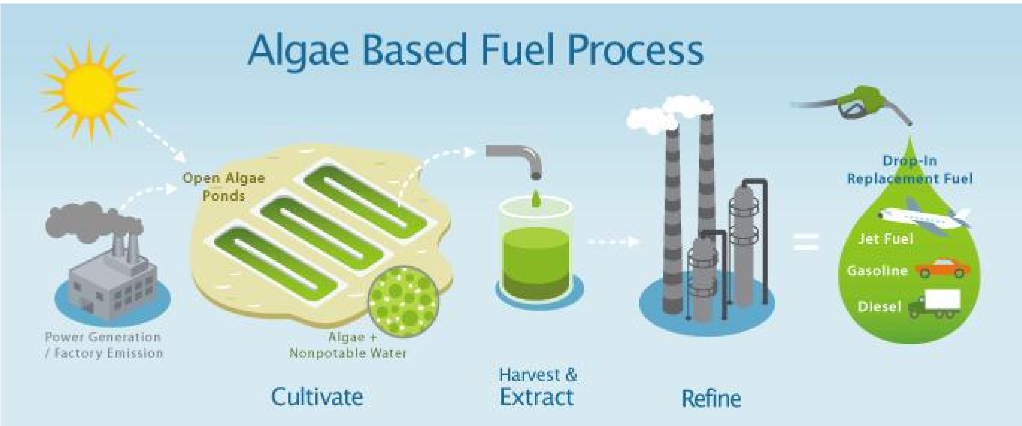
While all processes are well proven in the laboratory, there are numerous challenges to make them work on a large scale in an efficient, continuous and reliable manner that ensures potential for economic viability.

Algae biofuels are still at the research stage

Algae have long been touted as a sustainable feedstock for biofuels (biodiesel, bioethanol, biomethane) and valuable co-products from biorefineries. They can be cultivated on non-productive land (i.e. degraded, non-arable land) that is unsuitable for agriculture, or in brackish, saline and waste water from waste-water treatment plants.

Algae can be produced in open ponds, raceway ponds, closed photo-bioreactors and closed fermenter systems. The potential oil yields (litres/hectare) from algae are significantly higher than yields of oilseed crops. Theoretically, algae could produce around 45 000 litres of biodiesel/ha, compared to 1 500 litres from rapeseed, 4 500 litres from palm oil and 2 500 litres from maize.

Figure 65: Algae life-cycle



Biofuel production from algae is presently at the research and development stage. There are technical challenges and a need for innovation and technical improvement in all steps of the process (see figure above). Efforts are needed to develop and evaluate optimum strains of algae, with fast growth, process development, algae harvesting and oil extraction. Oil extraction faces substantial difficulties due to the high water content of algal biomass after harvesting.

Of the many different ways of generating hydrogen, biomass conversion is probably the cheapest renewable route. Methods investigated in the previous decade include:

- Special gasification or gasification followed by reforming of syngas;
- Fermentation of biomass to hydrogen (dark fermentation) or anaerobic digestion followed by methane reforming;
- Pyrolysis and reforming of bio-oil;
- Direct hydrogen production in a phototrophic environment (photo fermentation) by organisms.

Hydrogen is actually one of the easiest single products to make using gasification of biomass. Biological dark fermentation is also a promising production method for hydrogen, with a potential for commercial use in the long term. With further development of these technologies, biomass would no doubt play an important role in the development of a sustainable hydrogen economy (Ni et al., 2006).

6.3 Current economics of biofuels production

Before about 2005, when biofuels started to become a significant factor in agricultural markets, it was reasonable to suppose that real crop prices would continue their historical fall while crude oil prices would increase. It thus seemed that it would be only a matter of time before biofuels became cheaper than fossil fuels. What actually happened after 2005 was that crop prices increased and became linked to the price of crude oil. Thus first generation biofuels remain considerably more expensive than fossil fuels (see the cost-per-litre section above), despite steady progress in reducing costs and improving efficiency of the processing.

First-generation biofuels are now an efficient market in the EU

60-80 % of the costs of biofuels are related to feedstock, and therefore profitability depends on the price of crops and on that of crude oil. In the past there have been periods of 'bonanza' at times of high oil prices or excessive detaxation of biofuels. However, the market has matured as commodity traders have linked biofuel feedstock prices to the price of crude oil, while Member States have turned from detaxation of biofuel at the pump to blending mandates on road-fuel suppliers. Now, as reported in chapter 4, EU biofuel wholesale prices are roughly in line with production costs.

Even ethanol in Brazil is not quite as cheap as world petrol

If we do not count subsidies for biofuel production, ethanol from sugar cane in Brazil has the lowest unsubsidised production costs of any existing biofuel. This is a result of high yields, availability of bagasse waste to fuel the process, cheap labour on a large scale, and a long period of process optimisation. However, even with all these advantages, ethanol is

only competitive at the pump in Brazil because it is subject to a lower fuel tax (12-30 %) than is petrol (~54 %)[144]. There is also a mandate for blending of ethanol in petrol. Of course, if the EU imports ethanol from Brazil it has to pay the world commodity price, not the production cost in Brazil.

Second-generation biofuels production is not price-competitive with fossil fuel

At the time of writing, all working second- or third-generation biofuels plants were built for the purpose of research and development rather than immediate profit. Although biomass feedstock is cheaper per tonne than crops, the authors estimate that at least 80 % of the production cost of second-generation biofuels is a capital charge on the initial investment (if this is not reduced by grants and loan guarantees).

Straw is the cheapest large-scale source of lignocellulosic biomass in the EU, but is still needs to be collected, transported and stored, so that in the end it costs around EUR 60 per tonne at the plant (compared with a current feed-wheat price of ~EUR 180 per tonne). However, without higher incentives than for first-generation the lower feedstock cost is not sufficient to counter the much higher cost of the pioneering second-generation plants. More incentives are justified if one considers the low direct and indirect greenhouse gas emissions from straw-biofuel plants.

Cellulosic ethanol plants are technically possible

Various EU demonstration plants (listed in Appendix 8), built to investigate various proprietary technologies, have demonstrated that the process is technically possible. These include the Abengoa plant in Salamanca, Spain, the Clariant plant in Straubing, Germany, and Inbicon in Kalundborg, Denmark.

Several large plants are coming on line

The largest plant operating at the time of writing is the Chemtex second-generation cellulosic ethanol plant at Crescentino in Italy, which is intended to produce 76 million litres of ethanol per year and started working in October 2013.

In the US, three large-scale cellulosic ethanol facilities are scheduled to start production by the end of 2014 (INEOS in Florida, Abengoa in Kansas and POET/DSM in Iowa), as well as the large Liberty project in Iowa, USA (Liberty, 2013)) for converting corn stover (maize residues) to bioethanol. The Liberty plant is scheduled to start up in 2014 with a targeted bioethanol capacity of 94.5 million litres from only the C6 sugars.

Every time a plant opens on a bigger scale, it is announced as the 'first commercial-scale cellulose ethanol plant'. Whether a plant can be considered 'commercial' depends on whether one includes incentives, grants and subsidies in the calculation: no plant is expected to produce ethanol that is cheaper than untaxed petrol, or even first-generation biofuel.

They have lower costs if built in Brazil

Straw is the cheapest large-scale source of lignocellulosic biomass in EU, but it still needs to be collected, transported and stored, so that in the end it costs around EUR 60 per tonne at the plant (compared with a current feed-wheat price of ~ EUR 180 per tonne). However,

[144] Bergamasco and Machado (2008-08-27). The difference in taxation outweighs the effect of the Brazilian government fixing petrol prices at 15 % below international prices (data for December 2013).

without higher incentives than for first-generation, the lower feedstock cost is not sufficient to counter the much higher investment cost of the ring second-generation plants, if commercial interest rates and payback times are considered.

By contrast, at Brazilian sugar plants excess bagasse is available without transportation or collection costs. Furthermore, distillation facilities can be shared with the sugar-cane ethanol plant. Therefore any given lignocellulose ethanol plant will have lower costs if built in Brazil rather than in the EU.

This point has not been lost on the industry: a much-publicised project put forward by Shell and Iogen to build a 'commercial-scale' straw-to-ethanol plant in Canada was cancelled in 2012; Iogen has a new project in Brazil. The constructors of another famous demonstration plant (by Western Biomass/KL Energy/Blue-sugar) built in Wyoming in 2008 have recently filed for bankruptcy, and the business is for sale … perhaps to Brazil.

Thermochemical conversion technologies are also more expensive than fossil fuel

Appendix 8 lists the significant demonstration plants in EU.

A study (JRC 2008) found the black-liquor gasification route, integrated into a woodpulp mill, to be the potentially lowest-cost second generation biofuel route in EU. The process has now been demonstrated by Chemrec at one Swedish pulp mill, but even here costs are significantly higher than for fossil fuel. The process must be scaled to fit the size of the pulp mill, so it cannot be scaled up indefinitely. This plant produces dimethyl ether diesel fuel for fleet vehicles.

For a freestanding gasification-based biofuel plant, costs are higher, as demonstrated by the closure of the Choren demonstration plant in Germany. Although this plant had a very efficient gasifier, it failed at the stage of Fischer-Tropsch synthetic diesel production. This requires very expensive plant, and is usually considered viable only on a massive scale, such as in the Shell-Qatar natural-gas-to-liquids plant, which produces 140 000 barrels a day of petroleum fuel, and has itself suffered a huge cost overrun, so that it is not clear whether it meets the target of producing fuel competitive with that from refineries using crude oil at USD 40 per barrel. The capacity of the Choren plant was only 300 barrels per day. Some companies are of course working to make FT viable at smaller capacities.

Oil companies have moved investments in advanced biofuels to Brazil

Recent, more realistic cost projections, together with uncertainty in advanced biofuels policy, have caused major oil companies in Europe to reduce their investments in the field. They have cancelled joint agreements and advanced biofuels projects. At the same time, they are making significant investments in both first- and second-generation ethanol in Brazil where the cost base is lower. EU development of advanced biofuels is now done independently by the specialist technology and paper and pulp companies such as Clariant, POET, Abengoa, Mossi & Ghisolfi, KiOR and UPM.

6.4 Projections of costs of technologies for biofuel production

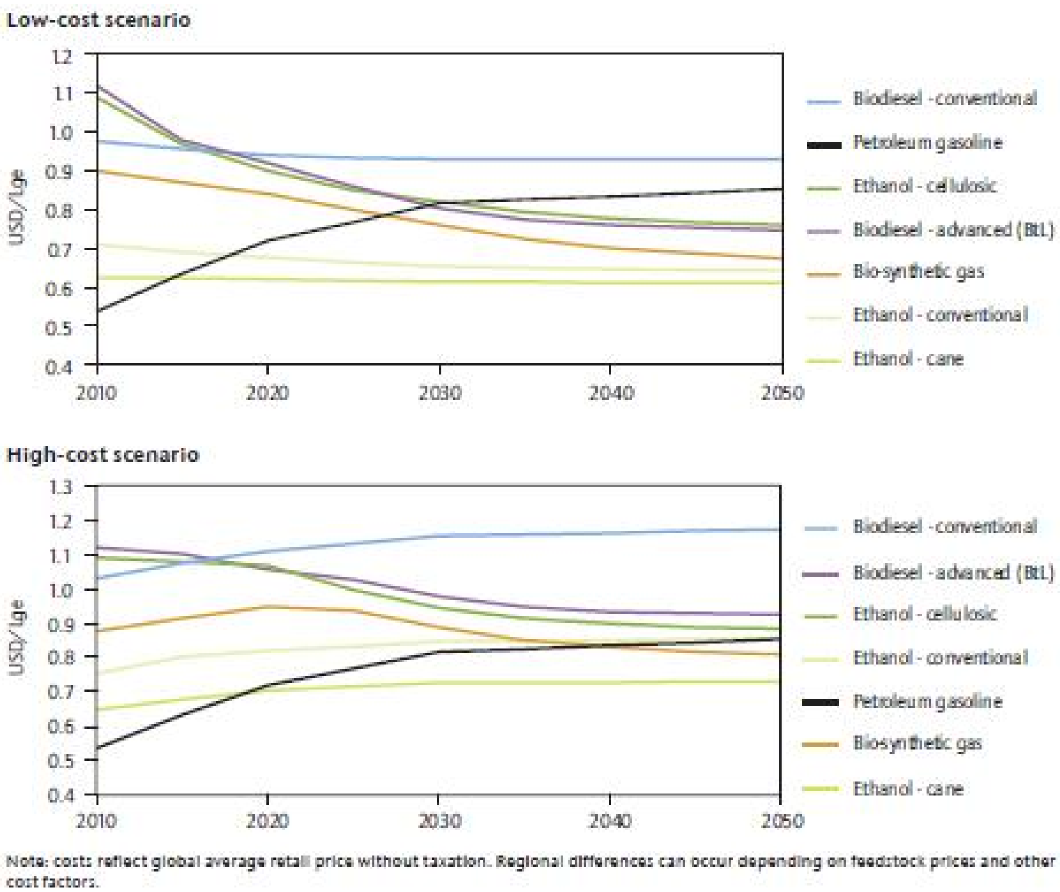
In its 2011 biofuels roadmap (IEA, 2011), IEA compares the costs of biofuels and petrol. This starts with estimated actual costs for 2010 and project cost evolution to 2050 using two different scenarios (Figure 66). Both scenarios assume that (inflation-adjusted) petrol prices will have increased by 34 % by 2020 and 55 % by 2030.

A low-cost scenario assumes minimal impact of increasing oil prices on biofuel production costs, so that the costs of the various biofuels fall with increased scale and efficiency of production. With this scenario, the cost of first-generation ethanol production falls to the petrol cost by 2018, sugar cane ethanol by 2014, second-generation biofuels by 2030, and compressed biomethane by 2027. However, conventional biodiesel production costs remain above those of petrol for the whole period to 2050.

In a high-cost scenario, oil prices are allowed to have an impact on the price of biomass feedstocks and hence on biofuel production costs. As a result, the IEA model predicts that only sugar cane ethanol (2019) and biomethane (2040) will cost less than petrol before 2050. While first-generation ethanol reaches parity with petrol in 2050, the production costs of other biofuels, including cellulosic ethanol, remain higher than petrol at USD 150/barrel beyond 2050.

There is no level of confidence assigned to the accuracy of the IEA models, or to any other cost model. Real cost data from the biofuels production companies will be necessary to calibrate and correct the models over time.

Figure 66: Costs of various biofuels compared with petrol



Note: Expressed in US dollars per litre petrol equivalent (LGE), so that each fuel is compared on the basis of equal energy content (source: IEA, 2011).

Two major factors affecting investment decisions, according to the European Industrial Bioenergy Initiative (EIBI, 2012), are the price of oil and the price of CO_2, both of which are influenced by policy and determined by the markets. The EIBI was launched in November 2010 as one of the European Industrial Initiatives (EIIs) set up within the frame

of the Strategic Energy Technologies (SET) Plan to promote and monitor demonstration of advanced bioenergy and biofuels projects in the period up to 2020.

The progress of 2nd generation biofuel production has been much slower than anticipated in RED, which reflected the optimistic projections circulating at the time. The problem is not so much technical as economic. The plants are extremely complex and capital-intensive, and this cost handicap cannot be recovered unless feedstock is very cheap, the plant is built on a vast scale, and/or there are valuable by-products.

The costs of second-generation and advanced biofuels are difficult to estimate owing to the confidential nature of the industrial developments. The EIBI (2012/2) has taken the approach of setting price targets for advanced/cellulosic biofuels. According to the EIBI, the prices before taxes that biofuels should achieve by 2020 (2010 base) are <EUR 0.50/litres for bioethanol and <EUR 0.75/litre for diesel substitute fuels; biomethane should be the same price as natural gas. Targets for 2015, when the first large-scale advanced biofuel demonstration plants should be in production, are: <EUR 0.70/litres for bioethanol, <EUR 1.05/litre for diesel substitute fuels, and for biomethane a price 50% higher than that of natural gas. The economic impact of biofuel production has been addressed in the study 'Economic Effects of Biofuel Production' (2011).

The costs of second-generation plants will come down if more are built or if they are scaled up.

It is often stated that second-generation biofuels can only be 'economic' if there are valuable chemical by-products (the 'biorefinery' concept). There are indeed many possibilities of co-producing complex organic chemicals; the challenge is to find ones with a large enough potential market to support a large-scale plant.

6.5 Needs and potentials for improvement of biofuel production processes

Outlook for emissions reduction of first-generation biofuels

Potential reduction of cultivation emissions

Although the matter is often not under the control of biofuel producers, there is large scope for reducing emissions and cultivation. Nitrous oxide emissions from fertilised soils can be reduced by appropriate tillage and more precise fertiliser dosing. Fertiliser producers in EU are committed to reducing emissions under the ETS. This gradually reduces cultivation emissions over time. Furthermore, incentivising farmers to buy fertiliser from low-emission factories would be a cheap method to reduce GHG emissions, whatever the crop is used for. On the other hand, limiting incentives to farmers supplying biofuel factories could simply result in other farmers buying the high-emission fertilisers. In the developed world, farmers are improving the ratio of crop to nitrogen input (see Section 2.2.3).

Substantial improvements in first-generation ethanol plants need substantial investment

In the EU, almost all bioethanol plants burn natural gas for process heat, principally for distillation and drying of DDGS. In a conventional plant, making one 1GJ ethanol requires about 0.4GJ natural gas. There have been continual improvements in plant efficiency, typically by better recycling of heat, but big efficiency gains need more investment, for example using combined heat-and-power and/or investing in the new but expensive technology of membrane distillation.

Using by-products for providing energy reduces calculated emissions, but at a price

Unlike with sugar-cane ethanol, production of EU biofuels gives by-products which are sold as animal feed, and this is important to the economics of the process. It is possible to reduce the calculated direct greenhouse gas emissions of the process by using some or all of the by-products for process heat instead of, e.g., natural gas.[145]

However, this requires more expensive equipment, and income from sale of animal feed is lost. Furthermore, it would remove the beneficial effect of by-products on indirect emissions from ILUC. Nevertheless, it can be interesting in a 'dry-mill'' ethanol plant, where the grain is first separated into different components, of which only the starch is used for ethanol. The cheapest component – bran- can then be burnt for energy.

Wet by-products, such as the liquid residue from distillation, are often used to make biomethane; this avoids the energy cost of drying them for animal feed, and illustrates the additional energy that could be recovered by producing biomethane from all the by-products of bioethanol and biodiesel production.

Biodiesel processing needs less energy than ethanol production, so there is less scope for saving energy in the processing stage. Using crude glycerine by-product for biogas instead of selling it can improve the calculated emissions savings.

CHP is good for emissions but not free

Any industrial process using heat will have lower emissions if it uses waste heat from electricity generation. However, installing combined-heat-and-power (CHP) in small standalone plants is expensive. Therefore it is rational to have incentives for co-locating any large process (including biofuel factories) which requires heat with electricity generating plants.

Brazilian ethanol/sugar plants have long resorted to cogeneration using bagasse for the internal power needs of the plant. However, they have more bagasse than is needed by an efficient plant, and now they are exporting excess electricity, competing in auctions with other renewable electricity sources, such as wood-chip power stations and hydroelectricity.

Sequestration of CO_2 should be additional

Ethanol plants produce pure CO_2 as a by-product of fermentation, and this can be sequestered to improve the apparent emissions balance. However, adding carbon dioxide from ethanol production to the liquefied gas market merely displaces emissions elsewhere. This is because all the liquefied carbon dioxide marketed in the EU comes from industrial processes which provide concentrated streams of CO_2 that would otherwise be vented. Sequestering CO_2 by piping off-gases to glasshouses is effective if it does not displace other waste CO_2.

[145] The calculated emissions include an allocation of emissions to the animal feed, which is lost in this case. But this effect is smaller than the emissions from fossil fuel saved.

Outlook for technology improvements in 2nd generation biofuels

Biochemical cellulosic ethanol

Pre-treatment is now better understood

Until around 1998, before the major research effort started, people thought that it would be sufficient to soak biomass in dilute acid as a pre-treatment. Now almost all plants use a much more energetic steam treatment. Nevertheless, ‘many challenges remain’ (Chundawat et al., 2011).

The progress of 2nd generation biofuel production has been much slower than anticipated in RED, which reflected the very optimistic projections circulating at the time. The problem is not so much technical as economic. The plants are extremely complex and capital-intensive, and this cost handicap cannot be recovered unless feedstock is very cheap, the plant is built on a vast scale, and/or there are valuable by-products.

Advanced enzymes improve yields

Second- or advanced-generation bioethanol is expected to be produced mainly using biochemical processes. The part of the process that receives the most attention, and where the greatest potential improvement can be expected, involves breaking open the cellulose to release the sugars needed for fermentation to ethanol. This is reflected in the number of recent European projects focused on this area; see for example the European Biofuels Technology Platform (EBTP, 2013). In essence, the combination of mechanical and chemical processes is integrated with the use of advanced proprietary enzymes and micro-organisms to bring the biomass into a form from which biofuel and bioproducts can be made efficiently. Enzyme companies therefore play a leading role in cellulosic ethanol technology development.

In 2013, one of the world’s leading enzyme companies, based in Europe, announced the introduction of two new enzyme technologies designed to increase ethanol yields substantially. One of the key ways to increase fuel yield is to be able to convert all available sugars to ethanol, not only the C6 sugars used in most first-generation biofuels processes.

By 2013, large-scale tests had been successfully performed to demonstrate up to 50 % yield improvement by converting both sugars of both C5 (not easily converted into fuel) and C6 (the type of sugar readily converted into fuel by well-known fermentation methods) types to ethanol. If this can also be achieved on a commercial scale there will be a significant saving in production costs. One technology example is Inbicon from Denmark, which is licensing three new commercial versions of its Inbicon Biomass Refinery. Two of these will ferment both the C5 and C6 sugars with the aim of increasing cellulosic ethanol yield by 50 % compared with current processes.

In order to be economically profitable, second-generation ethanol plants have been built as biorefineries

Although the complex chemistry of biomass conversion makes plants expensive, a potential advantage is that a great variety of organic compounds are produced, most of which are expensive to synthesise. Therefore if products can be separated and sold as chemicals, they can greatly improve the economics of the plant. For this reason, many large-scale facilities (completed, under construction or in planning) have the status of biorefineries. One problem is to identify products with a sufficiently large potential market for the size of the plant.

In the current state of the art for cellulosic ethanol production, 1 tonne of fuel can be produced from about 4.5 tonnes of straw (typically from 1 hectare). Lignin, one of the three main components of lignocellulosic biomass, is often used as a fuel to provide heat and electricity for the process, although it has the potential to produce higher-value biorefinery chemical products in the future.

Costs can often be better controlled if biofuel production plants are able to use a variety of feedstocks, and thereby reduce their dependence on a few sources of supply. There is, however, a technological challenge to being able to treat many feedstocks with the same high conversion efficiency to biofuels and high-quality chemicals and/or biomaterials. Most advanced biofuel facilities plan to use a range of different biomass feedstocks to maximise their own security of supply.

The main challenges for thermochemical processes are technological (gas cleaning and gas composition) and economic (low yields, high capital investments)

In general, many of the challenges related to pre-treating the biomass in order to facilitate feeding into the gasifier or pyrolyser have now been solved. In many cases, the tars from (fluidised bed) gasification can now be effectively managed. However, cost is a major issue. The main challenges are to obtain a synthesis gas from the gasifier that has an appropriate composition with respect to carbon monoxide (CO) and hydrogen (H_2) for the F-T catalyst (a metal such as cobalt or iron, or nickel if methane is required) to work at its best, and for the catalyst to remain active over long periods of time. Various process steps are required to pre-condition the gas from the gasifier before the F-T catalyst can be used, all of which add costs and reduce overall conversion efficiency. Developments in process optimisation are needed.

The first large project to produce synthetic natural gas to be injected into the natural gas grid will start in 2014

The next large demonstration-scale gasification project in Europe was commissioned in Sweden late in 2013. The GoBiGas project (GoBiGas, 2013) uses woody biomass to produce synthetic natural gas, the form of biomethane produced by gasification, which will be injected into the existing natural-gas grid. The initial challenge of the project is to get the technology working at a scale 10 times larger than previously achieved. The next stage of scale-up of the technology, four times larger (or 40 times larger than the pre-2013 scale), is envisaged for later in this decade. Clearly, numerous steps have to be taken in the scale-up from laboratory concept to a commercial-size production facility.

Pyrolysis has improved significantly in the last few years, and the bio-oil produced is almost ready to be traded as an intermediate fuel. Scale-up of production will not be achieved for some years

Bio-oil (sometimes called biocrude oil) is the main product of fast pyrolysis, and is a feedstock of growing importance in advanced biofuel production. Over the last three or four years, significant progress been made in the processing and handling of bio-oil, and large-scale demonstration facilities are now at the advanced planning phase. Bio-oil stability is now very well understood and trade in this intermediate fuel is almost ready to begin. More efficient catalysts are needed to lower production costs and achieve longer-term stability of the bio-oil, thereby giving it a longer ‘shelf-life’. The feasibility of large-scale production needs to be proved and this will take a few years.

Upgrading the 'biocrude' oil produced by pyrolisis can be done by hydrogenation in a refinery, but the cost of hydrogen is significant. Alternatively, the biocrude can be used as a fuel for a gasifier. Then the pyrolyser has the function of reducing the biomass volume and transport cost, by comparison with gasifying the biomass directly.

The main challenges for algal biofuels are improvement of energy balance during cultivation, harvesting, and pre-treatment of the feedstock

The main challenges associated with algae feedstocks are energy-efficient cultivation, harvesting and pre-treatment. Many of the processes for conversion to biofuels are very similar to those described above for first-generation and advanced biofuels. Given the right conditions, micro-algae can be produced more efficiently than land plants in terms of tonnes per hectare. This is mainly because of the presence of water, the intensity of incoming solar radiation and the absence of impact from poor soil quality that affects soil-grown plants. The availability of nutrients is also a factor.

There are basically two approaches. Open ponds are a simple way to produce algal biomass, using natural organisms. Closed photo bioreactors (PBRs), which are usually glass tubes exposed to light, can in principle be made sterile so that exotic and genetically engineered organisms, with high oil yield, can be used without invasion by natural organisms. They permit close control of nutrient supply and outgassing of N_2O (nitrous oxide – a GHG with 300 times the impact of CO_2) can be avoided. However, they cost much more.

In general, plants can capture a theoretical maximum of around 6 % of solar radiation. In practice, terrestrial plants in nature capture around 1 % of solar radiation, whereas algae should theoretically be capable of capturing up to 5 % under optimum conditions (Schenk, 2008). It is this high potential biomass yield that makes algae so attractive.

Numerous projects around the world have been carried out or are still under way. However, the algae sector still awaits a major breakthrough that will show whether its theoretical potential can be achieved. It would require the minimum input of energy to harvest and separate the biomass from water, to recycle the water and nutrients, and to extract the useful components of the algae for production of biofuels and value-added by-products (Posten, 2009).

Work continues on closed PBRs, and on open ponds, to advance understanding of how close it is possible to get to the theoretical maximum biomass yield, and how it might be possible to achieve a very high yield all year round in large-scale facilities.

Integration of micro-algae production with direct up-take of CO_2 from other industrial processes could potentially be exploited. Increasing the CO_2 concentration in the air circulated inside greenhouses for faster food production is already widely practised.

Most of the work on algae biofuels and biochemicals is still at laboratory or pilot stage

The most appropriate direct use of micro-algae for energy might be anaerobic digestion. This process can take in biomass with very high water content, thereby avoiding some of the energy-intensive pre-treatment processes required before making other biofuels. Work is ongoing on the production of various other biofuels and biochemicals in biorefinery concepts; all of the studies are at laboratory or pilot scale.

CONCLUSIONS

Aims of the report

EU biofuels policy aims at achieving GHG savings, security of energy supply and economic and employment benefits. The aim of this report is to analyse:

- the impact of biofuels on the above three objectives;
- other impacts: agriculture and crop prices, land-use changes, etc;
- how different types of biofuels differ in performance;
- how this performance can be improved in future.

Total cost of EU biofuels

The authors estimated the 2011 production cost of EU biofuels from raw materials and investment costs, and found that it was close to the EU wholesale price of biodiesel and ethanol. This indicates efficient competition between EU biofuel producers.

The estimates found in the literature of the cost of supporting biofuels in EU Member States in 2011 vary from EUR 7 to 8.4 billion, which corresponds to EUR 14 to 17 per person or to some EUR 26 to 32 per vehicle.

Most of this policy cost is accounted for by the extra production cost of EU biofuels compared to the production cost of the fossil fuels they replace: the authors estimate that this amounted to EUR 5.6 billion in 2011. The difference arises from the additional cost for blending and administration, as well as the profits of blenders and distributors.

Overall benefits of EU biofuels: emissions savings

In 2011 ethanol use in the EU saved about 6 Mt CO_2e of emissions, not considering ILUC emissions. If ILUC emissions are included, the savings from ethanol fall to 4.3 Mt of CO_2e.

In 2011 biodiesel use in the EU saved about 18 Mt CO_2e of emissions, not considering ILUC emissions. If ILUC emissions are included, biodiesel no longer saves emissions but increases them. The increase in emissions totalled 8 Mt of CO_2e in 2011.

Without considering ILUC emissions, EU biofuels saved about 24 Mt of CO_2 equivalent greenhouse gas emissions in 2011. Taking into account the ILUC emissions calculated for the Commission by IFPRI (Laborde 2011), biofuels in the EU increased greenhouse gas emissions by a net ~3.7 Mt of CO_2 equivalent in 2011.

Overall benefits of EU biofuels: security of supply

Biofuels replaced 5.1 % of EU road fuels and up to 2.2 % of EU crude oil use in 2011. However, some of the biofuel was imported: 23 % of biodiesel and 24 % of bioethanol were imported directly as finished products in 2011, as also arguably most of the vegetable oil feedstock. However, even for the part which is imported, it can be said that biofuels increase the range of sources of transport fuel supply.

Overall benefits of EU biofuels: impact on employment

Because any increase in public spending can be expected to increase employment, it is essential also to consider increases in taxation or fuel prices related to paying for biofuel subsidies. Models which do this conclude that the EU employment effects of biofuels are approximately neutral. Extra jobs are created in biofuel processing and farming, but these are offset by job losses in the rest of the economy due to the depressive effects of taxation or higher fuel prices.

Impacts of biofuels on agriculture

Vegetable oils easily replace each other in many applications, so it is important to look at the effects of biodiesel on the overall vegetable oil and oilseed market, and not just on the particular oils (mainly rapeseed) used directly for making biodiesel.

From the changes in the EU vegetable oil and oilseeds market from 2001 to 2011, it can be seen that:

- the entire increase in EU vegetable oil demand can be attributed to biodiesel;
- 57 % of that increase in demand was met by imports;
- As well as palm oil used directly for biodiesel, part of the rapeseed oil which was diverted to biodiesel from other EU uses was replaced by palm oil imports (although some of the increase in palm oil would have occurred anyway).

The effect on palm oil imports is particularly important because of the very high emissions associated with the oil-palm expansion on to tropical peatland.

It is difficult to distinguish the historical effects of EU ethanol production on the cereals market, because ethanol production is much less extensive and the cereals market is much larger. Economic models are needed (see below).

EU ethanol production uses about 10 % of the EU sugar beet crop. However, the reform of the EU sugar regime has been so profound that it is difficult to identify the specific effects of sugar-beet ethanol from historical data.

Effect on crop prices

Economic models show that EU biofuel policy has a significant impact on the world crop prices (in particular of oilseeds and vegetable oils). As EU is the world's largest agricultural importer, increasing crop prices generally mean an extra cost to EU. For example considering 2012 figures, a uniform 5 % increase in agricultural commodity prices would add EUR 0.45 billion to the EU's import bill.

Economic models report different crop price increases due to EU biofuels policy, largely because they assume different changes in bioethanol and biodiesel use. By adding a trendline to the model results for changes in world prices, the authors estimate that replacing 7 % of 2020 EU road fuel with 1st generation biodiesel and a further 3 % with 1st generation bioethanol would increase world vegetable oil prices by roughly 18 % and world cereals prices by roughly 2 %.

The commodity price of crops on the EU market rises more than the world price. The price rise of cereals for less than for oilseed crops because the market is much larger and

because part of the ethanol comes from sugar crops. On the other hand, cereals prices have a greater effect on food security.

EU biofuels produce animal feed as by-products, but also compete with the animal feed sector for cereals and land. Overall, several different economic models indicate that they have a roughly neutral effect on the EU livestock industry.

Biofuels increase commodity crop prices and hence land rents, so benefits are felt mostly by the owners of farms in areas with intensive grain production.

Biofuels are thought to have increased food price volatility by creating a link between crop prices and the crude oil price.

Additional production cost of biofuels per litre

Bioethanol, and to a lesser extent biodiesel, have lower energy content per litre than the fossil fuels they substitute. In low blends (<15 %), biofuels replace petrol and diesel on the basis of equal energy content for the same vehicle performance. Thus 1 litre of bioethanol replaces 0.66 litres of petrol, and one litre of conventional biodiesel replaces 0.92 litres of diesel.

Bearing in mind the lower energy content per litre of ethanol and biodiesel, the cost of replacing one litre of fossil fuel is about the same: wheat ethanol and rapeseed biodiesel are both about 67 % more expensive to produce than the petrol or diesel they replace (all at 2011 prices). Per GJ of fossil fuel replaced, the extra cost is EUR 9-11 per GJ for biodiesel, and 10-14 for ethanol.

Ethanol from sugar cane in Brazil has the lowest unsubsidised production cost of any existing biofuel. This is a result of high yields, availability of bagasse waste to fuel the process, large scale, cheap labour, and a long period of process optimisation. However, even with all these advantages, ethanol is only competitive at the pump in Brazil because it is subject to a lower fuel tax (12-30 %) than is petrol (~54 %)[146]. There is also a mandate for blending of ethanol in petrol in Brazil. Of course, if the EU imports ethanol from Brazil it needs to pay the world commodity price, not the production cost in Brazil. So in the EU, the extra cost for replacing fossil fuel with bioethanol from Brazil is still in the region of EUR 14/GJ.

Greenhouse gas savings per litre of biofuels, and cost of savings for different biofuels

The calculation of 'direct' (well-to-tank) emissions GHG from biofuels excludes the CO_2 released by burning carbon from biomass. The rationale for this is that it was absorbed from the air when the biomass was grown. Without this 'carbon-neutral' assumption, biofuels would emit considerably more greenhouse gas than the fossil fuels they replace.

Without including ILUC emissions, greenhouse gas emissions from commercially available biodiesel from crops (palm oil, soya beans, sunflower and rapeseed) are typically between 35 % and 50 % lower than those of the fossil diesel they replace. The cost of saving GHG emissions would then be at least EUR 100/tonne of CO_2 equivalent for palm oil biodiesel and EUR 330/tonne of CO_2e for rapeseed biodiesel.

[146] Daniel Bergamasco and Roberto Machado (2008-08-27). This effect outweighs the effect of the Brazilian government holding petrol prices below world levels.

However, if ILUC emissions, as estimated for the EC by IFPRI with the MIRAGE model, are added, first-generation biodiesels show higher emissions than the fossil fuels they replace, so the cost of GHG saving can be considered infinite. This would be different for biodiesels made from genuine waste materials, which generally have high savings and low ILUC emissions.

GHG savings from replacing petrol with bioethanol fuels depend on the source of the ethanol.

- Ignoring ILUC emissions, ethanol from sugar crops (beet or cane), or from straw, typically saves 50-90 % of the fossil emissions, but much less if one adds to sugar crops the ILUC emissions estimated for the EC by IFPRI[147].
- Ignoring ILUC emissions, ethanol from cereals typically saves about 20 % of petrol emissions, but very little if the ILUC emissions estimated for the Commission by IFPRI are added.

Even without considering ILUC emissions, the cost of saving GHG emissions works out at EUR 100-200/tCO_{2e} for sugar-based ethanol and EUR 300-800/tCO_{2e} for wheat ethanol.

Electric cars (charged with EU-mix electricity) save about half the GHG emissions of conventional fossil-fuel powered cars. Obviously savings are even higher if they are charged with electricity from biomass or other renewables. The cost of GHG savings would also be lower than biofuels if the extra cost of the car is not considered.

Direct and indirect land-use change (ILUC)

If biofuels are grown on previously uncultivated land, this generally causes direct land-use change emissions owing to the release of carbon from stocks in soils and standing biomass.

More usually, biofuels come from crops grown for food, which can divert food production on to new land and cause indirect land-use change (ILUC).

Sustainability criteria in EU directives exclude direct conversion of some types of land with high carbon stocks, but this does not prevent ILUC emissions.

Both RED and FQD mandate the Commission to assess the impact of ILUC emissions and to examine regulatory options for addressing it. The proposal on how to minimise the risks of ILUC issued in 2012 by the Commission (COM(2012)0595) has not been agreed by Member States or by Parliament, and therefore ILUC is still not addressed in EU legislation.

Estimating ILUC

Usually, economic models are used to estimate ILUC emissions. Models results generally agree that:

- ILUC emissions are significant.
- ILUC emissions of existing biodiesels are higher than those of ethanol, especially from sugar crops. This is mainly due to all vegetable oil demand increasing palm oil demand, which gives extremely high land-use-change emissions as it expands on to tropical peatland.

[147] ILUC emissions for wheat straw are not included in IFPRI analysis for the EC.

- Most ILUC from EU biofuels is outside Europe. This is because the common agricultural policy has the effect of restraining crop area change inside the EU.

The ILUC results of the long-established groups in charge of existing economic models are gradually converging. However, it is also possible to construct spreadsheet calculations of ILUC which assume a particular chain of consequences from an increase in biofuel demand. In this case a vast dispersion of results is possible depending on the details of the assumptions chosen.

Models work through price changes: biofuels increase crop prices, which boosts crop supply and suppresses competing demand, notably for food and animal feed. The by-products of biofuels mitigate their effects on animal feed supply, but the models predict a reduction in human food consumption.

As reduction in food consumption provides feedstock for biofuels without ILUC, this substantially reduces the estimates of indirect land-use change. Hence the models with the largest reduction in food consumption tend to show the lowest ILUC emissions.

Avoiding ILUC

By its nature, ILUC cannot be avoided if feed stocks are bought off the market. The only certain way is to approve biofuels only on a 'project basis', where the project must demonstrate how it will sequester additional carbon, for example by replanting abandoned or degraded land, by measures to increase yields, or by reducing food waste etc. This would also prevent food diversion to biofuels, as feedstock would necessarily come from additional crop production.

Yields and ILUC

Over recent decades, more than half of the increase in world crop production has come from yield increase rather than increases in harvested area.

However, in spite of large crop price increases, long-term data suggest a slowdown in yield growth rates in recent decades at world level, especially in developed countries. In particular, wheat yields in Europe have stagnated in recent years despite large rises in crop prices.

Nevertheless, what is important to ILUC models is how yields respond to crop price changes, in comparison with how crop area responds. Recent research suggests that yields may respond less to price than is assumed in the economic models used to estimate ILUC. That would mean models are underestimating ILUC.

Impact on water use and biodiversity

Biofuels have a larger water footprint than fossil fuels, so they use more freshwater resources. This could be problematic in regions which already experience water shortages, especially in fast-developing economies with growing demand for both food and energy.

Biofuels can have either a positive or negative impact on biodiversity, depending on the feedstock considered, previous land use and management practices. In the case of conversion of natural and semi-natural habitats the impact is in general negative. The use of crop residues and perennial crops usually has less negative impact on biodiversity than that of annual crops. Moreover, the impact linked to ILUC can be significant, although it is difficult to assess: although sustainability criteria in directives exclude biofuels grown on

land converted from areas of high biodiversity, this does not prevent indirect loss of biodiversity through ILUC.

Impact on EU refining industry

By 2020 the EU biofuels are expected to replace about 10 billion litres of petrol and 20 billion litres of diesel. However, this represents less than a quarter of the anticipated overall decline in EU demand for refinery products, owing to improvements in car and industrial efficiency, switching to natural gas, etc.

Simple distillation of crude oil yields a ‘natural’ ratio of diesel to petrol. However, the diesel/petrol ratio in EU demand is considerably higher than this, and is increasing with the growth in the proportion of diesel cars. EU refineries spend money and energy on increasing the diesel sector, but it soon becomes cheaper to import the extra diesel fuel as a finished product, and/or to export the excess petrol.

As biodiesel replaces diesel, it partly alleviates the imbalance between demand for diesel and petrol in the EU, whereas ethanol replacing petrol exacerbates it. Therefore ethanol is more damaging to the competitiveness of the EU refinery industry than is biodiesel.

Blending biodiesel in EU diesel reduces the need for crude oil imports. However, that is not necessarily the case for ethanol in petrol. As EU refineries already produce an excess of petrol compared to diesel, replacing some of the petrol market with ethanol may to some extent lead to more petrol exports rather than less crude oil imports. In this sense biodiesel is better for improving security of supply.

Vehicle compatibility of biofuels

Biodiesel could potentially cause problems in cars with certain types of particulate filter or after treatment devices when used at high blending ratios. However, there has been no problem up to the limit of 7 % blending, which is within the present EU diesel standard. This standard also covers cold-flow characteristics and, if respected, should prevent any problems of fuel supply blockage in the vehicle.

Car manufacturers need to avoid certain materials in their fuel systems in order to avoid degradation if more than 5 % ethanol is blended. This is the reason for the existence of the E5 ‘protection grade’ fuel standard. Modern cars should be able to cope with E10 (10 % ethanol) standard fuel.

Biofuels and vehicle air pollution

Biodiesel generally reduces emissions of particulate matter (PM) but increases emissions of nitrogen oxides (NOx), and the effects increase with blending level. Engine manufacturers may benefit from such NOx-PM tradeoffs to reduce emissions through proper engine calibration where multifuel compatible engines are developed. The use of biodiesel in blends of up to 7 % will not contravene the NOx emission standard, and it could even be used in areas suffering from photochemical pollution, providing benefits from the significant reduction of PM. The effect of ethanol blending on tailpipe pollutant emissions is equivocal: some pollutants significantly decrease and others significantly increase.

Ethanol increases evaporative emissions. Blends of 5-10 % considerably increase the vapour pressure of petrol. That increases the evaporation of VOCs (volatile organic compounds) from the fuel tank and other components. VOCs are of particular concern in combination with NOx, when they increase ozone formation.

Regarding non-regulated pollutants (benzene, toluene, ethyl benzene and aldehydes, etc), both for biodiesel and bioethanol, studies suggest that these can either increase or decrease and are not necessarily proportionally dependent on the blending ratio.

Second-generation biofuels

Second- (and third-) generation biofuels can widen the feedstock options and produce a larger amount of fuel for the market, with the potential for greater GHG emission savings compared to first generation biofuels. On the other hand, it is important to consider that any biomass tends to save more greenhouse gas, and at much lower cost, if burnt for heat or electricity than if made into liquid biofuel. This is a result of the JEC-Well-to-Wheel (WtW) and many other LCA studies, and is stated as well in the RED Impact Assessment[148]. This suggests that where there is a choice, biomass is better exploited for these uses.

Resource efficiency and sustainability considerations strongly favour the use of biomass residues such as manures, straws and logging residues. Almost half of the technical potential for biomass in the EU comes from agricultural and forestry residues.

However, many feedstocks proposed as ‘wastes’ or ‘residues’ have an existing use, and the full GHG and economic implications of diverting these to biofuel need to be investigated first. Similarly, the carbon implications of an increased use of forest biomass for bioenergy need to be well understood (see below).

Second-generation biofuels presently constitute an almost negligible share of the biofuels used in transport; according to Member States’ declarations in the National Renewable Energy Action Plans, only about 1 % of the target of the RED will come from advanced biofuels even in 2020.

Sustainability of the three main second-generation feedstocks

1. Forest biomass

Making and using biofuels from wood releases considerably more carbon per unit of energy than the fossil diesel or petrol they replace. However, traditionally, estimates of GHG savings have assumed that burning biomass is carbon-neutral because the trees will absorb that same carbon out of the air during their regrowth. Under this assumption, there are large savings of carbon emissions.

However, if the policy incentivises larger removal of wood for bioenergy from existing forests, the release of carbon by combustion is more or less immediate, but the compensating absorption of the carbon by increased tree growth will be spread over many years into the future; in the meantime there is a ‘carbon debt’. This is valid even if the forest is replanted and the rate of cutting is within the ‘maximum sustainable yield’. Therefore, if trees (stemwood) are felled specifically to make biofuels, GHG savings will be accrued only many decades or even centuries into the future, and such bioenergy will not contribute to reaching GHG reduction targets.

Forest logging residues are the branches and other parts of the trees which are traditionally left in the forest after harvest of stemwood; they are expected to provide most of the additional EU biomass for biofuels and bioenergy by 2020. In this case the carbon debt

[148] SEC(2008)0085.

lasts only for a period of time of the order of a decade or two, whilst waste wood has no carbon debt.

New plantations of trees or perennial biomass crops actually show a carbon credit as they are growing. However, unless they are on marginal or degraded land (where carbon stocks can only improve), direct or indirect land-use change emissions need to be accounted for. ILUC emissions of second generation ethanol from energy crops on existing cropland are likely to be similar to those of wheat ethanol.

Market-mediated impacts, such as displacement of wood from products or from other energy sectors, should be also included in the analysis of biofuel policies.

Furthermore, other climate forcers, such as surface albedo change and evapotranspiration, should be fully accounted for in order to properly evaluate the climate impacts of bioenergy beyond GHG emissions calculations.

2. Biofuels from waste and residues

Bioenergy from cereal straws, pruning residues, animal manures and residues from forestry logging operations will generally achieve GHG emissions savings compared to fossil fuels, even when all the direct and indirect impacts are considered.

Neither direct and indirect LUC emissions from straw (and other unused crop residues) are zero, but both are much lower than for crops or energy crops.

Residue removal can also reduce (or slow the increase rate of) the carbon stored in soil organic matter, and lead to some loss of biodiversity.

However, many waste/residue materials (other than straw) also have existing uses, which in some cases save more carbon emissions than does their use as biofuel feedstock.

Therefore, the consequences of diverting these materials to biofuel production must be considered, including price movements induced by incentives given to waste feedstocks: for example, the double accounting and the targets foreseen in the RED made used cooking oil more valuable than fresh oils, leading to opportunities for fraud.

3. Biomethane

Biomethane produced by anaerobic digestion of energy crops can potentially cause GHG emissions higher than fossil natural gas if production occurs without the proper technological and management choices. The following emissions of methane (and N_2O) can significantly reduce or fully cancel any GHG saving:

- From the storage of the digestate in an open tank;
- From accidental leakages and venting or flaring during anomalous conditions;
- From the off-gases released from biomethane upgrading plant;
- From the unburned methane released by the gas engine used for power production.

The anaerobic digestion of manures and residues using best practices can give excellent GHG savings. Best practices such as the use of gas-tight tanks for the storage of digestate and the installation of a flare should be strongly promoted to minimise methane emissions.

Prospects for improving biofuels

Outlook for cost reductions in first-generation biofuels

The outlook for the additional cost of first-generation biofuels over fossil fuels of course depends largely on how crop prices move compared to crude oil prices. Before about 2005, when biofuels started to become a significant factor in agricultural markets, it was reasonable to suppose that real crop prices would continue their historical fall, whilst crude oil prices would increase. In that case it seemed only a matter of time before biofuels would become cheaper than fossil fuels. What actually happened after 2005 was that, although the crude oil price rose, so did crop prices, and they became linked to the crude oil price.

Thus first-generation biofuels in the EU remain considerably more expensive than fossil fuels, despite steady progress in reducing costs and improving efficiency of processing. A projection by IEA suggests that ethanol from cereals could become cost-competitive with fossil fuel by 2020 under the most optimistic scenario, but there is no prospect of this for conventional biodiesel at least until 2050. The production cost of sugar-cane ethanol should soon become cheaper than that of petrol, but the EU will have to pay the world market price for this, not the production cost.

Outlook for emissions reductions in first-generation biofuels processing

Unlike sugar-cane ethanol, production of EU biofuels gives by-products which are sold as animal feed, and this is important to the economics of the process. It is possible to reduce the calculated direct greenhouse gas emissions of the process by using these by-products to heat the process, instead of e.g. natural gas.

However, this requires more expensive equipment, and the income from sale of animal feed is lost. Furthermore, this would remove the benefit which by-products have on indirect emissions from ILUC.

Any industrial process using heat will have lower emissions if it uses waste heat from electricity generation. However, installing combined-heat-and-power in small standalone plants is expensive. Therefore, it would be good to have incentives for co-locating many industrial processes (including biofuel factories) with electricity generating plants.

Brazilian ethanol/sugar plants are starting to use bagasse for electricity generation, which will further improve the already good greenhouse gas balance of the process, even if the investment would not be economic without state incentives.

Sequestration of CO_2 in off-gases (process exhaust gases) would reduce process emissions if the sequestration is additional, for example by new projects to supply waste gas to greenhouses, where some is sequestered in additional plant growth. Selling it as liquefied industrial gas does not give additional sequestration, because the market is already supplied entirely by CO_2 which would otherwise be emitted as waste gas.

Outlook for cost reduction of second-generation biofuels

The progress of second-generation biofuel production has been much slower than anticipated in RED, which reflected the very optimistic projections circulating at the time. The problem is not so much technical as economic. The plants are extremely complex and capital-intensive, and this cost handicap cannot be recovered unless feedstock is very cheap, the plant is built on a vast scale, and/or there are valuable by-products.

The economics of second-generation biofuel plants depend very much on scale. Cellulose ethanol demonstration plants of increasing size have opened, usually presented as 'the world's first commercial-size' plant, a term which has no precise meaning. The process is thus technically possible, but the economics are still unproven, and depend on how much value is placed on carbon emission reduction.

Thermochemical conversion of biomass via gasification can produce many types of fuel. JRC identified the most promising new biofuel route to be via black-liquor gasification, integrated into a woodpulp mill. This has now been demonstrated in one pulp mill, but even here costs are significantly higher than for fossil fuel. For a free-standing gasification-based biofuel plant, costs are much higher, as demonstrated by the closure of the Choren demonstration plant. Several second-generation plants have been seen to close soon after construction.

The specific investment costs of second-generation plants will come down if more of them are built, or if scale is increased. However, it is debatable whether and how long it will take for costs to become comparable with those for first-generation biofuels, let alone fossil fuel. The IEA has made estimates which range from 2026 to after 2050 depending on the particular biofuel, but the result depends critically on what crude oil prices, interest rates and feedstock prices are assumed.

It is often stated that second-generation biofuels can only be 'economic' if there are valuable chemical by-products: the 'biorefinery' concept. There are indeed many possibilities of co-producing complex organic chemicals; the challenge is to find ones with a large enough potential market to support a large-scale plant.

Waste and residues are attractive because of both cost and environmental sustainability. However, one needs enough feedstock in one place for a plant of commercial size, and to be sure that the supply of feedstock does not become too expensive because of restricted supply.

The US policy on second generation biofuels coordinates research on all stages of feedstock production, transport, processing and use. However, this involves picking winning technologies in advance. The European approach is more broad-based.

'Third-generation biofuel' usually means biofuel from algae. Many different approaches are being investigated and it is far too early to pick winners. A potential problem is scale-up of processes using pure strains of algae: the whole plant needs to be kept sterile to avoid invasion by natural organisms.

The difficulty for legislators is that industry wants favourable and stable incentives, but these must be based on uncertain forecasts. One solution is not to pick winners, but to incentivize the objectives of the policy and allow industry to find the most efficient solutions: for example, to reduce carbon emissions and increase security (and diversification) of supply. These issues could be addressed, for example, with a carbon emissions tax and fixed transport fuel tax reduction on fuels from domestic sources. The same incentives could then be applied to numerous industry sectors and transport solutions.

APPENDIX 1:
THE IMPACT OF DOUBLE COUNTING PROVISIONS IN THE RED DIRECTIVE ON THE MARKET IN USED COOKING OIL

This market analysis is aimed at identifying the attractiveness of committing fraud selling biodiesel made from fresh vegetable oil (FVO) as used cooking oil methyl ester (UCO) because of double counting and the targets foreseen in the Renewable Energy Directive (RED). This is to verify whether the claims that FVO is being sold as UCO, which are spreading on the press and in the biofuel sector in general, are reasonable.

UCO IN THE EU

UCO consists of oils and fats that have been used for cooking or frying (mainly deep-frying) in the food processing industry, restaurants and snack outlets, and for domestic frying. UCO can be collected and recycled to be used for further purposes, and can originate from both vegetable and animal fats and oils. It is estimated that currently around 90 % of cooking oils and fats used in the EU are produced from vegetable oils. However, in some Member States, such as Belgium, animal fats account for a relatively high share.

Even though core players on the UCO market (restaurants and fast-food chains) have recently reduced their output thanks to improved efficiency, a great potential still lies in households and small–scale restaurants. However, owing to the fragmentation of these actors, collection costs are significantly higher. Currently, approximately 35 % of the resource is collected in the EU, and 90 % of it is used for biodiesel production. Hart Energy (2013) estimates that the volume of UCO theoretically available in the EU could be as high as 2.4 million tonnes annually; however, each Member State has to have a well-developed recycling network in place. Estimates from the UCO industry suggest that approximately two thirds of the maximum volume could realistically be recovered (SEI, 2003): this would result in an obtainable UCO resource of about 1.6 million tonnes.

According to RED rules, biofuels produced from wastes account for double their actual energy content towards the overall target. Following the enforcement of the RED, an increasing number of EU Member States are implementing the double counting scheme into their national legislation (see the following figure).

Figure 67: Status of the implementation of double counting in EU Member States for used cooking oil (UCO) and animal fats (Cat. I, II and III)

In compliance with the RED, EU countries implement a double-counting scheme for waste based biofuels

	UCO	CAT I/II	CAT III	Market terms	Documents to provide
Germany	✓	✗	✗	From 2012, biofuels made from animal fats or animal oil (total or partial) are not countable towards the bio quota.	WTN, Nabisy, ISSCC/2BSvs, Declaration from the German producer
				Meant to be replaced by carbon footprint quotas for biofuel production by 2015	§ 7 der 36. BImSchV
Austria	✓	✓	✓	No feedstock restriction. Double counting effective from 6,6% of incorporation	
Belgium	na	na	na	Under development, announced for Sept. 2013	na
Denmark	✗	✓	✗		
Spain	na	na	na	Under development (discussion about the definition of waste and residue), announced for Jan. 2013	na
Finland	✓	✓	✓	Fatty acid based on palm oil included. The use of waste cooking oils not validated for the moment. Principle approved, the final act to follow.	
France	✓	✓	✗	Limit of 5% applied in 2012, under discussion for 2013	WTN, ISSCC/2BSvs, producer registration with the Ministry of Sustainable Development
Hungary	✓	✓	✓		
Ireland	✓	✓	✗		
Italy	✓	✓	✗	Constraint on the European origin of feedstock for biodiesel	WTN, ISSCC/2BSvs, declaration from the producer that UCO is produced in Europe
Holland	✓	✓	+/-	Exclusion of the Cat. III from January 2013	WTN, ISSCC, Dutch Double-Counting Certification
UK	✓	✓	✗	Regular application of the right to audit the collection of UCO from the restaurant to the production of biodiesel	WTN, ISCC, Auditing of the entire supply chain of feedstock

2

UCO = Used Cooking Oil - CAT I, II, III = *animal fat category* 1, 2 et 3

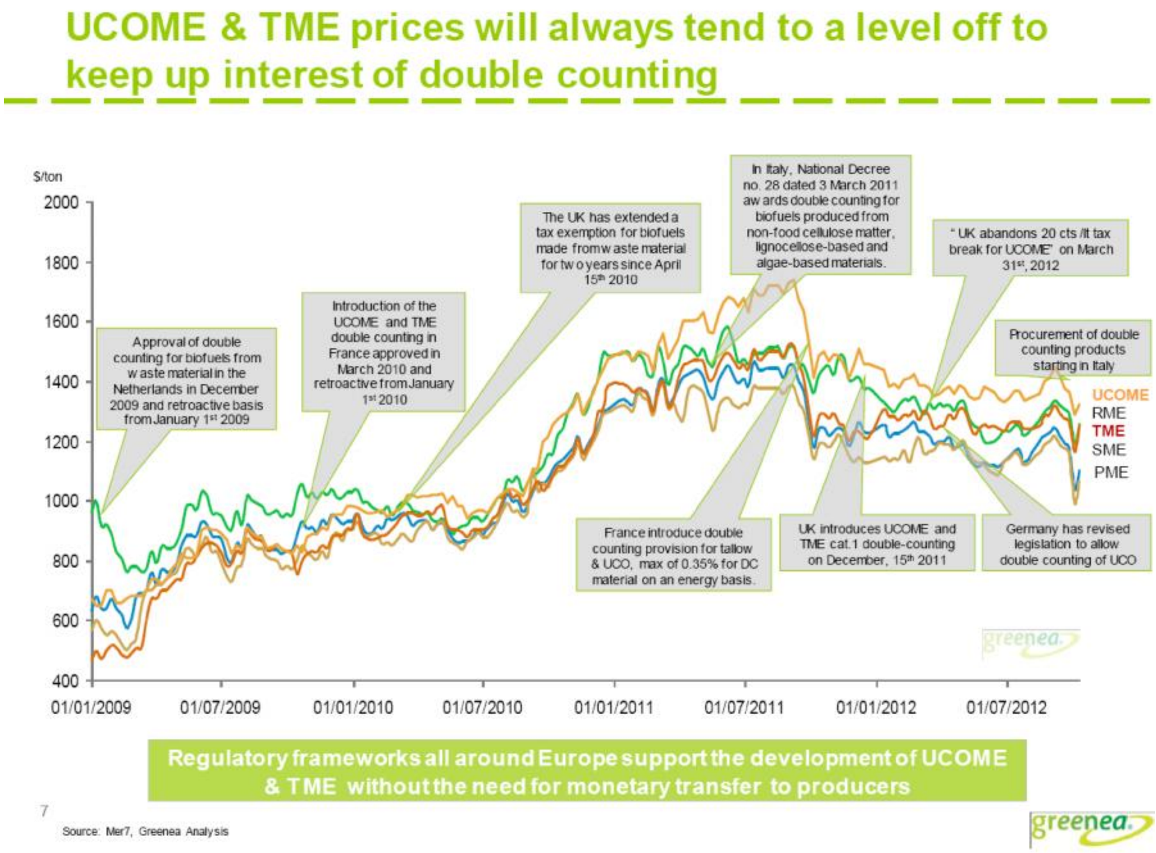
greenea

Source: GREENEA.

Designed to boost the market share of biofuels derived from waste and residues, which enjoy significantly better GHG savings performances, double counting schemes strongly impact the biodiesel market in the EU. As is shown in the figure below, the price of UCO is the highest among the fatty acid methyl esters (FAME), followed by rapeseed and tallow methyl esters (TME)[149]. Palm oil methyl esters are the cheapest.

[149] Tallow is a rendered animal fat.

Figure 68: Development of biodiesel (FAME) prices from 2009 to 2012



Conclusions

There is market attractiveness for unscrupulous economic operators to commit fraud and sell biodiesel from fresh vegetable oil methyl ester (such as SME, PME, RME) as UCO (or TME) because of the higher price of the latter. The profitability of such fraud is expected to increase in the future because of the expected increase in UCO prices. The double counting rule causes a distortion in the market resulting in higher prices for feedstock considered waste than for fresh feedstock. This might also happen for other residues/waste streams, leading to modification of industrial processing in order to obtain higher yields of waste residues than of the main product. Similar concerns have been voiced regarding 'single counting' biofuel feedstocks which do not have sustainability certification being sold as certified, here too in order to obtain a price premium.

APPENDIX 2: ESTIMATING HOW MUCH ANIMAL FEED BY-PRODUCT IS PRODUCED BY EU BIOFUEL FACTORIES

As explained in section 2.1.3, the amount of by-product from biofuels only tells half the story concerning the effects of biofuels on the livestock industry: much of the biofuel feedstock was taken from the livestock feed market in the first place, even if by-products return to it. The net effect, according to economic models, appears to be approximately neutral on the animal feed market, but there is a reduction in direct food consumption by humans (mostly outside the EU).

ePure (the association of EU ethanol producers) states that virtually all the feedstocks used for bioethanol production in the EU are from EU grown crops. According to the USDA 2012 EU Biofuels Annual, in 2012 bioethanol production in the EU used approximately 10.1 million tonnes of cereals and 10.3 million tonnes of sugar beet. In 2010, the figures were just over 8 million tonnes of cereals, and 10.7 million tonnes of sugar beet. The bioethanol production process produces a by-product, mostly in the form of dried distiller's grains with solubles (DDGS),[150] which can be used for animal feed. If we consider the year 2010, bioethanol production in the EU consumed the amounts of feedstock and produced the amounts of animal feed by-product shown below:

EU feedstock used for ethanol production	Amount of animal feed produced
3,733 kT of wheat	1,396 kT of wheat DDGS
2,530 kT of maize	751 kT of maize DDGS
1,122 kT of rye	420 kT of rye DDGS*
623 kT of barley	233 kT of barley DDGS*
10,705 kT of sugar beet	621 kT of sugar beet pulp

*Note: estimated using the ratio of DDGS produced from the wheat ethanol process, supplied to the authors by Lywood, W., ENSUS plc., 03/12/2010.

Approximately 45 % of the biodiesel produced in the EU comes from locally grown crops. The amounts of animal feed by-product produced in the EU are as follows:

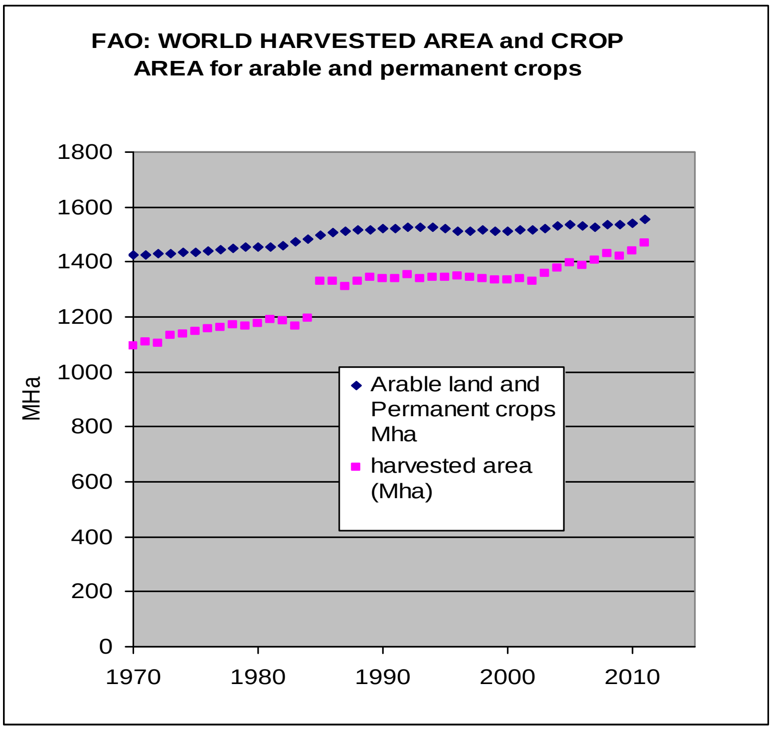
EU feedstock used for biodiesel production	Amount of animal feed produced
14,810 kT of rapeseed	8,323 kT rape meal
1,070 kT of soya beans**	581 kT soya meal
342 kT of sunflower seed	186 kT sunflower meal
Palm fruit	Not grown in EU
UCO & tallow	n/a

** Assumes the entire EU production of soya bean seeds were used for biodiesel production.

[150] DDGS are cereal by-products of the distillation process, derived mainly from protein, fibre and oil and used as animal feed.

During biodiesel production, another by-product, glycerine, is produced in the ratio of approximately 10 % of the mass of the vegetable oil feedstock used (it is replaced by methanol in the transesterification process). Traditionally, glycerine was predominantly used for industrial purposes (Elobio, 2009), but it can also be used as an animal feed constituent (Van Cleef et al., 2013). In 2010 glycerine production from EU-sourced crops stood at about 650 kT.

APPENDIX 3: FALLOW LAND IS JUST ONE COMPONENT OF FAO'S UNHARVESTED CROPLAND



The big jump in FAO harvested area between 1984 and 1985 (see graph) turned out to be merely the effect of adding 'pumpkins for fodder' to the FAO crops list.

The harvested area fell during the 1990s in ex-communist countries, following withdrawal of state production targets and land restitution to disparate private owners. This temporarily countered continued expansion in the rest of the world. The contraction in cropland should theoretically have followed with a lag of five years, as the FAO defines cropland as land which has been farmed in the previous five years. However, we suspect that this is expecting too much precision in national reporting to the FAO.

1. Not all 'unharvested cropland' is fallow

1.1. Missing crops

'Harvested area' is the sum of crop-area harvested of the crops in the FAOSTAT crop list. This does not include all crops. In spite of the considerable effect of adding 'pumpkins for fodder', the list still does not include such major and high-yielding crops as hay (16 % of US cropland), nor does it include improved pasture (think of Dutch polders). Such land is not available for cropping without a loss of other production, and is not fallow land.

1.2. Establishment years of permanent crops

For permanent crops, there is always an establishment period when the crop is not harvested. For palm oil that is about the first 5 to 7 years of a 25 to 30-year cycle (although some of that is in a denser nursery plantation). The fraction of unharvested oil-palm area depends on the age structure of the existing plantations, but Malaysian MPOB

data indicate a figure of 17 % of the harvested area in 2011. More importantly, sugar cane is harvested for only 5 years of a 6-year plantation cycle (20 % uncropped).

1.3. Missing harvests

If the crop fails, it is not harvested (or it is harvested for hay instead of grain: see point 1), and that land is not included in the harvested area, so it appears as uncropped.

1.4. US conservation reserve land appears to be considered 'fallow'

The FAO reported 70 million hectares more in unharvested cropland in the US than the fallow land in USDA data[151]. It appears that FAO unharvested cropland includes idled cropland under the Conservation Reserve Program and cropland used for pasture. The FAO seem to include conservation reserve areas as unharvested cropland, even though such areas should in fact be excluded from the FAO definition of cropland, as they have been out of production for more than 5 years.

2. Yields

2.1. Arid and marginal land

Siebert (Siebert S., F. T. Portmann, and P. Doll. 2010. 'Global Patterns of Cropland Use Intensity', Remote Sensing, 2(7): 1625–43) has shown that a large proportion of unharvested cropland appeared to be in arid regions of Central Asia and Africa, where shifting agriculture may crop one tract of land only once in 10 years or more, or else in the semi-desert western areas of the US, where the land is planted with an (unharvested) catch- or cover-crop in preparation for a crop proper in the subsequent year. Apart from doubts as to whether such land could be farmed more intensively, the yield would be very poor.

2.2. Farmers are less likely to crop low-yield fields

If unharvested cropland could support a national average yield, it would generally already be farmed. Therefore the yield on unharvested cropland is considerably lower than the national average, even if it is in a generally good farming area.

2.3 Double cropping does not mean double yield

Increasing cropping intensity by multiple cropping, again, does not increase production proportionally. Obviously, if the farmer could produce two harvests a year at the same yield as one he would be doing it already. In fact the decision to double-crop is a marginal one, which considers the reduction in yield-per-harvest. That reduction occurs because the growing season is shortened or crops are pushed out of their natural growing season.

3. Lost alternative uses of unharvested cropland

3.1 Foregone production

Even if not cropland according to the FAO, much unharvested cropland is in fact used for pasture or to grow hay, for which digestible energy yields can even exceed those for cereals. Unharvested cropland which is actually long-term idled land under conservation programmes sequesters carbon at a significant rate. The loss of these services needs to be accounted for when calculating ILUC area and emissions.

[151] http://www.ers.usda.gov/data-products/major-land-uses.aspx#25964.

3.2 Foregone soil improvement

In their decision not to crop a field in a particular year, farmers take into account the soil improvement which would boost the yield of a future crop, for example by ploughing in a legume cover-crop at the end of the season. This yield improvement is foregone if the land is cropped every year instead.

4. Source of FAO cropland data

The FAO cropland data date back to many years before satellite data came into wide use, and there is no evidence that there has ever been much correction. So the question of the source of these data is actually quite mysterious.

The M3 database of world cropland (Johnston, M., J.A. Foley, T. Holloway, C.J. Kucharik, and C. Monfreda, Resetting global expectations from biofuels, Environmental Research Letters 4:014004 (2009): doi: 10.1088/1748-9326/4/1/014004.), based on interpretation of satellite data, shows a significantly greater area under crops in the year 2000 than that reported under the FAO harvested area. Most of the difference is thought to be accounted for by subsistence agriculture in remote regions: the effect here is so strong that it results in much lower average yields in the M3 database. The question is, whether this remote cropland is included in FAO cropland (apparently it is not in the case of harvested cropland, for which the FAO yields are much higher).

5. CONCLUSIONS

The difference between FAO harvested area and FAO cropland (= unharvested cropland) greatly overestimates the area of what one would normally consider as fallow.

The net extra production which could be taken from unharvested cropland would be much less than that indicated by the fraction of area, thanks to poor yields and lost benefits.

APPENDIX 4: GHG EMISSIONS FROM DIFFERENT BIOFUELS PATHWAYS – TECHNICAL DETAILS

Table 40 shows the GHG emissions for the bioethanol pathways considered. These pathways are selected from the WTT v4 (2013) Appendix 2 EUR 26028 EN, available at http://iet.jrc.ec.europa.eu/about-jec/

This gives a full explanation of these pathways, using the same pathway codes.

WTT data are shown in the middle column with the uncertainty interval. In the third column of Table 40, the authors of this report have added to the WTT data the ILUC values proposed in COM(2012)0595 on a per crop group basis (or using the latest JRC-IFPRI estimate for straw).

Table 40: Bioethanol pathways considered and GHG emissions

Bioethanol specific pathways: WTW code and brief description	GHG emissions WTT (gCO_2eq/MJ)	GHG emissions including ILUC (gCO_2eq/MJ)
COG: conventional petrol	13.8	N/A
WTET2a: ethanol from wheat Natural-gas-fuelled CHP, credit for excess electricity; DDGS as animal feed (best pathway for wheat)	64.8 (61.4-68.2)	76.8
WTET1a: ethanol from wheat NG-fuelled boiler; DDGS as animal feed	69.4 (67.0-71.8)	81.4
SCET1: sugar cane to ethanol EtOH produced in Brazil, used in Europe, excess biogas to electricity credit for excess electricity	24.8 (22.7-26.9)	37.8
SBET1c: sugar beet to ethanol Pulp for combustion, waste water and slop for biogas, credit excess electricity from pulp (best sugar beet pathway)	17.8 (15.8–19.8)	30.8
SBET1b: sugar beet to ethanol Slop to biogas, animal fodder export; credit for pulp as animal feed	27.2 (24.7–29.3)	40.2
SBET1a: sugar beet to ethanol Animal fodder export; credit for pulp as animal feed	40.3 (37.4–42.6)	53.3
STET1: wheat straw to ethanol Ethanol with SSCF process, wheat straw transported for 500 km	9.2 (9.1-9.2)	13.2
CRETUS: Ethanol from US maize grain Ethanol produced in the USA and used in the EU; DDGS as animal fodder	68.9 (66.7-70.4)	80.9
CRET2a: Ethanol from EU maize grain NG CHP, credit for excess electricity; DDGS as animal fodder	80.3 (76.8-83.4)	92.3

Table 41 offers a brief overview of the different biodiesel pathways (first column), showing the WTT GHG emissions without ILUC (second column) and with the ILUC values proposed in COM(2012)0595 per crop groups.

Table 41: Biodiesel pathways considered and GHG emissions

Biodiesel-specific pathways: WTW code and brief description	GHG emissions WTT only (gCO_2eq/MJ)	GHG emissions including ILUC (gCO_2eq/MJ)
ROFA1: biodiesel (FAME) from rapeseed Propylene glycerol replacement (credit for glycerol as chemical); credit for seed meal as animal feed (best pathway for rapeseed)	53.9 (48.6-60.5)	108.9
ROFA3: biodiesel (FAME) from rapeseed Glycerol to fuel; credit for seed meal as animal feed	57.0 (49.8-63.7)	112
ROFA2: biodiesel (FAME) from rapeseed Glycerol and rapeseed meal as animal feed	58.7 (51.5-64.7)	113.7
SOFA3: biodiesel (FAME) from sunflowers Glycerol for biogas; credit for sunflower seed meal as animal feed	45.9 (42.4-49.4)	100.9
SYFA3c: biodiesel (FAME) from soya beans Glycerol to biogas and soya bean meal to animal feed	60.7 (46.8-74.6)	115.7
POFA3b: biodiesel (FAME) from palm oil Imported palm oil (16 % grown on peat) Glycerol to fuel, CH_4 recovery, heat credit Credit for kernel meal as animal feed (best case)	31.2 (30.6-31.7)	86.2
POFA3a: biodiesel (FAME) from palm oil Imported palm oil (16% grown on peat). Glycerol to fuel, no CH_4 recovery, heat credit Credit for kernel meal as animal feed	50.8 (50.2-51.4)	105.8
POFA3c: biodiesel (FAME) from palm oil. Imported palm oil (16 % grown on peat). Glycerol to fuel, no CH_4 recovery, no heat credit. Credit for kernel meal as animal feed	62.6 (62.0-63.1)	117.6

The values reported in Table 40 and Table 41 show the wide variability of GHG figures for similar biofuel pathways. For example, for biodiesel from palm oil pathways POFA3b and POFA3c show quite different results. The differences are that in POFA3b, 'CH_4 recovery' means that the methane emissions from the pond of rotting palm oil mill effluent are collected (a practice that a few mills are starting to follow), and a 'heat credit' is given for the export of nutshells (for use as fuel) in excess of those used for heating the oil mill.

Glycerol by-product (about 10 % of the biodiesel output) has a wide range of uses, from chemical product (highest GHG credit) to animal feed (lowest GHG credit). Its use as a fuel yields a credit in between these – it can be burned or co-fired directly, or added to a biogas digestor before the resulting biogas is burned: the results are almost the same.

GHG savings of bioethanol pathways (in the final column) are reported in terms of a percentage obtained by comparing biofuel GHG emissions with GHG emissions from the reference pathway 'Petrol from crude oil' (named COG1 in the WTT v4 report). Petrol emissions considered are 87.2 gCO_2eq/MJ (13.8 gCO_2eq/MJ for the supply and 73.4 gCO_2eq/MJ for the combustion of petrol).

The authors of this section selected a sub-group of WTT pathways which probably occur in practice, but even then there were several pathways for each type of biofuel. So to simplify the discussion, we show here only the range of results for each crop.

However, it should be noted that the merged averages are simple arithmetic averages, even if most of the more favourable pathways are at the moment only employed in a minority of production (producer organisations have not published data on the mix of pathways actually employed). We repeat that the uncertainty range presented is only for 60 % probability, and we have considered only the most common pathways for biofuel production. Therefore there may be numerous specific exceptions. Furthermore, the soil-N_2O emissions and ILUC factors are both uncertain.

Table 42: GHG emissions for bioethanol from different crops

Bioethanol fuels (merging specific WTW pathways)	GHG emissions WTT (gCO_2eq/MJ)	GHG savings WTT (%)	GHG emissions incl. ILUC (gCO_2eq/MJ)	GHG savings incl. ILUC (%)
EU wheat to ethanol (merging WTWT2a and WTWT1a)	67.1 (±5.2)	23% (±6%)	79.1 (±6.5)	9% (±8%)
Brazilian sugar cane to ethanol (SCET1)	24.8 (±2.1)	72% (±2%)	37.8 (±7.1)	57% (±8%)
EU sugar beet to ethanol (SBET1c, SBET1b, SBET1a)	28.4 (±13.4)	67% (±15%)	41.4 (±14.3)	52% (±16%)
Ethanol from maize grain (CRETus, CRET2a)	74.6 (±8.4)	14% (±10%)	86.6 (±8.9)	0.7% (±10.3%)
EU wheat straw to ethanol (STET1)	9.2 (±0.5)	89% (±5%)	13.2 (±3.7)	85% (±5%)

Similarly, in Table 43 the biodiesel-specific pathways are merged into a homogeneous set of pathways, generically describing different biodiesel fuels. GHG savings are reported in percentage terms in comparison with the 'diesel from oil' pathway.

GHG savings of biodiesel pathways have been calculated by comparing biofuel GHG emissions with GHG emissions from the reference pathway 'Diesel from crude oil' (named 'COD1' in the WTT-4 report). Diesel emissions considered are 88.6 gCO_2eq/MJ (15.4 gCO_2eq/MJ for the supply and 73.2 gCO_2eq/MJ for the combustion).

Table 43: Biodiesel pathways considered and GHG emissions

Biodiesel fuels: (merging homogeneous WTW pathways)	GHG emissions WTW only (gCO_2eq/MJ)	GHG savings WTW only (%)	GHG emissions incl. ILUC (gCO_2eq/MJ)	GHG savings incl. ILUC (%)
Biodiesel (FAME) from rapeseed (merging ROFA1, ROFA3 and ROFA2)	56.5 (±9.2)	36 % (±10 %)	111.5 (±21.2)	- 26 % (±24%)
Biodiesel (FAME) from sunflowers (SOFA3)	45.9 (±4.0)	48 % (±4 %)	100.9 (±15.1)	- 14 % (±17 %)
Biodiesel (FAME) from soya beans (SYFA3c)	60.7 (±13.9)	31 % (±16 %)	115.7 (±18.4)	-31 % (±21 %)
Biodiesel (FAME) from palm oil (POFA3b, POFA3a, POFA3c)	48.2 (±16.3)	46 % (±18 %)	103.2 (±17.2)	-17 % (±19 %)

GHG emissions and GHG savings including ILUC are presented for completeness' sake in the last two columns. The numbers in red appear thus because the emissions from these biodiesels are higher than those from conventional diesel (negative GHG savings).

APPENDIX 5: DETAILED ANALYSIS OF BIOENERGY-INDUCED ENVIRONMENTAL IMPACT USING RESIDUES AND WASTES

This annex expands the description given in Section 5.3 of the environmental impact caused by an increased removal of agricultural and forest residues compared to the baseline described. Below, each removal effect is analysed in details and the sources substantiating the conclusions are listed.

A.5.1 Cereal straws

Removal effects[152]

Straw removal potentially leads to diverse environmental impact, the most significant being decrease in SOC, soil nutrients and soil fertility, levels of which will depend on site-specific characteristics

Soil organic carbon (SOC)[153] and nutrients: Removal of agricultural residues from the field reduces soil carbon and nutrient pools. This removes the carbon and nutrients contained in the residues, increases run-off and soil erosion, and accelerates organic matter mineralisation under the bare soil surface because of alterations in soil temperature and moisture regimes (Blanco-Canqui and Lal, 2009; Johnson et al., 2010).

The SOC decreases in proportion to the rate of residue removal (Liska et al., 2014), but the magnitude of the decrease depends on a variety of factors. These include the antecedent SOC concentration, soil type, quality of residue, rate of fertiliser application, topography and climate. Although in most situations straw removal has a relatively small effect on total SOC (Lemke et al., 2010; Powlson et al., 2011), even the removal of a small percentage of residues from fields can have a negative impact on the soil properties (Powlson et al., 2011).

Agricultural residues are also an important reservoir of essential macronutrients and micronutrients. The negative impact of crop residue removal on total carbon and nitrogen pools is generally larger than that on other nutrients (Blanco-Canqui and Lal, 2009), but phosphorus and potassium removals can also be significant (Powlson, 2006). Therefore, decreased nutrient input needs to be compensated by increased application of fertilisers. Concerning cereal straws in particular, due to the high C/N ratio of the material, incorporation in the soil and subsequent microbial decomposition might immobilise soil-N. As a result, in many cases nitrogen fertilisation is planned independently from the incorporation or not of straws. Other nutrients such as K and P are more likely to need to be replenished by additional use of mineral fertilisers.

Soil fertility: Straw removal has a larger impact on the soil microbial biomass than on total SOC, which in turn influences soil physical properties and fertility. Microbial biomass influences formation of stable aggregates by producing organic binding agents (Powlson et al., 2011; Watts et al., 2001). The impact of residue removal on crop yields is highly variable and depends on factors such as: the tillage method; cropping systems; duration of

[152] Many of the empirical results are obtained in extreme conditions (complete removal of residues from the soil) in order to amplify the differences between management conditions. Partial retention is thus included in the mitigation option.

[153] Soil organic carbon (SOC) is the amount of elemental carbon contained in soil organic matter. It is generally agreed that this amounts to about 58 % of SOM.

tillage and crop management; soil-specific characteristics (e.g. texture and drainage); topography; and climate during the growing season. It is generally considered that residue removal can have an adverse effect on yields in dry conditions, due to decrease in soil water content (Blanco-Canqui and Lal, 2009).

In some regions in Europe, especially southern Europe, SOC content is already low and decreasing, with 74 % of the land being covered by soils with low or very low organic carbon (JRC-IES, 2012). As a result, straw removal in such areas would mean not only a lower SOC but also a faster fall towards levels of SOC at which cultivation would no longer be possible (Vito, 2011).

Finally, it should be considered that eventual losses in productivity in low-SOC soils would cause even less residues to be produced and incorporated in the soil, with a subsequent vicious circle which could lead to an irreversible loss of productive land (Zdruli, 2004).

Nitrous oxide (N_2O) emissions: N_2O is formed in soils during nitrification and denitrification processes. These can occur simultaneously and are driven by soil micro-organisms, oxygen, temperature, water content, available carbon, soil physical properties and other factors. In general, it is considered that straw removal decreases N_2O emissions (Cherubini and Ulgiati, 2010; Monteleone et al., 2013). However, these emissions vary significantly depending on complex interaction between residue characteristics, fertiliser application, management practices and soil and climate conditions.

Pest and diseases: In general, it is expected that straw incorporation in situ would increase the severity of cereal diseases. However, the effect often seems to be relatively small and often short-lived (Jenkyn et al., 2001). Also, some disease-producing organisms can be enhanced by residue removal. In general, the main effect of residue removal, especially in the short term, is decreased amounts of crop debris, which for many pathogens is an important source of propagules. However, the debris is also an important habitat for a wide range of micro-organisms, some of which may be competitors or antagonists of some of the pathogenic species (Jenkyn et al., 2004).

Biodiversity and water: Residue removal from agricultural fields might have a negative impact on species that depend on agricultural habitats, e.g. farmland birds. Lower input of fresh organic matter into the soil will impact species living on the soil surface and in the soil, and this could have a cascade effect on these ecosystems as a whole (Kretschmer et al., 2012). Also, increased removal of agricultural residues might increase soil erosion and nutrient leaching, causing problems with sediment delivery and eutrophication (proliferation of plant life in response to excessive nutrients) in nearby waters.

Co-products from bioenergy production could be applied back to the fields, partly mitigating removal effects

Use of by-products and mitigation: Conversion of straw to ethanol generates a residue (or co-product, depending on definitions) that is very high in lignin, carbon and nitrogen content. Application of these co-products back to the fields might partly offset the negative impact of residue removal on SOM, nutrients and soil properties (Blanco-Canqui and Lal, 2009). Alternatively, when straw is used in combustion processes, the residual ashes contain part of the removed nutrients (especially phosphorus and potassium), which could be applied back to the soil. However, logistical problems, an uncertain regulatory framework and variable chemical composition of the ashes could hinder their effective reutilisation.

Furthermore, biochars, by-products of flash pyrolysis processes to produce pyrolysis oils, are receiving increasing amount of attention as potential soil amendment materials. Use of biochars has been associated with increased yield and reduction of N_2O emissions from N-fertilisation (Liu et al., 2013). However, the debate on the advantages and risks of using biochar on soils is still ongoing (Mukherjee and Lal, 2014).

Partial retention of straw could limit or avoid some of the impact analysed here, but in many cases the magnitude of such impact is proportional to the amount of residues removed/incorporated. Therefore, removing 30 % of the straw would still have a larger negative impact by comparison with leaving it all. One of the principles of conservation agriculture, furthermore, is the need for permanent or semi-permanent soil cover, which is also achieved by leaving all residues on the field (BEFSCI FAO, 2012).

Residues removal should be accompanied by management practices – among them reduced tillage, cover crops, or manure application – which can offset potential adverse impact.

A.5.2 Pruning residues

Removal/displacement effects

Pruning residues could be used for bioenergy production or applied back to the fields, improving on current management by protecting the soil and providing nutrients

Greenhouse gas (GHG) savings: The use of pruning residues for energy production can save fossil GHG emissions by replacing fossil fuels. This effect would be immediate in case of alternative on-site combustion. However, in case of landfilling, decay rates of the wood would be very slow, so that GHG advantages respect to fossil sources may not be immediate but rather delayed in time.

Soil improvement: Pruning residues can be returned to the soil as a part of conservation soil management practices (e.g. no tillage, cover crops). This practice can reduce soil erosion and increase soil organic carbon, which enhances soil quality and fertility (Repullo et al., 2012; Nieto et al., 2010; Montanaro et al., 2012; Montanaro et al., 2010). However, in some cases a longer period might be needed (up to 10 years) for changes in SOC to become evident. This is especially important in the Mediterranean region, where soils generally have low content of organic matter and low fertility (Zdruli et al., 2004). The situation is aggravated because crops are often cultivated in sloping areas with poor soil covering and, owing to characteristics of the Mediterranean climate, including irregular rainfall with heavy storms in autumn and winter which lead to soil erosion. Therefore, displacement of pruning residues could have a negative impact on soil properties.

A.5.3 Feedlot manures

Removal/displacement effects

In order to analyse the actual impact of biogas production, it is important to consider the differences (in terms of fertilising potential and direct emissions) between digestate and solid manure, and between digestate and liquid slurry. From the existing literature it is possible to infer the following:

- Soil organic carbon (SOC) content is likely to increase less if digestate is used rather than raw manure or slurry

The more labile part of the organic matter content of the manure is digested to biogas, so the carbon content in the digestate is undoubtedly lower than in the untreated manure. This could potentially have negative effects on the long-term accumulation of SOC, which is proven to take place with constant application of manure (Hao et al., 2003; Haynes et al., 1998; Khaleel et al., 1981; Sanchez et al., 1989). However, the digestate is richer in more stable, undigestible compounds (e.g. lignin) which are known to be precursors of soil organic matter (SOM) formation (Lorenz et al., 2007). The presence of recalcitrant molecules contributes actively to the SOM in a short period (Tambone et al., 2010). Consequently, the high carbon losses during digestion may not correspondingly reduce the subsequent carbon retention in soil (Möller, 2009; Reinhold et al., 1991).

Long-term trials and numerical modelling are being carried out, especially in Europe. A long-term simulation shows a slight decrease in accumulation of SOC when digested pig slurry is applied compared to raw slurry (Jørgensen and Petersen, 2006). Cayuela et al. (2010) have presented a lab-scale experiment where the carbon emissions from cow and pig manures (and associated digestates) applied on soil were measured for a period of 60 days. They found that residues application increased the absolute carbon content in the soil and that indeed a larger share of the initial C applied was retained in the soil when digestates were used. However, they also found that the absolute C left in the soil was actually higher for manures than for digestates. The long-term effects of using digestate on SOC are not yet fully clear or quantified at this stage.

However, application of manure or slurry with higher amounts of easily degradable carbon can enhance nitrogen immobilisation, denitrification and N_2O emissions from soil (Alburquerque et al., 2012).

- Macronutrients (phosphorus and potassium) availability in digestate is unaffected by the anaerobic digestion

Macronutrients are generally not affected by the digestion; they are maintained in the digestate and recirculated to the field as they would have been by using manure (Möller and Stinner, 2010).

- Nitrogen in plant-available forms is increased in digestate compared to raw slurry, but the advantage is only short-term

Digestion has little or no effect on the total nitrogen content of digestate (around 5-6 % of nitrogen losses in the digester) (Battini et al., 2014). However, anaerobic digestion has been shown to increase the share of plant-available nitrogen in digestates compared to farmyard manure and even to liquid slurries. This characteristic has raised much interest, since it could potentially lead to savings of synthetic fertiliser when applying digestate.

According to some studies (Gutser et al., 2005; Fouda et al., 2013) a continuous application of digestate would supply more nitrogen to the plant in the year of application. At the same time, it would cause a lower accumulation of nitrogen in the soil compared to the continuous application of manure. Other studies indicate that, despite this positive effect in the short term, digestate and undigested cattle slurry would in the long term have the same fertilising effect, so no savings of synthetic fertiliser could be achieved (Schröder et al., 2007; Smith et al., 2010; Lukehurst et al., 2010).

Additional long-term experimental trials are essential to further clarify the effects of digestate application. The practical implications of specific soil and climate conditions,

and the impact of specific crop types, will have to be evaluated. Human psychology and farmers' habits will also need to be taken into account when developing appropriate guidelines for the use of digestate.

As a first assumption, it can be considered that the potential for synthetic nitrogen-fertiliser substitution is equal between digestate and undigested slurry.

- Soil health and productivity can be increased by using digestate in the short term, but long-term effects are uncertain

  Crop yields are strictly connected to the supply of nitrogen. Some experimental studies have reported higher yields of grasses and herbs after digestate application in the short term. This is probably because of the higher nitrogen availability (Bougnom et al., 2012, Möller et al., 2008). Digestate has also been shown to achieve higher dry-matter yields and nitrogen uptake in non-legume crops (e.g. spring wheat) compared with untreated manure, if incorporated in the soil after field spreading (Möller et al., 2008).

  In general, crops with short and intensive growth periods of nitrogen uptake are the best suited to benefit from the higher mineral nitrogen present in digestate (Svensson et al., 2004; Möller et al., 2008). Long-term, well-structured research is a priority in this area, because there are currently few experimental results, and these range widely between no effect and significant yield improvements (IEA, 2013).

  However, considering that no study reports a worsening of the productivity when digestate is used, it can be assumed for now that the impact of digestate on crop yields is equal to using slurry.

- Using digestate may cause increased leaching of nitrates, but this is not evident from field trials

  The higher content of plant-available nitrogen in digestate could potentially lead to a higher leaching of nitrates (and subsequent eutrophication in nearby water) if the timing between digestate application and crops absorption is not optimal. However, this has not been recorded so far in the few field trials results available (Möller and Stinner, 2009; Svoboda et al., 2013).

- Direct emissions of GHGs are significantly reduced when biogas is produced

  Digestate also has an effect on direct emissions of methane, N_2O and ammonia during storage and field application. Emissions of methane are much lower for the digestate because a large part of the easily digestible matter has been already converted and captured in the biogas plant. This causes a large advantage in terms of GHG emissions for the digestate, even if it is stored in open pools.

  Furthermore, digestate seems to cause lower N_2O emissions from field application (Crolla and Kinsley, 2013) compared to raw manure. In fact, the higher amount of easily degradable carbon contained in raw manure enhances nitrogen immobilisation, denitrification and N_2O emissions from soil. However, N_2O emissions seem to slightly increase during storage of digestate. Experimental data concerning these emissions are still very scarce.

Higher ammonia emissions from field application of digestate are reported. However, these can be prevented and reduced by applying the most suitable technology when spreading digestate on the field (Nyord et al. 2012).

Finally, it should be considered that the use of manures for bioenergy promotes the storage of the digestate in gas-tight tanks, which reduces methane emissions compared to solid manure and slurry storage in open pools.

- Odours decrease and veterinary safety increases for digestate compared to raw manures

  Anaerobic digestion decomposes the main molecules responsible for unpleasant odours contained in the original manures, so that digestate has a significantly lower impact (IEA, 2013). Furthermore, the relatively high temperatures in the digesters significantly decrease the concentrations of many of the pathogens present in the raw slurry (IEA, 2013).

- Soil biodiversity is maintained even though soil microbial biomass increases less than when using raw manures

  Biological activity in soil is maintained with digestate application (Fuchs et al., 2008). Digestate increases soil microbial biomass and dehydrogenase activity, which is reported to be a valid biomarker to indicate changes in microbial activity (Melero et al., 2006), although this effect is lower than with manure application (Alburquerque et al., 2012).

- Improved application techniques are essential to prevent emissions and optimise the fertiliser potential of digestate

  Where digestate is used, it is essential for it to be incorporated into the soil to prevent significant ammonia emissions and to minimise other GHG emissions (Wulf, 2002).

  Better synchronisation of crop nitrogen demand with nitrogen supplied can be achieved using digestate rather than slurry, due to the chemical nature of nitrogen content in digestate (which is more similar to synthetic fertiliser). However, further research is needed into proper agricultural techniques for timely application of digestate; the economic balance will also need to be evaluated.

  As mentioned above, promoting the construction of gas-tight tanks for the storage of digestates would guarantee significant GHG emissions reductions, making biogas from manure basically a GHG emissions-free fuel and, in turn, would help to significantly mitigate GHG emissions from agriculture (Battini et al., 2014).

A.5.4 Forest logging residues

Removal effects

It is generally considered that environmental risks may increase with the implementation of more intensive forest management (including removal of forest residues). The following issues have been identified by various studies (e.g. Lattimore et al., 2009; Fritsche et al., 2012; Lamers et al., 2013; Wall, 2012):

- Soil organic carbon (SOC) seems not to be significantly affected by removal of harvest residues

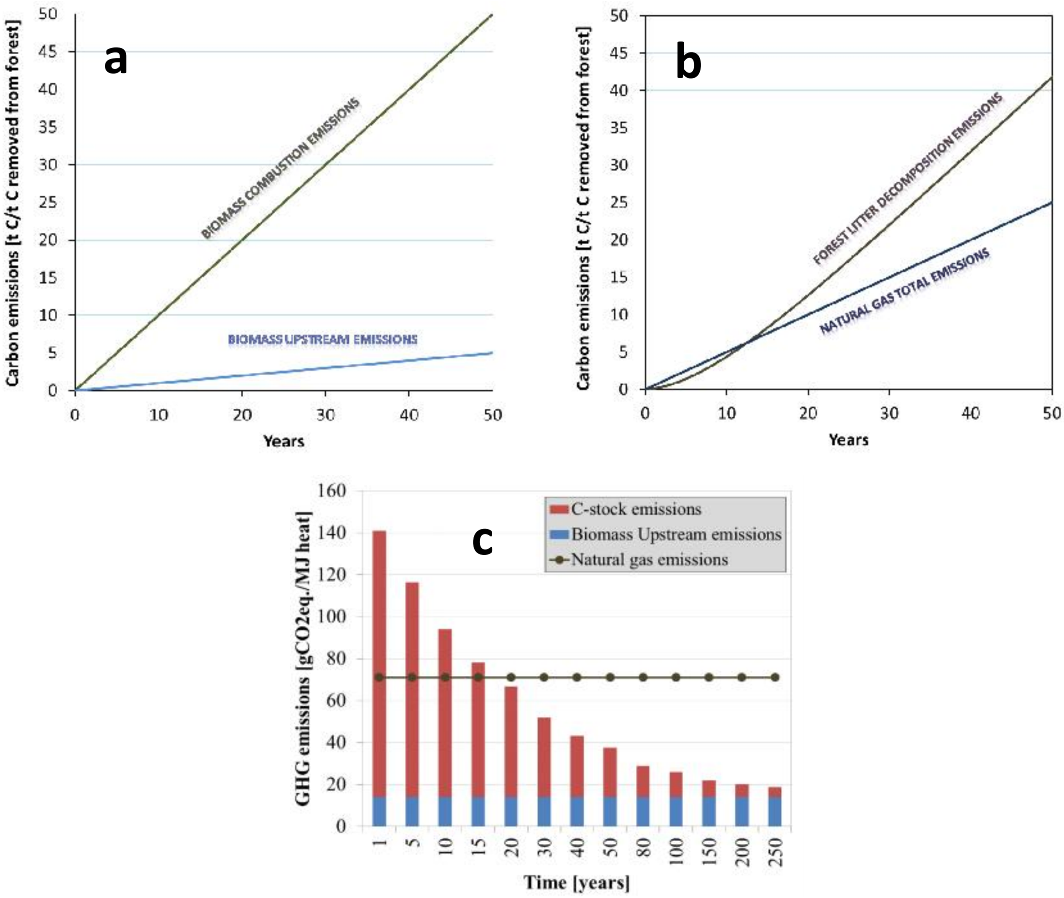
  A significant reduction of SOC associated with whole-tree harvesting has been predicted by various modelling studies. However, meta-analyses of field studies

have not substantiated such results. Only a small percentage of the experimental data analysed has indicated a decrease in SOC when removing residues (Johnson and Curtis, 2001; Nave, 2010; Wall, 2012). However, the effects on SOC may become evident in the very long term, so a clearer picture will emerge with continuing research.

- Timing of carbon release and climate impact: when the reference system is included in the carbon accounting of bioheat from branches, GHG savings are achieved only after more than 15 years

When residues are left on the forest floor, the rate at which they decompose depends on climatic conditions and the size of the wood fragments. However, it is slower than direct combustion for energy (Figure 69 a and b). The difference in atmospheric carbon associated with the use of bioenergy compared to natural decay causes higher GHG emissions than the fossil system for a period of time that can range from a few years (twigs removed to substitute coal systems) up to more than 60 years (for stumps removed to substitute natural gas boilers). See Figure 69 c and JRC-IET (2013a) for a comprehensive review.

Figure 69: Carbon emissions from the production of heat in a pellet stove for pellets from branches



Data are relative to 1 tonne of carbon (tC) removed from the forest floor. Fossil substitute is considered to be a natural gas domestic boiler: Figure 69a – bioenergy system; 69b – fossil system with residues left on the forest floor; 69c – GHG emissions for 1 MJ of heat produced from wood pellets from branches when the carbon stock change in the forest litter are added to the upstream emissions. Background data are taken from JRC, 2014.

Another relevant issue associated with the climate impact of removing logging residues from the forest floor is the influence on surface albedo. It has been hinted, in fact, that a forest floor without litter might favour the growth of grass, which has higher reflectivity than wood. This would have a mitigating potential (Cherubini et al., 2012).

- Soil nutrients pools are little affected by the removal of residues, but the effect may be more relevant on low-fertility soils

Nitrogen and phosphorus are the two key nutrients that may limit forest growth. Nitrogen availability has generally shown varying responses to harvesting, but atmospheric deposition is considered to be, in most cases, adequate to replenish it. Losses of nutrients in areas of low atmospheric deposition of phosphorus, potassium, calcium and magnesium may be of greater concern because these elements are not quickly replenished. Experimental results indicate consistently significant decreases in calcium, potassium, magnesium and phosphorus when logging residues are removed. Increase in the acidity of soil is also recorded (Watt, 2012). Soils with low fertility and smaller nutrient pools are more likely to suffer from the removal of residues and nutrients (Fritsche et al., 2014).

It is important to keep in mind, though, that many empirical tests, in order to amplify the magnitude of the results, apply a complete removal of all residues basically leaving the soil bare. These results should thus be considered as the higher boundary of potential impacts.

- Physical properties may be affected negatively (increased erosion) but also positively (warmer soil)

Increased risk of surface erosion is due to the exposure of mineral soil, which provides routes for accelerated water movement (e.g. roads and skid trails), and the removal of natural debris jams. Moreover, the increased use of machinery to collect residues (Hakkila, 2004) can cause soil compaction leading to a decrease in soil aeration, water infiltration and root growth (Fritsche et al., 2014; Grigal, 2000). However, mild compaction has been shown to have no significant negative effects on tree growth (Holub, 2013). Residues removal could also have a positive effect, such as earlier warming of soil in the spring and consequently earlier and greater root growth (Devine and Harrington, 2007).

- Impacts on site productivity seem to be few or absent, and to vary considerably depending on site-specific differences and different management practices

Many studies have shown results that are not statistically different when comparing trees grown on sites where residues either are or are not collected. However, some results have shown smaller diameters for trees grown in areas where residues were regularly removed. This has been linked to the initial soil nutrients capital and the relative fraction of nitrogen removed with the residues (Egnell et al., 2011; Holub et al., 2013; Thiffault et al., 2011).

- Biodiversity is affected, especially the abundance and diversity of bird and invertebrate species. Forest simplification and facilitating invasive species are also possible risks

Increased harvesting of forest residues can have a negative impact on forest biodiversity. This is primarily due to the removal of niche habitats (i.e. dead and downed wood), with a potential cascade effect on the whole ecosystem (Bunnell and Houde, 2010). Reported data indicate a significant reduction in abundance and

diversity of bird species when deadwood is removed from the forest. The main effect was reported for cavity-nesters (e.g. woodpeckers). A possible correlating factor is reduced numbers of invertebrates and insects in areas where forest residues are extracted. When the residues are harvested and stored in piles at roadside, they attract insects searching for breeding substance. When the residues are removed and transported to power plants, the larvae and offspring of the insects are trapped and removed from the forest, not only reducing the abundance of insects but also removing an important source of food for birds (Riffell, 2011; Victorsson and Jonsell, 2013).

Another important issue is linked with forest simplification and the possible introduction of new invasive species in heavily harvested stands (Fritsche et al., 2012).

- The spread of pests and disease seems to be prevented by the removal of stumps and infected root systems

Removal of stumps and coarse roots has been shown to be a very effective method to prevent the spread of diseases caused by fungal pathogens such as root rot (Cleary et al., 2013).

- Mitigation measures are available to recirculate lost nutrients, but their practical and economic effectiveness is still to be verified

Leaving foliage on the forest floor could largely mitigate the losses of nutrients and growth losses associated with the removal of logging residues (Egnell, 2011).

Mitigation of soil acidification via liming could be considered, but negative effects on tree growth have been reported when applying lime on forest soils (Saarsalmi et al., 2011). Reapplication of combustion ashes could also return some macronutrients to the soil, but the eventual positive effects of ash application on tree growth are still uncertain. Data even suggests decreased growth when ashes are recirculated on less fertile soils (Demeyer et al., 2001; Aronsson and Ekelund, 2004; Stupak et al., 2007).

Nitrogen is almost completely released during combustion, so it is not present in ashes and will need to be supplied via synthetic or organic fertilisers. Experimental data have shown increased growth rates in fertilised forests, but guidelines in some countries still advise against synthetic forest fertilisation (Fritsche et al., 2012; Stupak et al., 2007). A combination of ash recirculation and urea supply has shown increased volume production of almost 45 % compared to the control study (Saarsalmi et al., 2012).
Negative impacts of residues accumulation have also been reported. An abundant bed of residues, for instance, may delay the stand establishment by as long as one year (Hakkila, 2004), and excessive, long-term accumulation of residues on the forest floor could limit productivity (Grigal, 2000).

A.5.5 Qualitative assessment of increased removal of residues for bioenergy purposes

The qualitative assessment presented in the following table indicates the overall performance of different residues in respect of various impacts. with the aim of underlining certain critical issues that should not be neglected in the policy process. Risks and benefits were assessed as regards the likelihood, level and reversibility of an impact. Likelihood represents the probability that an impact (risk and benefit) associated with the removal of

the material from its non-bioenergy use will occur. It is assessed using values between 0 and 2, from 'impact not occurring' to 'high probability'. The impact level represents the magnitude and quality (risk or benefit) of an impact. Impact level is assessed with value between -2.5 and 2.5, where negative values represent benefits and positive values risks. Reversibility represents the possibility and the time needed for natural recovery of the initial status once management is reverted back to its original situation. Reversibility considers that most of the risks and benefits are associated with a change in management, meaning that as long as the change is maintained the impact is happening and the recovery time only starts after equilibrium under new management has been reached. Artificial recovery measures are not assessed in the table because they are included as a separate item under mitigation measures. Reversibility is assessed with values between 1 (indicating that natural recovery is possible in the short term) and 2 (indicating either that natural recovery is not possible or that it occurs only in the long term). At the end, scores were multiplied and risk/benefits divided into various categories.

Additionally, the assessed categories are colour-coded based on the 'confidence level'. This is a qualitative assessment of the quality and quantity of empirical and modelling evidence to support a statement (IPCC, 2013). Multiple sources indicating a certain impact with a high level of agreement assign very high confidence to a statement. Few sources with differing results account for a very low level of confidence.

Table 44: Qualitative assessment of various environmental impacts caused by the use of biomass residues for energy as compared with their baseline uses

One neutral category(😐), three positive categories (Low ≥-1 (☺); Medium -4<x<-1 (☺☺); High ≤ -6 (☺☺☺)) and three negative (Low x≤1 (☹); Medium 1<x<4 (☹☹); High x≤6 (☹☹☹)). Confidence is depicted in the colours of the cells: high confidence (green ■); medium confidence (mustard ■); low confidence (blue ■).

	Total GHG emissions compared to fossil fuels	SOM/SOC	Nutrients pool	Soil health and productivity	N_2O, CH_4 emissions	Pests, diseases, odours	Biodiversity	Water	Displacement effects
Straw (Baseline considers straw left on field)	Decrease in soil carbon; Decrease in above-ground biomass not significant due to short decomposition time of straw ☺☺☺	Decrease of SOM/SOC due to reduced input of organic matter ☹☹☹	Decreased nutrient pools (mainly N, P, K) due to reduced inputs ☹☹☹	Reduced soil fertility due to changes in soil physical properties ☹☹☹	Decrease of N_2O due to straw removal ☺☺	Increased occurrence of some diseases, but decrease of others; in general the effect is small and short-lived ☺☺	Potential impact on soil species and species dependent on the agricultural habitats ☹☹	Increased soil erosion and nutrient leaching due to straw removal; increased use of mineral fertilisers ☹	Displacement likely to occur; mushroom production especially vulnerable due to no viable alternatives currently ☹☹
Pruning residues (Baseline is removal from soil)	GHG savings due to replacement of fossil fuels ☺☺☺	Decrease of SOM/SOC due to reduced input of organic matter and increased soil erosion ☹☹☹	Decrease of nutrient inputs and increase of losses via soil erosion and leaching ☹☹☹	Reduced soil fertility due to soil erosion and changes in soil physical properties ☹☹☹	☺	☺☺	Decrease of organic inputs into soil affecting soil biodiversity; potential impact on species depending on this type of agricultural habitat ☹☹	Increased soil erosion and nutrient leaching; increased use of mineral fertilisers ☹☹	Low risk of displacement as this feedstock is generally not utilised ☹

	Total GHG emissions compared to fossil fuels	SOM/SOC	Nutrients pool	Soil health and productivity	N_2O, CH_4 emissions	Pests, diseases, odours	Biodiversity	Water	Displacement effects
Manure (Baseline considers use as organic amendment)	Significant GHG savings due to replacement of fossil fuels and decrease of CH_4 emissions from bad agricultural practices ☺☺☺	Carbon content in digestate is lower than in untreated manure. Long-term impacts on SOC are still unclear ☹☹☹	Macronutrients (P, K) are generally not affected by the digestion Anaerobic digestion increases the share of inorganic-N in digestate ☺	Potentially no differences in long-term fertiliser potential. In the year of application and in the short term, digestate presents higher fertiliser potential than slurry/manure ☺☺	Lower CH_4 emissions because easily digestible matter has been converted and captured during biogas production ☺☺☺	Reduction of odours and risk of animal diseases ☺☺☺	Soil microbial biomass increases, but less than when untreated manure is applied ☹☹	Potentially higher leaching of nitrates ☹☹	No alternative use
Forest residues (Baseline considers residues left on forest floor)	Short term: Forest residues left on the forest floor decompose at a slower rate than in the case of bioenergy; impact is time-dependent and will depend on the type of residue used ☹☹ Long-term: ☺☺☺	Decrease of SOC has been predicted by modelling studies, but field studies have not substantiated the magnitude of such results ☹☹	Decrease in nutrient pools (P, K, Ca, Mg) Limited effect on nitrogen ☹☹	Highly variable results. Some reports of lower tree growth when residues were collected ☹☹	No significant impact ☺	Positive impact on controlling the spread of root diseases ☺☺	Removal of snags and coarse deadwood has an impact on biological abundance and diversity of bird species Removal of logging residues after storage at roadside could constitute an ecological trap for insects ☹☹☹	No significant impact ☺	No alternative use

APPENDIX 6: ARTICLE 7a OF THE FUEL QUALITY DIRECTIVE – AN IMPLEMENTING ACT

Complex concerns stall the reporting methodology of the FQD

Article 7a of the FQD introduces the requirement for fuel and energy suppliers to report from 2011 on concerning the GHG intensity of the fuel they supply. The aim is to assess progress towards meeting the overall FQD target of reducing by 6 % per unit of energy the life-cycle GHG intensity of fuel/energy by 2020 compared to 1990.

However, the decision-making process for defining implementing rules for the reporting requirement for fuel and energy suppliers is currently stalled. The options considered range from a methodology based on the average default GHG intensity values by fuel types (based on the fuel mix in the EU or per Member State) to one based on separate GHG intensities for individual categories of feedstock. Intermediate or 'hybrid' methodological options are also being considered.

Positions have not been reconciled at the time of writing. The oil and refining industry, some oil-exporting countries and certain Member States favour the methodology based on average default GHG intensity values. This is based on the arguments that it is economic (it involves no increases in administrative burden) and transparent (by reducing the risks of fraud, it avoids market distortion while allowing control by Member States). This option also permits controlling the average GHG intensity of fuels traded in the EU, in view of their 6 % GHG intensity reduction. It is therefore seen as potentially minimising the risks (and related costs) of fraudulent behaviour and crude switching[154]. Conversely, the methodology based on separate GHG intensities for individual categories of feedstock is expected to send market signals incentivising suppliers with a better-than-average performance.

[154] Crude switching can be described as ''cleaner'' crudes being attracted to the European market (as a second-order effect of the FQD Art. 7a reporting mechanism) in a context of: (a) higher costs for European industrial users and end-users; and (b) inadequacy of the European refining sector set-up. As ''dirtier'' crudes would be diverted to non-European markets, life-cycle GHG intensity of transport crudes would be transferred or ''switched'' outside EU borders. In terms of overall result, it may be expected that no global gains in GHG reductions would be achieved.

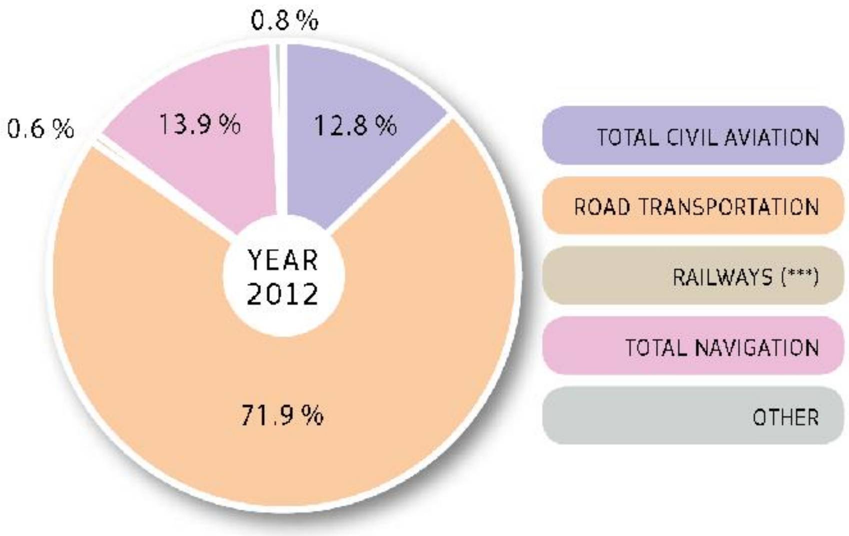
APPENDIX 7:
BRIEF CONSIDERATIONS ON NON-ROAD TRANSPORT MODES

Energy demand generated by road transport substantially outweighs all other transport modes but is not the sole target of EU regulation

The road transport sector is by far the biggest consuming fuel/energy sector in the EU. Nevertheless, the RED and FQD address other transport modes as well.

Transport consumes approximately one-third of energy in the EU. Within the transport sector, road transport is responsible for over 80 % of energy consumption (approximately one-quarter of total EU energy consumption).

Figure 70: Final energy consumption for the EU-28 by sector (year 2012)



Source: European Commission, EU Transport in Figures. Statistical Pocketbook 2014.

Although the rail and maritime sectors have also begun to experiment with biofuels as a means of reducing the carbon intensity of their operations[155], the biggest developments have occurred in the commercial aviation sector.

Energy demand generated by air transport is growing rapidly

Air transport is the fastest growing energy/fuel-demanding mode, although it is still a long way behind road transport. Despite the 2008 economic downturn, world air traffic has grown continuously, usually at rates higher than the growth in world GDP. Growth has not been uniform and has varied from country to country, with a recent acceleration of demand in emerging countries. EU air traffic weathered the 2008 economic downturn and was already showing positive signs at the end of 2009. By 2011, the number of passengers exceeded

[155] Florentinus A. et al. ''Potential of biofuels for shipping'', Final report, Ecofys Project number: BIONL11332, (2012) http://www.ecofys.com/files/files/ecofys_2012_potential_of_biofuels_in_shipping_02.pdf

records for 2008. International organisations[156] and industry players[157] broadly agree on air traffic annual growth rates of approximately 3-4 %.
Fuel demand from aviation will not grow at a similar pace thanks to efficiency improvements. Nevertheless, the dynamism of the air transport sector, and the specificities of fuels suitable for aviation[158], mean there are no easy non-fossil alternatives in terms of drop-in fuels. This makes air transport the biggest 'competitor' to road transport in the demand for biofuels. Indeed, the aviation industry faces a set of environmental and energy challenges, and several airlines have identified biofuels as a means to reduce their dependency on oil while enhancing environmental performance.

Table 45: Final energy consumption in Mtoe for the EU-28 by sector and per transport mode (year 2012)

	ALL SECTORS	INDUSTRY	TRANSPORT	Road	Railways	Air	Domestic navigation	Pipelines	HOUSEHOLDS, SERVICES, ETC.	Households	Agriculture	Services, etc.
EU28	1104.5	282.8	351.7	287.5	7	49.1	4.4	3.6	470	289.2	25	155.9
Share	100%	26%	32%	82%	2%	14%	1%	1%	43%	62%	5%	33%

Source: European Commission, EU Transport in Figures. Statistical Pocketbook 2014.

In the short term it is not easy to foresee an alternative energy source(s) capable of replacing to a significant extent the fossil energy used by air transport. This difficulty arises mainly from the existence of strict fuel requirements in order to ensure efficient and safe performance of aircraft, and from the non-availability of alternative fuel(s) in sufficient quantity.

Liquid biofuels are today the only alternative to jet fuel from fossil sources, as they have the potential to deliver both on the environmental and the oil dependence concerns and can be 'dropped-in' to existing refuelling infrastructure and aircraft engines.

The air transport industry and operators have subscribed to a non-mandatory target for alternative fuel uptake

The European Advanced Biofuels Flightpath[159] is an industry-wide initiative intended to speed up the market uptake of aviation biofuels in Europe. It provides a roadmap for achieving an annual production of two million tonnes of sustainably produced biofuel for aviation by 2020. However, this is not a mandatory target imposing a legal obligation on regulated parties.

[156] See various studies and statements by, among others, the International Civil Aviation Organization (ICAO), EUROCONTROL, and the International Air Transport Association (IATA).
[157] See studies and statements by, among others, Airbus, Boeing, Bombardier, Embraer and Rolls-Royce.
[158] Aircraft require a high-density energy fuel (in terms of MJ/l) in order to minimise the volume of the tanks carried.
[159] Commission technical paper, ''2 million tonnes per year: a performing biofuels supply chain for EU aviation'', (2011).

Worldwide, research and development activities regarding new types of alternative fuels for aviation have increased significantly over the last decade. Over 1500 passenger flights fuelled by a blend of fossil-based and bio-based jet fuel have taken place so far: the share of biofuels in total fuel consumption by commercial aviation is estimated at 0.5 % in 2010.
It is certainly worth highlighting the fact that the main driver for aviation to switch part of its demand to alternative fuels is that of reducing its GHG emissions and allowing aviation supply to meet projected growth in demand growth while at the same time diversifying its sources of fuel supply. Sustainability of the biofuels is therefore a key prerequisite.

Advanced biofuels are still far from attaining commercial production, so the target will not be easily met. However, traded prices of advanced biofuels may be considerably influenced by demand from the air transport sector. This may also be an important leverage factor during the current transition from the pilot/demonstrator phase to intense market competition for very limited supplies.

Today, there are different routes to produce biojet fuel from a variety of feedstocks of non-fossil origin. The Hydrogenated Vegetable Oil (HVO) and the Fischer-Tropsch (FT) have been certified by ASTM[160] as suitable for use in blending up to 50 % with fossil jet fuel, but the landscape is rapidly evolving: a recent revision of ASTM D7566 standard in fact approved the first sugar-to-aviation fuel technology pathway, which is referred to as Synthesised Iso-Paraffinic fuel (SIP), produced from hydroprocessed fermented sugars.

Ongoing concerns expressed on safety grounds include reliability of bio-based components in terms of fuel quality and constant fuel purity, including storage.

It is also important to draw attention to the fact that other non bio-based pathways for alternative aviation fuels are currently being researched. Gas-to-liquid is currently considered the most interesting of these alternative options.

If one examines the availability of bio-based alternative jet fuel which can be expected from conversion processes which are technologically mature today, a broadbrush estimate indicates that approximately 140 ktonnes of Fischer-Tropsch fuel per year, with the addition of approximately a maximum of 50 tonnes resulting from municipal waste treatment, could be made available to the European aviation industry in the context of domestic production (but not necessarily of domestic feedstocks).

It follows, as mentioned above, that in order to meet the 2 million tonnes aspirational target set in the Flightpath 2020 in 2011, a considerable share of HVO produced in Europe could be absorbed by the aviation sector in competition to demand for diesel fuel generated by the road transport sector. As mandatory targets for renewable fuels uptake are laid down by EU rules for the road transport sector but not for aviation, while the aviation segment (EU domestic flights only for the time being and subject to revision of ICAO's[161] position in 2016) is subject to the Emissions Trading Scheme (ETS), it is reasonable to expect that fierce competition between the two modes may occur.

160 ASTM D7566 standard specification - http://www.astm.org/Standards/D7566.htm
161 ICAO is the International Civil Aviation Organisation, one of the specialised UN agencies.

Non-mandatory targets for biofuels in aviation have been adopted in other parts of the world as well, which could in fact exacerbate competition for scarce resources. In the US the Federal Aviation Administration (FAA) aims for 1 billion gallons of jet fuel to come from alternative renewable sources from 2018, representing 1.7 % of predicted fuel consumption of US carriers. In 2013, the 'Flightpath to Aviation Biofuels in Brazil'[162] was adopted. Indonesia has introduced a biojet fuel mandate of 2 %, starting in 2016 and rising to 5 % by 2025.
The EU policy framework for climate and energy in the period from 2020 to 2030[163] does not indicate specific sub-targets for the use of renewable fuels in the transport sector: if confirmed, this could have an impact on the development of both demand and supply for biofuels generated by the aviation sector.

As has been briefly sketched out above, expectations concerning development of biofuels in the aviation sector are far from being stable, which makes any analysis very tentative. In order to improve analytical capacity while at the same time defining common ground for discussion at global level, the ICAO Assembly's Resolution A38-18 reaffirmed member states' support for the development and deployment of sustainable alternative jet fuels as part of a basket of measures to reduce aviation GHG emissions. As a result, in November 2013 the ICAO Committee for Aviation Environmental Protection (CAEP) Steering Group created the Alternative Fuel Task Force, with the remit of evaluating the range of potential greenhouse gas (GHG) emissions reductions from the use of alternative fuels in aviation up to 2050.

In order to fulfil this mandate, the AFTF identifies and characterises ranges for lifecycle GHG emission estimates for alternative jet fuel pathways, and assesses potential alternative jet fuel availability between today and 2050. The work of the group is scheduled to be finalised in the course of 2016.

[162] http://www.fapesp.br/publicacoes/flightpath-to-aviation-biofuels-in-brazil-action-plan.pdf
[163] COM(2014)0015, 2 January 2014.

APPENDIX 8: EUROPEAN LARGE-SCALE DEMONSTRATION PROJECTS

23 low-carbon projects will be financed under the NER300 funding scheme

Summaries of projects were published in July 2012 (NER300, 2012[1]) following the first NER300 funding call. Subsequently, the projects to receive funding were announced in December 2012 (NER300, 2012[2]). The NER300 funding programme will support 23 low-carbon economy projects, eight of which are the bioenergy projects listed in the following table.

Table 46 : NER300 bioenergy projects in the 2012 funding call

Project	Date of entry into operation	Long stop date	Maximum funding (€)	Funding rate (€/MWh)
SE BIOa Pyrogrot	03.12.2015	02.12.2020	31 404 829	12.15610
SE BIOc GoBiGas phase 2	31.12.2016	30.12.2021	58 797 168	20.16160
IT BIOg BEST	01.06.2013	31.05.2018	28 430 147	26.79768
FI BIOe BTL (Ajos)	31.12.2016	30.12.2021	88 486 580	17.38795
FR BIOd UPM Stracel BTL	31.12.2015	30.12.2020	169 960 000	36.88385
DE BIOh Verbiostraw	03.01.2014	02.01.2019	22 272 049	59.14538
NL BIOd Woodspirit	28.11.2016	27.11.2021	199 000 000	16.72407
PL BIOg CEG Goswinowice	01.07.2014	30.06.2019	30 875 015	29.40478

The European Industrial Bioenergy Initiative (EIBI) is a public-private partnership set up to monitor and promote the commercialisation of advanced biofuels

The EIBI has set up key performance indicators (KPIs) for use in monitoring the continued development of technologies towards commercialisation (EIBI, 2012/2).

Table 47: Projects linked to the European Industrial Bioenergy Initiative (EIBI)

EIBI value chain	Project	Country of facility	Size	Comment
1. Synthetic liquid fuels and/or hydrocarbons through gasification and thermo-cracking	Güssing	AT	Pilot	
	Bioliq	DE	Pilot	
	BioDME	SE	Demonstration	
	BioTfueL	FR	Demonstration	NER300 funded
	BioBTL	FI	Demonstration	NER300 funded
2. Biomethane and other gaseous fuels through gasification	ECN	NL	Pilot	
	GAYA	FR	Demonstration	
	GoBiGas	SE	Demonstration	NER300 funded
	Innovación	SP	Flagship	
	GoBiGas	SE	Flagship	
3. High-efficiency heat and power through thermochemical conversion	Fundación Cidaut	SP	Pilot	
	Güssing	AT	Demonstration	
	ENERCORN	SP	Demonstration	
	RECOMBIO	DE	Demonstration	
	EMPYRO	NL	Demonstration	
	Trivinco International	SP/Chile	Flagship	
	Fundación Cidaut	SP	Flagship	
4. Intermediate carriers through e.g. pyrolysis and torrefaction	Bioliq	DE	Pilot/Demonstration	
	PYTEC	DE	Pilot/Demonstration	
	BTG	NL	Pilot/Demonstration	
	2G_Bio-Oil	FI	Pilot/Demonstration	
	BioTfueL	FR	Pilot/Demonstration	
	Fortum	Fi	Pilot/Demonstration	
	Sunpine	SE	Flagship	
	Pyrogrot	SE	Flagship	NER300 funded
5. Ethanol and higher alcohols from lignocellulosic biomass through chemical and biological processes	SEKAB	SE	Pilot	
	Futurol	FR	Pilot	
	Fredericia	DK	Pilot	
	KACELLE	DK	Demonstration	DONG/Inbicon
	LED	SP	Demonstration	Abengoa
	Babilafuente	SP	Demonstration	FP5 - NNE5 - 00685
	FibreEtoH	FI	Demonstration	UPM

EIBI value chain	Project	Country of facility	Size	Comment
	BornBioFuel	DK	Demonstration	
	Chemtex	IT	Demonstration	NER300 funded
	BIOLYFE	IT	Demonstration	FP7-239204 - Chemtex
	CEG	PL	Demonstration	NER300 funded
	Sunliquid	DE	Flagship	Süd-Chemie
6. Hydrocarbons through biological and/or chemical synthesis from biomass containing carbohydrates	Virent	US	Pilot/Demonstration	
	LS9	US	Pilot/Demonstration	
	Solazyme	US	Pilot/Demonstration	
	Avantium	NL	Pilot/Demonstration	
	ProBio3	FR	Pilot/Demonstration	
	Neste Oil	FI	Pilot/Demonstration	
	Gevo	US	Flagship	
	Amyris	BRA	Flagship	
7. Bioenergy carriers from micro-organisms (algae, bacteria) from CO_2 and sunlight	There are many known projects not yet included in the EIBI			

Linked to the EIBI are projects funded through the BioEnergy Sustaining The Future (BESTF) programme, which is focused on bioenergy demonstrations. BESTF is part of ERA-NET+, one of the tools of the 7th Framework Programme that encourages coordination of research programmes across the EU. It is in the process of launching, managing and financing a joint call for bioenergy demonstrator projects supported by national programmes in the EU. The Commission will complement funding. The successful projects will be at a stage of development that should lead to commercial deployment within three to four years, will be industry-led and will involve partners from at least two Member States. The new projects are expected to start in January 2014. In July 2013, the European Council proposed a regulation for a Bio-based Industries Joint Undertaking (BBI JTI) (EC, 2013), with funding of EUR 1 billion from Horizon 2020 and EUR 2.8 billion from industry. The Bio-based Industries Consortium (BIC: formerly BRIDGE2020) (Bio-consortium, 2013) has already been established and has around 50 members (large and small companies, clusters and organisations).

The European Biofuels Technology Platform also monitors EU projects concerning second- and future-generation biofuels (EBTP, 2013).

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