HIGH ETHANOL BLENDS

FUEL ETHANOL DEMAND-SUPPLY SCENARIOS 2017-2035

Final Report

for

ePURE

Submitted by

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Executive Summary

The High Ethanol Blends study provides an independent review of potential future fuel ethanol demand between 2017 and 2035 (primarily in the EU but also worldwide) arising from the introduction of higher ethanol blends in petrol than currently covered by the Fuel Quality Directive; and assesses whether this demand could be met by sustainably produced ethanol. The study presents scenarios which show that potential ethanol supply far exceeds potential demand in 2035 for an E20 or E25 ethanol blend in Europe. These scenarios are based on the technical potential for ethanol demand and supply rather than applying the equilibrium approaches of economic models.

The supply potential is made after accounting for feedstock use for food and other uses, based on rain-fed cultivation potential, current GMO policies, and current performance of conversion technologies, as well as the present sustainability standards of the Renewable Energy Directive. Under these scenarios, both the EU and the Rest of World have the technical capacity to be self-sufficient in food and livestock feed as well as feedstock crops for other uses than ethanol.

In order to determine a credible upper limit on EU ethanol demand, the analysis assumes a set of assumptions that would 'maximise ethanol demand within reason'. Reasoned assumptions regarding passenger car sales, vehicle efficiency improvements, user mileage trends and the timing of the phase in of the corresponding biofuel blends were compiled. EU passenger car fleet development was then modelled, splitting Ethanol Compatible Gasoline Vehicles (ECGVs) by the maximum ethanol blend that they can accept (whether E5, E10, E20/25, E85) and taking into account the existing fleet composition, vehicle sales, retirement, and the growth in alternative (e.g. electric) fuel vehicles. By factoring in the assumptions regarding vehicle efficiency improvements, user mileage trends and phase-in of biofuel blends, a technical constraint on the amount of ethanol that the car parc can safely accept (without risk of engine damage) was determined. This approach generates a technical limit on transport ethanol demand within reason.

Under the E25 scenario, potential EU-27 ethanol demand in 2035 would be around 21% of the EU-27 technical supply potential (17% under the E20 scenario).

EU-27 ethanol demand potential and proportion of potential supply, 2035

	Mtoe	Million m^3	% share
Ethanol supply potential	50.3	98.9	-
Ethanol demand – E20	8.4	16.5	16.7%
Ethanol demand – E25	10.3	20.2	20.5%

Source: Agra CEAS Consulting and E4tech.

Given the future enlargements plans of the EU, the study also considered the supply potential of an enlarged European region made of the EU-28 and 12 neighbouring countries, which would increase the supply potential by 9.4 Mtoe, reaching 59.7 Mtoe by 2035.

Under scenarios for the Rest of the World which also maximise ethanol demand within reason, focusing on Brazil and the US as the two largest demand centres, demand in 2035 ranges from 87 Mtoe to 192 Mtoe (170 to 378 million m^3), with the supply potential at 4,544 Mtoe (8,937 million m^3). This suggests that EU ethanol demand resulting from the introduction of E20 or E25 blends would remain marginal in the global context.

1. Introduction and background

Agra-CEAS Consulting and E4tech have been commissioned by ePURE to undertake an assessment of the potential market for higher blends of ethanol. The aim of the study is to enable ePURE to provide the automotive industry and other stakeholders with an independent review of potential future fuel ethanol demand (primarily in the EU-27 but also worldwide) arising from the introduction of high ethanol blend compatible gasoline vehicles, and to assess whether this demand could be sustainably met.

2. Task 1: EU and World Ethanol Demand Scenarios

Task 1 of this study was carried out by E4tech.

E4tech

Note: The EU and World Ethanol Demand Scenario analysis contained within this report was carried out in 2012-2013 based on policies in place and published data available at that time.

2.1. Objectives and overview

The overall objective of Task 1 is to assess the possible evolution of EU-27 transport ethanol demand and key sensitivities for the period 2017[1]-2035 through scenarios which 'maximise ethanol demand within reason'. This was achieved by carrying out the following steps:

1. assessing existing data on the drivers of transport fuel demand;
2. developing a credible transport fuel demand dataset (two possible scenarios);
3. analysing key sensitivities relating to fuel ethanol consumption;
4. comparing ethanol demand dataset with existing datasets.

Where appropriate, the analysis has focussed on transport ethanol demand over other transport fuels since the primary aim of the study is to understand the potential of high ethanol blends. Given that passenger cars represent the only transport mode which will draw demand for significant volumes of ethanol, the analysis is primarily concerned with this mode, and frames future ethanol demand within the overall energy demand expected for these vehicles.

In **step 1** existing data on the drivers of transport fuel demand was compiled. The key drivers determining future ethanol fuel demand were identified and became the focus of the study. The exercise established that the most important factor in determining 'maximum ethanol demand within reason' will be the levels of penetration in the passenger car fleet of 'Ethanol Compatible Gasoline Vehicles' (ECGV) capable of accepting higher blends (e.g. E10, E20, E85).

[1] 2017 is chosen as the reference year to align with the scenarios in the original JEC publication *EU renewable energy targets in 2020* (JEC, 2011a) which assume that E20 blends are introduced from 2017 onwards

In **step 2** the information compiled in step 1 was used to build a credible transport fuel demand dataset while maximising the ethanol demand. From the analysis in step 1 it was established that a bottom-up approach based around the evolution of the ethanol-compatibility of the gasoline passenger car fleet approach was the most appropriate means to determine maximum ethanol demand, with due consideration given to the other key demand drivers identified. The technical capacity for the vehicle fleet to accept high ethanol blends forms the basis of the analysis. Two scenarios were developed assuming different ECGV technologies come to market at the end of this decade. Total passenger car transport fuel demand was then determined.

In **step 3** the sensitivity of the ethanol demand to the key drivers was assessed and each of these drivers scrutinised to understand their influence.

In **step 4** existing EU-27 ethanol demand data sets were evaluated and compared to the data set developed in the previous steps.

2.2. Assessment of existing data on drivers of fuel demand

An initial assessment was made of several key drivers of fuel demand to understand their relevance to establishing future ethanol demand. Historical data and existing projections on relevant drivers were collected and assessed, and from this key data sets and assumptions were compiled to feed into the development of the transport fuel demand data set in step 2. The following key drivers were examined:

- **Passenger car sales:** Overall demand for passenger travel will clearly be a major determinant of transport fuel demand. Data from the European Commission indicates a growth in passenger kilometres in cars of around 1% per annum over the last 10 years (EC, 2012). This is projected to continue at a rate of around 0.4% per annum for passenger cars (IEA, 2012). Even assuming an increased average occupancy level per car by 2035 this corresponds to at least an additional 40 million passenger cars (PCs) on European roads. A robust estimate of the future fleet size is important in determining fuel demand. Data from Eurostat and the European Transport Statistical Pocketbook (EC, 2012) forms the basis of the analysis in step 2 (see section 2.3.2.2).

- **Gasoline to diesel vehicle sales ratio:** The relative share of gasoline and diesel passenger cars (both historically and projecting forward) is clearly a critical determinant in the demand for these fuels. Historical EU PC sales data (gasoline, diesel and AFVs) has been compiled from various literature sources (JRC, 2003; EEA, 2006; ICCT, 2011; EEA, 2012a). The EEA's regular reports Monitoring CO2 emissions from new passenger cars in the EU (EEA, 2012a, 2006) show a clear picture of the shift in preference towards diesel cars over the last two decades (see Figure 2.1), driven principally by a desire for more fuel efficient vehicles. This means that there is a considerable legacy in the fleet of vehicles which cannot accept ethanol as a fuel.

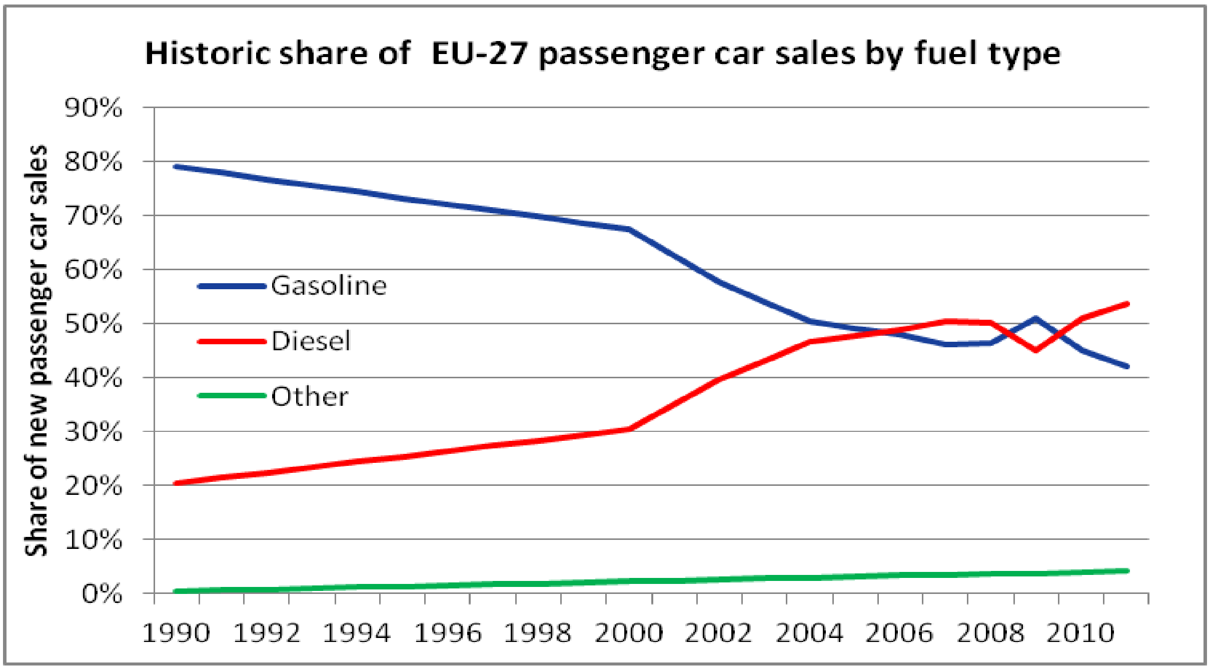

Figure 2.1: Historical share of EU-27 passenger car sales by fuel type

Source: E4tech, based on EEA data

The continuation of this trend would restrict ethanol demand going forward, as ultimately the demand is constrained by the number of vehicles that can accept ethanol. However there is reason to believe that Europe could see a rebound in sales of ECGVs. This will be partly driven by the increasing competition for diesel or middle distillate fuel from other transport sectors (e.g. marine engines needing low sulphur fuel, growth in aviation, growth in HGV transport). On top of this supply-side pressure, several OEMs also recognise the potential to meet increasingly stringent tailpipe emission targets with gasoline engines. European OEMs may favour highly specified, downsized gasoline engines, using turbocharging to restore performance and other features such as direct injection (VW group, Ford, BMW, Mercedes) or variable valve actuation (Fiat group) to enhance efficiency. The best of these engines can deliver CO2 emissions within 10% of a comparable diesel; with micro/mild hybridisation, the diesel's efficiency can be matched, and some claim that the cost of these new gasoline engines is lower than the diesel, due to the latter's emission control costs. Thus in developing a data set for maximum ethanol demand within reason it is reasonable to assume a shift in sales towards gasoline vehicles.

- **Market penetration of E20/25 vehicles:** Crucial to understanding the potential for ethanol uptake is the rate at which ECGVs capable of accepting higher ethanol blends are introduced to the European market. Higher volume gasoline-ethanol blends (e.g. E20) will not be introduced to European forecourts until a significant share of vehicles capable of taking these blends is on the road. The penetration of such vehicles is one of the major constraints on ethanol demand, as future uptake of the fuel will be limited by the engine technologies in the fleet which can accept it at high blends.

Consultation with various OEMs has indicated that there are currently only very limited numbers of passenger cars on European roads which can safely accept blends of E20 or above. Very little information exists on the compatibility of the current European PC fleet with other ethanol blends (e.g. E5, E10). No forecast of the development of this fleet in terms of blend-compatibility exists either. This is very important to understand as vehicles sold today could still be on the road in 20 years time, and thus vehicles capable of accepting blends no higher than 10% will still be in the vehicle parc.

Thus, the future composition of the ECGV fleet will be a crucial driver of ethanol demand and it is important to model how this composition could evolve. Determining this forms a major part of step 2 and is explained in section 2.3.

- **Market penetration of Flex-Fuel Vehicles:** Similarly, the future penetration of Flex Fuel Vehicles (FFVs) in the fleet will be an important driver of demand. FFVs are vehicles capable of accepting very high ethanol blends, and in a European context are vehicles optimised to run on an 85% ethanol blend. Data on the numbers of FFVs on EU roads is very limited since FFVs only feature in significant numbers in Sweden. Sales data from several sources (EEA, 2012; BAFF, 2012; JATO, 2011) was compiled and indicates that there are less than 300,000 FFV cars in operation Europe. Although relatively small, the ethanol volume one car can accept is over 20 times higher than the current EU average ethanol blend. If policy support for FFVs (in the interest of greater fuel security) were to continue in Sweden or be replicated in other Member States, the penetration of FFVs could be important. The role of FFVs in determining future ethanol demand is discussed in section 2.3.2.2.

- **Fuel usage reduction policies:** The most relevant fuel reduction policy affecting future ethanol consumption is the EU mandate on passenger car tailpipe emissions currently legislated at 95gCO2/km by 2021. Historical tailpipe emission data was compiled from EU data (EEA 2012, 2009, 2005) and combined with the 2020 target to understand how car efficiency is expected to improve. Very little data is available forecasting how this average will evolve to 2035. The methodology and assumptions taken forward to the demand modelling for estimating future vehicle efficiency are outlined in section 2.3.3.

- **Sales of Alternative Fuel Vehicles:** The future role of ethanol could be limited by the enhancement of alternative low-carbon vehicle solutions such as Electric Vehicles (EVs) or Fuel Cell Electric Vehicles (FCEVs). Support for other passenger car technologies such as Liquefied Petroleum Gas (LPG) or Natural Gas (NG) vehicles could also take away from the future market share of ECGVs. Historic data on sales of these Alternative Fuel Vehicles (AFVs) from Eurostat was compiled. Forecasts for the penetration of these vehicles vary greatly but some measure of agreement within the automotive industry was reached with the ERTRAC Research and Innovation roadmap (ERTRAC, 2011) which projects the share of sales of AFV passenger cars reaching around 15% by 2030.

- **Non-fuel ethanol demand:** The largest market sector for bio-ethanol is by far in transport fuel (and fuel additives), although there are some niche markets appearing for use as a feedstock in the chemicals industry (e.g. bio-ethylene production in Brazil). The use of bio-based ethanol in the EU automotive industry is largely directed by the EU's renewable transport target for 2020 and associated national mandates, whilst similar mandates or incentives do not exist for industrial or chemicals uses. Demand for bio-ethanol in the chemical sector is therefore highly price sensitive, and will depend on the relative prices of fossil-based chemicals (e.g. fossil ethylene) compared to their bio-ethanol based alternatives. In most world regions (including Europe), fossil-based chemicals are currently significantly cheaper to produce than bio-based chemicals, hence the chemical sector demand for bio-ethanol is minimal. In contrast, transport bio-ethanol demand in Europe is primarily driven by mandated targets, and hence is relatively price insensitive (since fuel suppliers are required to meet the targets). It is therefore unlikely that non-fuel bio-ethanol demands in Europe will have a significant impact on EU transport bio-ethanol demands. If transport mandates are under-supplied, bio-ethanol prices will tend to rise, ensuring bio-ethanol use in transport is prioritised over other industries. If transport mandates are met, then bio-ethanol prices could fall, and the chemicals sector could have access to higher volumes of lower cost bio-ethanol.

  We judge that this picture is likely to remain to 2035 for several reasons: in Europe there are currently no significant plans to introduce targets for bio-chemical production (chemical sector demand remains price sensitive), bio-ethanol import tariffs into Europe remain high (and hence European prices stay high), and any change in crude oil prices will impact both overall transport and chemical sector demands. However, the absence of a dedicated EU transport sector target after 2020 introduces uncertainty as to what each Member State will do with their national obligations or incentives, and hence on the overall level of demand and willingness to pay for bioethanol as a transport fuel. Nonetheless, since we are considering 'maximum ethanol demand within reason' it is reasonable to assume for the scenarios investigated that non-fuel bio-ethanol demand does not materially impact transport ethanol demand.

- **Oil Price:** Several sources of oil price forecasts were examined (EIA, 2012; World Bank, 2012). Forecasts understandably vary greatly. In the EIA Annual Energy Outlook (EIA, 2012) the 2035 figures in the low and high oil price scenarios are \$53/barrel and \$187/barrel respectively. There is also uncertainty regarding the price at which ethanol becomes competitive with gasoline, depending to some extent on relative currency exchange rates. Clearly high oil prices will make ethanol an attractive option and encourage uptake. For the purposes of this analysis it is assumed that ethanol is competitive with gasoline, and drivers will use the highest blends available to them at forecourts.

The information gathered forms the basis of the development of the EU-27 transport ethanol demand in step 2. Further detail on the data sets and assumptions applied are given in section 2.3.

2.3. Development of EU-27 ethanol demand scenarios

This section outlines the methodology, assumptions and data sets used in developing an EU-27 transport ethanol demand data set for the period 2017-2035 which reflects the maximisation of ethanol demand within reason. The analysis in step 1 led to the understanding that transport ethanol demand will ultimately be constrained by the types of ECGVs present in the EU passenger car parc and the maximum ethanol blends which they can accept. The uptake of ethanol is limited by the technical capacity within the fleet to accept the varying blends. Thus the basis of the modelling is the establishment of a European passenger car fleet data set broken down by the following six 'vehicle classes':

1. E5 cars (can accept up to 5% ethanol blend)
2. E10 cars (can accept up to 10% ethanol blend)
3. E20/25 cars (can accept up to 20/25% ethanol blend)
4. E85 cars / flex-fuel vehicles (FFVs) (can accept up to 85% ethanol blend)
5. Diesel cars
6. Alternative Fuel Vehicles (EV, FCEV, LPG, NG)

The goal is to develop ethanol demand projections based on the likely penetration of ethanol compatible vehicle technologies capable of accepting blends higher than those currently on the market (i.e. E5, E10 compatible vehicles). Thus the analysis represents an assessment of the technical limit on transport ethanol uptake within reason. The focus of the analysis is on passenger cars as this represents the transport mode that will account for the vast majority of ethanol demand to 2035. An assessment of the National Renewable Energy Action Plans indicates that non-passenger car transport ethanol demand (motorcycles, vans, buses etc.) represents less than 5% of total ethanol demand. Thus the demand analysis is based around the evolving EU passenger car fleet size and energy requirements, with an additional 5% added to this demand to account for the contributions of the marginal transport modes.

Two scenarios are constructed in the analysis; one in which E20 vehicles are brought to market; another in which E25 vehicles are brought to market:

- **Reference demand scenario:** E20 compatible gasoline vehicles are brought onto the market to replace new sales of E5 and E10 vehicles and alongside E85 flex fuel vehicles.
- **Higher demand scenario:** E25 compatible gasoline vehicles are brought onto the market to replace new sales of E5 and E10 vehicles and alongside E85 flex fuel vehicles.

It is assumed that a widespread phase-in of further ECGV technologies capable of accepting even higher blends (e.g. E30) will not occur before 2035.

2.3.1. Methodological approach

The general approach taken in constructing ethanol demand forecasts to 2035 is:

1. The number of each ECGV type (E5, E10, E20/25 and FFV) in the EU passenger car fleet is determined for all years to 2035 using a vehicle parc model that captures new technology introduction, vehicle sales and scrappage.
2. The average annual fuel use per single passenger car is projected to 2035, capturing expected efficiency improvements and user mileage trends.
3. Combining Steps 1 and 2, the total (liquid) fuel demand of each ECGV type is determined annually to 2035. This fuel demand is then broken into its gasoline and ethanol constituents to determine the maximum ethanol demand per ECGV type. Combining the demand of all vehicle types yields the total ethanol demand to 2035.

The same approach is used to determine passenger car diesel fuel demand. A schematic of this methodology is presented in Figure 2.2. The 'vehicle class' refers to the six types of car listed at the beginning of section 2.3 (E5, E10 etc.). The individual approaches and assumptions made within each of these 3 steps are explained in more detail in sections 2.3.2 to 2.3.4. A more detailed explanation of key model assumptions can be found in the sensitivity analysis in section 2.5 and also Appendix 1.

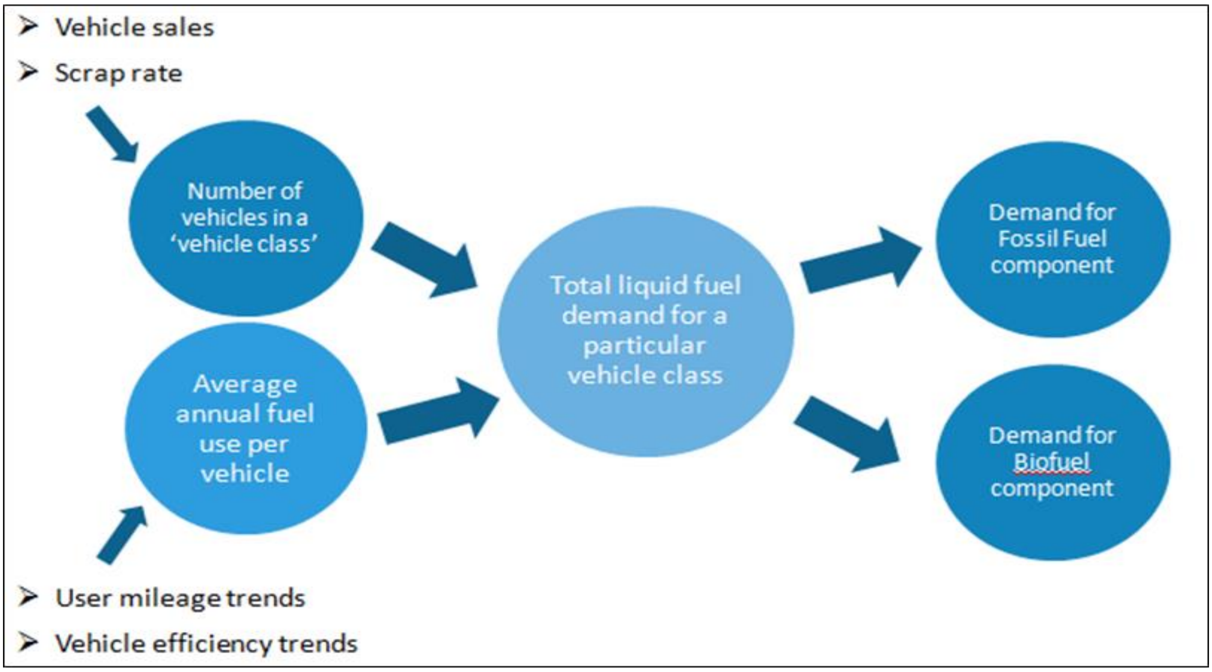

Figure 2.2: Methodological approach to estimating fleet fuel demand

Source: E4tech

2.3.2. Passenger car fleet composition

No existing estimate of the share of E5, E10, and other ECGVs within the European passenger car fleet exists so historic sales data must be used to build up a picture of the current fleet and how it could evolve to 2035. The vehicle stock for each vehicle type from 1980 to 2035 is calculated by adding the annual sales of new cars to the stock:

$$Vehicle\ stock = surviving\ vehicle\ stock + sales\ of\ new\ cars \qquad (1)$$

The approaches used to determine surviving vehicle stock and future sales are outlined here.

2.3.2.1. Surviving vehicle stock

The on-road fleet composition is modified by old vehicles being removed from the fleet. The surviving vehicle stock for each vehicle type is calculated by multiplying sales for a particular year by the survival stock rate for that year. The survival stock rate is the share of vehicles still in use at a certain time after their sale and is given by the equation[2]:

$$Survival\ rate\ (t) = 1 - \frac{1}{1+e^{-\beta(t-t_0)}} \qquad (2)$$

where t_0 is the median age of vehicles when they are scrapped, t is the present age of a given vehicle, and β is a parameter that expresses how quickly vehicles are retired around t_0. Initially, the parameters t_0 and β for each vehicle type are selected arbitrarily, then calibrated to fit historical data and historical data projections (see section 2.3.2.3). The survival rate function is illustrated in Figure 2.3 for different values of β.

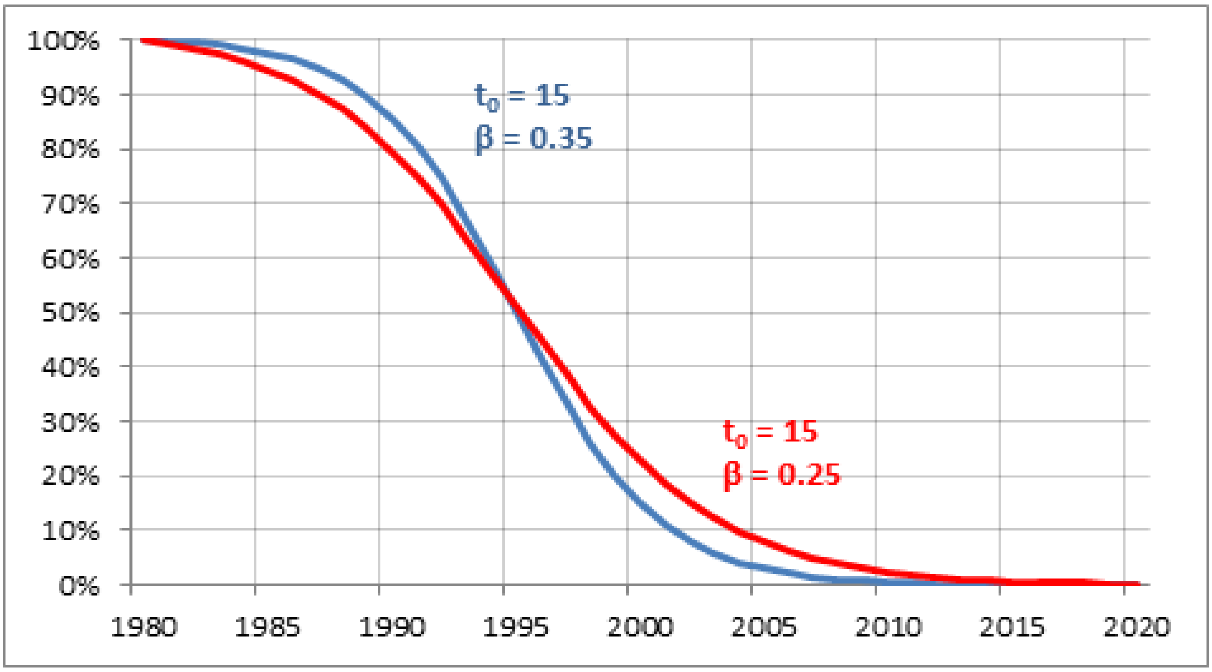

Figure 2.3: Examples of survival rate curves for different values of β

Source: E4tech

[2] Taken from Bodek & Powell (2008), page 8.

2.3.2.2. Sales of new cars

Historic EU passenger car sales data (gasoline, diesel and AFVs) is taken from various literature sources (JRC, 2003; EEA, 2006; ICCT, 2011; EEA, 2012a). Pre-2001 data is for EU-15 so an additional 5%[3] is added to the sales figures to estimate EU-27 new car sales. The total vehicles sales forecast is obtained by extrapolating the historic trend based on the average annual growth in sales between 1980-2011 (around 0.9% p.a.). This sees sales rise from 12.7 million passenger cars in 2011 to 15.7 million in 2035. To establish how the number of gasoline, diesel and AFV sales evolves the following assumptions were made after consultation with automotive industry representatives:

- The AFV sales share rises linearly from a 2011 figure of 4.2% (E4tech estimate) to 15% of total new car sales in 2035;
- The gasoline share of non-AFV sales rises linearly from 44% in 2011 (based on data from the EEA new car emissions report) to 60% in 2020 and remains at this share until 2035 (i.e. the gasoline/diesel sales ratio is 60/40).

The total gasoline sales in each year are then split between the four types of ECGV. It is assumed that when a new ECGV is introduced to the market (e.g. E20 cars) its sales are ramped up gradually over a number of years to phase out sales of the previous vehicle type (e.g. E10). An exception is FFV cars for which it is assumed that sales increase linearly to represent 2% of new gasoline car sales by 2035 (around 1% of all passenger car sales). The following years are chosen for the introduction to the market of each technology based on discussions with representatives from within the automotive industry:

- <1980: E5 cars;
- 1995: E10 cars (full substitution of E5 cars by 1999);
- 2012: E20/25 cars (full substitution of E10 cars by 2021);
- 2005: FFV cars.

This generates the annual sales data for each of the six vehicle types.

The starting point for modelling the future fleet composition is the EU-27 1980 fleet. Limited data is available covering all current Member States, so it is assumed that the 1980 passenger car fleet was composed of 95%[4] gasoline-based vehicles (assumed to all be E5 cars) and 5% diesel-based vehicles. The evolution of the stock is then calculated using equation *(1)* for each vehicle type.

2.3.2.3. Vehicle stock calibration

In order to calibrate the parameters t_0 and β within the survival vehicle stock equation, (partial) real data (for 1980-2011) for total vehicle stock and a projection of this data based on historic trends (for 2012-2035) are used. Total stock is calculated by multiplying the motorisation rate data (number of EU passenger cars per 1000 people) from Eurostat by EU population. Motorisation rate is

[3] See Appendix 1 for justification

[4] The fuel demand results for 2035 are not sensitive to this assumption since the entire 1980 fleet will have been scrapped by 2035.

extrapolated from 2011 to 2035 and combined with Eurostat population projections to estimate the vehicle stock in 2035. Using the real sales data and sales projections (section 2.2) average values for t_0 and β are determined by matching the calculated stock with the real and projected stock. Values for t_0 and β for each vehicle type within the model are then adjusted around these average values to reflect the differing lifetimes and rates of degradation of the various vehicle technologies (e.g. AFVs expected to have slightly lower t_0 to reflect shorter expected lifetime of EVs due to battery degradation[5]).

The model was able to successfully reproduce the passenger car fleet mix for 2009 (62% gasoline, 35% diesel (ACEA, 2011)) from the 1980 mix. Thus there can be reasonable confidence in the estimates for the parameters in the survival stock equation and the future fleet projections.

2.3.3. Average passenger car fuel use

Many factors affect annual car fuel use, including vehicle size and weight, engine technology, mileage, drive-cycle etc. The most reliable indicator of how the fuel efficiency of new passenger cars has evolved over the last two decades is the emissions data presented in the European Environment Agency's annual report *Monitoring CO_2 emissions from new passenger cars in the EU* (EEA, 2012a). This new car fleet average emission data (in gCO_2/km) forms the basis of the forecast of future passenger car fuel use. The following simple equation is used to calculate fuel use:

$$E = \frac{e \times d}{C} \times R \qquad (3)$$

where *E* is the average annual car (liquid) fuel use (in MJ), *e* is the car emission factor (gCO_2/km), *d* is the average distance travelled per passenger car (km), *C* is the fuel carbon intensity (gCO_2/MJ), and *R* is a conservative factor to account for the differences between test-cycle-condition emissions and real-driving-condition emissions (see below). This equation allows an estimate of average car fuel use per year to be made based on the forecast for average car tailpipe emissions.

Historic EU average new car CO_2 emissions data for 1995-2011 is taken from the EEA reports. Figures for 2012-2020 are determined by interpolating between the 2011 figure and the European Commission 2021 target of $95gCO_2/km$ established in the *EU Regulation on passenger cars (REGULATION (EC) No 443/2009)*. In order for the analysis to reflect a scenario in which ethanol demand is maximised within reason, it is assumed that beyond 2021 no further EU mandate for tailpipe CO_2 emissions is implemented (i.e. no further legislated demand made of vehicle manufacturers). Instead it is assumed that the average fleet emissions decline at the average rate observed between 1995-2006, before formal CO_2 exhaust legislation was introduced by the Commission. A projection based on these assumptions gives an average new car emission figure (for all passenger cars) of around 78g/km by 2035. In principle a mandate targeting a lower average figure than this could be introduced but this would correspond to lower overall fuel consumption (and therefore ethanol demand) thus for the purposes of maximising ethanol demand within reason it is

[5] This assumes that EV batteries are not replaced once their performance has degraded.

assumed that tailpipe emissions decline in line with technological developments without added incentive from mandated targets.

This figure then needs to be disaggregated to establish the contributions of ECGVs, diesel vehicles and AFVs to reaching this value based on their relative share of sales and potential for emission reductions. Based on analysis of the relative shares of EV, LPG, NG and FCEVs in the AFV fleet it is assumed that AFV emissions will reach an average of 20g/km by 2035. Combining this figure with the AFV penetration figures from section 2.3.2 allows the 78g/km fleet average to be split between AFV and non-AFV (i.e. diesel and gasoline) vehicles. For non-AFVs an average figure of around 89g/km is generated for 2035. This is subsequently disaggregated into future gasoline car and future diesel car emissions by scaling the non-AFV figure using historic emission reduction trends for gasoline vehicles. This approach yields new gasoline car emissions of 85g/km and diesel car emissions of 94g/km[6] for 2035. The gasoline fleet emissions were then estimated for each year from 2010 onwards. To account for the fact that real-driving-condition emissions are very often higher than test-cycle-condition (those under the New European Driving Cycle) driving emissions, a conservative factor is included to reflect this discrepancy. The calculated fleet emissions are increased by 15% to account for this, based on estimates by the JEC (JEC, 2011b).

While total EU passenger-km are expected to continue to grow, the annual distance covered per passenger car in the EU has been in decline over the last two decades and is expected to continue to do so. EU car-km data (BITRE, 2012) is extrapolated to 2035 to reflect this trend. It is recognised that the average mileage of a gasoline, diesel and alternative fuel vehicle (e.g. EVs) will differ. Diesel cars are favoured by drivers who cover more miles annually due to their more favourable fuel economy. It is assumed that currently diesel cars travel on average 30%[7] further per year than gasoline cars. It is assumed further that this gap in mileage will gradually close as the fuel economy of gasoline cars approaches that of diesels. This redistribution in average gasoline/diesel mileage is achieved by assuming that drivers who transfer from diesel cars to gasoline cars take their driving habits with them (i.e. transfer their higher mileage to their gasoline vehicle). In this way the gap between average diesel and gasoline mileage closes slightly, although diesels continue to be favoured for long-distance driving on the whole. Using these assumptions and the fleet composition from section 2.3.2, the average annual distance covered per gasoline and diesel car are calculated (around 12 (14.5) thousand km per gasoline (diesel) car in 2035). Figure 2.4 indicates how the average passenger car mileage evolves to 2035.

[6] See section 2.5.8 for further discussion of this forecast

[7] See Appendix 1 for detail.

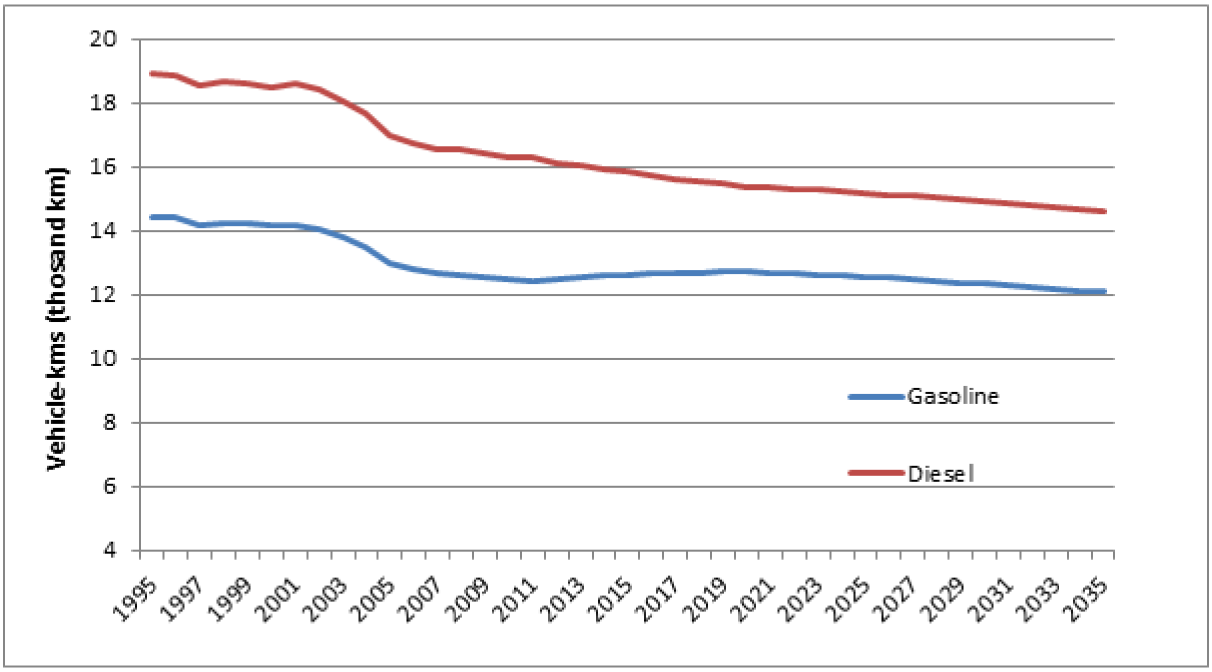

Figure 2.4: Projected evolution of average annual distance travelled by individual passenger cars

Source: E4tech

The carbon intensity of each fuel (in gCO_2/MJ) is calculated using figures from the JEC well-to-wheels study (JEC, 2007) and by assuming an increasing average biofuel blend to 2035 in the gasoline or diesel fuel.[8] Combining all of these elements in equation *(3)* gives a forecast of how the annual gasoline and diesel passenger car fuel demand will evolve to 2035.

2.3.4. Total fuel demand

The annual fuel demand for each set of ECGVs is determined by multiplying the number of each vehicle in the stock by the average gasoline vehicle fuel demand. This assumes that individual E5, E10, E20/25 and flex-fuel vehicles will have the same annual fuel demand.[9] The total fuel energy demand per ECGV type is then broken down into its gasoline and ethanol constituents, by assuming that vehicles use the maximum ethanol blend they can accept (e.g. E10 vehicles all use a 10% blend). In the case of E20/25 a gradual phase-in of the 20/25% blend fuel across Europe is assumed to take place from 2017-2022 such that from 2022 onwards these vehicles run on their maximum blend. FFVs are assumed to operate on an 85% blend. While often ECGVs will be run on fuels with lower blends, this assumption is made to meet the study's objective of investigating what could be the maximum ethanol demand within reason.

Adding the ethanol demand of all EGCV types together yields the total passenger car ethanol demand to 2035. To account for the ethanol demand from motorcycles and vans, an additional 5% is

[8] The assumption regarding the average biofuel blend to 2035 will not significantly affect the calculated average fuel carbon intensity, since the carbon content (gCO_2/MJ fuel) of gasoline & ethanol, and diesel & biodiesel are within 2% of each other (~74gCO_2/MJ).
[9] Some discussion regarding this assumption is provided Appendix 1.

added to give a final transport ethanol demand. The analysis also yields estimates of passenger car gasoline and diesel demand.

2.4. Demand results

The modelled EU-27 passenger car vehicle stock from 1980-2035 and its breakdown by vehicle type is presented in Figure 2.5. The dashed black line represents the total stock calculated by multiplying motorisation rate with population while the solid black line indicates the total stock modelled based on the assumptions within the analysis. The rebound in sales predicted for gasoline vehicles beyond 2015 can be noted with the Total ECGV line. Total stock reaches 279 million by 2035 with E20/25 cars constituting around 40% of this. The data is presented in Table 2.1.

Table 2.1: Projected split of passenger car fleet (million vehicles)

	2015	2020	2025	2030	2035	2035 Share
E5	24.4	12.0	5.5	2.5	1.1	0%
E10	106.5	94.3	70.2	48.1	30.4	11%
E20/25	6.0	29.8	63.3	91.6	113.1	41%
E85	0.4	0.8	1.2	1.6	2.0	1%
Diesel	108.2	113.3	113.2	111.7	110.1	39%
AFV	3.1	6.3	10.7	16.1	22.2	8%
Total	**249**	**257**	**264**	**272**	**279**	**100%**

Source: E4tech

Ethanol demand forecasts are shown in Figure 2.6 for the two scenarios in which either E20 or E25 vehicle technology is brought to market. The E20 (E25) scenario projects a 2035 total transport ethanol demand of around 8.4 Mtoe (10.3 Mtoe).[10] The rapid growth in demand between 2017-2022 corresponds to the parallel phase-in of E20 vehicles and E20 fuel blends. Beyond 2022 growth in demand is less aggressive, because while the stock of higher-blend-compatible ECGVs grows, overall liquid fuel demand reduces as vehicle fuel economy improves. Also, the absence in the modelling of possible future ECGV technologies capable of accepting even higher blends means that the growth in demand seen during the transition from E10 to E20 vehicles is not sustained.

[10] For figures in litres see Appendix 2

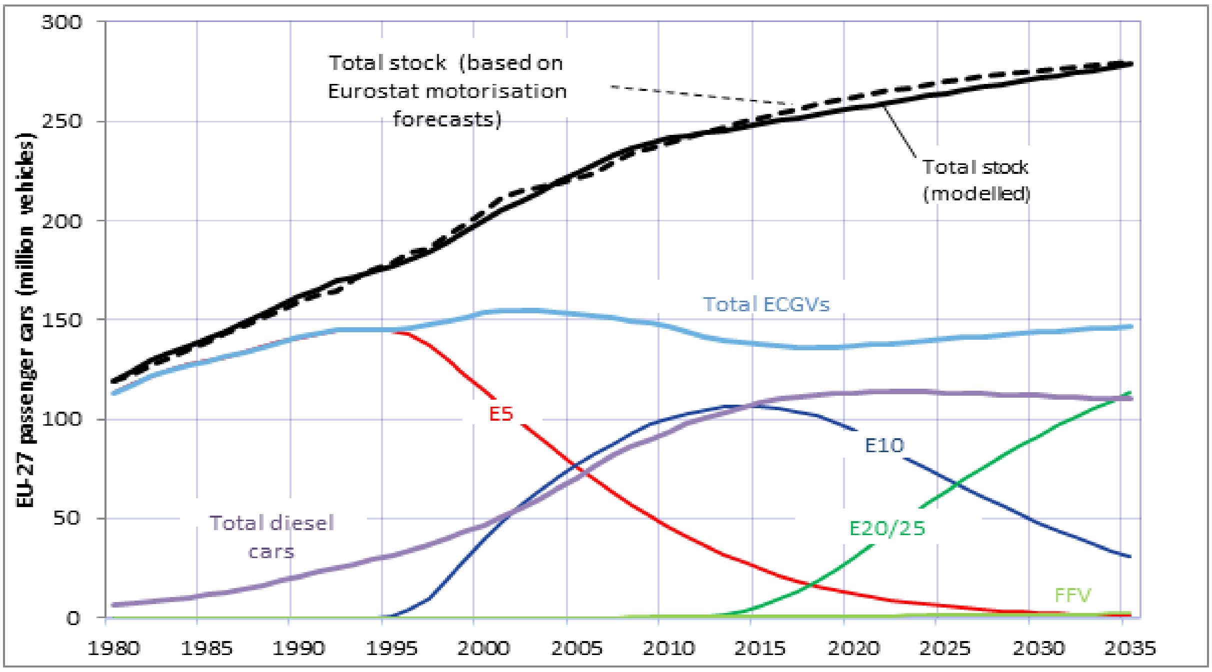

Figure 2.5: EU-27 passenger car fleet (million vehicles). The gasoline fleet consists of E5, E10, E20/25 and FFV cars (share of AFVs not included)

Source: E4tech

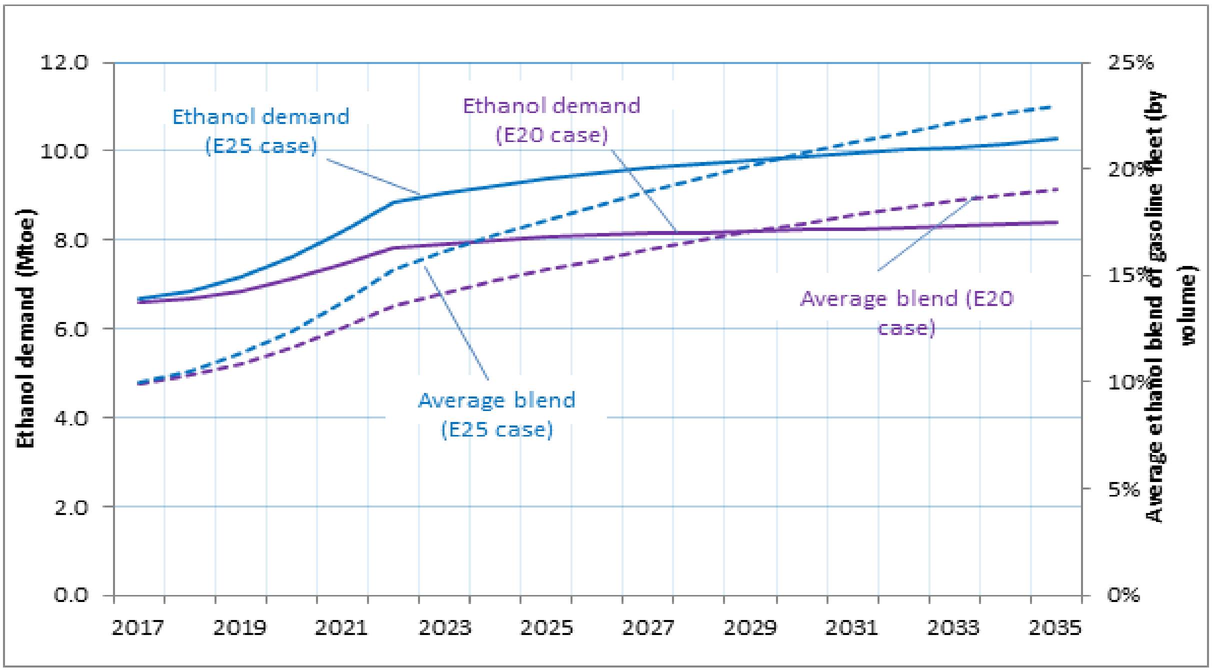

Figure 2.6: EU-27 ethanol demand (solid lines) and average gasoline fleet ethanol blend (dashed lines) for the two scenarios (E20 and E25 vehicles on the market).

Note: For data in litres see Appendix 2.
Source: E4tech

It should be noted that the 2020 ethanol demand in the E20 (E25) scenario is 7.1 (7.6) Mtoe, which is almost identical to the combined forecasts laid out in Member State NREAPs (~7.1Mtoe). For the E20 (E25) scenario this represents 8% (8.5%) of the projected overall liquid fuel demand of gasoline passenger cars *by energy content.*

Figure 2.7 illustrates how total passenger car fuel demand is expected to evolve in the E20 scenario. A modest increase in ethanol demand contrasts with a 37% reduction in overall fuel demand (between 2017-2035) to just over 115 Mtoe, due to the combination of increasing vehicle fuel economy with a reduction in annual mileage.

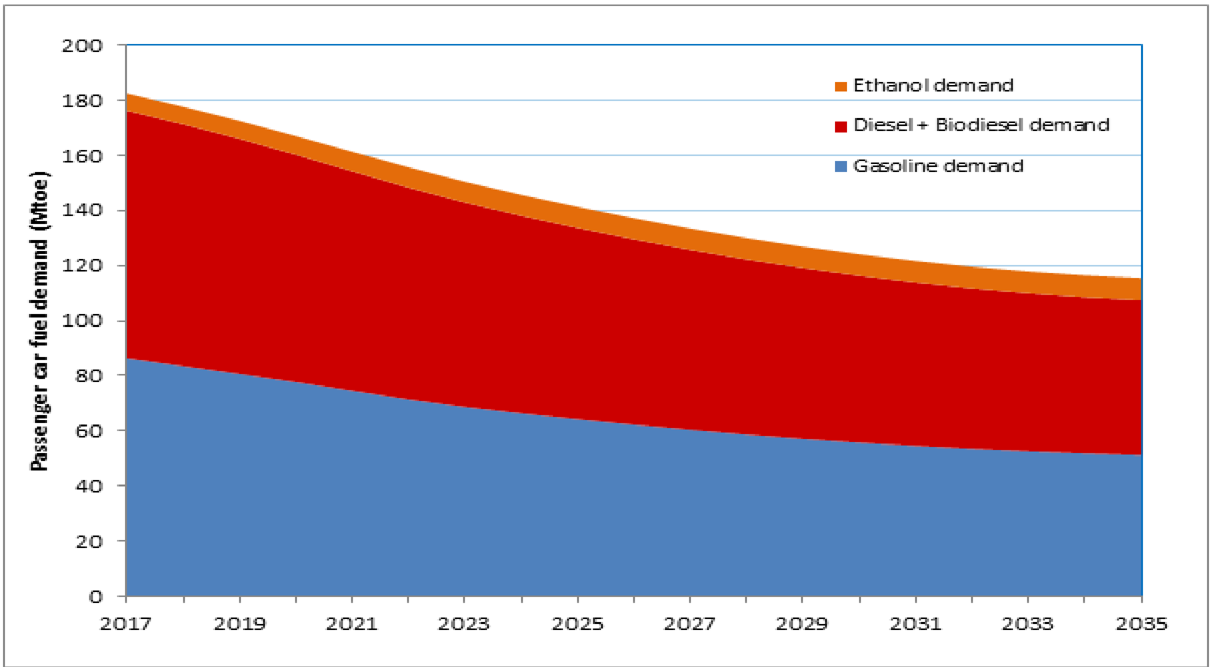

Figure 2.7: Passenger car fuel demand forecast (E20 scenario). Diesel and biodiesel demand are combined

Source: E4tech

2.4.1. Ethanol demand in the context of total transport energy

The ethanol demand projection can be viewed in the context of total EU transport energy demand in order to get a sense of the contribution ethanol could make to meeting the 2020 transport target, and its role in 2035. In the publication *EU Energy, Transport and GHG Emissions Trends to 2050* (DG ENER, 2013), a joint work by several EC Directorates, total energy demand for the whole EU transport sector is estimated to reach 359 Mtoe in 2020, dropping to 354 Mtoe by 2035. The results of the ethanol forecasts are presented in the context of this figure and others in Table 2.2 below. The transport biodiesel demand figures presented here are forecasts taken from the NREAP variant scenario in the Biomass Futures Study (Intelligent Energy, 2012). The 2020 figure is based on Member State projections set out in the NREAPs. Based on the EC transport energy demand forecast and the maximum ethanol demand projected in this study, biofuels could be expected to meet around 8.5% of total transport energy demand by 2020, rising to around 10.5% by 2035.

Table 2.2: Ethanol demand in context of total EU transport demand

	2020	2035
Total Transport Energy Demand (Mtoe)	359	354
Transport Gasoline Demand (Mtoe)	81.9	54.0
Transport Ethanol Demand, E20 scenario (Mtoe)	7.1	8.4
Transport Biodiesel Demand (Mtoe)	22.4	26.6
Gasoline Share of Transport Energy	22.8%	15.3%
Biofuel Share of Transport Energy	8.5%	10.5%
Ethanol Share of Transport Biofuel	23.4%	22.6%
Ethanol Share of Total Gasoline	8.7%	15.6%

Source: E4tech; based on DG ENER (2013) and Intelligent Energy (2012).

2.5. Sensitivity analysis

A sensitivity analysis has been performed in order to assess key sensitivities relating to fuel ethanol consumption, and identify the parameters which have the greatest influence on future demand. The analysis is based on the results of the E20 vehicle scenario.

Figure 2.8 gives an indication of the sensitivity of 2035 ethanol demand to variations in the key model parameters. The figures in parenthesis on the left-hand side represent possible uncertainties in the values of these parameters. The three values are those which would generate lower ethanol demand, base case ethanol demand, and higher ethanol demand respectively. Some elaboration on each of these parameters is provided below.

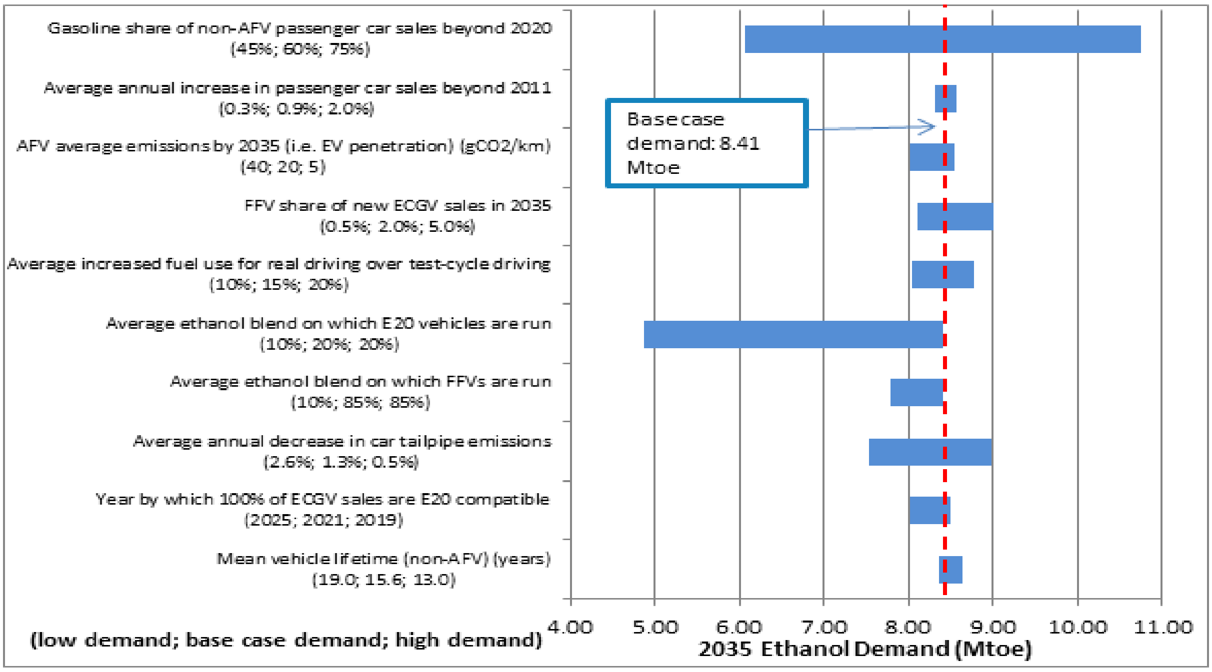

Figure 2.8: Sensitivity of key model parameters.

Note: Figures in parenthesis represent parameter values which result in low demand; base case demand; high demand respectively.
Source: E4tech

2.5.1. Gasoline share of sales

The ethanol demand forecast is highly dependent upon the assumption regarding the future sales split between gasoline- and diesel-based vehicles. This is perhaps the most crucial parameter when assessing future demand as can be noted from Figure 2.8. The future sales split will depend upon the differing cost of buying and operating each vehicle type, as well as on their potential for emission reduction.

Thus the base case assumption that the market will see a rebound in sales of gasoline passenger cars is crucial. There is reason to believe that this is a fair assumption and that a partial resurgence in ECGV sales will occur (see section 2.2). Thus, the base case assumes that, rising from a share of around 45% today, 60% of all non-AFV passenger car sales will be ECGVs by 2020 (with this split remaining constant until 2035). A more pronounced rebound to sales of 75% would see demand grow to 10.8 Mtoe, a 28% increase on the base case. The sales share in 2011 was around 45% (EEA, 2012a) which is selected as a lower bound in the sensitivity analysis, and would see demand drop to 6.1 Mtoe.

2.5.2. Increase in passenger car sales

Projections for future passenger car sales do not impact significantly on the overall ethanol demand. This is because the future improvements in ECGV fuel efficiency assumed in the base case are not dramatic enough to lead to significant variations in demand with more (or less) state-of-the-art vehicles on the road than older models. The baseline growth in sales (0.9% annually) is the average growth in new car registrations observed between 1980 and 2011. This sees sales grow from 12.7 million in 2011 to 15.7 million in 2035 (highest sales in the past were 15.6 million in 2006). The growth assumption in the high (low) scenario leads to sales of 20.4 million (13.6 million) by 2035.

2.5.3. AFV average emissions

The future average emissions for the AFV category will reflect the evolution of the AFV technology fleet. A higher penetration of electric vehicles or FCEVs will bring the average down towards zero. Other AFV technologies such as LPG and NG do not have the same emissions reduction potential, although there is scope for blending of biomethane with NG vehicles. A lower average AFV emission figure results in higher ethanol demand for the ECGV fleet. This is because higher sales of EVs means that less severe emission reductions are demanded of gasoline and diesel vehicles to meet the legislated targets (since EVs are considered zero emission vehicles). Thus car fuel use will not decline as rapidly as in the base case, and overall ethanol demand will be higher. The analysis indicates that this is not a sensitive parameter, since the overall penetration of AFVs is quite low. The base case assumption that 15% of 2035 car sales are AFVs is based on the projections in the ERTRAC Research and Innovation roadmap (ERTRAC, 2011) with the share of sales increasing linearly from the current figure.

2.5.4. FFV share of ECGV sales

Flex-fuel vehicles are likely to remain a niche market to 2035, predominantly in Sweden but also Hungary, Germany, France, Czech Republic and others. FFVs are given political support in these countries, largely because they afford some opportunity for energy security through diversification of the transport fuel mix. The base case assumption is that support continues for FFVs in this small subset of Member States and FFVs account for 2% of ECGV sales in 2035. If adoption of the FFVs was more widespread (5% of ECGV sales) ethanol demand would rise to around 9.0 Mtoe by 2035 (assuming all vehicles are fuelled with an 85% ethanol blend). This higher value is similar to the sales assumption for FFVs made by the JEC in the reference scenario in the *EU renewable energy targets in 2020* report (JEC, 2011a) (around 1% of all sales in 2020).

2.5.5. Disparity between test- and real-driving fuel use

Passenger car fuel reduction potentials in the model are based on the extrapolation of historic new fleet tailpipe emissions, but a conservative factor is added to the projections to account for the disparity between the test cycle driving conditions and real-life driving conditions. Work carried out by the JEC (JEC, 2011b) indicates that this factor ranges from 10-20%. A baseline value of 15% is chosen, but increasing this to 20% would see fuel demand reach 8.8 Mtoe.

2.5.6. Fuel blend used by E20 vehicles

The baseline assumes that E20 blends are phased in from 2017 and will be available across the entire EU from 2022, with all E20 vehicles running on a 20% blend from then. If E20 fuel does not become available widespread across Europe, operators of E20 vehicles will be forced to use gasoline with lower ethanol blends. Moreover a high ethanol price relative to the oil price could make E20 a less economically attractive option for consumers, and this could result in users choosing the lower blends in forecourts. In the instance where only 10% blends are introduced to filling stations (or preferred by customers based on price), ethanol demand is significantly lower at around 4.9 Mtoe. Thus the 2035 demand is highly dependent upon how Member State biofuel mandates and the overall renewable transport target evolve, as this will influence the availability of particular fuel blends across Europe, and the time at which they are introduced. Price will also be critical to uptake by consumers. If E10 blends are available alongside E20 blends and are more affordable ethanol demand might drop significantly. Also, if biodiesel represents a more affordable option for fuel suppliers to meet their blending requirements this could potentially limit the roll-out of E20 blends. Ultimately however the same technical constraints regarding blending limits apply to biodiesel-compatible diesel vehicles as well. Feedback from representatives in the automotive industry suggests that the costs of adapting engine technology to accept blends above B7 could be expensive compared to the modifications to spark ignition engines. Thus for the purposes of this analysis of maximum ethanol demand it is considered appropriate to assume that ethanol remains competitive compared to biodiesel road fuels.

2.5.7. Fuel blend used by flex-fuel vehicles

Given the low penetration of FFVs in the base case, the ethanol demand is less sensitive to the fuel blend used by these cars. However, applying the same assumption as above (only 10% blends are widespread) would see a slight decrease in demand (7.8 Mtoe).

2.5.8. Average decrease in car tailpipe emissions

As outlined in section 2.3.3, the pre-mandate average tailpipe emission reduction rate (1995-2006) is applied in order to forecast to 2035. This corresponds to an annual reduction of 1.3%. This is a difficult parameter to predict because the future evolution of fleet tailpipe emissions will largely be driven by European Commission legislation which is yet to be proposed (there are no formal targets beyond 95g/km in 2021), and this legislation could embrace new test cycles and credits for AFVs beyond 2020. It is difficult to speculate about what goals will be set and how they might be met. Traditional internal combustion engines are fundamentally limited in the tailpipe reductions they can deliver. A technological barrier of around 70gCO_2/km has been suggested (Dunmore & Lewis, 2012) as achievable by combining technologies and techniques which are commercially available today (light weighting, improved aerodynamics, reduced driveline friction, thermal management, regenerative braking etc.). Beyond this figure a switch to plug-in hybrid or full electric vehicles may be required. The baseline projections for 2035 new gasoline vehicles (85g/km) are thus considered to be reasonable.

Higher volume ethanol blends offer the potential for further efficiency improvements, since the increased octane number can allow for higher compression ratios. However the requirement for E20 compatible vehicles to also be compatible with straight gasoline means that this advantage of higher blends is unlikely to be captured. Without adjustment of compression ratio, the impact of ethanol blend level is a secondary effect that is likely to be specific to an individual combustion system. However, such effects do not tend to be highly negative, therefore there is no reason to believe that these baseline efficiency improvements cannot be achieved in tandem with increasing blend levels.

In the sensitivity analysis a scenario has been explored in which continued demands are made of OEMs to reduce fleet emissions. The average annual decrease in emissions for 1995-2011 has been higher than the pre-mandate period at around 1.9%. In order to meet the 2021 target of 95g/km, this rate of change will need to increase further. Assuming the 2020 target is met, the average emission reductions for 1995-2020 will come to around 2.6% annually. Applying this more aggressive reduction out to 2035 gives a fleet average of 64g/km[11]. Assuming the same penetration of EVs as the base case, this means the gasoline fleet (including mild, full and plug-in hybrids) must deliver 69g/km (77g/km for diesel vehicles). This scenario would see ethanol demand drop to around 7.5 Mtoe. A high scenario in which the vehicle fleet average reaches just 88g/km would see demand rise to 9.0 Mtoe. This is clearly quite a sensitive parameter and future demand will depend greatly on the political will to push for more stringent targets. The base assumption is considered to be a realistic one given some debate calling for greater reductions, balanced against the need to preserve economic health for OEMs and consumers.

2.5.9. Year in which all new ECGV sales are E20 compatible

The evolution of the ECGV fleet is an important consideration, but the rate at which new engine technologies are phased in is not critical to demand in 2035. The base case assumes a complete shift to E20 compatible ECGVs by 2021 (phased in from 2017). A delay to 2025 would result in a small but appreciable reduction in demand (8.0 Mtoe). However, the average blend used by these vehicles (see section 2.5.6) has a much greater overall impact on demand.

2.5.10. Mean vehicle lifetime

Variations in mean vehicle lifetime will make some difference to ethanol demand since earlier retirement means that the fleet is composed of more fuel efficient vehicles. This parameter depends implicitly on the average decrease in new car emissions and thus could lead to some significant variation in ethanol demand. Ultimately mean vehicle retirement age will depend on how vehicle sales grow in the future (assuming that the fleet size grows as assumed in the base case). In the base case however the relatively conservative reduction in new car emissions to 2035 means that the average vehicle lifetime does not impact fuel demand significantly.

2.6. Evaluation of results compared to existing forecasts

Several existing forecasts for future EU ethanol demand have been examined and compared with the model projections. Existing forecasts include:

- **FAPRI:** The FAPRI-ISU 2011 *World Agricultural Outlook* contains projections to 2025 for EU ethanol consumption (FAPRI, 2011).

[11] For comparison, the IEA 450 scenario (an ambitious scenario which sets out an energy pathway consistent with the goal of limiting the global increase in temperature to 2 degrees Celsius) assumes that the passenger light duty vehicle fleet averages 65g/km in 2035

- **PRIMES:** Scenarios to 2030 derived using the PRIMES model for DG ENER's *EU Energy Trends to 2030* (Intelligent Energy, 2012). The main scenarios are:
  - Reference scenario;
  - Decarbonisation scenario;
  - Sustainability scenario;
  - Max biomass scenario;
  - NREAP variant scenario.
- **JEC:** Scenarios to 2020 taken from the revised *EU renewable energy targets in 2020* report (JEC, 2014). The analysis includes four scenarios. Here the reference scenario has been examined, as well as scenario 2 as it assumes that E20 vehicles are brought to market and the corresponding biofuel blends are available.
- **EU NREAPs:** The projected ethanol demand for all Member States in 2020 according to National Renewable Action Plans was examined.

These forecasts vary widely in their projections, so the underlying assumptions have been examined and compared with those made in the above analysis. A selection of these forecasts is plotted in Figure 2.9. Note that none of these studies extend to 2035.

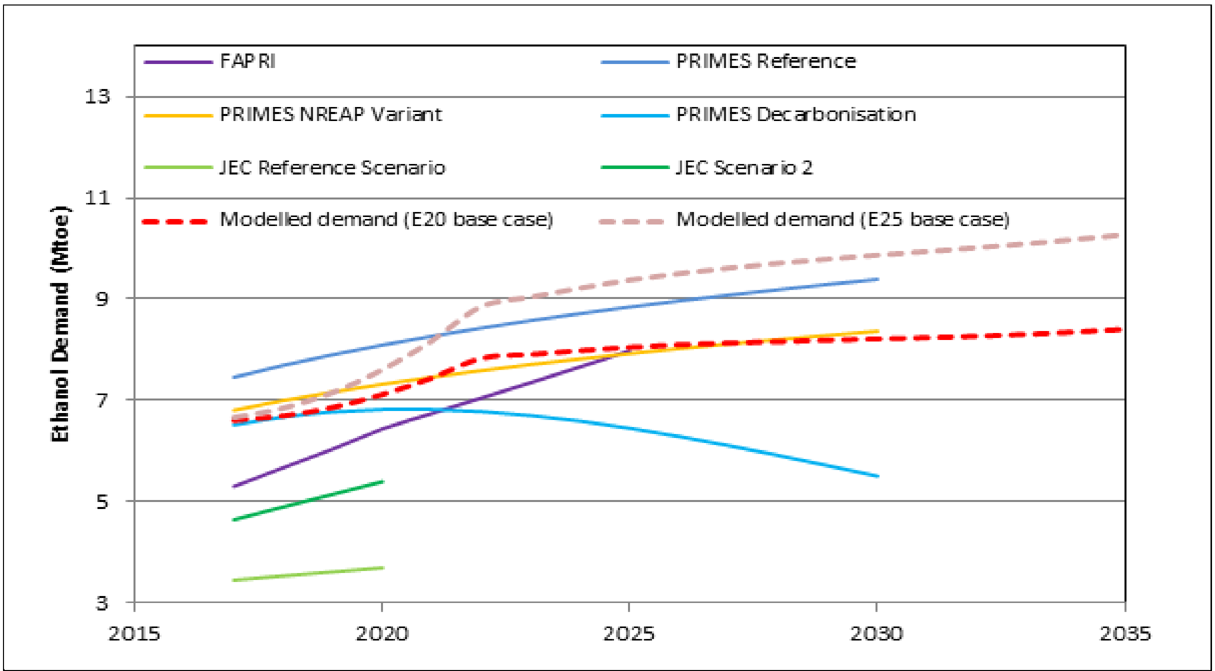

Figure 2.9: Selected ethanol demand scenarios

Notes: Dashed lines represent modelled demand
Source: E4tech

The **FAPRI** forecast is generated using the FAPRI/CARD international ethanol model, which examines and projects the production, use, stocks, prices and trade for ethanol for several countries and regions of the world (FAPRI, 2012). While both the E20 forecast and FAPRI project a quite aggressive uptake of ethanol from 2017, FAPRI does not foresee the levelling off after 2022 that results from the growing saturation of E20 vehicles in the fleet. Both projections agree on a 2025 demand of around 8 Mtoe (as does the PRIMES NREAP variant scenario). Demand projections within the model supposedly adhere to biofuel mandates, however the 2020 demand does not reach the required level estimated by the NREAPs (around 7.1 Mtoe). The FAPRI model does forecast a relatively rapid growth in demand to 2025 but this trend may not necessarily continue beyond 2025.

In contrast to the approach used in this report the FAPRI model takes into account the relative prices of ethanol and gasoline when modelling demand. The approach described in section 2.3.4 assumes that it always makes economic sense for fuel suppliers to provide E10 and E20 blends regardless of oil price. For the purposes of assessing the maximum potential ethanol demand this assumption that ethanol is always cost competitive is considered to be fair. The volatility and uncertainty of oil prices makes an assessment of future cost competitiveness difficult.

PRIMES is a demand-driven partial equilibrium model for European Union energy markets used for policy impact analysis up to 2030. It was used in scenario analysis for the study *EU Energy Trends to 2030* commissioned by DG ENER. For almost all scenarios the overall demand for final biomass energy products is fixed and the model computes the optimal use of resources to meet the demand in various sectors in each scenario laid out in the study. The exception is an 'NREAP variant' scenario in which demand is derived from the NREAPs. Thus ethanol demand varies widely between different scenarios. The reference scenario assumes that various transport policy targets are realised. However, the targets assumed for CO_2 emissions from cars are outdated (assumes 135g/km target for 2015 and 115g/km for 2020) which will result in higher fuel demand. This scenario thus projects higher ethanol demand in 2020 than the targets laid out in the NREAPs. It can be noted from Figure 2.9 that the PRIMES NREAP variant scenario projects a very similar rate of growth to the E20 scenario with almost identical demand forecast for 2030. The 'decarbonisation scenario' has also been included in Figure 2.9 as an example of one of the forecasts projecting a minor role for ethanol in the transport energy mix. It assumes the demand for fossil fuels decreases compared to the reference scenario, in part due to the large-scale electrification of transport. All scenarios are constructed such that RED and FQD targets are met, thus the contribution of biomass to the overall energy mix is quite high.

The **JEC** forecasts use the Fleet and Fuels (F&F) model which is based on historical road fleet data (both passenger and freight) in 29 European countries (EU-27 plus Norway and Switzerland). The approach taken in this study is very close to that used in the formation of the E20/E25 scenarios here, although the assumptions made by the JEC regarding uptake of ethanol blends as not as generous as those made here. The JEC study assumes that the diesel/gasoline new car sales share is 50%/50% by 2020. It assumes a more optimistic increase in sales reaching 16 million car sales in 2020 (compared with 13.8 million in the E20 base case). The reference scenario does not assume that E20 vehicles and blends are brought to market by 2020, assuming instead that E10 blends are the standard blend until 2020. This scenario also assumes lukewarm consumer acceptance, with only 36% of drivers refuelling E10 compatible vehicles with E10 fuel in 2020. Thus it projects lower demand in 2020 than any of the other scenarios (3.7 Mtoe). Scenario 2 introduces E20 vehicles and blends from 2019[12] onwards, thus only reaching minor penetrations by 2020. In this scenario E20 only represents 1.4% of total gasoline fuel sales by 2020, compared to over 20% in the E20 scenario in this study. This is due to the fact that in the E20 scenario it is assumed that E20-compatible vehicles are gradually introduced to the market from 2012 onward (thus a much higher share of compatible vehicles in the fleet by 2020) and the corresponding E20 blends are more widespread across the EU by 2020. While the JEC Scenario 2 forecasts higher ethanol uptake than the reference scenario, it still only reaches 5.4 Mtoe by 2020. As with the FAPRI forecast, there is no indication that the trends in these scenarios will continue beyond 2020.

An analysis of the **NREAPs** of all Member States indicates a total ethanol demand of around 7.1 Mtoe in 2020, identical to that forecast in the E20 case (7.6 Mtoe in the E25 case). An assessment of these forecasts implies that this is quite an ambitious target given the progress that has been made in the past few years. Many Member States' ethanol demand forecasts represent an optimistic outlook to 2020 as several of the NREAPs are very ambitious about the contribution of ethanol (e.g. Italy, UK). For instance, the UK project an ethanol consumption of 1.7 Mtoe in 2020, compared to actual demand of 0.39 Mtoe in Year 5 of the RTFO (2012/13). This would require reaching an average UK blend of 15% by volume. The total EU ethanol demand projected by the NREAPs would translate to an average blend across the continent of 11.1% by volume which would essentially require the replacement of E5 blends with E10 (and higher) in all Member States by 2020.

A recent study by E4tech conducted on behalf of a consortium of automotive and fuel companies (E4tech, 2013) also examined EU road transport fuel and biofuel consumption, including an assessment of ethanol uptake. However none of the scenarios investigated in the report were built around assumptions based on maximising ethanol demand to the same extent as in this current study. As a result the scenarios with highest ethanol demand in that report are not as high as those investigated here. The scenario with highest demand in the E4tech study forecasts demand of around 7.0 Mtoe in 2030 compared to 8.2 Mtoe in the E20 scenario here. The E25 scenario forecast for 2035 gives a higher demand figure than for any of the other scenarios examined here, implying that it represents a fair benchmark of the ceiling on transport ethanol demand within reason.

2.7. Summary

Ethanol demand datasets have been generated for two different ECGV deployment scenarios. The model has been calibrated with historic data and the projections are largely aligned with existing forecasts with similar assumptions. The sensitivity analysis indicates that the most critical assumptions when forecasting ethanol demand are regarding:

- The gasoline/diesel vehicle sales ratio;
- Member State biofuel mandates and the renewable transport target;
- New car tailpipe emissions targets.

[12] Note that in the original JEC publication (JEC, 2011a) the year for introduction of E20 vehicles was 2017 rather than 2019, hence the scrutiny of the period 2017-2035 in this report.

In the analysis the uptake of ethanol has been constrained based on the composition of the ethanol compatible gasoline vehicle fleet and it's capacity to accept higher ethanol blends. This takes into account the current composition of the fleet and it's likely evolution. Where appropriate assumptions have been made which maximise ethanol demand within reason. Given these factors, it is difficult to envisage EU ethanol demand surpassing that which has been forecast here, unless vehicles capable of accepting even higher blends (E30 and above) are brought to market from the mid-2020s.

Road transport ethanol demand in the E20 (E25) scenario presented here is projected to reach 8.4 (10.3) Mtoe by 2035. Analysis of other studies reveals ethanol demand projections for 2020 ranging from 3.7Mtoe (JEC Reference scenario) to 8.1 Mtoe (PRIMES reference scenario) compared to a 2020 ethanol demand in the E20 (E25) scenario of 7.1 (7.6) Mtoe.

2.8. Global ethanol demand forecast summary

A further task was undertaken to assess the global road transport ethanol demand from 2017 to 2035 through selected feasible scenarios which 'maximise ethanol demand within reason.' The outputs of this assessment are summarised briefly here. This assessment was based on publicly available data sets and derived based on a top-down approach, applying reasoned assumptions. The main focus was on the two major ethanol demand regions - the US and Brazil, complemented with demand forecasts for the EU-27 and the Rest of the World (RoW). The purpose of this analysis was to place possible EU ethanol demand within the context of global demand.

To forecast the world ethanol demand from 2017 to 2035 two global datasets were used as the basis of the analysis:

1. **World Agricultural Outlook 2011. Food and Agricultural Policy Research Institute (FAPRI, 2011):** This outlook provides bio-ethanol consumption, production, ending stocks and net trade data for the main countries to 2025.
2. **World Energy Outlook 2011. International Energy Agency (IEA, 2011):** The World Energy Outlook provides a dataset for global transport and biofuel transport demand for all sectors for key countries and regions to 2035. The Outlook provides three scenarios; the New Policies Scenario which assumes an increase in ethanol blending mandates in the US and Brazil; the Current Policies Scenario which assumes that ethanol targets in Brazil remain stable around 20-25%; and the 450 Scenario which is based on more ambitious carbon reduction targets.

Several global ethanol demand forecasts were built from these datasets building on analogous assumptions to those in the EU case study. The global ethanol demand projection based on four different scenarios (three based on data from the IEA World Energy Outlook 2011, and one based on an extrapolation of the FAPRI Global Agricultural Outlook 2011), are presented in Figure 2.10.

The violet scenario represents the most conservative outlook based on FAPRI data with global ethanol demand reaching 100 Mtoe (FAPRI, 2011). The three IEA scenarios project ethanol demand ranging from 115 Mtoe in the Current Policies Scenario to 200 Mtoe in the 450 Scenario. The Current Policies Scenario is based on policies that were in place mid-2011 such as the 10% renewable transport target for 2020 in the EU or the Renewable Fuel Standard in the US. This scenario forecasts a higher ethanol demand projection of around 150 Mtoe. The high ethanol demand forecast of 200 Mtoe in the 450 Scenario is based on an energy roadmap that aims to limit average global temperature increase to 2°C (IEA, 2011). Given the current policy environment, the range of 100-150 Mtoe of global ethanol demand seems more realistic than the high 200 Mtoe value.

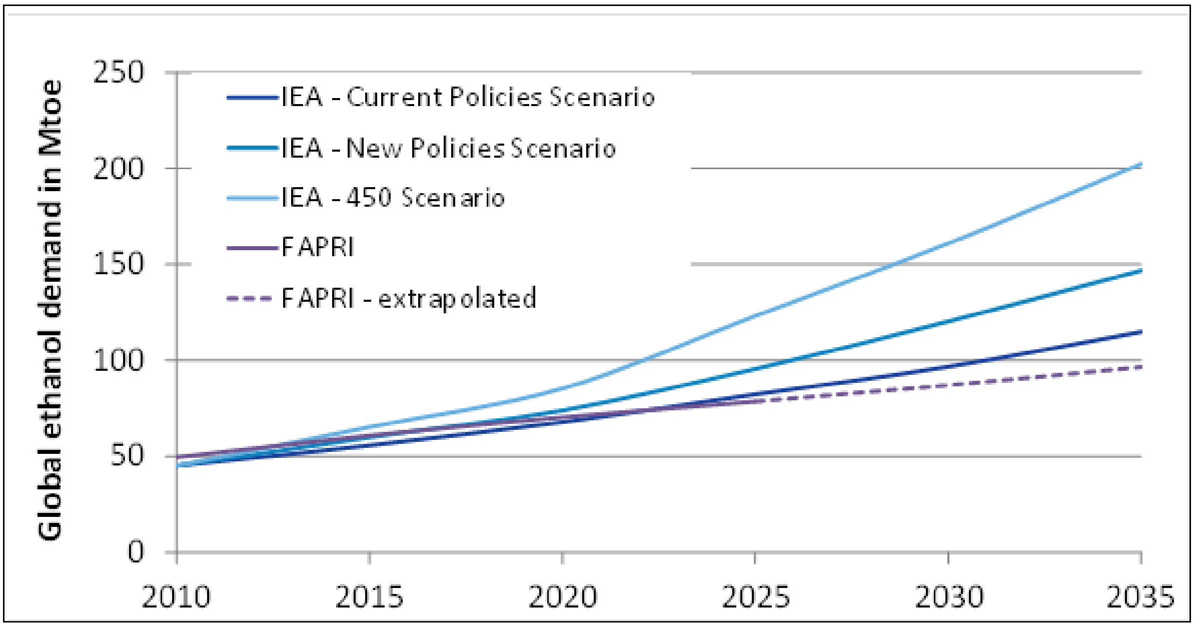

Figure 2.10: Global ethanol demand scenarios to 2035

Notes: see appendix for data in litres.
Source: E4tech; based on FAPRI (2011) and IEA (2011).

Brazil and the United States have the largest ethanol demand share today and are expected to remain the two main demand regions with 34% and 46% of total ethanol demand in 2035 respectively (see The demand in Brazil grows at 3% per year, stronger than in the US (around 2% p.a.). The remaining 2035 world ethanol demand shares are 9% for the EU-27 and 12% for the Rest of the World.

The difference in ethanol demand between the US and the EU-27 can be explained by a combination of several factors:

- The share of gasoline cars is much higher in the US than in the EU-27;
- The fuel efficiency of gasoline cars in the US is lower than in the EU-27;
- The average annual mileage in the US is higher than in the EU-27.

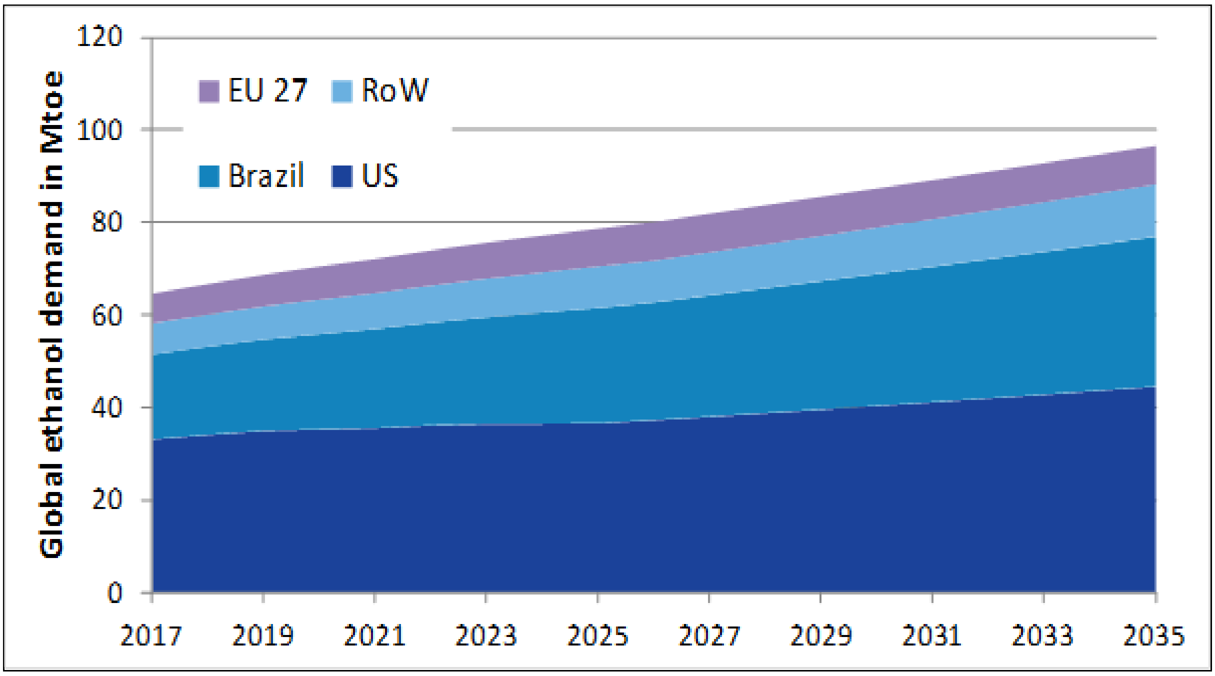

Figure 2.11: Low scenario for global ethanol demand with share of main regions or countries

Notes: see appendix for data in litres.
Source: E4tech; based on FAPRI (2011) for US, Brazil and RoW; and based on Task 1 results for EU-27

The assessment of global ethanol demand for transport found that demand is expected to grow from circa 60-75 Mtoe in 2017 to somewhere between 100-150 Mtoe in 2035 depending on the scenario. In general global ethanol demand growth to 2035 will mainly be driven by policy. Currently, bio-ethanol demand outside the European Union is much higher and this is not expected to change before 2035. The EU may represent a modest 12% share of global ethanol demand by the end of the projection period. In contrast Brazil and the US are projected to remain the two largest demand countries representing up to 80% of total global ethanol demand. Given the timeframe to 2035 is beyond the current policy horizon, there is considerable variation in the demand datasets presented.

Appendix 1. Additional Model Assumptions

Presented here are some additional assumptions that are built into the model, along with some justification for each.

Parameter	Assumption	Notes
EU-27 increase on EU-15 car sales	EU-27 passenger car sales are 5% higher than EU-15 total	Based on an average of data from 2001-2011 comparing EU-15 and EU-27 new car sales (EEA, 2012a, p.7)
Additional distance travelled by diesel cars (over gasoline vehicles)	Diesel cars currently travel 30% further annually	Based on the observation that diesel vehicles are currently preferred for longer distance driving given the more favourable fuel economy. The 30% estimate is based on data taken from the EMEP/CORINAIR Emission Inventory Guidebook for EU cars (EMEP, 2007) comparing the annual distance travelled by diesel and gasoline passenger cars. It is assumed that this difference will become less-pronounced as the efficiency of gasoline vehicles improves (see section 2.3.3)
Fuel demand of E5, E10, E20/25, E85 vehicles	Assume that all ECGVs have the same annual fuel demand	Vehicles operating on different ethanol blends will consume varying amounts of fuel. However studies have indicated that when the different lower heating values of gasoline and ethanol are taken into account, energy consumption is very similar between different ECGVs (Zhai et al., 2012). Thus this assumption is considered fair, especially given the far greater sensitivity of the overall demand to parameters such as gasoline/diesel ratio and reduction in fuel use.

Appendix 2. Summary of EU and Global Ethanol Demand

			2017		2020		2025		2030		2035	
			Mtoe	Bln. Litres	Mtoe	Bln. Litres	Mtoe	Bln. Litres	Mtoe	Bln. Litres	Mtoe	Bln. Litres
EU	**E20 case**	**Ethanol**	6.6	13.0	7.1	14.0	8.1	15.8	8.2	16.2	8.4	16.5
		Gasoline	86	112	78	101	64	84	56	73	51	67
	E25 case	**Ethanol**	6.7	13.1	7.6	15.0	9.4	18.4	9.9	19.4	10.3	20.2
		Gasoline	86	112	77	101	63	82	54	71	49	64
Global	**FAPRI**	**Ethanol**	65	127	70	137	79	154	87	171	97	190
	IEA - Current Policies		61	119	68	133	82	162	97	190	115	226
	IEA - New Policies		65	128	74	146	96	188	120	237	147	289
	IEA - 450		73	144	85	167	123	242	161	317	202	398

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3. Task 2: EU and World Ethanol Supply Scenarios

Task 2 of this study was carried out by Agra CEAS Consulting.

Note: The EU and World Ethanol Supply Scenario analysis contained within this report was carried out in 2013-2014 based on policies in place and published data available at that time.

3.1. Introduction and background

The purpose of this analysis is to answer the question of whether sustainable ethanol production could meet the expected increased demand for ethanol resulting from the introduction of higher ethanol blends for use in new E20 or E25 vehicles (shown in the scenarios in task 1 of the study) as well as indicating a potential maximum ethanol supply based on a set of carefully considered assumptions. The scenarios are based on technical potential rather than economic modelling.

A number of hypotheses are tested:

- Firstly that the world can produce all the food it needs and still produce ethanol sustainably.
- Secondly that the 'rest of the world ('RoW')' region can produce all the food it needs without the need for imports of food from the EU-28 and neighbouring countries.

3.2. Methodological summary

The methodology can be summarised as follows:

1) **Estimate of land availability and suitability for rain-fed crop cultivation.** A number of constraints are applied, including:

   - Constraint 1 (a): 'Sustainability' – land used for biofuel production should meet the sustainability criteria set out in the EU Renewable Energy Directive (2009/28/EC). Further details are outlined in chapter 4.1.
   - Constraint 2: 'Food-first' - the area of land available for biofuel feedstock production is limited by a 'food first' constraint, i.e. the area of suitable land net of food crop cultivation and livestock grazing required to meet EU and world food demand in 2017 and 2035. Further specific constraints are made regarding crop yields and water availability (see constraint 5) as well as assumptions regarding the use of gmo technology (see constraint 6). Further details are outlined in chapter 4.1.
   - Constraint 3: 'Biodiesel' – in the context of biodiesel blending mandates in a number of countries worldwide, the availability of land for ethanol feedstock production is constrained

by the amount of land required for biodiesel feedstock production. Further details are outlined in chapter 4.3.

- Constraint 4: 'Energy crops for non-transport renewable energy' – the availability of land for ethanol feedstock production is constrained by the amount of land required for energy crop production for power generation, in the context of policy mandates (where applicable). Further details are outlined in chapter 4.4.

- Constraint 5: 'Water' – the land suitability analysis is based on the potential for rain-fed crop cultivation in 2017 and 2035. Currently, some crops grown for food use require irrigation while the majority do not. Food crops grown in 2017 assume a combination of rain-fed and irrigated cultivation based on current production practices. Food crops grown in 2035 assume agro-climatically achievable yields under rain-fed conditions, with the exception only of rice. All biofuel feedstock in 2017 are based on rain-fed conditions and crop yields and on agro-climatically achievable yields under rain-fed conditions 2035. Further details are outlined in chapter 4.5.

- Constraint 6: 'GMO' – current GMO policies are maintained, i.e. GMO crop production will continue in countries which currently make use of such technology (e.g. maize and soybeans in Brazil and USA), whereas in countries such as the EU where the use of GMO technology is currently limited there would be no change in policy. Details are outlined in chapter 4.6.

2) **Estimate potential supply of biomass for feedstock and ethanol supply.** Potential ethanol supply from first generation feedstocks subject to land availability and suitablity constraints is analysed. In addition, the potential supply and use of other biomass streams suitable for ligno-cellulosic ethanol production are assessed. Assumptions are made regarding the availability of ethanol converesion technologies and scenarios developed for ethanol supply in 2017 and 2035. One specific consttaint is applied:

- Constraint 7: 'Other biomass use for non-transport renewable energy' – in the context of non-transport renewable energy use policy mandates (where applicable), the availability of land for ethanol feedstock production is constrained by the amount of land required for biomass feedstock production for power generation. Details are outlined in chapter 5.7.

3.3. Geographical coverage

The primary focus of the study is the EU-28 and 12 neighbouring countries (NC-12); followed by the rest of the world. EU neighbouring countries included in this analysis are:

- EU candidate countries[13] – Iceland, Montenegro, Serbia, Macedonia;
- EU potential candidate countries[14] – Albania, Bosnia & Herzegovina;
- Other EFTA countries – Norway, Switzerland;

[13] The list of EU candidate countries included in the study excludes Turkey.

[14] The list of EU potential candidate countries included in the study excludes Kosovo.

- Other neighbouring countries - Belarus, Moldova, Ukraine.

3.4. Project time horizon

Scenarios are developed for two specific periods, 2017 and 2035. Assumptions for 2017 scenarios are generally based around an extension of current practices based on historical data and published forecasts. In 2035, the principle of testing technical potential subject to specific assumptions and constraints is explored.

4. Estimate of land availability and suitability for rain-fed crops

Ethanol feedstock production requires land, whether for cultivating crops or harvesting biomass from forestry, etc. The analysis is based on a land balance model approach, which estimates land areas on which crops may be cultivated and excludes areas required for other uses, e.g. *inter alia* food production, nature conservation, urbanisation, etc. The remaining net land area is then allocated to biofuel feedstock crop cultivation[15].

The availability of land suitable for crop cultivation is estimated based on the FAO/IIASA (2012[16]) *Global Agro-Ecological Zones* database assessment, which combines soil, terrain (elevation, slope, aspect) and climate characteristics with crop production requirements to estimate the suitability of land for crop production. As part of the analysis of GAEZ data, a number of constraints are applied which exclude certain types of land use in order to arrive at an estimate of land suitability for rain-fed crop cultivation in the 'EU-28 & NC-12' and 'RoW' countries. These constraints are examined in the following sections of the report.

4.1. Constraint 1: Sustainability

Given the study purpose to consider the technical potential for biofuel feedstock production to supply the EU and world market, the land used for biofuel production should meet the sustainability criteria set out in the EU Renewable Energy Directive (2009/28/EC) on the assumption that these are adopted worldwide. These criteria are set out in Article 17 sections 3, 4 and 5 of the Directive, which specifically preclude biofuel production from land classified as:

- primary forest and other wooded land;
- land designated for nature and rare, threatened or endangered species protection purposes;
- highly bio-diverse grassland, wetlands and peat land.

Forest land (see Table 4.2) is assessed according to the definition of the FAO Global Forest Resource Assessment. Statistical data from the Global Forest Resource Assessments (FAO 2010[17]) are included in the GAEZ data (at a resolution >50% land cover) and forecast area in 2017 and 2035 are based on historical rates of de-/afforestation using FAO data (1993-2011), which suggest that forest cover globally has been decreasing by around 0.16% per year (CAGR) over the past two decades, although for the 'EU-28 & NC-12' countries this trend is the reverse, with forest area increasing by around 0.49% per year (CAGR) (0.40% in the EU-28 and 0.87% in the NC-12). Forest land is excluded from the area of land deemed suitable for crop production, however, a separate assessment of the potential sustainable biomass yield which could be used as feedstock for 2nd generation ligno-cellulosic ethanol production is made (see chapter 5).

Other **protected areas** (including wetlands defined in accordance with the 1971 Convention on Wetlands) refers to land protection status by type of national or international protection scheme

[15] This is in addition to biomass residues used for from food crop cultivation or other land for biofuel feedstock.

[16] FAO/IIASA (2012). *Global Agro-Ecological Zones.* Data portal v.3.0.

[17] FAO (2010). *Global Forest Resource Assessments (FRA2010)*. FAO, Rome, Italy.

based on the World Database of Protected Areas (WDPA, 2009[18]) and data from the NATURA 2000 network (see Table 4.1 and Figure 4.1 below). For the purposes of this study, these protected areas are assumed not to meet the sustainability criteria set out in Directive 2009/28 and are thus excluded from the area of land deemed suitable for crop cultivation. It should be noted that protected status is given to some areas of forest land and to avoid 'double counting' these areas are excluded from the 'protected' area total given (see Table 4.2). Furthermore, the area of land currently enrolled in the US Conservation Reserve Programme is not included in the category of 'strictly protected' land since it is a voluntary scheme and land could be returned to agricultural production when the contracts expire. The forecast for 2017 and 2035 does not include an estimate of additional land likely to be given protected status during the period.

Table 4.1: National and international protected areas (million hectares)

	World		RoW		EU-28 & NC-12		*Of which* EU-27	
	Mio. ha	%	Mio. ha	%	Mio. ha	%	Mio. ha	%
ASEAN Heritage	3.7	0.3%	3.7	0.3%	0.0	0.0%	0.0	0.0%
IUCN II National Park	246.0	17.6%	243.5	18.5%	2.5	3.3%	0.0	0.0%
IUCN III Natural Monument	16.3	1.2%	16.2	1.2%	0.1	0.1%	0.0	0.0%
IUCN IV Habitat Management	185.2	13.3%	183.6	13.9%	1.6	2.1%	0.0	0.1%
IUCN Ia Strict Nature Reserve	60.8	4.4%	60.2	4.6%	0.6	0.7%	0.0	0.0%
IUCN Ib Wilderness Area	94.4	6.8%	94.4	7.2%	0.0	0.0%	0.0	0.0%
IUCN V Protected Landscape	187.4	13.4%	186.5	14.1%	0.9	1.2%	0.0	0.0%
IUCN VI Managed Resource	239.8	17.2%	239.8	18.2%	0.0	0.0%	0.0	0.0%
National (forest)	64.5	4.6%	64.5	4.9%	0.0	0.0%	0.0	0.0%
National (non-forest)	95.9	6.9%	95.9	7.3%	0.0	0.0%	0.0	0.0%
Natura2000 (limited agric. use)	12.6	0.9%	0.0	0.0%	12.6	16.4%	12.5	18.1%
Natura2000 (no agric. use)	57.1	4.1%	0.1	0.0%	57.0	74.5%	56.7	81.7%
Ramsar Convention (Wetlands)	45.4	3.3%	44.6	3.4%	0.9	1.1%	0.0	0.0%
UNESCO-MAB Biosphere Reserve	18.2	1.3%	18.1	1.4%	0.1	0.1%	0.0	0.0%
World Heritage Convention	67.8	4.9%	67.5	5.1%	0.3	0.3%	0.0	0.0%
Total protected	**1,395.2**	**100.0%**	**1,318.7**	**100.0%**	**76.5**	**100.0%**	**69.3**	**100.0%**
- of which no agricultural use	955.4	68.5%	892.3	67.7%	63.0	82.3%	56.8	81.9%
- of which limited agricultural use	439.8	31.5%	426.3	32.3%	13.5	17.6%	12.5	18.1%

Source: Agra CEAS Consulting; based on GAEZ.

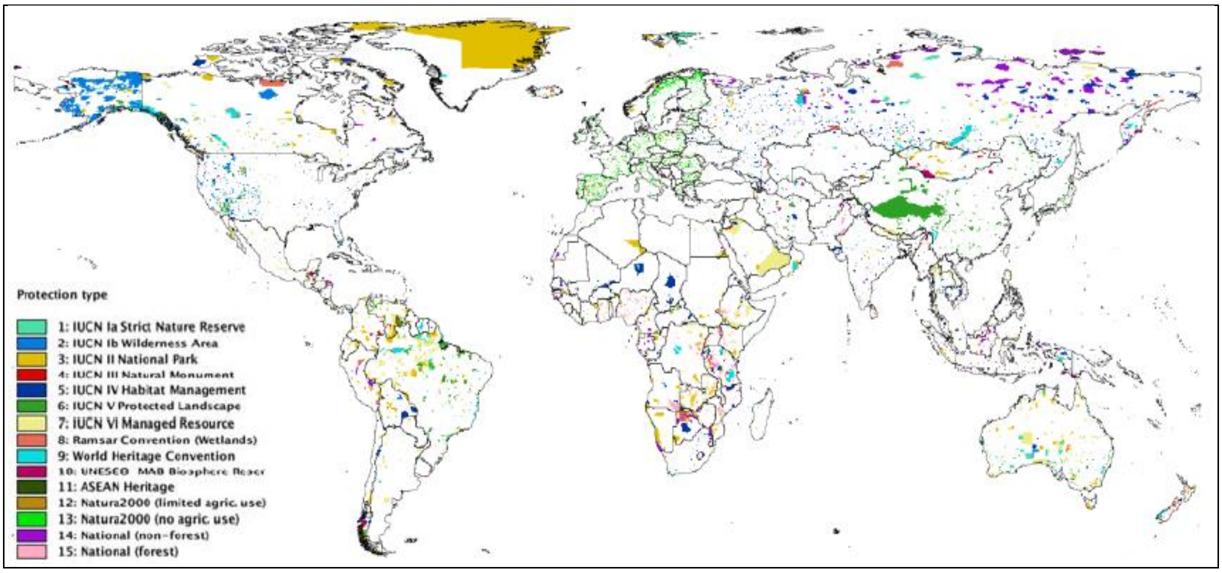

Figure 4.1: Protected areas

Source: GAEZ.

[18] WDPA (2009). *World Database of Protected Areas*. UNEP and IUCN.

Urban expansion (see Table 4.2) in 2017 and 2035 is estimated based on the GAEZ 'built-up' land classification (>50% land cover) and forecast growth extrapolated from data published in academic literature. UN (2012)[19] projections show an increase in urban population of 1.35 billion by 2030. However, little is known about future locations, magnitudes, and rates of urban expansion. Seto, *et al.* (2012[20]) suggest a 185% increase in global urban area (compared to 2000) if current trends in population density continue and all areas with high probability undergo urban land conversion. Based on an analysis of this data, assumed rates of urban expansion compared to 2000 area for the 'EU-28 & NC-12' are 29% in 2017 and 60% in 2035 (data for 'western' and 'eastern' Europe); and for the 'RoW' are 113% in 2017 and 232% in 2035.

4.1.1. Net land suitability

The net result is an estimate of land suitability for rain-fed crop cultivation amounting to around 2.553 billion hectares in 2017 and 2.622 billion hectares in 2035 (see Table 4.2 below); of which:

- 'EU-28 & NC-12': 0.271 billion hectares in 2017 (0.179 bn. for EU-27); and 0.254 billion hectares in 2035 (0.167 bn. for EU-27) (note increase in forest and built-up area); and
- 'RoW': 3.623 billion hectares in 2017; and 3.646 billion hectares in 2035.

As can be seen in the data below, the decrease in net land suitability in the 'EU-28 & NC-12' is due to increases in both forest cover and urban expansion; whereas an increase in 'RoW' net land suitability is due to a decrease in forest cover (see section 4.1).

Table 4.2: Land suitability for rain-fed crop[1] cultivation, 2017 and 2035 (million hectares)

	2017				2035			
	World	RoW	EU-28 & NC-12	*Of which* EU-27	World	RoW	EU-28 & NC-12	*Of which* EU-27
Total Land	**13,178.5**	**12,592.3**	**586.2**	**429.7**	**13,178.4**	**12,592.2**	**586.2**	**429.7**
Forest [2]	3,566.8	3,390.5	176.3	148.2	3,469.6	3,277.2	192.4	159.1
Strictly Protected (excl. in forest)	509.0	468.1	41.0	38.3	509.0	468.1	41.0	38.3
Urban & built-up [2]	42.3	37.9	4.4	3.9	64.6	59.1	5.5	4.9
Barren & sparsely vegetated [2]	2,428.6	2,422.7	5.9	0.9	2,428.6	2,422.7	5.9	0.9
Inland water	184.1	176.8	7.4	6.0	184.1	176.8	7.4	6.0
Net land suitable for agriculture [3]	**6,447.7**	**6,096.4**	**351.3**	**232.5**	**6,522.5**	**6,188.3**	**334.1**	**220.6**
- of which in agricultural use (av. 03-12) [4]	*4,911.1*	*4,653.0*	*258.0*	*189.6*	*4,911.1*	*4,653.0*	*258.0*	*189.6*
Net land suitable for r-fed crops	**3,894.3**	**3,623.0**	**271.3**	**179.2**	**3,900.1**	**3,645.9**	**254.2**	**167.3**
- of which crops cultivation (av. 03-12) [5]	*1,532.8*	*1,361.8*	*171.1*	*121.5*	*1,532.8*	*1,361.8*	*171.1*	*121.5*
Balance [6]	**2,553.3**	**2,473.4**	**80.0**	**53.3**	**2,622.4**	**2,542.4**	**80.0**	**53.3**

Note: [1] Suitability for rain-fed crops – cereals, roots and tubers, sugar crops, pulses, oil crops, vegetables and fruits.
[2] >50% land cover classes.
[3] Land suitable for rain-fed crops and livestock grazing. Includes crop land, grassland pasture, low density woodland, etc.
[4] Cultivated arable land, permanent crops and grassland pasture (FAO).
[5] Arable land and permanent crops (FAO).
[6] Grassland pasture and low density woodland; suitable for livestock but not suitable for rain-fed crops.
Source: Agra CEAS Consulting; based on FAO and GAEZ.

Land suitability for rain-fed crops is defined on the basis of the proportion of maximum constraint free yields attainable for a range of crop types; i.e. prime (>85%), good (55-85%), moderate (25-55%),

[19] United Nations (2012). World Urbanization Prospects - 2011 Revision. (United Nations, New York).
[20] Seto, K.C., Güneralp, B., and Hutyrac, L. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences of the United States of America* (Washington, DC).

marginal (>0-25%). Data for 25 different crop types were compiled for two time periods (1961-1990 and 2011-2040) under two scenarios (high and intermediate inputs/management). From this, a single 'mixed input/management' scenario was derived whereby the best land (i.e. prime and good land) is used for high input level farming (full mechanisation, low labour intensity, commercial objectives), while moderate and marginal land is assumed to use an intermediate level of inputs (mixture of commercial and subsistence production). This approach is consistent with other studies and reflects the impact of diminishing marginal returns on input applications[21]. Since crop land has multiple competing potential uses (i.e. the same land could be used for growing *inter alia* cereals or oilseeds), a weighted average land use suitability for the various crop types was calculated and a forecast for 2017 and 2035 interpolated from the 1961-1990 and 2011-2040 time period data (see Table 4.2). The forecasts also incorporate changes in agro-climatic conditions; including inter alia land degradation, as well as forest cover, protected status and the impact of population growth on urban expansion (see section 4.1).

It should be noted that the analysis of crop yields (see sections 4.2.1, 4.3 and 5.2) provides forecast average yields for each crop type across the area of suitable land in each of 198 individual countries. This therefore removes any need to arbitrarily allocate specific crops grown for various uses (e.g. food or biofuel) to the various categories of suitable land (e.g. prime, good, moderate or marginal).

It should also be noted that while the land area deemed suitable for crop cultivation exceeds the area currently utilised, additional land may not readily be brought into production due to a number of potential technical, economic and/or socio-political constraints. Furthermore, the resolution[22] of GAEZ land cover may actually under-report some land use types, for example forest and urban (built-up) and barren/sparsely vegetated land class data covers areas with >50% density, suggesting that some low density areas of forest/woodland or population may be under-reported. However, analysis of the achievability of bringing additional land deemed suitable for crop cultivation is therefore beyond the scope of this study.

[21] While crop yield potential is greatest on the best quality land, productivity gaps on poorer quality land are narrower. Most studies (including FAO (2012) *World Agriculture Towards 2030/2050)* are based on a derived 'mixed level of inputs' scenario whereby the greatest resource input is targeted at land which is likely to show the greatest productivity response, while additional land is also brought into production under appropriate input levels (balance of input to output response) to manage factors such as ecosystem fragility. Since land suitability is determined by constraint-free yield potential, this approach applies equally to land regardless of location in the northern or southern hemisphere and is therefore considered to fit well with the study ToR objectives to 'maximise ethanol supply within reason'.

[22] According to GAEZ, the geo-referenced global climate, soil and terrain data are combined into a land resources database, commonly assembled on the basis of global grids, typically at 5 arc-minute and 30 arc-second resolutions.

4.2. Constraint 2: 'Food First'

Chapter 4.1.1 establishes the total area of land suitable for crop cultivation. For the purposes of this study, the area of land available for ethanol feedstock production is limited by a 'food first' constraint, i.e. net of food crop cultivation required to meet EU and world food demand in 2017 and 2035. Note that this is the area of land available for dedicated biofuel feedstock production, as separate assessments of feedstock production from other biomass are made including *inter alia* food crop residues, forest residues and other biomass sources (see chapter 5).

Future demand for food is estimated from projections of global population growth (UN, 2013[23]) and per capita food consumption (FAO, 2012[24]) (see Table 4.3 and Table 4.4 below).

Table 4.3: World population, 2017-2035 (1,000 head)

	Av. 2005-2007	2017	2035
EU-28 & NC-12	591,409	603,163	601,272
Of which EU-27	*494,720*	*509,241*	*514,015*
RoW	6,002,068	6,881,157	8,142,174
World	**6,593,477**	**7,484,320**	**8,743,446**

Source: *World Population Prospects: 2012 revision* (UN, 2013).

Per capita food requirements are met through the consumption of a 'basket' of different food products. Each product is consumed in varying quantities and has a different nutritional content. Per capita food consumption is then multiplied by forecast population in 2017 and 2035 to give total food consumption and commodity composition. Estimates for fruit, vegetable and meat consumption by type were assessed using supplemental data from FAO food balance sheet data and the OECD-FAO forecasts (FAO, 2013).

Table 4.4: World food consumption and commodity composition, 2017 - 2035 (Mio. t)

	2017				2035			
	World	RoW	EU-28 & NC-12	*Of which* EU-27	World	RoW	EU-28 & NC-12	*Of which* EU-27
Cereals	1,189.4	1,088.9	100.5	84.8	1,402.6	1,302.9	99.7	85.2
Fruits	510.2	451.4	58.8	53.1	596.0	537.4	58.6	53.6
Oilseeds & products (oil equiv.)	96.7	84.9	11.7	9.9	126.1	113.9	12.2	10.4
Pulses, dry	47.4	45.6	1.8	1.5	58.6	56.8	1.8	1.6
Roots and tubers	526.1	480.7	45.3	38.3	647.4	604.0	43.4	37.1
Sugar & sugar crops (raw sugar equiv.)	171.5	151.3	20.2	17.1	213.5	193.8	19.7	16.9
Vegetables	935.2	864.8	70.4	59.4	1,092.5	1,022.4	70.1	60.0
Total crop products	**3,493.9**	**3,184.8**	**309.0**	**264.1**	**4,157.1**	**3,851.2**	**305.9**	**264.7**
Meat (carcass weight)	312.5	262.3	50.2	42.4	404.4	351.2	53.2	45.5
- of which bovine	*67.7*	*57.4*	*10.2*	*8.6*	*87.6*	*76.7*	*10.8*	*9.3*
- of which ovine	*14.2*	*13.1*	*1.2*	*1.0*	*18.4*	*17.2*	*1.2*	*1.0*
- of which pig meat	*113.4*	*89.9*	*23.6*	*19.9*	*146.8*	*121.8*	*25.0*	*21.3*
- of which poultry meat	*117.1*	*101.9*	*15.3*	*12.9*	*151.6*	*135.4*	*16.2*	*13.8*
Milk and dairy (fresh milk eq.)	652.1	526.6	125.4	105.9	820.8	689.9	130.9	111.9
Total livestock products	**964.5**	**788.9**	**175.6**	**148.3**	**1,225.2**	**1,041.1**	**184.1**	**157.4**

Notes: Food use of cereals (wheat, rice and coarse grains) includes the grain equivalent of beer consumption and of corn sweeteners; Vegetable oils includes all oils from oilseeds but excludes oils from other crops e.g. rice bran oil and maize germ oil.
Source: Agra CEAS Consulting; based on UN (2013), FAO Food Balance sheets and FAO (2012).

[23] UN (2013). *World Population Prospects: 2012 revision*. United Nations, New York, USA.
[24] FAO (2012). *World Agriculture Towards 2030/2050*. FAO, Rome, Italy.

4.2.1. Food crops

Based on the food consumption forecasts, an equivalent agricultural land area which would be required for food production in 2017 and 2035 is estimated using on achievable crop yields. Two scenarios for potentially achievable crop yields are considered:

- In **2017**, expected yields are based on the development of agricultural productivity in the context of broader macro-economic trends. This has been calculated from historical crop yields in each of 198 countries using FAO data in two recent time periods (2003-2007 and 2008-2012); an expected continuation of annual average yield growth trends; and with reference to published forecasts (e.g. OECD-FAO, DG Agriculture and USDA).
- In **2035**, potential yields are based on the assumption of closing productivity gaps through optimal use of agricultural technology, i.e. closing the gap between yields achieved under optimal field trial conditions and those achieved at a commercial scale by farmers. Analysis is based on weighted average agro-climatically achievable crop yield[25] data from GAEZ under rain-fed conditions, with the exception of rice (since paddy rice is grown under controlled water flow irrigation). This means that for a number of crops, yields will be lower than for 2017 despite the implicit closing productivity gaps relative to historical rain-fed yields. This is most notable for sugar, root crops and vegetable yields.

For each of the main food groups, a weighted average yield was calculated for 25 individual crops (see Table 4.5). Area, yield and output data in the two recent time periods (2003-07 and 2008-12) for each crop in 198 individual countries was analysed and weights assigned based on crops with an output share >10% within each food group in either one or both of the 'EU-28 & NC-12' and 'RoW'.

Table 4.5: Food crop yield assumptions, 2017 and 2035 (t/ha)

	2017			2035		
	RoW	EU-28 & NC-12	*Of which* EU-27	RoW	EU-28 & NC-12	*Of which* EU-27
Cereals	3.33	4.80	5.62	5.20	7.63	7.69
Fruits	12.42	13.05	26.09	5.15	1.23	2.13
Oilseeds (oil equiv.)	1.71	0.81	0.90	2.46	1.22	1.27
Pulses	1.18	2.43	2.53	2.34	2.65	2.74
Roots & Tubers	13.29	22.75	27.16	7.29	8.47	8.76
Sugar (raw equiv.)	5.74	7.76	10.36	0.56	0.91	1.01
Vegetables	23.56	73.86	88.87	4.41	5.65	5.68

Note: The crops included in each category are: Cereals - wheat, rice, maize, barley; Fruits - banana, citrus, coconut; Oilseeds (oil equivalent) - soybeans, sunflower, rapeseed, palm, olive oils; Pulses (bean (dry), chickpea, cowpea, pea (dry); Roots & Tubers - potato, sweet potato, cassava; Sugar crops (raw sugar equivalent) - sugar cane, sugar beet; Vegetables - cabbage (& brassicas), carrots (& turnips), onions (dry), tomatoes.
Source: Agra CEAS Consulting; based on FAO and IIASA/GAEZ.

The area of land required to meet food crop demand is calculated and presented in Table 4.14 in section 4.2.3 below, which indicates that both the 'EU-28 & NC-12' (and EU-27) and 'RoW' regions

[25] Agro-climatically attainable yield estimates for rain-fed crops in the 30-year period 2011-2040. The dataset is the result of calculations for climate, general agro-climatic indicators, crop-specific agro-climatic assessments, water-limited biomass and yield, agro-climatic constraints.

can be technically self-sufficient in food crop production based on the scenario and assumptions described.

4.2.2. Meat and dairy products

Meat and dairy product consumption (see Table 4.4) requires the production of both livestock and agricultural commodities for livestock feeding. There are two main components of livestock herd numbers; firstly the number of livestock maintained from year to year (stocks) (which includes both breeding animals and production animals, e.g. dairy cows and laying hens); and secondly the production of animals slaughtered for meat each year.

The total number of animals required to meet livestock products consumption in 2017 and 2035 is estimated based on an analysis of historical meat yields (meat output and number of animals slaughtered) and milk yields (milk output and number of dairy cows) on a per country basis using FAO data in two recent time periods (2003-2007 and 2008-2012) and projected at an expected continuation of annual average yield growth trends (CAGR)[26] (see Table 4.6 below).

Table 4.6: Livestock herd numbers, 2017 and 2035 (million head of livestock[1])

	2017				2035			
	World	RoW	EU-28 & NC-12	*Of which* EU-27	World	RoW	EU-28 & NC-12	*Of which* EU-27
Total Cattle	**1,564.7**	**1,432.1**	**132.6**	**97.2**	**2,015.3**	**1,876.9**	**138.4**	**104.3**
Slaughtered (total head)	316.7	272.0	44.7	30.6	408.0	361.2	46.7	32.9
Dairy cows	281.2	257.5	23.7	16.4	351.0	330.1	20.8	15.2
Other (breeding & growing)	966.7	902.6	64.1	50.2	1,256.5	1,185.6	70.9	56.2
Total Sheep	**1,932.8**	**1,827.7**	**105.1**	**104.1**	**2,478.0**	**2,370.5**	**104.5**	**101.0**
Slaughtered (total head)	901.2	834.9	66.2	65.9	1,155.4	1,087.7	65.9	64.0
Breeding herd	1,031.6	992.7	38.9	38.2	1,322.6	1,282.8	38.7	37.1
Total Pigs	**1,016.9**	**847.3**	**169.6**	**134.1**	**1,316.0**	**1,142.9**	**173.1**	**138.1**
Slaughtered (365day feeding equiv.)[2]	568.3	459.6	108.7	87.9	735.5	624.6	111.0	90.6
Slaughtered (total head)	*1,430.7*	*1,157.0*	*273.6*	*221.3*	*1,851.5*	*1,572.2*	*279.3*	*228.0*
Breeding herd	448.6	387.7	60.9	46.2	580.5	518.4	62.1	47.6
Total Poultry (bn. head)	**27.4**	**25.2**	**2.2**	**1.7**	**33.4**	**31.3**	**2.1**	**1.7**
Slaughtered (365day feeding equiv.)[3]	8.8	7.6	1.1	0.9	10.6	9.5	1.1	0.9
Slaughtered (total bn. head)	*75.5*	*65.8*	*9.6*	*8.1*	*92.0*	*82.6*	*9.4*	*8.1*
Breeding/laying flock (bn. head)	18.7	17.7	1.1	0.7	22.8	21.8	1.0	0.7

Note: [1] poultry data in billion head. [2] Pigs for slaughter are assumed to have a 180 day growth cycle and require feeding for 145 days (35 days to weaning). [2] Poultry for slaughter are assumed to have a 42 day growth cycle.
Source: Agra CEAS Consulting; based on FAO.

Stocks in 2017 and 2035 are calculated based on a ratio of herd stocks to production animals (animals slaughtered or producing dairy cows) annually in 2013-2012 and the forecast of the number of animals slaughtered to supply food (meat) demand and number of dairy cows to supply dairy product demand (Table 4.4).

It should be noted that livestock bred for meat have varying growth periods from birth to slaughter, ranging from 42 days for broiler chickens (poultry meat) up to 36 months for some types of grass reared beef. A reduction factor is therefore applied to indicate a '365-day equivalent' number of

[26] Unlike crops, there are no agro-climatically achievable livestock meat yield data; however, agro-climatically achievable yields are used in 2035 for the forage and protein-rich feed crops used for livestock feed requirements.

animals which can be used for calculating annual feed requirements on a comparable basis. Since sheep (lambs) are typically grazed for 8-12 months outside on grass, there is no risk of 'double counting' and a reduction factor is not applied; similarly for cattle which may be grazed for up to 36 months before slaughter and are therefore captured by the total stocks data.

Ruminant livestock (cattle and sheep) are fed a combination of forage and protein-rich feed materials, whereas pigs and poultry can be fed exclusively on protein-rich diets. Forage and protein-rich feed demand, supply and land area requirements are analysed in the following sections.

4.2.2.1. Forage demand

Ruminant livestock (sheep and cattle) require a minimum quantity of roughage/fibre to maintain digestive function, which is primarily supplied by forage feeds; approximately 50% of total dry matter intake in cattle and 75% for sheep on an annualised basis. Sources of forage for feeding ruminants include direct grazing of grassland pasture and feeding forage crops, e.g. silage grass, silage maize and agricultural residues (straw). Ruminants are able to meet all their nutrient requirements from grazing pasture (with mineral supplements as necessary), supplemented by preserved forage (straw, hay or silage) when required. However, protein-rich feed materials are used to increase enterprise output (e.g. milk or meat) due to their higher protein and metabolisable energy content. Table 4.7 presents total ruminant livestock feed intake requirements on a dry matter basis.

Table 4.7: Feed intake for ruminant livestock, (DM, t/head)

	Summer kg DM/day	Winter kg DM/day	Average kg DM/day	Average t DM/year
Sheep	1.20	0.60	0.90	0.30
Cattle - beef	9.10	5.00	7.00	2.60
Cattle - dairy	11.40	8.80	10.10	3.70
Cattle – other	10.30	6.90	8.60	3.20

Source: Agra CEAS Consulting.

Pasture grass yields in the 'EU-28 & NC-12' and 'RoW' are significantly lower on a dry matter basis than for other crops and given that much of the land on which pasture grasses are the dominant land cover is not suitable for rain-fed crop cultivation or high input level management, yields are effectively agro-climatically constrained. Projections for 2017 and 2035 based on analysis of historical data are presented in Table 4.8 below.

Table 4.8: Rain-fed pasture grass yield, 2017 and 2035 (DM, t/ha)

	2017	2035
EU-28 & NC-12	0.79	0.87
EU-27	0.80	0.90
RoW	0.97	0.95

Source: Agra CEAS Consulting; based on FAO and GAEZ.

Not all forage requirements are necessarily met by direct grazing, particularly for cattle. Given the study aims to maximise ethanol supply within reason, a number of assumptions are made to minimise livestock use of land suitable for rain-fed crop production:

- Grassland pasture for direct grazing is maximised subject to dietary constraints outlined below. The area of grassland pasture in the 'EU-28 & NC-12' and 'RoW' is limited to the land suitability assessment (see Table 4.2 in section 4.1.1), i.e. the balance of land suitable for rain-fed agriculture but not suitable for rain-fed crop cultivation.

- Total feed demand for sheep can be met from a combination of forage (75% total DM intake) and protein-rich feed materials (25% total DM intake). Forage demand can be met entirely through direct grazing of grassland pasture (including preserved forage in winter, i.e. hay).

- Total feed demand for cattle would be met from a combination of forage (50% total DM intake) and protein-rich feed materials (50% total DM intake). Any forage requirements not met through direct grazing of grassland pasture is supplied from cultivated forage crops[27].

The proportion of total forage demand which can be supplied by direct grazing of grassland pasture is calculated and presented in Table 4.9 below.

Table 4.9: Forage demand for ruminant livestock, 2017 and 2035 (DM, mio. t)

	2017				2035			
	World	RoW	EU-28 & NC-12	*Of which* EU-27	World	RoW	EU-28 & NC-12	*Of which* EU-27
Cattle (50% forage diet)	**2,478.7**	**2,274.1**	**204.6**	**150.5**	**3,189.8**	**2,977.2**	**212.7**	**160.8**
- of which from grass pasture	2,038.7	1,998.8	39.8	19.0	1,937.0	1,891.9	45.1	25.3
- of which from forage crops	440.1	275.3	164.8	131.4	1,252.9	1,085.3	167.6	135.5
Sheep (75% forage diet)	**434.9**	**411.2**	**23.6**	**23.4**	**557.5**	**533.4**	**24.2**	**22.7**
- of which from grass pasture	434.9	411.2	23.6	23.4	557.5	533.4	24.2	22.7
- of which from forage crops	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total forage from grass pasture	**2,473.5**	**2,410.1**	**63.5**	**42.4**	**2,494.5**	**2,425.2**	**69.3**	**48.0**
% of total forage	84.9%	89.7%	27.8%	24.4%	66.6%	69.1%	29.2%	26.2%
Total forage from crops	**440.1**	**275.3**	**164.8**	**131.4**	**1,252.9**	**1,085.3**	**167.6**	**135.5**
% of total forage	15.1%	10.3%	72.2%	75.6%	33.4%	30.9%	70.8%	73.8%
Total forage	**2,913.6**	**2,685.3**	**228.3**	**173.9**	**3,747.4**	**3,510.5**	**236.9**	**183.6**

Source: Agra CEAS Consulting.

Additional forage crop cultivation is required to supply the balance of cattle forage feed demand. Preferred forage crops vary by country, driven by yield potential, with the main crops grown worldwide being alfalfa, grass silage and maize silage. The selection is based on a dry matter yield maximising equation and the area of land required calculated from yield projections for 2017 and 2035 (methodology as per food crop yields, see section 4.2.1) (see Table 4.10 below). The area of land required to meet demand for additional forage crops is calculated and presented in Table 4.14 in section 4.2.3 below, which indicates that both the 'EU-28 & NC-12' (and EU-27) and 'RoW' regions can be technically self-sufficient based on the scenario and assumptions described.

[27] In practical terms, this means intensive (high density) dairy and beef production systems.

Table 4.10: Forage crop yield, 2017 and 2035 (DM, t/ha)

	2017				2035			
	World	RoW	EU-28 & NC-12	*Of which* EU-27	World	RoW	EU-28 & NC-12	*Of which* EU-27
Yield (DM, t/ha)	-	1.78	2.91	2.79	-	1.70	3.38	3.57

Note: Forage crops include alfalfa, grass silage, maize silage.
Source: Agra CEAS Consulting.

The remaining 50% of total cattle feed and 25% of sheep feed on a dry matter intake basis is supplied from protein-rich feed materials (see section 4.2.2.2 below).

4.2.2.2. Protein-rich feed demand

Non-ruminant livestock (i.e. pigs and poultry) are predominantly fed on protein rich feed materials (rather than forage), which include cereals and oilseeds, as well as biofuel co-products such as DDGS-type feeds and oilseed meals. In addition, part of ruminant diets can be met using protein rich feed materials (in addition to forage); i.e. in this scenario 50% of dry matter feed intake for cattle and 25% for sheep. Feed requirements for non-ruminant livestock feeding is estimated based on an assumed quantity of dry matter intake per animal (see Table 4.11 below).

Table 4.11: Feed intake for non-ruminant livestock, (DM, t/head)

	Low kg DM/day	High kg DM/day	Average kg DM/day	Average t DM/year
Pigs - gilts	1.36	1.70	1.53	0.56
Pigs - sows	1.60	2.06	1,83	0.67
Poultry – Layers (per 1,000 head)	81.90	85.78	83.84	30.60
Poultry – Broilers (per 1,000 head)	74.27	76.33	75.3	27.48

Note: calculations are on a dry matter basis.
Source: Agra CEAS Consulting; based on Westerndorf (1998)[28] and NRC (1987)[29].

Table 4.12 below presents estimated total demand for protein rich feed ingredients by type of livestock. The calculation is based on the total number of livestock required to supply livestock product demand (see Table 4.6), feed demand for non-ruminant livestock (see Table 4.11) and non-forage feed demand for ruminants (see section 4.2.2.1).

Table 4.12: Total protein-rich feed material demand, 2017 and 2035 (DM, mio. t)

	2017				2035			
	World	RoW	EU-28 & NC-12	*Of which* EU-27	World	RoW	EU-28 & NC-12	*Of which* EU-27
Non-ruminants - Pigs	618.8	517.2	101.6	80.2	800.8	697.1	103.8	82.6
Non-ruminants - Poultry	811.3	693.3	59.7	44.0	918.4	859.8	58.6	44.0
Ruminants - Cattle [1] and Sheep [2]	440.1	275.3	164.8	131.4	1,252.9	1,085.3	167.6	135.5
Total protein-rich feed demand	**1,870.2**	**1,485.7**	**326.1**	**255.6**	**2,972.1**	**2,642.2**	**329.9**	**262.1**

Notes: [1] 50% of total feed requirement; [2] 25% of total feed requirement.
Source: Agra CEAS Consulting; based on Westerndorf (1998) and NRC (1987).

[28] Westendorf, M.L.1., Dong, Z.C., Schoknecht, P.A. (1998). *Recycled cafeteria food waste as a feed for swine: nutrient content digestibility, growth, and meat quality.* J Anim Sci. 1998 Dec; 76(12):2976-83.
[29] NRC (1987). *Nutrients requirements of beef cattle.* National Research Council, Washington, D.C., USA.

Protein-rich feed materials are used to increase enterprise output (e.g. milk or meat) due to higher protein and metabolisable energy content relative to forage. Since feed represents the major cost to livestock producers, maximising feed usage efficiency is an economic calculation. However, the use of protein-rich feed materials is constrained by the nutritional values (protein, energy, vitamin and mineral) and digestibility of the feed materials, the nutrient requirements of animals, as well as the constraints of the voluntary feed intake level of the animals since palatability of feed materials varies both between ingredients and by livestock species, so feed rations have to be formulated to take into consideration maximum inclusion levels. This is particularly the case for poultry, since only around 40-55% of the diet can be formed from oilseed meals (30-40% soybean meal) and DDGS (10-15%). Therefore a minimum of 45% of protein rich feed materials is assumed to be supplied from cereal crops.

The main protein-rich feed materials of agricultural origin (i.e. excluding fish-meals, etc.) include cereals and oilseeds grown specifically for livestock feed; oilseed meal co-products from food processing and biodiesel production; and DDGS-type feeds (distillers grains and gluten feeds) co-products from the ethanol industries. The estimated supply of protein-rich feed materials produced as co-products of these three industries is presented in Table 4.13 below. Feed co-products from ethanol are the result of 1st generation ethanol supply scenarios in chapter 5.2.

Table 4.13: Supply of protein-rich feed materials, 2017 and 2035 (million tonnes)

	2017				2035			
	World	**RoW**	**EU-28 & NC-12**	***Of which* EU-27**	**World**	**RoW**	**EU-28 & NC-12**	***Of which* EU-27**
Total protein-rich feed demand	**1,870.2**	**1,485.7**	**326.1**	**255.6**	**2,972.1**	**2,642.8**	**329.3**	**262.1**
Food industry co-products	**413.0**	**374.5**	**38.6**	**32.6**	**506.5**	**467.1**	**39.5**	**33.7**
Sugar - beet pulp	17.1	9.2	7.8	6.6	8.4	0.8	7.6	6.5
Sugar - cane molasses	20.7	20.7	-	-	4.2	4.2	-	-
Oilseeds - meal/cake	375.3	344.5	30.7	25.9	493.9	462.0	31.8	27.2
Biodiesel co-products	**92.4**	**58.5**	**33.9**	**33.9**	**141.2**	**109.7**	**31.5**	**31.5**
Oilseed meal	77.3	43.4	33.9	33.9	114.0	82.5	31.5	31.5
Palm kernel meal	15.1	15.1	-	-	27.2	27.2	-	-
Ethanol industry co-products [4]	**82.8**	**66.0**	**16.9**	**8.9**	**77.9**	**70.5**	**7.4**	**7.0**
DDGS-type feeds	66.5	50.4	16.1	8.2	59.6	52.9	6.6	6.2
sugar beet pulp	0.7	0.0	0.7	0.7	0.7	0.0	0.7	0.7
sugar cane molasses	15.6	15.6	0.0	0.0	17.6	17.6	0.0	0.0
Total co-product supply	**588.3**	**498.9**	**89.3**	**75.4**	**725.6**	**647.2**	**78.4**	**72.2**
Cultivated protein crops	**1,282.0**	**986.8**	**236.8**	**180.2**	**2,246.5**	**1,995.6**	**250.9**	**189.9**
Cereals for poultry	365.1	312.0	26.9	19.8	413.3	386.9	26.4	19.8
Cereals/ oilseeds for other livestock	916.8	674.8	209.9	160.4	1,833.2	1,608.7	224.5	170.1
Total protein-rich feed supply	**1,870.2**	**1,485.7**	**326.1**	**255.6**	**2,972.1**	**2,642.8**	**329.3**	**262.1**

Notes: [1] excludes by-products of cereals processing.
[2] includes soybean, sunflower, rapeseed, palm and olive oils.
[3] excludes palm meal.
[4] see ethanol supply scenarios in chapter 5.2.
Source: Agra CEAS Consulting.

The area of land required to meet demand for protein-rich feed crops is calculated and presented in Table 4.14 in section 4.2.3 below, which indicates that both the 'EU-28 & NC-12' (and EU-27) and 'RoW' regions can be technically self-sufficient based on the scenario and assumptions described.

4.2.3. Land area required for food production

Using data for world food consumption and commodity composition (see Table 2.4) and forecast food crop yields (see Table 2.5), the area of land required to produce sufficient food crops to meet demand in 2017 is calculated at 598 million hectares globally, which amounts to just 15% of land suitable for rain-fed crop cultivation. Under this scenario, food crop demand in the 'EU-28 & NC-12' region could be supplied using 17% of land suitable for rain-fed crop cultivation; i.e. around 46 million hectares (33 Mha (18%) for EU-27) (see Table 2.6).

The area of land required increases under the rain-fed agro-climatically achievable crop yield assumptions in 2035 to 1.201 billion hectares globally, equivalent to 31% of land suitable for rain-fed crop cultivation. Nevertheless, food crop demand in the 'EU-28 & NC-12' region could be supplied using 44% of land suitable for rain-fed crop cultivation; i.e. around 111 million hectares (76 Mha (46%) for EU-27).

Land area required to meet all agricultural crop production on land suitable for rain-fed crop cultivation includes land required to produce protein-rich feeds for livestock (note the area of grassland grazing as well as the potential supply of co-products from food, ethanol and biodiesel crops is assessed separately). Total land use required to meet food demand, including livestock products (meat and dairy products) amounts to around 30% of global land area deemed suitable for rain-fed crop cultivation; i.e. around 1.155 billion hectares. In the 'EU-28 & NC-12' region, this total amounts to 56% of suitable land areas, or around 152 million hectares (112 Mha (62%) for EU-27).

Under the rain-fed agro-climatically achievable crop yield scenario in 2035, global land use to meet food demand amounts to 2.305 billion hectares (59% of land area suitable for rain-fed crop cultivation); and around 193 million hectares in the 'EU-28 & NC-12' region (76% of land area suitable for rain-fed crop cultivation) (139 Mha (83%) for EU-27).

Table 4.14: Land area required to supply food crop demand, 2017 and 2035 (million ha)

	2017				2035			
	World	**RoW**	**EU-28 & NC-12**	***Of which* EU-27**	**World**	**RoW**	**EU-28 & NC-12**	***Of which* EU-27**
Land suitability for rain-fed crops	**3,894.3**	**3,623.0**	**271.3**	**179.2**	**3,900.1**	**3,645.9**	**254.2**	**167.3**
Cereals	347.8	326.9	20.9	15.1	263.7	250.6	13.1	11.1
Fruits	41.4	36.8	4.5	2.0	153.3	105.6	47.7	25.1
Oilseeds (oil equiv.)	64.1	49.6	14.5	11.1	56.3	46.3	9.9	8.2
Pulses	39.5	38.8	0.7	0.6	25.0	24.3	0.7	0.6
Roots & Tubers	38.2	36.2	2.0	1.4	88.0	82.9	5.1	4.2
Sugar (raw equiv.)	29.0	26.4	2.6	1.6	367.3	345.7	21.6	16.6
Vegetables	38.1	37.2	1.0	0.7	247.4	234.9	12.4	10.6
Sub-total food crop area	**598.0**	**551.8**	**46.2**	**32.5**	**1,200.9**	**1,090.3**	**110.6**	**76.3**
Share	15.4%	15.2%	17.0%	18.1%	30.8%	29.9%	43.5%	45.6%
Forage crops	211.0	154.5	56.5	47.1	686.9	637.5	49.4	38.0
Protein feed crops	345.5	296.2	49.3	32.0	416.7	383.8	32.9	24.7
Sub-total livestock feed crop area	**556.5**	**450.7**	**105.9**	**79.1**	**1,103.6**	**1,021.3**	**82.3**	**62.7**
Share	14.3%	12.4%	39.0%	44.2%	28.3%	28.0%	32.4%	37.5%
Total crop area required	**1,154.5**	**1,002.4**	**152.1**	**111.6**	**2,304.5**	**2,111.6**	**192.8**	**139.0**
Share %	29.6%	27.7%	56.1%	62.3%	59.1%	57.9%	75.9%	83.1%

Source: Agra CEAS Consulting.

4.3. Constraint 3: Biodiesel

4.3.1. Biodiesel demand forecast

The availability of land for ethanol feedstock production is also constrained by land use for biodiesel, given that many countries worldwide have either transport biofuel and/or specific biodiesel blending mandates. Biodiesel demand is estimated based on published forecasts for countries identified as having implemented or being expected to implement mandates in 2017 and 2035.

There are 14 countries[30] which are reported to either currently have mandates in place or are expected to implement mandates by 2017, namely: Argentina (B10), Brazil (B5), Canada (1.8% energy equivalent), Ecuador (5%), Indonesia (B2.5), Malaysia (B7), Paraguay (1%), Peru (2%), Philippines (B2), South Africa (B5), South Korea (B2.5), Thailand (B5), USA (4.845 million m^3), Uruguay (B2). A further 2 countries/regions, the EU-28 and India, have renewable energy mandates.

Desk research led to the conclusion that while published biodiesel demand forecasts are based on policy assumptions for biodiesel mandates and/or targets (which are the major driver since consumption in almost all countries worldwide is dictated by on-going policies), they do not limit biodiesel demand to mandated quantities and are therefore based on contribution to the likely total transport energy mix. For example, the OECD-FAO *Agricultural Outlook (2013-22)* specifies the USA biodiesel mandate (RFS2) at 4.845 million m^3, yet projects biodiesel demand to exceed this from 2020-23 due to the impact of an ethanol blend-wall and difficulty fulfilling the cellulosic ethanol mandate (FAO projects 6.158 m. m^3 in 2023).

Forecasts of biodiesel demand in 2017 and 2035 are presented (see Table 4.15 below) for the countries listed above which have or are expected to implement biodiesel and/or renewable energy mandates in the period:

- Scenarios for the 'EU-28 & NC-12' are based on the EU *Biomass Futures (PRIMES model, reference scenario)* (EC, 2012[31]) projections for the EU-27 (no data for Croatia) with interpolation of data for intervening years. There are no biodiesel mandates in the NC-12 countries. The PRIMES model differentiates non-fungible[32] and fungible[33] biodiesel demand.
- Scenarios for the 'RoW' countries with biodiesel mandates in 2017 are based on the OECD-FAO *Agricultural Outlook (2013-22)*. The forecast is extended to 2035 based interpolation of *World Energy Outlook 2013 (New Policies Scenario)* (IEA, 2013[34]) data. The share of 'RoW'

[30] In recent years, a number of countries other (mainly developing) have implemented ambitious biodiesel mandates with the primary objective to increase energy independence or security. These include: *Costa Rica (B20)*, *and Taiwan (1%)*; however, no published forecasts were available for these countries since expectations area that authorities will not enforce mandates on the assumption that large share of either feedstock or biodiesel would need to be imported.

[31] EC (2012). *EU Biomass Futures*. European Commission.

[32] Non-fungible biodiesel is 1st generation biodiesel which requires blending to fuel specifications to run in conventional engines or at higher blends requires engine modifications.

[33] Fungible biodiesel is advanced or 2nd generation biodiesel which can be produced to meet specifications which allow use in conventional engines, e.g. Fischer-Tropsch (FT)-synthesis.

[34] IEA (2013). *World Energy Outlook 2013*. International Energy Agency, Paris, France.

biodiesel produced from vegetable oils is based on interpolation and extension of OECD-FAO forecasts which suggest a declining world share from 83% in 2012 to 78% in 2022, less the 'EU-28 & NC-12' forecast quantity. The balance of biodiesel production is assumed to be fungible and produced from waste oil feedstock (see section 4.3.2).

Table 4.15: Biodiesel demand scenarios, 2017 and 2035 (1,000 m^3)

	2017				2035			
	World	RoW	EU-28 & NC-12*	*Of which* EU-27	World	RoW	EU-28 & NC-12*	*Of which* EU-27
Non fungible	23,541.5	10,670.2	12,871.3	12,871.3	33,341.6	20,292.1	11,961.7	11,961.7
Fungible	5,702.6	*3,334.0*	2,368.5	2,368.5	14,377.8	*4,915.5*	9,462.4	9,462.4
- of which HVO	*5,577.1*	*3,334.0*	*2,243.0*	*2,243.0*	*12,343.4*	*4,915.5*	*7,428.0*	*7,428.0*
- of which F-T synthesis	*125.5*	-	*125.5*	*125.5*	*2,034.4*	-	*2,034.4*	*2,034.4*
Biodiesel	**29,244.1**	**14,004.2**	**15,239.9**	**15,239.9**	**46,631.6**	**25,207.6**	**21,424.1**	**21,424.1**

Notes: * Biodiesel scenario (see assumptions in the text above) is for countries with mandates – there are no mandates for NC-12 countries and so the EU-27 total is the same as for the EU-28 & NC-12.
Source: Agra CEAS Consulting; based on OECD-FAO, IEA, Biomass Futures, E4tech.

4.3.2. Biodiesel feedstock

It is assumed that any feedstock grown and biodiesel conversion technology used in the 'EU-28 & NC-12' would meet the sustainability criteria set out in the EU Renewable Energy Directive (2009/28/EC); but this requirement is not applied to the rest of the world ('RoW').

For the 'EU-28 & NC-12' region, the PRIMES model (for EU-27) differentiates between non-fungible and fungible biodiesel. Feedstock for non-fungible diesel is assumed to be vegetable oils. Fungible biodiesel feedstock are assumed to be waste oils (cooking oil and tallow) and wood, with shares interpolated from *A harmonised auto-fuel biofuel roadmap for the EU to 2030* (E4tech, 2013[35]).

For the 'RoW' region, vegetable oil feedstock use in 2017 is based on OECD-FAO (2013)[36] forecasts and assumed to be non-fungible, with extension to 2035 based on the biodiesel demand forecast in section 4.3.1 above using an esterification factor of 0.9936 (BioGrace, v.4c[37]). The balance of biodiesel production is assumed to be fungible and use waste oils (cooking oil and tallow) at a hydrogenation factor of 0.967 (see Table 4.16).

[35] E4tech (2013) *A harmonised auto-fuel biofuel roadmap for the EU to 2030*. E4tech

[36] FAO (2013). *OECD-FAO Agricultural Outlook 2013-2022*. FAO, Rome, Italy.

[37] BioGrace, v.4c. *Harmonised Calculations of Biofuel Greenhouse Gas Emissions in Europe*. Project funded by the Intelligent Energy Europe Programme Contract number: IEE/09/736/SI2.558249.

Table 4.16: Biodiesel feedstock demand scenarios, 2017 and 2035 (1,000 t)

	2017				2035			
	World	RoW	EU-28 & NC-12*	*Of which* EU-27	World	RoW	EU-28 & NC-12*	*Of which* EU-27
Vegetable oils	23,693.1	10,738.9	12,954.2	12,954.2	32,461.5	20,422.8	12,038.7	12,038.7
- of which Palm oil	*3,704.3*	*3,704.3*	-	-	*6,667.8*	*6,667.8*	-	-
Waste oils (HVO)	5,767.4	3,447.8	2,319.6	2,319.6	12,764.7	5,083.2	7,681.5	7,681.5
Wood (F-T synthesis)	725.6	-	725.6	725.6	13,384.3	-	13,384.3	13,384.3
Feedstock	**30,186.1**	**14,186.7**	**15,999.4**	**15,999.4**	**58,610.5**	**25,506.0**	**33,104.5**	**33,104.5**

Note: * Biodiesel scenario (see assumptions in section 4.3.1) is for countries with mandates – there are no mandates for NC-12 countries and so the EU-27 total is the same as for the EU-28 & NC-12.
- FAME biodiesel produced from vegetable oils – esterification factor 0.9936 (BioGrace, v.4c).
- HVO biodiesel produced from waste oils – hydrogenation factor 0.967 (BioGrace, v.4c; factor as for rape/sunflower/soy oils).
- FT-synthesis biodiesel from wood – conversion factor 0.173 (UK carbon calculator[38]).

Source: Agra CEAS Consulting; based on OECD-FAO and IEA.

It is assumed that wood chip feedstock for Fischer-Tropsch is a product of forest industries as opposed to production of energy crops. On this basis, the area of land suitable for rain-fed crops required for biodiesel feedstock is limited to oilseed production and calculated from rain-fed crop yield analysis. The results are presented in Table 4.17 below.

Table 4.17: Land area required to supply biodiesel feedstock, 2017 and 2035 (million ha)

	2017				2035			
	World	RoW	EU-28 & NC-12*	*Of which* EU-27	World	RoW	EU-28 & NC-12*	*Of which* EU-27
Oilseed crop yield (oil t/ha) [1]	-	0.2	0.7	0.7	-	0.4	1.2	1.2
Oilseed demand (Mt)	20.0	7.0	13.0	13.0	25.8	13.8	12.0	12.0
Oilseed area (Mha)	**59.7**	**39.9**	**19.8**	**19.8**	**48.1**	**37.8**	**10.3**	**10.3**
Palm oil crop yield (oil t/ha)	-	3.4	-	-	-	4.8	-	-
Palm oil demand (Mt)	3.7	3.7	-	-	6.7	6.7	-	-
Palm oil area (Mha)	**1.1**	**1.1**	-	-	**1.4**	**1.4**	-	-
Total biodiesel feedstock area	**60.8**	**40.9**	**19.8**	**19.8**	**49.5**	**39.2**	**10.3**	**10.3**
Land suitability for rain-fed crops	3,894	3,623	271	271	3,900	3,646	254	254
Share %	1.6%	1.1%	7.3%	7.3%	1.3%	1.1%	4.1%	4.1%

Notes: * Biodiesel scenario (see assumptions in section 4.3.1) is for countries with mandates – there are no mandates for NC-12 countries and so the EU-27 total is the same as for the EU-28 & NC-12.
[1] weighted average of soybean, sunflower and rapeseed oils.

Source: Agra CEAS Consulting.

Oilseed meals produced as biodiesel co-products are returned to the livestock feed sector as a valuable source of protein-rich feed materials for ruminant and non-ruminant livestock (see Table 4.13 in section 4.2.2.2).

[38] DfT (2012). *UK carbon calculator. Manual and program for calculating carbon savings in line with 2014 Renewable Transport Fuel Obligation guidance.* DfT, UK.

4.4. Constraint 4: 'Energy crops for non-transport renewable energy'

The availability of land for ethanol feedstock production is also constrained by land use for energy crop production specifically for non-transport renewable energy (other biomass is considered in section 5.7) in the context of policy mandates where applicable, e.g. the EU Renewable Energy Directive (2009/28). The non-transport renewables sector includes energy for heat, power and combined heat and power (CHP).

Forecasts for non-transport renewable energy use from energy crops are limited. This analysis is based on two such published forecasts: *Biomass Futures (PRIMES model, reference scenario)* (EC, 2012)[39], which indicates that EU-27 energy crop demand is limited to the power sector; and *World Energy Outlook (new policies scenario)* (IEA, 2013)[40], which forecasts the supply/demand for power from renewables by world region.

In the absence of other forecasts, the use of energy crop biomass for power generation in the 'EU-28 & NC-12' region is assumed match that forecast for the EU-27 in 2017 and thereafter to rise by 1.0% per year from 2020 to 2035. The share of power generated from energy crops biomass in total power from bio-energy in the 'RoW' is assumed to match that for the 'EU-28 & NC-12' region. Energy crops are assumed to be short-rotation wood biomass crops, e.g. src willow, chestnut, polar, etc. Regional yields are based on forest biomass productivity (see section 5.5).

Table 4.18: Renewables-based power generation from energy crops, 2017 & 2035 (TWh)

	2017				2035			
	World	RoW	EU-28 & NC-12*	*Of which* EU-27*	World	RoW	EU-28 & NC-12*	*Of which* EU-27*
Total power from renewables[1] (TWh)	5,386.7	4,335.7	1,051.0	1,051.0	11,612.0	9,723.0	1,889.0	1,889.0
Power from bio-energy (TWh)	536.7	239.2	297.5	297.5	1,477.0	942.3	534.7	534.7
- from other biomass (TWh)	371.3	165.5	205.8	205.8	1,104.2	704.4	399.8	399.8
- from energy crops (TWh)	**165.3**	**73.7**	**91.7**	**91.7**	**372.8**	**237.8**	**135.0**	**135.0**
Share of power from renewables %	3.1%	1.7%	8.7%	8.7%	3.2%	2.4%	7.1%	7.1%
Share of power from bio-energy %	30.8%	30.8%	30.8%	30.8%	25.2%	25.2%	25.2%	25.2%

Notes: * Renewable power scenario is based on available global and regional forecasts (see assumptions in the text above) and therefore due to data limitations the EU-27 total is the same as for the 'EU-28 & NC-12'.

[1] includes variable renewables, i.e. solar photo-voltaic and wind.

Source: Agra CEAS Consulting; based on EC (2012) and IEA (2013).

The quantity of energy crops required to meet this demand is analysed based on crop yield assumptions outlined in section 5.3.1 below. The efficiency of power conversion is assumed to be 0.72 MWh/t. Based on these assumptions, the quantity of energy crop feedstock and the area of land required for cultivation are estimated in Table 4.19 below.

[39] EC (2012) *Biomass Futures – PRIMES model Reference Scenario*: assumes that national targets to achieve emissions and energy mandates under the Renewable Energy Directive (2009/28) and the GHG Effort Sharing Agreement (2009/406/EC) are achieved in 2020.

[40] IEA (2013) *World Energy Outlook 2013 - New Policies Scenario*: takes account of broad policy commitments and plans that have been announced by countries, including national pledges to reduce greenhouse-gas emissions and plans to phase out fossil-energy subsidies, even if the measures to implement these commitments have yet to be identified or announced. This broadly serves as the IEA baseline scenario.

Table 4.19: Biomass and land area required to supply non-transport energy demand from energy crops, 2017 and 2035 (million tonnes; million hectares)

	2017				2035			
	World	RoW	EU-28 & NC-12*	*Of which* EU-27*	World	RoW	EU-28 & NC-12*	*Of which* EU-27*
Power from energy crops (TWh)	**165.3**	**73.7**	**91.7**	**91.7**	**372.8**	**237.8**	**135.0**	**135.0**
Power conversion efficiency (MWh/t)	-	0.72	0.72	0.72	-	0.74	0.74	0.74
Energy crop demand (Mt)	**229.1**	**102.1**	**127.0**	**127.0**	**501.5**	**320.0**	**181.6**	**181.6**
Energy crop yield (t/ha)	-	9.96	4.10	4.10	-	9.96	4.10	4.10
Energy crop area (Mha)	**41.2**	**10.2**	**31.0**	**31.0**	**76.4**	**32.1**	**44.3**	**11.7** [1]
Net suitable land availability	2,679.0	2,579.6	99.4	47.7	1,546.0	1,495.0	51.0	18.0
Energy crops share %	1.5%	0.4%	31.2%	64.9%	4.9%	2.1%	86.8%	65.1%

Notes: * Renewable power scenario is based on available global and regional forecasts (see assumptions in the text above) and therefore due to data limitations the EU-27 total is the same as for the 'EU-28 & NC-12'.

[1] Assumes 32.6 Mha grown in the wider 'EU-28 & NC-12' region.

Source: Agra CEAS Consulting.

4.5. Constraint 5: Water

The land suitability analysis is based on the potential for rain-fed crop cultivation in 2017 and 2035. This assumption is made in order to avoid as far as possible issues regarding the sustainability of water resources and irrigated crop land areas.

Currently, some crops grown for food use require irrigation while the majority do not. Food crops grown in 2017 assume a combination of rain-fed and irrigated cultivation as a continuation of current agricultural practices. Food crops grown in 2035 assume agro-climatically achievable yields under rain-fed conditions; with the exception of rice (see section 4.2.1).

All biofuel feedstock crop yields are based on rain-fed yields in 2017 and on agro-climatically achievable yields under rain-fed conditions 2035.

Table 4.20: Crop yields and water use assumptions

	2017	2035
Food crops	Rain-fed & irrigated yields	Agro-climatically achievable rain-fed yields
Biofuel crops (1st gen.)	Rain-fed yields	Agro-climatically achievable rain-fed yields
Energy crops	Rain-fed yields	Estimated rain-fed yields
Forest biomass	Estimated rain-fed yields	Estimated rain-fed yields

4.6. Constraint 6: GMO

It is assumed that current GMO policies are maintained, i.e. GMO crop production will continue in countries which currently make use of such technology (e.g. maize and soybeans in Brazil and USA), whereas in countries such as the EU where the use of GMO technology is currently limited there would be no change in policy.

4.7. Conclusion: Area of land available for ethanol feedstock crop production

Table 4.1 presents the potential use of land suitable for rain-fed crop cultivation in the 'EU-28 & NC-12' and 'RoW' regions, subject to the six constraints set out and analysed above. The analysis suggests that subject to the constraints and assumptions stated, land use for food, feed and bio-energy (biodiesel and biomass for power) would utilise around 32% of total land suitable for rain-fed crop production globally in 2017 and around 75% of the land resource in the 'EU-28 & NC-12' countries (91% in the EU-27). This suggests that both the 'EU-28 & NC-12' and 'RoW' regions can be technically self-sufficient in food and livestock feed based on the scenario and assumptions described. Furthermore, the technical scenarios suggest that the regions can be separately self-sufficient in feedstock production to supply forecast biodiesel and renewable power[41] from energy crops demand under these scenarios.

As a result of restricting crop production for food and energy to agro-climatically achievable yields under rain-fed conditions, despite the effective assumption of closing productivity gaps, the restriction of water availability results in increased demand for land suitable for rain-fed crop cultivation in 2035 to around 62% globally and 98% in the 'EU-28 & NC-12' (96% in the EU-27).

The net result is that land suitable for rain-fed crop cultivation and technically available for ethanol feedstock crop production under these scenarios totals around 2.6 billion hectares (68%), of which 68 million hectares (25%) in the 'EU-28 & NC-12' countries (17 Mha (9%) in the EU-27) in 2017; decreasing to 1.5 billion hectares (38%) globally and 6.1 million hectares (2%) in the 'EU-28 & NC-12' countries (6 Mha (4%) in the EU-27) in 2035.

Table 4.21: Land availability for ethanol feedstock crops, 2017 and 2035 (million ha)

	2017				2035			
	World	RoW	EU-28 & NC-12	*Of which* EU-27	World	RoW	EU-28 & NC-12	*Of which* EU-27
Land suitable for rain-fed crops	**3,894.3**	**3,623.0**	**271.3**	**179.2**	**3,900.1**	**3,645.9**	**254.2**	**167.3**
Food crops	598.0	551.8	46.2	32.5	1,200.9	1,090.3	110.6	76.3
Forage feed crops	211.0	154.5	56.5	47.1	686.9	637.5	49.4	38.0
Protein feed crops	345.5	296.2	49.3	32.0	416.7	383.8	32.9	24.7
Biodiesel feedstock crops	60.8	40.9	19.8	19.8	49.5	39.2	10.3	10.3
Energy crops (for power)	41.2	10.2	31.0	31.0	76.4	32.1	44.3	11.7 *
Total use	**1,256.5**	**1,053.6**	**202.9**	**162.4**	**2,430.4**	**2,183.0**	**247.4**	**161.0**
Share %	32.3%	29.1%	74.8%	90.6%	62.3%	59.9%	97.3%	96.2%
Net land suitable for r-f crops	**2,637.8**	**2,569.3**	**68.4**	**16.8**	**1,469.7**	**1,462.9**	**6.8**	**6.3**
Share %	67.7%	70.9%	25.2%	9.4%	37.7%	40.1%	2.7%	3.8%

Notes: * Assumes 32.6 Mha grown in the wider 'EU-28 & NC-12' region. See section 4.4.
Source: Agra CEAS Consulting.

[41] Under this scenario, the EU-27 would import some feedstock for renewable power generation from the wider 'EU-28 & NC-12' in 2035.

5. Ethanol supply potential

At the world scale, food commodity production is equal to consumption with net trade flows balancing surplus and deficit regions. In the analysis presented in chapter 4, two hypotheses were tested and demonstrated to be confirmed.

Firstly, the 'RoW' region can be technically ≥100% self-sufficient in food production, including land for the cultivation of forage and protein feeds for livestock. Furthermore, the analysis of biodiesel demand and energy crops for non-transport renewable energy use also demonstrated that surplus land suitable for rain-fed crop cultivation could technically be used for ethanol feedstock cultivation.

Secondly, as the above hypothesis was proved correct, it is further demonstrated that the 'EU-28 & NC-12' region could also be ≥100% self-sufficient[42], subject to the same set of constraints; and that surplus land suitable for rain-fed crop cultivation could also technically be used for ethanol feedstock cultivation. The results of this analysis are presented in section 4.7.

Ethanol supply potential is determined by the net availability of land suitable for feedstock crop production, the availability of biomass for use as ethanol feedstock and the efficiency of converting biomass to ethanol. Given that a sizeable potential resource of not only land suitable for both 1st and 2nd generation ligno-cellulosic feedstock production, but also other potential sources of biomass is identified, the following chapter presents an assessment of various biomass supply sources; determines the quantity of biomass demand for non-transport renewable energy use; and presents a scenario for maximum ethanol supply potential within reason, subject to a number of specific assumptions and constraints relating to the use and efficiency of ethanol conversion technology in 2017 and 2035 and the types and quantities of biomass use for feedstock.

5.1. Commercially available ethanol technology in 2017 and 2035

The ethanol supply scenarios are based on the following technical assumptions with regard to ethanol conversion technology and efficiency. Throughout the period from 2017 to 2035, available technologies are assumed to be:

- 1st generation ethanol from sugar and starch crops; and
- 2nd generation ethanol from ligno-cellulosic biomass.

No assessment is made regarding the rate at which new technologies might be commercialised. Therefore, the study assumes that in 2017, current (i.e. 1st gen. sugar and starch) technologies and new technologies which are already at a demonstration or early commercial stage (i.e. 2nd generation ligno-cellulosic) are considered 'commercially available' in 2017. It is further assumed that assumed that such technologies are modified as necessary to meet the EU RED (2009/28) and 60% GHG emissions criteria. This includes the assumption that all plants can use fossil process fuel.

[42] Under this scenario, the EU-27 would import some feedstock for renewable power generation from the wider 'EU-28 & NC-12' in 2035.

In 2035, other new ethanol production technologies that are expected to be demonstrated by that time are considered 'commercially available' and are assumed to meet the EU RED and 60% GHG emissions criteria.

Ethanol and co-product conversion efficiencies are assumed to increase between 2017 and 2035. For 1st generation technologies this increase over the period is assumed to be 3.0%. For 2nd generation technologies the increase is assumed to be 6.0% (E4tech, 2013).

Table 5.1: Conversion efficiencies per tonne of feedstock, 2017 and 2035

	Ethanol (m^3/t)		Co-products (t/t feedstock)	
	2017	2035	2017	2035
Wheat (DDGS/gluten feed) – wet mill	0.37	0.38	0.24	0.25
Coarse grains (DDGS) – dry mill	0.40	0.41	0.32	0.33
Sugar beet (beet pulp)	0.10	0.10	0.05	0.05
Sugar cane (cane molasses)	0.08	0.09	0.03	0.03
Wheat and other cereal residues	0.29	0.31	-	-
Corn residues	0.30	0.32	-	-
Rice residues	0.19	0.20	-	-
Pulses residues	0.20	0.22	-	-
Oilseed residues	0.12	0.13	-	-
Miscanthus	0.29	0.30	-	-
Wood	0.22	0.23	-	-
Municipal waste	0.11	0.11		

Notes: ethanol efficiency in m^3 per tonne of feedstock; co-product efficiency in tonne co-product per tonne feedstock.
Source: Agra CEAS Consulting..

5.2. Scenario 1: 1st generation feedstock supply

The analysis in chapter 4 suggests that sufficient land resource suitable for rain-fed crop cultivation exists subject to the 6 constraints analysed; and that surplus land suitable for rain-fed crop production could be made available in both the 'EU-28 & NC-12' and 'RoW' regions to support ethanol feedstock crop production.

The first scenario presented here is for 1st generation feedstock use for ethanol production, based on the following assumptions:

- The main starch and sugar crops used worldwide for commercial scale 1st generation ethanol production are wheat, maize, sugar beet and sugar cane.
- In 2017, forecast exportable surpluses of wheat and maize (the region has historically been a net importer of sugar) from the 'EU-28 & NC-12' are diverted to ethanol production. In addition, forecast commodity use for ethanol production is also used.
- In 2035, 'EU-28 & NC-12' feedstock use for ethanol is based on forecast commodity use for ethanol production.
- 'RoW' feedstock use for ethanol production is based on forecast commodity use for ethanol production.

Commodity use for ethanol production and the exportable surplus of grains is based on the European Commission (2013[43]) *Prospects for agricultural markets 2013-2022* forecasts and the OECD-FAO (2013[44]) *Agricultural Outlook 2013-2022*. For the 'EU-28 & NC-12', data availability is limited to the EU-28 and Ukraine. The forecasts provide an outlook to 2022/23 and thereafter feedstock use for 1st generation ethanol production to 2035 is held constant. This assumes that ethanol output under the scenario is sufficient to meet current mandates for 2020; and secondly that the direction of public policy, as well as commercial R&D and investment effort is increasingly focussed on 2nd generation technologies and thus energy crop cultivation (see scenario 2 in section 5.3).

The quantity of biomass used for 1st generation ethanol production in 2017 and 2035 under the scenario outlined above is presented in Table 5.2 below, while ethanol output is presented along with the other ethanol scenarios in Table 5.11 (see section 5.8 below).

Table 5.3 presents the potential availability (and share) of land suitable for rain-fed crop cultivation, net of land other land uses as outlined in section 4.7 above; and the area (and share of net land potentially available) used for 1st generation ethanol feedstock crop production under the scenario outlined above. In all, this amounts to around 162 million hectares (6%) of net land suitable for rain-fed crop production globally and around 15 million hectares (22%) in the 'EU-28 & NC-12' countries (8 Mha (50%) in the EU-27) in 2017; decreasing to 107 million hectares (7%) globally and 6 million

[43] European Commission (2013). *Prospects for agricultural markets 2013-2022.* European Commission.
[44] FAO (2013). *OECD-FAO Agricultural Outlook 2013-2022*. FAO, Rome, Italy.

hectares (81%) for the 'EU-28 & NC-12' (5 Mha (85%) in the EU-27) in 2035. This decrease in land requirement, despite an increase in ethanol output through greater feedstock use, is the result of closing productivity gaps by assuming agro-climatically achievable crop yields under rain-fed conditions in 2035.

Table 5.2: Scenario 1: 1st generation Biomass feedstock use, 2017 and 2035 (mio. t)

	2017				2035			
	World	RoW	EU-28 & NC-12	*Of which* EU-27	World	RoW	EU-28 & NC-12	*Of which* EU-27
Scenario a) – Conversion of forecast 'EU-28 & NC-12' exportable surplus to ethanol production								
Wheat	18.0	-	18.0	11.5	-	-	-	-
Coarse grains	21.5	-	21.5	2.8	-	-	-	-
Sugar beet	-	-	-	-	-	-	-	-
Sugar cane	-	-	-	-	-	-	-	-
Sub-total	**39.5**	**-**	**39.5**	**14.3**	**-**	**-**	**-**	**-**
Scenario b) – Forecast use of feedstock for ethanol								
Wheat	7.8	1.1	6.7	5.9	10.1	2.7	7.4	6.8
Coarse grains	166.3	156.2	10.2	9.6	172.6	158.1	14.5	13.8
Sugar beet	14.8	-	14.8	14.8	14.5	-	14.5	14.5
Sugar cane	519.7	519.7	-	-	568.7	568.7	-	-
Sub-total	**708.6**	**677.0**	**31.7**	**30.4**	**765.9**	**729.5**	**36.4**	**35.1**
Total (a+b)								
Wheat	25.9	1.1	24.7	17.4	10.1	2.7	7.4	6.8
Coarse grains	187.8	156.2	31.6	12.5	172.6	158.1	14.5	13.8
Sugar beet	14.8	-	14.8	14.8	14.5	-	14.5	14.5
Sugar cane	519.7	519.7	-	-	568.7	568.7	-	-
Total	**748.1**	**677.0**	**71.1**	**44.7**	**765.9**	**729.5**	**36.4**	**35.1**

Source: Agra CEAS Consulting.

Table 5.3: Land availability and use for 1st gen. feedstock crops, 2017 and 2035 (mio.ha)

	2017				2035			
	World	RoW	EU-28 & NC-12	*Of which* EU-27	World	RoW	EU-28 & NC-12	*Of which* EU-27
Net land suitable for feedstock crops	2,637.8	2,569.3	68.4	16.8	1,469.7	1,462.9	6.8	6.3
Share of total suitable land %	67.7%	70.9%	25.2%	9.4%	37.7%	40.1%	2.7%	3.8%
Land use for 1st gen. feedstock crops	161.7	146.8	14.9	8.4	107.2	101.7	5.5	5.3
Share of net suitable land %	6.1%	5.7%	21.8%	50.2%	7.3%	7.0%	80.9%	84.5%

Source: Agra CEAS Consulting.

5.3. Scenario 2: ligno-cellulosic biomass from energy crops

In addition to 1st generation ethanol feedstock production, the balance of net land suitable for rain-fed crop cultivation is technically available for energy crop cultivation as feedstock for 2nd generation ligno-cellulosic ethanol production. These include miscanthus, switchgrass and reed canary grass, which are selected based on the availability of rain-fed agro-climatically achievable yield data[45]. Of these, miscanthus has the highest crop yield potential in both 'EU-28 & NC-12' and 'RoW' countries, based on yield assumptions outlined in section 5.3.1 below.

[45] Agro-climatically achievable yield data for short-rotation coppice (SRC) willow and other woody biomass is not provided by GAEZ.

Table 5.4 presents the land area potentially available for the cultivation of crops for ethanol feedstock, including 1st generation feedstock from scenario 1 (see section 5.2) and for 2nd generation ligno-cellulosic ethanol from energy crops (scenario 2).

Table 5.4: Land availability and use for feedstock crops, 2017 and 2035 (mio.ha)

	2017				2035			
	World	RoW	EU-28 & NC-12	*Of which* EU-27	World	RoW	EU-28 & NC-12	*Of which* EU-27
Net land suitable for r-f crops	**2,637.8**	**2,569.3**	**68.4**	**16.8**	**1,469.7**	**1,462.9**	**6.8**	**6.3**
Share of total suitable land %	67.7%	70.9%	25.2%	9.4%	37.7%	40.1%	2.7%	3.8%
1st gen. feedstock crops*	**161.7**	**146.8**	**14.9**	**8.4**	**107.2**	**101.7**	**5.5**	**5.3**
Share of net suitable land %	6.1%	5.7%	21.8%	50.2%	7.3%	7.0%	80.9%	84.5%
2nd gen feedstock crops	**2,476.1**	**2,422.5**	**53.6**	**8.4**	**1,362.5**	**1,361.2**	**1.3**	**1.0**
Share of net suitable land %	93.9%	94.3%	78.2%	49.8%	92.7%	93.0%	19.1%	15.5%
Total use of net suitable land	**2,637.8**	**2,569.3**	**68.4**	**16.8**	**1,469.7**	**1,462.9**	**6.8**	**6.3**
Share %	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Note: * see ethanol supply scenario 1 in chapter 5.2

Source: Agra CEAS Consulting.

Table 5.5: Scenario 2: Energy crop biomass supply scenario, 2017 & 2035 (mio. t)

	2017				2035			
	World	RoW	EU-28 & NC-12	*Of which* EU-27	World	RoW	EU-28 & NC-12	*Of which* EU-27
Miscanthus (Mt)	34,665.3	33,915.5	749.8	116.9	19,074.6	19,056.5	18.0	13.6

Source: Agra CEAS Consulting.

5.3.1. Miscanthus crop yields

There is currently a great deal of research into yield improvements and cultivation practices for miscanthus. The most common variety under research appears to be *giant* miscanthus (Miscanthus x giganteus) is a hybrid variety produced by a cross between M. sacchariflorus (a tetraploid species) and M. sinensis (a diploid species). M. sacchariflorus is characterized by fast-growing rhizomes and high productivity in warm, wet areas, whereas. M. sinensis is found in montane environments that frequently have cold winters. The hybrid giant miscanthus is sterile, grows larger than both parent species and inherited good cold tolerance. Miscanthus species are closely related to sugar cane and have been used to breed disease resistance and cold tolerance into sugarcane varieties. It is therefore thought that factors resulting in yield advances for sugar cane may also be applicable for improving miscanthus crops (Heaton et al., 2014)[46].

There is a growing literature for miscanthus crop yields from across the world, however, unlike food crops there is no single source of yield data on a per country basis. While GEAZ provides data for agro-climatically achievable energy crop yields under rain-fed conditions, ranging from 1.38 DMt/ha in the 'EU-28 & NC-12' countries to 2.047 DMt/ha for the 'RoW' countries, these are not equivalent to the yields presented in the academic literature.

[46] Heaton, E.A., Boersma, N., Caveny, J.D., Voigt, T.B., Dohleman, F.G. (2014). *Miscanthus (Miscanthus x giganteus) for Biofuel Production.* North Dakota State University Extension Service. eXtension Foundation.

In Europe, miscanthus trials conducted at 16 locations across 10 EU countries were carried out from 1992 onwards under the EU Miscanthus Productivity Network project. Results showed average yields ranging from 11t/ha and 18.3t/ha, with yields of up to 24t/ha achieved in South European countries where water was not a limiting factor (Jones & Walsh, 2001)[47]. In the subtropical environment of West-Africa, miscanthus trials begun in 2007 are expected to attain average dry weight biomass yields of up to 30t/ha (Ahondjon, 2007)[48]. In the USA, trials over a 3-year period resulted in average annual harvestable biomass yields 30t/ha and up to a maximum of 61t/ha with 'minimal' agricultural inputs. The researchers noted that 'given that there has been little attempt to improve the agronomy and genetics of these grasses compared with the major grain crops, these efficiencies are the minimum of what may be achieved' (Heaton, et al. 2008)[49]. In southern Africa, trials in Northern KZN are reported to yield up to 60t/ha (SAAEA, 2010)[50]. Current miscanthus yields in the UK, where the crop is cultivated for use as a (co-firing) fuel for power generation are approximately 12-15 DM t/ha (approximately 15-18 crop t/ha) (NNFCC, 2010)[51].

Of particular note is the recent work by Liu et al. (2012)[52] which analyses yield and output potential of Miscanthus lutarioriparius in the in the semiarid and semi humid regions of the Loess Plateau in China, one of the most seriously eroded regions of the world that is consequently particularly rich in marginal land. Using a radiation model developed from previous field experiments in Qingyang (Gansu Province), the authors introduced annual precipitation as an additional variable and estimated that after excluding high-quality cropland and pasture and land suitable for afforestation, a total of 33.3 Mha of marginal land were left available for producing miscanthus at an average yield of 16.8t/ha for a total annual output of around 0.56 billion tonnes. The analysis of environmental factors indicated that erosion, aridity, and field steepness were the primary contributors to the poor quality of the marginal land; and that a change of land use from traditional agriculture to energy crop production may prevent further erosion and land degradation in the region.

Clearly, there is a need for further research including crop trials over a wide range of agro-climatic conditions globally before a comprehensive picture of the agro-climatic yield potential for various miscanthus varieties is known. Nevertheless, assuming a lower yield range based on the data presented above would suggest that crop yields of around 14t/ha (approximately 9.8 DMt/ha) are known to be achievable across a range of agro-climatic conditions, with much higher yields achievable under more optimal conditions (as indicated by the US and southern African trials data).

[47] Jones M.B., Walsh M. (2001). *Miscanthus for energy and fibre*, James & James, 192 pp.

[48] Ahondjon, J-N. (2007). *Plantations Africaines de Miscanthus.* Tela Botanica, March 26, 2007.

[49] Heaton, E.A., Dohleman, F.G., Long, S.P. (2008). *Meeting US biofuel goals with less land: the potential of Miscanthus*. Global Change Biology (2008) 14, 1–15, doi: 10.1111/j.1365-2486.2008.01662.x.

[50] SAAEA. (2010). Miscanthus X Giganteus (Sterile Hybrid) in South Africa. Southern African Alternative Energy Association (SAAEA).

[51] NNFCC (2010). *Miscanthus (Miscanthus x giganteus) crop factsheet*. National Non-Food Crops Centre, York, UK.

[52] Liu, W., Yan, J., Li, J. and Sang, T. (2012). *Yield potential of Miscanthus energy crops in the Loess Plateau of China*. GCB Bioenergy, 4: 545–554. doi: 10.1111/j.1757-1707.2011.01157.x

5.4. Scenario 3: ligno-cellulosic biomass from crop residues

In addition, agricultural residues from crops grown both to meet future food demand and from 1st generation biofuel feedstock could increasingly be gathered for potential use as 2nd generation ligno-cellulosic feedstock. The most common sources of these agricultural residues arise from cereal straws, e.g. wheat and barley straw, for which baling technology is commercially widespread. Increasingly, there is interest in other types of straw such as corn stover, rice and soybean hulls, as well as oilseed straws. These potential feedstock are considered in the supply scenarios in Table 5.7 below.

The quantity of residue is estimated on the basis of a harvest index calculation[53]. A reduction factor must be applied to remove non-recoverable biomass from the total, including straw stubble left on the ground. In this scenario, it is assumed that 2/3rds of crop residues are recoverable, including straws, as well as seed hulls/pods. Nevertheless, it should be noted that harvest indices are variable both according to the growing conditions encountered by the crop and even among varieties of the same crop grown under optimal conditions. Past improvements in the major food crop species such as wheat have largely resulted from increases in the harvest index rather than increases in the total biomass produced by each plant, residue production may decrease as cereal yields increase.

The ratio of agricultural residues to grain/seed output is calculated as:

Grain yield x ((1-HI)/HI)

Harvest indices are presented in Table 5.6 below. It should be noted, however, that there are additional crop residues which are not estimated here, including for example citrus pulps and residues from vegetable crops which may have value as biomass for ethanol and/or livestock feed.

Table 5.6: Harvest indices for selected agricultural crops, 2017 and 2035

	2017	2035
Wheat	0.51	0.51
Other cereals	0.55	0.55
Corn	0.52	0.52
Rice	0.50	0.50
Rapeseed	0.35	0.35
Soybean	0.50	0.50
Sunflower	0.50	0.50
Pulses	0.25	0.25

Source: Agra CEAS Consulting.

[53] A harvest index is a ratio of grain to biomass yield. It should be noted that not all biomass is harvestable, i.e. below ground roots and the first few centimetres of stalk where the harvester makes a cut are generally considered unrecoverable. Losses include chaff, i.e. the dry, protective casings of cereal grain, or similar fine, dry, scaly plant material such as scaly parts of flowers, or finely chopped straw.

Table 5.7: Scenario 3: 2nd generation feedstock use scenarios, 2017 and 2035 (mio. t)

	2017				2035			
	World	RoW	EU-28 & NC-12	*Of which* EU-27	World	RoW	EU-28 & NC-12	*Of which* EU-27
Scenario 3 a) – residues from food crops								
Wheat/barley/oats.	151.8	118.8	33.0	27.8	251.4	209.2	42.2	37.8
Corn	299.2	277.0	22.2	18.0	385.5	372.5	13.0	9.7
Rice	270.1	269.4	0.8	0.6	245.5	244.9	0.6	0.5
Rapeseed	31.8	11.4	20.4	18.7	37.1	17.1	20.0	17.0
Soybean	18.5	17.9	0.6	0.2	32.6	32.1	0.5	0.4
Sunflower	9.4	3.1	6.4	3.3	12.2	5.1	7.2	5.9
Pulses	93.8	90.3	3.5	3.0	116.1	112.5	3.6	3.1
Sub-total	**780.8**	**697.5**	**83.3**	**68.7**	**964.2**	**880.8**	**83.4**	**71.3**
Scenario 3 b) – residues from livestock feed crops								
Cereals / oilseeds	660.7	532.9	127.9	83.0	1,213.1	1,077.6	135.5	101.7
Sub-total	**660.7**	**532.9**	**127.9**	**83.0**	**1,213.1**	**1,077.6**	**135.5**	**101.7**
Scenario 3 c) – residues from biofuel feedstock crops								
Wheat	16.4	0.7	15.7	11.0	6.4	1.7	4.7	4.3
Corn	114.4	95.1	19.3	7.6	105.2	96.3	8.9	8.4
Oilseeds	93.1	59.6	33.5	36.1	150.6	119.4	31.1	30.5
Sub-total	**223.9**	**155.5**	**68.4**	**54.7**	**262.1**	**217.5**	**44.7**	**43.2**
Total								
Total	**1,665.4**	**1,385.9**	**279.5**	**206.5**	**2,439.5**	**2,175.9**	**263.6**	**216.2**

Source: Agra CEAS Consulting.

5.5. Scenario 4: ligno-cellulosic biomass from forest resources

Forestry residues are estimated in the same way as other wastes, i.e. as a fraction of the unused biomass produced by existing forest industries. The main source of data is the FAO as well as any other published assessments of biomass productivity. The potential for harvesting biomass from mature forests is controversial and many studies exclude mature forestry from biomass-for-energy estimates considering it better to retain the carbon stored due to a potentially unacceptable impact on biodiversity and the risk of significant carbon emissions resulting from land use change. However, a number of studies do include estimates based on the gross annual forest growth increment (net primary production (NPP)) as a proxy for the technical potential and limit this by the fractions deemed available and accessible (it is implicit that a proportion of mature forest would become managed "re-growth" forest and that this category of biomass overlaps with traditional firewood gathering).

Slade et al. (2011)[54] reviews available literature on estimating the size of biomass resources. In particular, two studies stand out as the basis for further analysis by other studies; Johansson (1993)[55] and Yamamoto (2001)[56]. According to Slade et al. (2011),

- Johansson (1993) estimates forestry residues based on FAO industrial round wood production figures and makes 3 key assumptions: i) that total production would increase in

[54] Slade, R., Saunders, R., Gross, R., Bauen, A. (2011). *Energy from biomass: the size of the global resource*. UKERC, Imperial College London.

[55] Johansson, T.B., Kelly, H., Reddy, A.K.N., Williams, R.H. (1993). A renewables intensive global energy scenario (RIDGES) (appendix to Chapter-1). In Johansson et al. (Ed.) *Renewable Energy: Sources for Fuels and Electricity*. Washington, D.C, Island Press.

[56] Yamamoto, H., Fujino, J. and Yamaji, K. (2001). *Evaluation of bioenergy potential with a multi-regional global-land-use-and-energy model.* Biomass and Bioenergy, 21, 185-203.

line with population; ii) that 45% of the harvested wood would end up as mill residues (of which 75% could be recovered for energy purposes); and iii) that harvest residues normally left in the forest could also be collected (forest residues were estimated to be 0.39 times round wood production, 50% of which was assumed to be recoverable). These fractions were applied globally, but were derived from literature on forestry production in the United States.

- Yamamoto (2001) estimates basic availability of resources (i.e. land and residues) based on Johansson (1993) and other literature. The area of forested land is not permitted to change, but increasing demand for forest products mean that by 2100 a quarter of the global mature forested area has been harvested and re-afforested – i.e. natural forest becomes managed forest. Region specific yield estimates for primary forest productivity are provided.

The potential forest biomass is calculated based on the forest area (see section 4.1.1) and yields given by Yamamoto (2001). A recoverability rate of 50% is assumed. From this total, the quantity of wood biomass required to meet industrial round wood demand; as well as non-transport renewable energy demand (excluding energy crops; see section 4.4) is calculated (see section 5.7) and removed from the potential supply availability for ethanol production. Based on the forecast quantity of industrial round wood demand, the potential supply of recoverable residues are estimated. Note that in order to meet total demand for wood biomass for industrial and power use, under these scenarios for yield and recoverability, the 'EU-28 & NC-12' region would be a net importer of wood biomass and thus ethanol is produced from wood waste as a by-product of inter alia timber and paper industries, rather than from harvesting primary forest biomass.

The results of these calculations are presented in Table 5.10 below; while potential ethanol output under this scenario is presented in section 5.8 (see Table 5.11) below.

Table 5.8: Biomass from forest resources, 2017 and 2035 (million tonnes)

	2017				2035			
	World	RoW	EU-28 & NC-12	*Of which* EU-27	World	RoW	EU-28 & NC-12	*Of which* EU-27
Unprotected forest area (Mha)	3,120.4	2,966.3	154.2	129.6	3,120.4	2,966.3	154.2	129.6
Productivity (t/ha/yr)	-	10.0	4.1	4.1	-	10.0	4.1	4.1
Recoverability	-	50.0%	50.0%	50.0%	-	50.0%	50.0%	50.0%
Recoverable biomass (Mt/yr)	**15,094.6**	**14,778.5**	**316.1**	**265.8**	**15,094.6**	**14,778.5**	**316.1**	**265.8**
Industrial round wood demand	**1,617.0**	**1,274.9**	**342.1**	**313.4**	**1,849.5**	**1,508.5**	**341.0**	**316.3**
Of which Industrial wood residues	412.3	325.1	87.2	79.9	471.6	384.7	87.0	80.7
Biomass for non-trans energy *	**2,023.1**	**1,479.3**	**543.8**	**543.8**	**3,807.5**	**2,842.2**	**965.4**	**965.4**
Net exports / (imports)	-	569.8	-569.8	-591.4	-	990.3	-990.3	-1,015.9
Net biomass availability	**11,454.5**	**11,454.5**	**0.0**	**0.0**	**9,437.6**	**9,437.6**	**0.0**	**0.0**

Note: * see constraint 7: 'Other biomass use for non-transport renewable energy' in section 5.7 below.
Source: Agra CEAS Consulting.

5.6. Scenario 5: biomass from municipal waste

Robust data on waste production is not available and therefore estimates based on FAO data and other published sources are used. The methodology amounts to a top-down estimate of the amount of waste likely to be produced per unit of economic activity in different industrial sectors, per head of population, and/or per head of livestock; as well as an assumption regarding recoverability. As above, the two main sources used for the methodological assessment are:

- Johansson et al. (1993) assume that Municipal Solid Waste (MSW) in OECD countries will be generated at a constant rate of 300kg per capita per year, and that 75% of this will be recoverable for energy purposes.
- Yamamoto et al. (2001) estimates that 20% of food supply will end up as kitchen refuse and that 75% of this could be used for energy purposes.
- Both studies estimate that 20% of food supply will end up as human faeces and that 25% of this could be recovered.

Based on the forecast of food demand and population growth in 2017 and 2035, the quantity of kitchen and human waste which is estimated to be recoverable is calculated. The results are presented in Table 5.9; while potential ethanol output under this scenario is presented in section 5.8 (see Table 5.11) below.

Table 5.9: Biomass from municipal waste, 2017 and 2035 (million tonnes)

	2017				2035			
	World	RoW	EU-28 & NC-12	*Of which* EU-27	World	RoW	EU-28 & NC-12	*Of which* EU-27
Food (million tonnes)	4,458.4	3,973.8	484.7	412.4	5,382.3	4,892.3	490.0	422.1
Kitchen waste (recoverable)	668.8	596.1	72.7	61.9	807.3	733.8	73.5	63.3
Human waste (recoverable)	222.9	198.7	24.2	20.6	269.1	244.6	24.5	21.1
Total municipal waste	**891.7**	**794.8**	**96.9**	**82.5**	**1,076.5**	**978.5**	**98.0**	**84.4**

Source: Agra CEAS Consulting.

5.7. Constraint 7: 'Other biomass use for non-transport renewable energy'

The availability of biomass for ethanol production is constrained by biomass demand for non-transport renewable energy generation in the context of policy mandates where applicable, e.g. the EU Renewable Energy Directive (2009/28). Note that energy crops grown specifically to meet non-transport renewable energy demand is assessed separately under constraint 4 (see chapter 4.4).

Non-transport renewable energy use is estimated based on published forecasts of the energy and feedstock mix to meet specific mandates where such policy frameworks are expected to exist from 2017 onwards. In this context, forecasts for non-transport renewable energy use from 'other biomass' are limited and this analysis is based on forecasts of total bio-energy for heat and power use (net of the forecast of energy crops use for power generation (see section 4.4)). As in the previous assessment for non-transport use of energy crops, this assessment is based on two such published forecasts: *Biomass Futures (PRIMES model, reference scenario)* (EC, 2012); and *World Energy Outlook 2013 (new policies scenario)* (IEA, 2013).

Table 5.10: Net[1] energy and biomass demand for non-transport use, 2017 and 2035

	2017				2035			
	World	RoW	EU-28 & NC-12*	*Of which* EU-27*	World	RoW	EU-28 & NC-12*	*Of which* EU-27*
Net[1] power from biomass (TWh)	**371**	**165**	**206**	**206**	**1,104**	**704**	**400**	**400**
Heat from biomass (TWh)	**12,956**	**11,981**	**975**	**975**	**14,910**	**14,024**	**886**	**886**
- modern (wood pellets) (TWh)	4,858	4,214	644	644	7,001	6,178	823	823
- traditional (solid wood) (TWh)	8,097	7,767	330	330	7,908	7,845	63	63
Wood pellets for power [2] (MWh/t)	0.72	-	-	-	0.72	-	-	-
Wood pellets for heat [3] (MWh/t)	1.92	-	-	-	3.91	-	-	-
Solid wood for heat [4] (MWh/t)	0.83	-	-	-	4.20	-	-	-
Wood pellets (Mt)	**732**	**418**	**314**	**314**	**1,843**	**1,252**	**591**	**591**
Solid wood (Mt)	**836**	**801**	**34**	**34**	**816**	**809**	**7**	**7**

Notes: * Renewable energy scenario is based on available global and regional forecasts (see assumptions in the text above) and therefore due to data limitations the EU-27 total is the same as for the 'EU-28 & NC-12'.

[1] net of biomass from energy crops which is counted under constraint 4 (see section 4.4).

[2] efficiency of electricity conversion 0.72 MWh/t of harvested feedstock.

[3] efficiency of heat conversion 1.92 MWh/t of harvested feedstock.

[4] efficiency of heat conversion 0.83 MWh/t of harvested feedstock.

Source: Agra CEAS Consulting; based on EC (2012), DfT (2012), IEA (2012b)[57] and IEA (2013).

Traditional biomass use refers to the use of wood, charcoal, dried animal dung, etc. for cooking and heating in the residential sector. The efficiency of energy conversion for traditional biomass heating systems is low at around 20%; here it is assumed that demand is met by solid wood fuel at a heat conversion efficiency of 0.83 MWh/t of harvested feedstock.

Large-scale biomass combustion plants to produce heat are a mature technology; in many cases the heat generated is competitive with that produced from fossil fuels. Modern on-site technologies include efficient wood log, chips, and pellet burning stoves, municipal solid waste (MSW) incineration, and use of biogas. Bio-energy heat can also be produced in co-generation power plants, when there is a steady heat demand, for instance from industry or a district heating network. Here it is assumed that demand is met by wood pellets at a heat conversion efficiency of 1.92 MWh/t of harvested feedstock and an electricity conversion efficiency of 0.72 MWh/t of harvested feedstock.

[57] IEA (2012b). *Technology roadmap: bioenergy for heat and power*. International Energy Agency, Paris, France.

5.8. Summary of ethanol output scenario results:

The results of the 5 ethanol production scenarios are presented in Table 5.11 below.

Under the scenarios presented, total ethanol output potential 'EU-28 & NC-12' amounts to some 339.4 million m^3 (122.9 million m^3 in the EU-27) in 2017; and 117.4 million m^3 (98.9 million m^3 in the EU-27) in 2035. Of this total:

- Ethanol from 1st generation feedstock (wheat, coarse grains, sugar crops) contributes:
  - 23.3 million m^3 in 2017 and 10.3 million m^3 in 2035 in the 'EU-28 & NC-12';
  - 12.9 million m^3 in 2017 and 9.8 million m^3 in 2035 in the 'EU-27'.
- Ethanol from 2nd energy crops cultivated on land suitable for rain-fed crop cultivation (net of demand for food and other uses) contributes:
  - 215.8 million m^3 in 2017 and 5.5 million m^3 in 2035;
  - 33.6 million m^3 in 2017 and 4.1 million m^3 in 2035 in the 'EU-27'.
- Ethanol from 2nd generation crop residues contributes:
  - 70.7 million m^3 in 2017 and 70.2 million m^3 in 2035;
  - 49.9 million m^3 in 2017 and 56.6 million m^3 in 2035 in the 'EU-27'.
- Ethanol from 2nd generation forest biomass resources (net of other demand) contributes:
  - 19.1 million m^3 in 2017 and 20.2 million m^3 in 2035;
  - 17.5 million m^3 in 2017 and 18.8 million m^3 in 2035 in the 'EU-27'.
- Ethanol from 2nd generation municipal waste (food waste and sewage) contributes:
  - 10.5 million m^3 in 2017 and 11.2 million m^3 in 2035.
  - 8.9 million m^3 in 2017 and 9.7 million m^3 in 2035 in the 'EU-27'.

Under the scenarios presented, total ethanol output potential 'RoW' amounts to some 13,019.5 million m^3 in 2017; and some 8,580.7 million m^3 in 2035. Of this total:

- Ethanol from 1st generation feedstock (wheat, coarse grains, sugar crops) contributes 106.0 million m^3 in 2017 and 114.8 million m^3 in 2035;
- Ethanol from 2nd energy crops cultivated on land suitable for rain-fed crop cultivation (net of demand for food and other uses) contributes 9,761.3 million m^3 in 2017 and 5,813.8 million m^3 in 2035;
- Ethanol from 2nd generation crop residues contributes 361.1 million m^3 in 2017 and 613.1 million m^3 in 2035;
- Ethanol from 2nd generation forest biomass resources (net of other demand) contributes 2,583.8 million m^3 in 2017 and 2,283.7 million m^3 in 2035;
- Ethanol from 2nd generation municipal waste (food waste and sewage) contributes 85.8 million m^3 in 2017 and 112.0 million m^3 in 2035.

Table 5.12 presents the ethanol demand scenarios from the task 1 analysis and compares this to the potential ethanol supply scenarios. This suggests that potential ethanol supply far exceeds ethanol demand under E20 and E25 scenarios for the EU as well as 'RoW' ethanol demand.

- Under an E20 blend scenario, EU-27 demand would account for:
  - 3.8% of potential 'EU-28 & NC-12' ethanol supply in 2017 and 14.1% in 2035;
  - 10.6% of potential 'EU-27' supply ethanol supply in 2017 and 16.7% in 2035.
- Under an E25 blend scenario, EU-27 demand would account for:
  - 3.9% of potential 'EU-28 & NC-12' ethanol supply in 2017 and 17.2% in 2035;
  - 10.6% of potential 'EU-27' supply ethanol supply in 2017 and 20.4% in 2035.

Note: The EU and World Ethanol Demand Scenario analysis contained within this report was carried out in 2012-2013 based on policies in place and published data available at that time.

Table 5.11: Ethanol supply scenarios, 2017 and 2035 (million m^3; Mtoe)

	Ethanol – million m^3								Ethanol – Mtoe							
	2017				2035				2017				2035			
	World	RoW	EU28 & NC12	*Of which* EU-27	World	RoW	EU28 & NC12	*Of which* EU-27	World	RoW	EU28 & NC12	*Of which* EU-27	World	RoW	EU28 & NC12	*Of which* EU-27
Scenario 1 – 1st generation feedstock																
1a) F'cast exports	15.3	0.0	15.3	5.4	0.0	0.0	-	-	7.8	0.0	7.8	2.7	0.0	0.0	-	-
1b) F'cast EtOH use	114.1	106.0	8.0	7.5	125.1	114.8	10.3	9.8	58.0	53.9	4.1	3.8	63.6	58.4	5.2	5.0
Total	**129.4**	**106.0**	**23.3**	**12.9**	**125.1**	**114.8**	**10.3**	**9.8**	**65.8**	**53.9**	**11.9**	**6.6**	**63.6**	**58.4**	**5.2**	**5.0**
Scenario 2 – 2nd generation energy crops																
Energy crops	9,977.1	9,761.3	215.8	33.6	5,819.3	5,813.8	5.5	4.1	5,072.8	4,963.1	109.7	17.1	2,958.8	2,956.0	2.8	2.1
Total	**9,977.1**	**9,761.3**	**215.8**	**33.6**	**5,819.3**	**5,813.8**	**5.5**	**4.1**	**5,072.8**	**4,963.1**	**109.7**	**17.1**	**2,958.8**	**2,956.0**	**2.8**	**2.1**
Scenario 3 - 2nd generation agricultural residues																
Food crop residues	191.4	171.8	19.6	16.2	258.5	237.8	20.6	17.7	97.3	87.4	9.9	8.2	131.4	120.9	10.5	9.0
Feed crop residues	190.3	153.5	36.8	23.9	370.3	329.0	41.4	31.0	96.7	78.0	18.7	12.2	188.3	167.3	21.0	15.8
Biofuel crop residues	50.1	35.8	14.3	9.8	54.4	46.2	8.2	7.9	25.5	18.2	7.3	5.0	27.7	23.5	4.2	4.0
Total	**431.7**	**361.1**	**70.7**	**49.9**	**683.2**	**613.1**	**70.2**	**56.6**	**219.5**	**183.6**	**35.9**	**25.4**	**347.4**	**311.7**	**35.7**	**28.8**
Scenario 4 - 2nd generation forest biomass																
Ind. wood residues	90.4	71.3	19.1	17.5	109.7	89.4	20.2	18.8	46.0	36.3	9.7	8.9	55.8	45.5	10.3	9.5
Net Forest biomass	2,512.5	2,512.5	0.0	0.0	2,194.3	2,194.3	0.0	0.0	1,277.5	1,277.5	0.0	0.0	1,115.7	1,115.7	0.0	0.0
Total	**2,603.0**	**2,583.8**	**19.1**	**17.5**	**2,304.0**	**2,283.7**	**20.2**	**18.8**	**1,323.4**	**1,313.7**	**9.7**	**8.9**	**1,171.4**	**1,161.1**	**10.3**	**9.5**
Scenario 5 - 2nd generation municipal waste																
Municipal waste	96.3	85.8	10.5	8.9	123.2	112.0	11.2	9.7	49.0	43.6	5.3	4.5	62.7	57.0	5.7	4.9
Total	**96.3**	**85.8**	**10.5**	**8.9**	**123.2**	**112.0**	**11.2**	**9.7**	**49.0**	**43.6**	**5.3**	**4.5**	**62.7**	**57.0**	**5.7**	**4.9**
Total	**13,237.5**	**12,898.1**	**339.4**	**122.9**	**9,054.8**	**8,937.4**	**117.4**	**98.9**	**6,730.5**	**6,557.9**	**172.6**	**62.5**	**4,603.8**	**4,544.1**	**59.7**	**50.3**

Note: The EU and World Ethanol Demand Scenario analysis contained within this report was carried out in 2012-2013 based on policies in place and published data available at that time.

Source: Agra CEAS Consulting.

Table 5.12: Ethanol demand and proportion of potential supply, 2017 and 2035 (million m^3; Mtoe)

	Ethanol – million m^3								Ethanol – Mtoe							
	2017				2035				2017				2035			
	World	RoW	EU-28 & NC-12*	*Of which* EU-27	World	RoW	EU-28 & NC-12*	*Of which* EU-27	World	RoW	EU-28 & NC-12*	*Of which* EU-27	World	RoW	EU-28 & NC-12*	*Of which* EU-27
E20 demand scenario																
FAPRI	127.0	114.0	-	13.0	190.0	173.5	-	16.5	65.0	58.4	-	6.6	97.0	88.6	-	8.4
IEA current policies	119.0	106.0	-	13.0	226.0	209.5	-	16.5	61.0	54.4	-	6.6	115.0	106.6	-	8.4
IEA new policies	128.0	115.0	-	13.0	289.0	272.5	-	16.5	65.0	58.4	-	6.6	147.0	138.6	-	8.4
IEA - 450	144.0	131.0	-	13.0	398.0	381.5	-	16.5	63.0	56.4	-	6.6	202.0	193.6	-	8.4
% of supply																
FAPRI	1.0%	0.9%	3.8%	10.6%	2.1%	1.9%	14.1%	16.7%	1.0%	0.9%	3.8%	10.5%	2.1%	1.9%	14.1%	16.7%
IEA current policies	0.9%	0.8%	3.8%	10.6%	2.5%	2.3%	14.1%	16.7%	0.9%	0.8%	3.8%	10.5%	2.5%	2.3%	14.1%	16.7%
IEA new policies	1.0%	0.9%	3.8%	10.6%	3.2%	3.0%	14.1%	16.7%	1.0%	0.9%	3.8%	10.5%	3.2%	3.1%	14.1%	16.7%
IEA - 450	1.1%	1.0%	3.8%	10.6%	4.4%	4.3%	14.1%	16.7%	0.9%	0.9%	3.8%	10.5%	4.4%	4.3%	14.1%	16.7%
E25 demand scenario																
FAPRI	127.0	113.9	-	13.1	190.0	169.8	-	20.2	65.0	58.3	-	6.7	97.0	86.7	-	10.3
IEA current policies	119.0	105.9	-	13.1	226.0	205.8	-	20.2	61.0	54.3	-	6.7	115.0	104.7	-	10.3
IEA new policies	128.0	114.9	-	13.1	289.0	268.8	-	20.2	65.0	58.3	-	6.7	147.0	136.7	-	10.3
IEA - 450	144.0	130.9	-	13.1	398.0	377.8	-	20.2	63.0	56.3	-	6.7	202.0	191.7	-	10.3
% of supply																
FAPRI	1.0%	0.9%	3.9%	10.7%	2.1%	1.9%	17.2%	20.4%	1.0%	0.9%	3.9%	10.7%	2.1%	1.9%	17.3%	20.5%
IEA current policies	0.9%	0.8%	3.9%	10.7%	2.5%	2.3%	17.2%	20.4%	0.9%	0.8%	3.9%	10.7%	2.5%	2.3%	17.3%	20.5%
IEA new policies	1.0%	0.9%	3.9%	10.7%	3.2%	3.0%	17.2%	20.4%	1.0%	0.9%	3.9%	10.7%	3.2%	3.0%	17.3%	20.5%
IEA - 450	1.1%	1.0%	3.9%	10.7%	4.4%	4.2%	17.2%	20.4%	0.9%	0.9%	3.9%	10.7%	4.4%	4.2%	17.3%	20.5%

Note: * EU-27 demand as a share of 'EU-28 & NC-12' supply.

Note: The EU and World Ethanol Demand Scenario analysis contained within this report was carried out in 2012-2013 based on policies in place and published data available at that time.

Source: Agra CEAS Consulting & E4tech.

6. Sensitivity analysis

The sensitivity of ethanol output potential to the substitution of cereal (wheat and coarse grains) straw biomass for energy crops to meet demand for power generation from energy crops (see constraint 4 in section 4.4) is tested in Table 6.1 below. This suggests that substituting straw biomass for energy crop feedstock to meet renewable power demand would result in additional ethanol output amounting to some 5.6 million m^3 globally in 2017 and 9.8 million m^3 in 2035:

- In the EU-27 (and 'EU-28 & NC-12') countries, an additional 3.1 million m^3 in 2017 and 3.5 million m^3 of ethanol could be produced (note: see section 4.4 for scenario assumptions); and
- In the 'RoW' countries, an additional 2.5 million m^3 in 2017 and 6.2 million m^3 of ethanol could be produced.

Table 6.1: Sensitivity analysis: effect of substituting cereal straw biomass for energy crops to meet non-transport renewable power from bio-energy demand (constraint 4)

	2017				2035			
	World	**RoW**	**EU-28 & NC-12**	***Of which* EU-27**	**World**	**RoW**	**EU-28 & NC-12**	***Of which* EU-27**
Power demand (TWh)	**165.3**	**73.7**	**91.7**	**91.7**	**372.8**	**237.8**	**135.0**	**135.0**
Feedstock requirement								
Straw pellets (Mt)	152.3	67.9	84.4	84.4	343.4	219.1	124.3	124.3
Wood pellets (Mt)	229.1	102.1	127.0	127.0	501.5	320.0	181.6	181.6
Ethanol equivalent								
Straw pellets (Mm^3)	44.7	19.9	24.8	24.8	106.8	68.1	38.7	38.7
Wood pellets (Mm^3)	50.3	22.4	27.9	27.9	116.6	74.4	42.2	42.2
Additional ethanol (Mm^3)	**5.6**	**2.5**	**3.1**	**3.1**	**9.8**	**6.2**	**3.5**	**3.5**

Note: Renewable power scenario is based on available global and regional forecasts (see assumptions in section 4.4) and therefore due to data limitations the EU-27 total is the same as for the 'EU-28 & NC-12'.
Source: Agra CEAS Consulting.

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