FUTURE DEVELOPMENT OF 2^{ND} GENERATION BIOFUELS IN TRANSPORT CONSIDERING LEARNING RATES

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ABSTRACT

The aim of this paper is to illustrate the biofuel model BioPOL and its new developments, to describe a set of scenarios, in which BioPOL was applied and to discuss the results of the scenarios.

BioPOL was developed and applied within the several European projects, among them TRIAS, PREMIA, HOP!, iTREN-2030 and GHG TransPoRD (Schade et al., 2008, Wiesenthal et al., 2009, Schade et al., 2007, Schade et al., 2010). This paper refers to the latter project GHG TransPoRD. The BioPOL model is a system dynamics model that is constructed on the VENSIM modelling platform. A detailed description of the BIOPOL model can be found in Schade&Wiesenthal (2011).

The BioPOL model is a recursive dynamic model that is constructed in the VENSIM modelling platform. It is based on a year-by-year simulation of biofuel production, production cost and biofuel demand until 2030. The model delivers detailed outcomes for the different types of biofuels with regard to production capacity and produced volumes, costs and well-to-wheel emissions of greenhouse gases. It considers the main production pathways of biofuels, namely first generation biodiesel with rapeseed and sunflower and first generation ethanol with cereals and sugar beet. Furthermore, it includes advanced 2nd generation pathways from ligno-cellulosic feedstock. An important issue of BioPOL is the improved way in which learning for 2nd generation is considered.

The paper refers to the work carried out in the GHG TransPoRD project. The main objective of GHG-TransPoRD was to support the EU in defining a feasible research and policy strategy for GHG reductions of transport that fits to the overall GHG reduction targets of the EU. As part of this strategy, the project developed a reference scenario and a set of GHG emission scenarios. A set of GHG emission reduction scenarios were developed varying the technical measures to reduce GHG emissions. The technical measures refer to all transport modes including new vehicle technologies like electric vehicles and hydrogen vehicles. In addition, different biofuel types were pushed into the market according to the definition of the GHG emission reduction scenarios.

In these scenarios, BioPOL was applied together with energy model POLES and the transport model ASTRA. The model set derives detailed results on transport performance, economic indicators (e.g. GDP), vehicle stocks, energy demand, fuel consumption and GHG emission.

This paper focuses on the energy demand, the fuel consumption and the consumption of different biofuel types.

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[1] The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission

1. INTRODUCTION

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In these scenarios, BioPOL was applied together with energy model POLES and the transport model ASTRA. The model set derives detailed results on transport performance, economic indicators (e.g. GDP), vehicle stocks, energy demand, fuel consumption and GHG emission.
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2. APPROACH

2.1. Basic structure of BIOPOL

The BioPOL model is a recursive dynamic model that is constructed in the VENSIM modelling platform. It is based on a year-by-year simulation of biofuel production, production cost and biofuel demand until 2030. The model delivers detailed outcomes for the types of biofuels considered with regard to production capacity and produced volumes, costs and well-to-wheel emissions of greenhouse gases.
The model focuses on the main production pathways of biofuels, namely conventional biodiesel based on the two feedstocks rapeseed and sunflower and conventional ethanol based on cereals and sugar beet. Furthermore, it includes advanced 2nd generation pathways from ligno-cellulosic feedstock (i.e. ethanol and synthetic diesel BtL). The model does not assess the direct use of vegetable oils as

transport fuels, which in the year 2008 accounted for only 4% of the total biofuel consumption (in energy content; Eurobserver, 2009). Also the use of biogas as transport fuel was not included as the uptake of biogas is mainly driven by the deployment of gas-fuelled vehicles; yet, the modelling of changes in the vehicle fleet go beyond the scope of the BioPOL model.
Figure 1 illustrates the main feedback loops of the BioPOL model. Feedback loop 1 'feedstock prices' describes the main feedback loop between feedstock prices, biofuel demand and biofuel production. If biofuel demand increases then the (domestic) biofuel production capacity and biofuel production increase. The related increase in feedstock demand means that feedstock prices, and with them biofuel production costs, also increase, resulting in higher market prices of biofuel. The latter are then compared with the market prices of fossil fuels to determine the biofuel demand which triggers biofuel capacity and biofuel production.

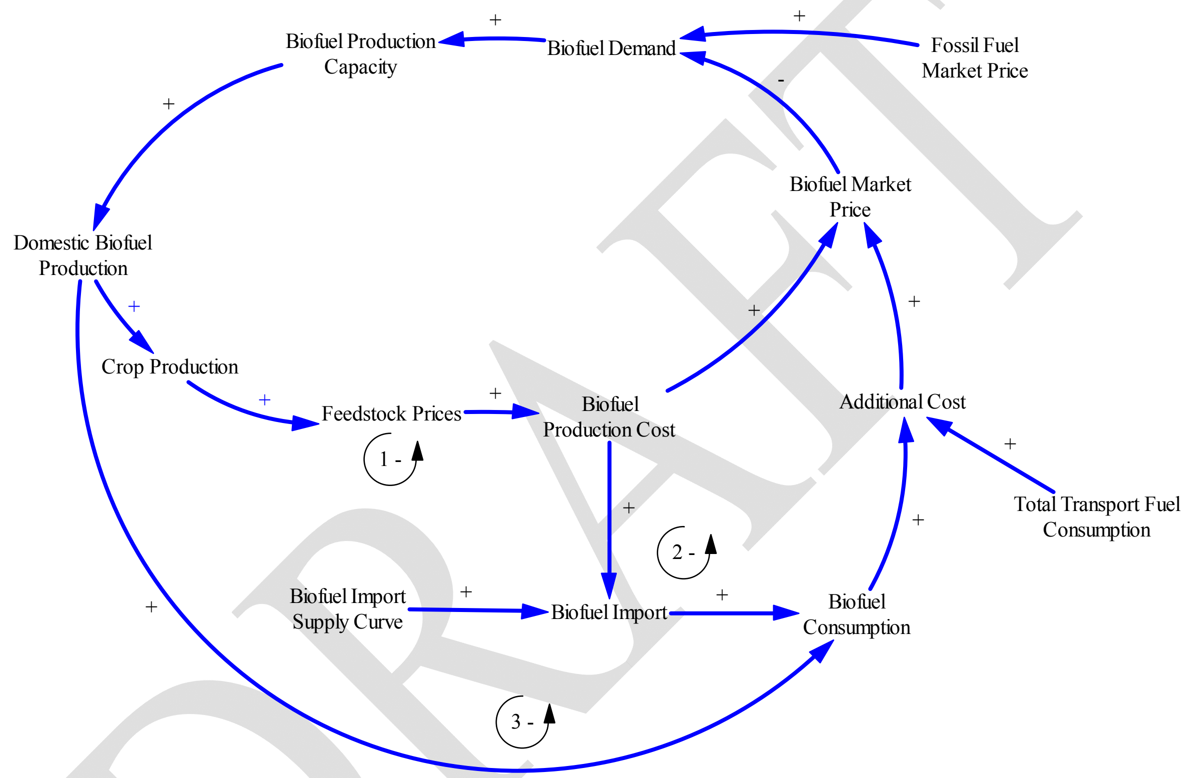


Figure 1: Basic feedback loop structure of the BioPOL model; *Source*: based on Schade&Wiesenthal (2011)

Feedbackloop 2 'biofuel imports' describes the relation between domestic biofuel production cost, biofuel imports, biofuel demand and domestic biofuel production. Rising domestic biofuel production leads to higher biofuel production cost which in turn increase the amount of imported biofuels. The biofuel imports are modelled with an exogenous biofuel import supply curve. Note that for imported biofuels, no production costs are being calculated as it is reasonable to assume that imported biofuels will not be sold at the production costs in the EU. This is due both to import duties of the WTO (protecting the domestic market) and a motivation of producers to sell their biofuels at the highest price possible, thus equaling the lowest price of domestically produced biofuels. For that reason, one could estimate for imported biofuel to take the lower end of the EU domestic biofuel market prices. We assumed some strategic pricing so that the costs of imports are slightly (5%) below that of domestically produced biofuels. The resulting volumes of biofuels that are imported into the EU at that price are determined based on cost-supply curves, which are taken from Resch et al. (2009).

Feedback loop 3 'technical adaptations' focuses on additional costs – reflecting technical adaptations – related to certain levels of biofuel consumption. Once biofuel consumption (equalling domestically produced biofuels and imports) exceeds certain share and passes from low blends to higher blends or pure biofuels, additional costs occur due to distribution and blending and potentially adaptation of car engines. These lead to additional costs that form part of the market prices of biofuels.

The market prices of fossil fuels and the total transport fuel consumption are treated exogenous in BioPOL in order to reduce complexity and to carry out the sensitivity analysis in this paper. However, it has been shown (Schade et al., 2007; Fiorello et al., 2009) that the BioPOL model can be linked to the energy model POLES, which then enables the additional analysis of the impact of biofuel consumption on the price of fossil fuels and transport energy demand.

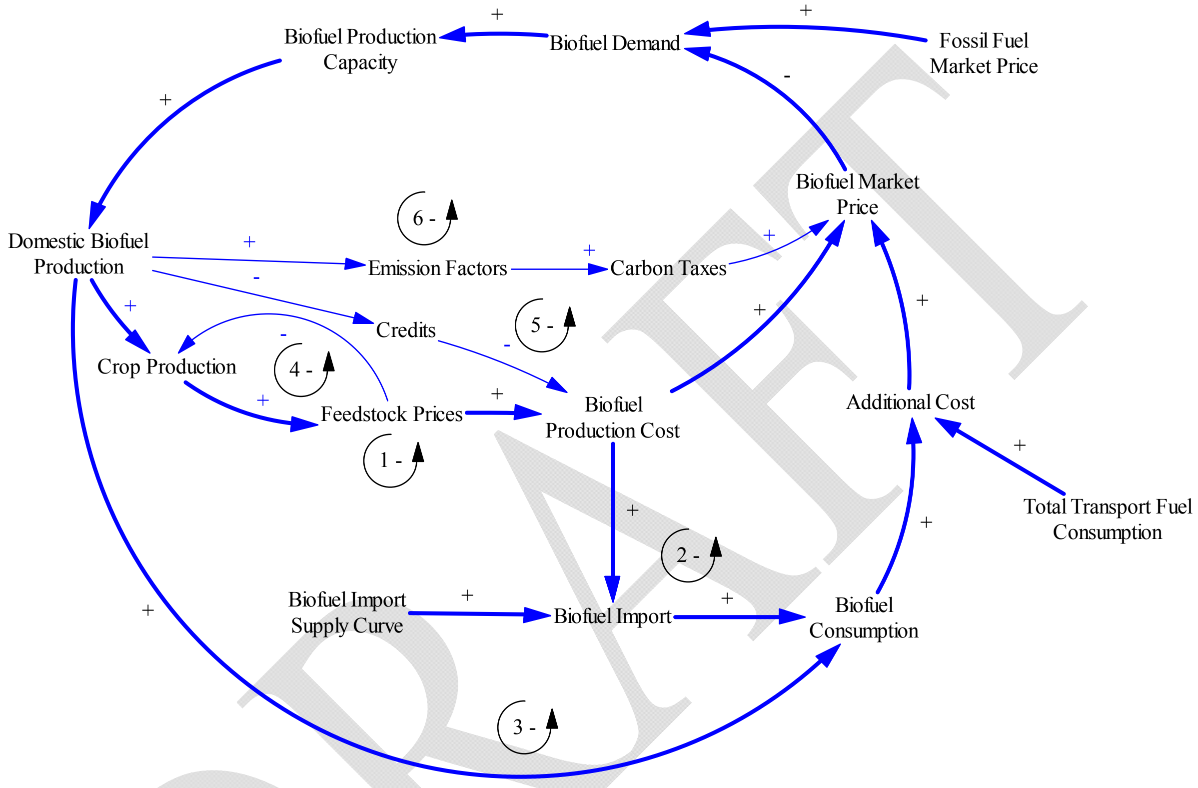


Figure 2: Further feedback loops within the BioPOL model

Besides the three main feedbackloops BioPOL contains further feedbackloops as illustrated in Figure 2. Feedback loop 4 'crop production' determines the share of different crop types (e.g. wheat and sugarbeet). An increasing domestic biofuel production leads to rising production of the crops they are consisting of according to the share of crops in one biofuel. For example bioethanol is produced by 75% of the feedstock coming from wheat and 25% by sugarbeet. The induced increase of crops leads in turn to higher feedstock prices of both crop types applying. As there increase might be different due to different feedstock elasticities the price relation might alter. The new feedstock prices have an impact on the share of wheat and sugarbeet with which bioethanol is produced in the next year.

Feedbackloop 5 'credits' describes the relation between domestic biofuel production, credits and biofuel market cost. The price obtained for by-products need to be considered in the net biofuel production costs. The way in which by-products are used (e.g. as chemical or animal feed; as energy use or feed) can have a significant impact on the net costs. In order to not over-estimate the benefits and be more realistic vis-à-vis a saturation of by-product markets, it is assumed that in the case of glycerine from biodiesel production by-products will be used for animal feed rather than as chemical substitute. DDGS (distiller's dried grains with solubles) from ethanol production will primarily be used as animal feed (80% of total volume) until production levels reach around 5000 toe. With increasing production volumes, the energetic use of DDGS increases up to a share of 80% of all by-products at production levels of 12000 toe. Similar to this, feedback loop 6 'emission factors' focuses on the impact of how by-products are used on the emission factors of biofuels. Emission factors change whether the by-products are used as chemical or animal feed. In scenarios in which a carbon tax is applied the tax level is affected by the use of the by-products which then changes the biofuel market price.

It has to be clarified that the shown feedback structures are not relevant for all types of biofuel and all types of crops. Table 1 llustrates on which biofuel or a crop type a feedbackloop is referring to. While in the feedbackloop 1 the biofuel production of all biofuel types is affecting all feedstock types other feedbackloops only refer to sub-set of biofuel or feedstocks. Especially feedbackloop 2, 5 and 6 refers only to biofuels of the 1st generation. The feedbackloop 3 instead considers bioethanol, biodiesel and ligno-cellulosic but not BTL. For BTL no technical adaptations are required as car and truck engines can use BTL without adaptations, while in all other cases smaller technical adaptations are required once they exceed a certain blend (e.g. diesel with a 7% blend of biodiesel).

Table 1: Biofuel and crop types in feedbackloops

Nr	Feedback-loop	Bio-ethanol	Wheat, Sugar-beet	Bio-diesel	Rape-seed, Sun-flower	Ligno-cellu-losic	Straw, Farmed wood	BTL	Waste and farmed wood
1	feedstock prices	X	X	X	X	X	X	X	X
2	biofuel imports	X		X					
3	technical adapta-tions	X		X		X			
4	crop production		X		X				
5	Credits	X		X					
6	emission factors	X		X					

2.2. Main model equations

The model equations can be grouped into three blocks:

- the biofuel production cost and the feedstock prices
- the market prices of biofuels, fossil fuels and the incentive to increase biofuel production capacity
- the biofuel production capacity and the domestic biofuel production

In this paper we explain only a couple of important equations. A more detailed explanation on the equations can be found in Schade&Wiesenthal (2011).

In a first step, the model calculates the production cost *'cbf_b'* per unit of tonne of oil equivalent (toe) for each type of domestically produced biofuel (see equation 1). cbf_b depends on capital costs, fixed operational costs, energy costs and feedstock minus the price obtained for by-products. The way how the production cost and its components are derived is shown in the following equations:

$$cbf_b = cap_b + opf_b + ope_b + fsb_b - crd_b \tag{1}$$

With cbf: cost of biofuels per toe
cap: capital cost of biofuels per toe
opf: fixed operational cost of biofuels per toe
ope: costs of the energy input for biofuels per toe
fsb: feedstock cost of biofuels per toe
crd: credits cost of biofuels per toe
index b: bioethanol, biodiesel, ligno-cellulosic, BTL

In a second step, the model calculates an equilibrium point for the penetration of biofuels as a function of final price of biofuels relative to the pump price of fossil fuels. It first determines the final market price of biofuels (per litre) based on the production costs *'cbf'* (see equation 2), the prices of imported biofuels and the applicable tax '*tbf*'. This is included through a proxy *'xbf'*. The incentive 'bfi' is determined through the relation of biofuel prices to fossil prices; its level depends on the distance to the equilibrium point and the profit margin (see equation 3).

$$pbf_b = (\frac{cbf_b}{lpt_b} + tbf_b + xbf_b) \qquad (2)$$

$$bfi_b = \frac{(\frac{pff_b}{pbf_b} - 1)}{ebg} \qquad (3)$$

With pbf: market price of biofuels per liter
cbf: cost of biofuels per toe
tbf: tax of biofuels per liter
xbf: extra cost (like cost for adaption of vehicles) of biofuels per liter
lpt: conversion of toe into liter
bfi: incentive for increasing biofuel capacities
pff: market price of fossil fuels per liter
pbf: market price of biofuels per liter
ebg: elasticity of biofuel production second generation on feedstock cost
index b: bioethanol, biodiesel, ligno-cellulosic, BTL

In a third step, the model derives the domestic biofuel production. The amount of biofuels produced is basically determined by the installed production capacities, which in return depend on the incentive for producers to invest in additional capacities for each type of biofuel. This means that the trend in the annual biofuel production tends to converge towards the equilibrium point where the final price of biofuels equals that of the fossil substitutes.

2.3. Main input parameters and output variables

The previous description focused on the main variables and the main equations. Besides those variables the model provides certain relevant output variables like additional production costs, avoided GHG emissions and the net benefit.

The additional costs are derived multiplying the biofuel consumption with the cost differences between biofuels and fossil fuels. The avoided GHG emissions are calculated on the basis of the biofuel and fossil fuel consumption and their GHG emission factors. To receive the net benefit the avoided GHG emissions are multiplied with the carbon value and additional production costs are subtracted.

Figure 3 gives an overview of the use of the exogenous input parameters and of endogenous auxiliary variables which were not explained in detail in the previous sections such as the fossil fuel production costs and the operational energy cost.

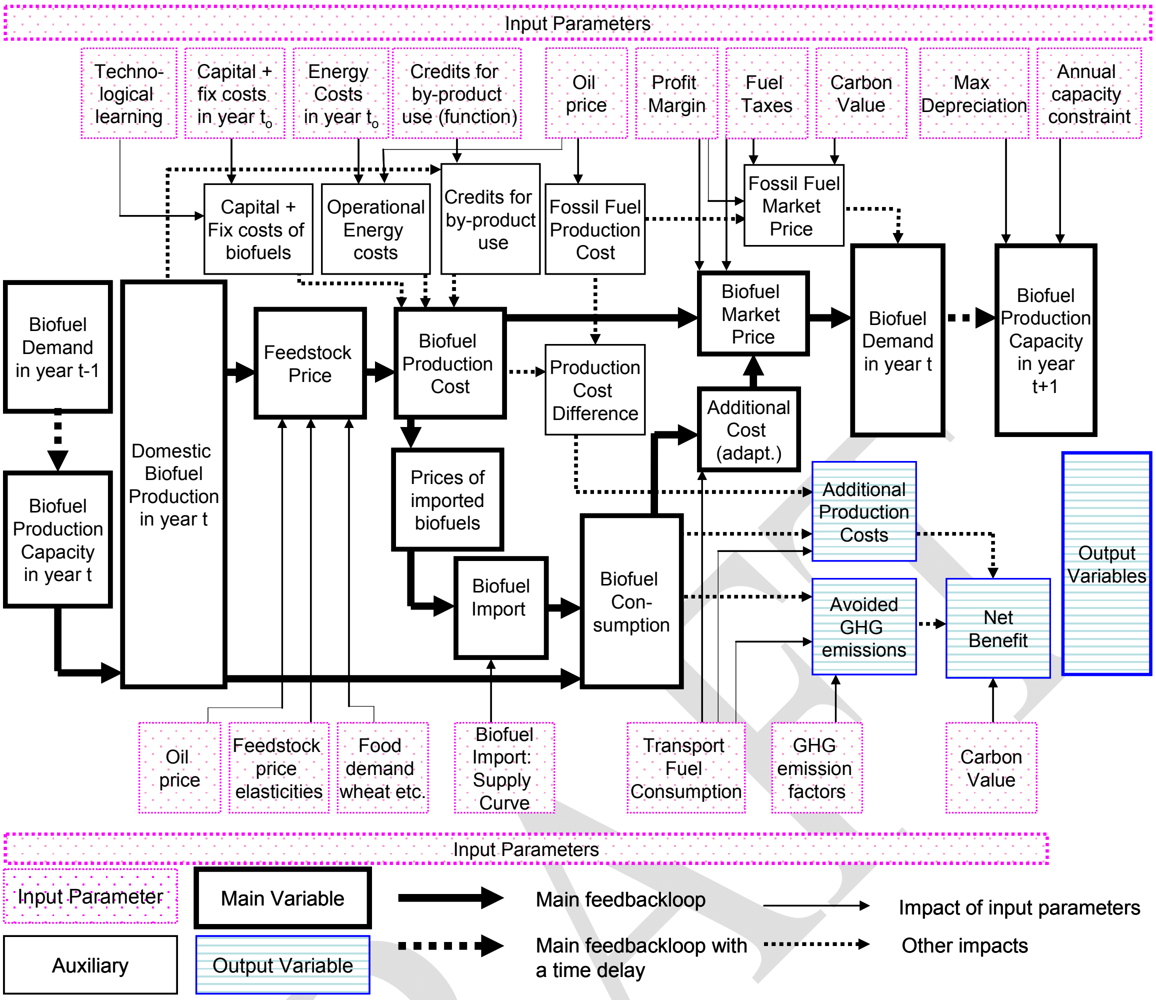


Figure 3: Interaction of factors affecting supply and demand of biofuels in BioPOL; *Source*: Schade&Wiesenthal (2011)

The BioPOL model depends on a number of exogenous parameters. In order to ensure consistency between inherently interlinked parameters such as the production processes and emissions that are specific for every biofuel production pathway and are sensitive to the way of accounting for e.g. by-products, an effort has been made to stay close to a limited number of studies only. Here, the Well-to-Wheel Analysis from JEC (JRC/EUCAR/CONCAWE, 2007, 2008) was chosen as a reference work.

2.4. GHG Emission Reduction

The well-to-wheel emissions of biofuels are largely influenced by the use of the primary feedstock and the use of the by-products and the related credits calculated for them. Also potential land-use change can largely influence the total greenhouse gas emissions; however, this is usually not been included in the well-to-wheel emissions provided.

Figure 4 below provides an indication of the potential emission savings when replacing one energy unit fossil fuels with biofuels. 1st generation biofuels turn out tor reduce GHG emission rather in the range of 20 to 70%, while GHG emission reductions of 2nd generation biofuels are higher (80 to 95%). The only exemption to this pattern are the GHG emission savings of 1st generation biogas, which are in the range of 70-80%.

However, Gameson (2010) points out that further improvements of GHG emission reductions can be realised by using cleaner energy sources and by adding new enzymes and microbes which enhance the conversion efficiency.

Note that the specific emission reductions as shown above in Figure 4 do not take into account the effects of indirect land use changes. These can largely influence the net emissions as shown for example in WBGU (2010), in Al –Raffai et al. (2010) and in (Croezen, 2010). Moreover, Crutzen et al. (2008) pointed out that that the N2O emissions caused by fertilizer use should be well above the default values of the IPCC approach. Applying a higher conversion factor from N to N2O could lead to higher specific emissions of biofuels.

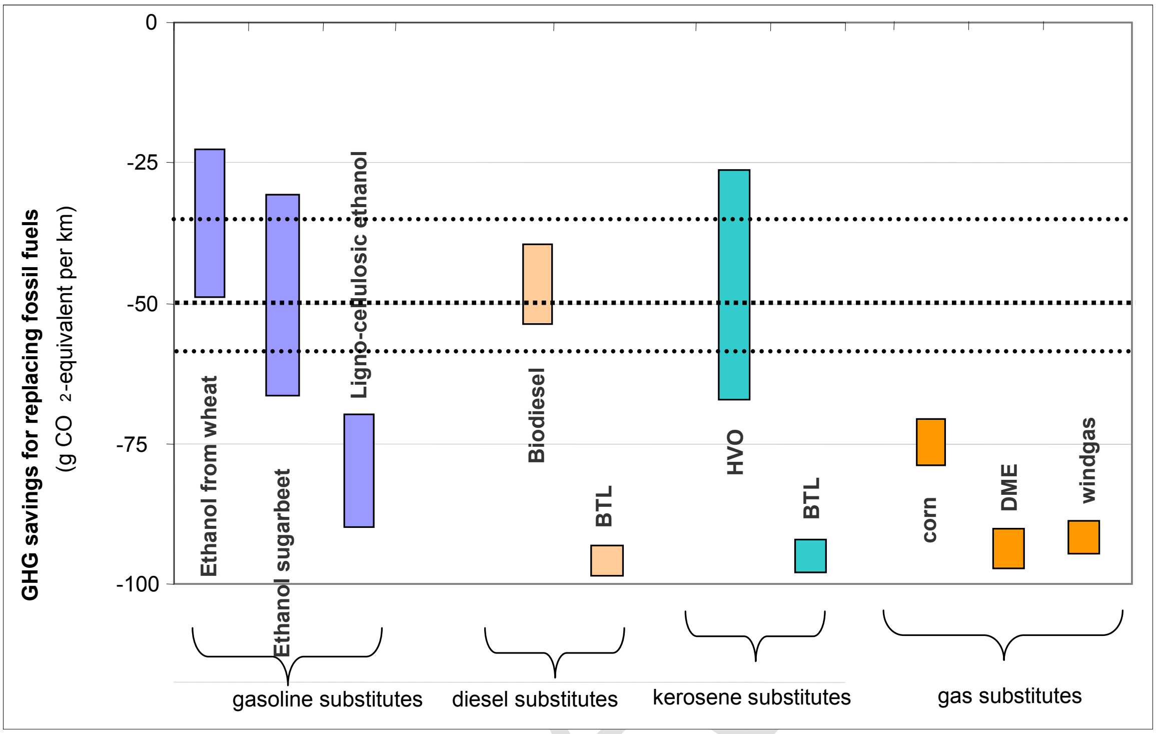


Figure 4: GHG emission reduction

2.5. Learning

Learning curves are a major vehicle to describe the relation between RD input and technological development. It is taken in to consideration that market activities influencing technological developments of e.g. biofuels take place EU and non-EU. Therefore, trends for RD investment and biofuel production outside of EU have been developed and kept fix for all scenarios, while they vary in the EU depending on the scenario. The trend of the investment cost is then derived on the global RD investments and the global cumulative production of a specific biofuel technology. In the case of biofuel the most relevant technologies were investment cost decrease significantly due to learning were ligno-cellulosic ethanol, BTL and DME.

A specific issue related to the learning curve approach is the valley of the death. Due to a lack of competitiveness of new technologies they do not enter the market. As they do not enter the market the cumulative production doesn't rise and they do not learn sufficiently to gain the necessary level of competitiveness. To overcome the valley of death in some cases investment programs are assumed, which push some of the new technologies in the market.

1.1.1. Biofuel production plants

The estimation of learning rates is based on a time series of biofuel production plants. The information on biofuel production plants stem from databases from IEA/OECD ((IEA bioenergy, 2008; IEA bioenergy, 2010) and biofueldigest (biofueldigest, 2011). They were completed with company information to fill the gap when investment figures or the status of a specific plant was missing. In several cases financial data were missing and had to be completed by company information gained from internet or company brochures.

Table 2 shows a selection of the resulting database on biofuel production plants that was used to estimate the learning rates. The database contains information on the location, raw material, pathway, type of facility, capacity, plant type, private investment, public funding, status of the plant and starting year. The database considers plants producing biobutanol, Fischer-Tropsch diesel (BTL), dymethyl ether (DME), methanol, ammonia, biogas (SNG), ligno-cellulosic ethanol, algae-based biofuels, biodiesel from starch and hydrotreated vegetable oils (HVO). No 1st generation biofuels are considered. It contains information on operational and planned power plants between 1990 and 2016. It is distinguished between pilot, demonstration and commercial production plants.

Table 2: Biofuel production plants

Project.project_owner	Project.project_name	Project.location_city	Country.name	Rawmaterial.name	Project.input	Product.name	Project.output_1	Type.name	Project.total_investment	Project.total_investment_currency	Project.funding	Project.funding_currency	Status.name	Project.start_up
Butamax Advanced	Biobutanol dem	Hull	United Kingdo	other	various fee	biobutanol;	15	demo	0				planned	2010
Amyris-Crystalsev	Amyris USA	Emeryville	United States	fermentabl	sugarcane	hydrocarbo	xx	pilot					operational	2008
Amyris-Crystalsev	Amyris pilot Bra	Campinas	Brazil	fermentabl	sugarcane	hydrocarbo	xx	pilot					under constru	2009
Amyris Crystalsev	Amyris commer	Sertaozinho	Brazil	fermentable sugars		hydrocarbo	88000	commer	***100000000***	***USD***			planned	2010
Cutec	pilot	Clausthal-Zeller	Germany	lignocellulo	Straw, woo	FT-liquids;	0	pilot					operational	1990
CHOREN Industrie	alpha plant	Freiberg	Germany	lignocellulo	dry wood c	FT-liquids;	*500*	pilot					on hold	2003
Vienna University c	FT pilot	Güssing	Austria	lignocellulo	syngas fron	FT-liquids;	0	pilot					operational	2005
BFT Bionic Fuel Te	OFT Alyssa	Aarhus - odum	Denmark	lignocellulo	straw pellet	diesel; hyd	200	demo	600000	EUR	private		operational	2008
Southern Research	technology deve	Durham	United States	lignocellulo	Cellullulosic	FT-liquids;	3500	pilot	40000000	USD	14000000	USD	operational	*2008*
NSE Biofuels Oy, a	demo	Varkaus	Finland	lignocellulo	forest resid	FT-liquids;	656	demo					operational	2009
GTI Gas Technolog	pilot	Des Plaines	United States	lignocellulo	forest resid	FT-liquids;	26	pilot			2000000	USD	under constru	2010
CHOREN Fuel Freib	beta plant	Freiberg	Germany	lignocellulo	dry wood c	FT-liquids;	13500	commer	100000000	EUR			under commis	2010
New PageBiofuels LLC		***Wisconsin***	***United State***	***lignocellu***	***Forest res***	***FT-liquids***	***16000***	***demo***	***84000000***	***USD***	***3000000***	***USD***	***planned***	***2012***
Flambeau River Bio	Project Trixie	Park Falls	United States	lignocellulo	Forest resid	FT-liquids;	***18000***	*pilot*	***84000000***	USD	3000000	USD	planned	2012
Research Triangle	Synfuel product	Research Triang	United States	lignocellulosics		FT-liquids;	22	*pilot*	3000000	USD	2000000	USD	planned	

Source: IEA/OECD, biofueldigest, gap-filled with company information

In total, we investigate the data of some 80 power plants out of which the major part are pilot power plants. In general pilot plant shave a rather small capacity below 1000 t/a, demonstration facilities are bigger and most of the commercial plants are designed for more than 100000 t/a. Commercial plants became operational after 2007 starting with HVO (2007) and DME (2009). The first amounts of ligno-cellulosic ethanol from commercial plants were produced in 2010 (Range Fuels, 2010).

The number of pilot plants is increasing very strongly. While there were only 6 pilot plants in 2005, the number of pilot plants increased to 24 in 2010 and is expected to increase further. During the same time period the cumulative amount of investment quadrupled (seeFigure 5).

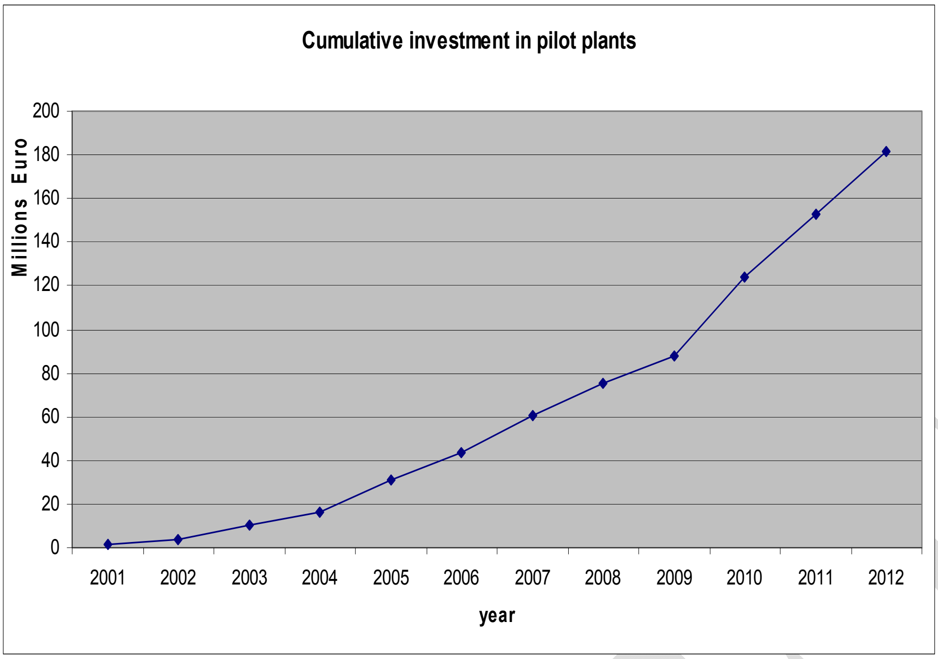


Figure 5: Cumulative investment in pilot plants
Source: Own calculation based on data from IEA/OECD, biofueldigest, company information

While HVO is already produced in large quantities ligno-cellulosic ethanol production facilities form with 50 plants the biggest part of the plant database followed by BTL plants with 14 facilities. Especially, ligno-cellulosic and BTL are expected to have much higher cost reduction compared to other types of biofuels e.g. methanol (OECD, 2008b). Figure 6 shows the development of the production capacity of different biofuel production pathways. HVO and DME plants are already in a commercial phase, but a high number lingo-cellulosic, BTL and other 2nd generation biofuel plants are expected to become operational in the coming years.

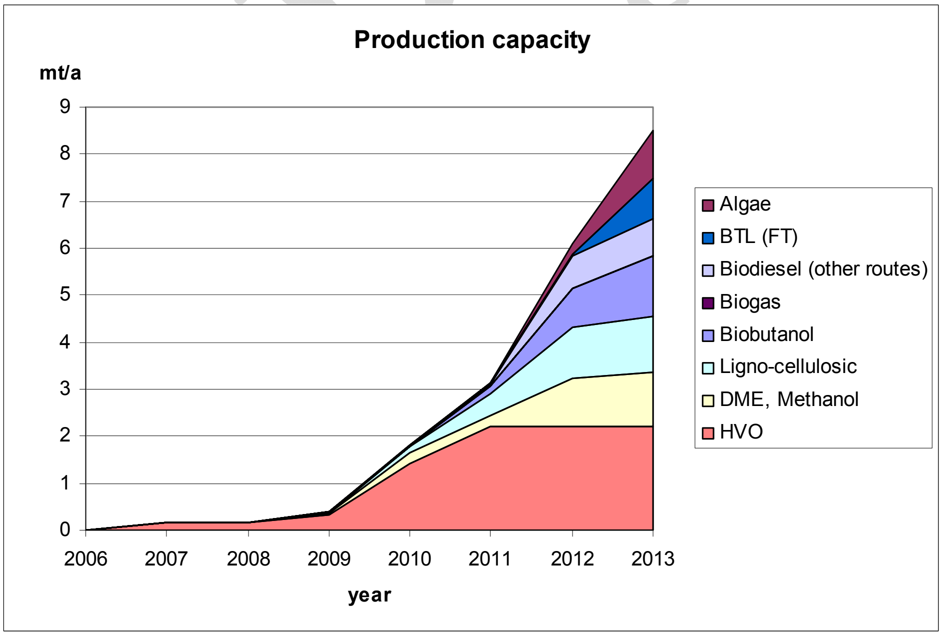


Figure 6: Development of biofuel production capacity
Source: Own calculation based on data from IEA/OECD, biofueldigest, company information

1.1.2. Learning rate of biofuel production

The learning rates of biofuel production were estimated based on the concept of a One-Factor-Learning Curve (OFLC) and – if possible – on a Two-Factor-Learning Curve (TFLC). In both cases the capital cost per capacity forms the independent variable. For the OFLC the capital cost per unit production depends on the development of the cumulative capacity:

$$C_{t,y} = mQ_{t,y}^{-\varepsilon} \qquad \textbf{(4)}$$

with C = Capital costs per capacity, €/(t/a)
Q = Cumulative Capacity, t/a
ε = Elasticity of learning (learning index)
m = normalisation parameter with respect to initial conditions
t = Technology
y = Period (year)

The parameters of the OFLC were estimated for ligno-cellulosic ethanol, BTL and DME. Figure 7 illustrates the decrease of capital cost, while the cumulative capacity of pilot, demonstration and commercial plants increased for ligno-cellulosic. Based on 38 data points we derived an elasticity of learning of -0.36 which equals a learning rate of 0.22.

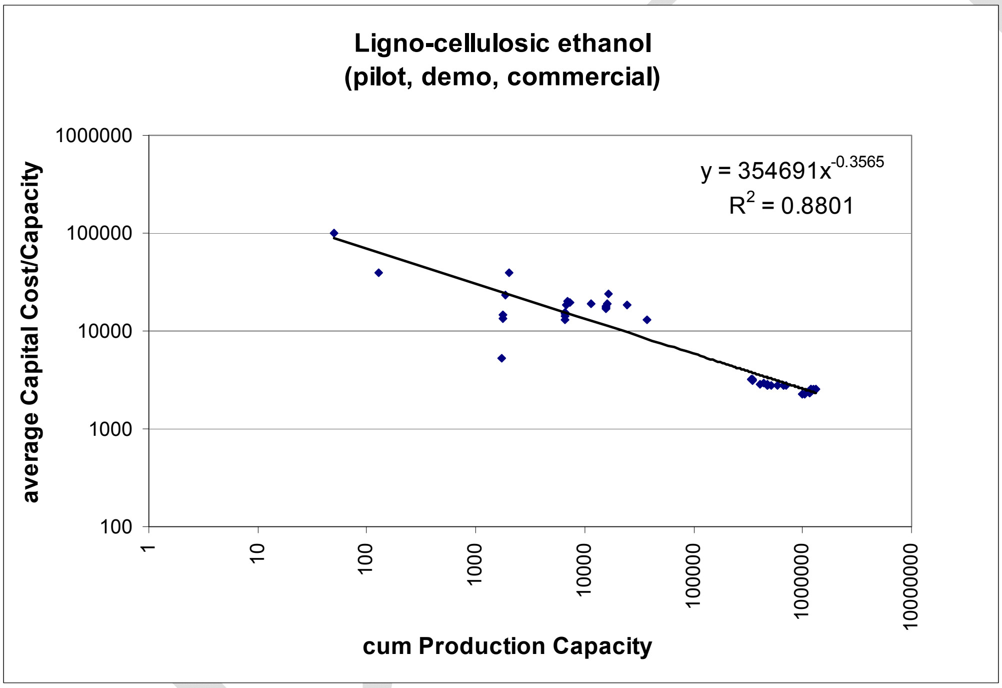


Figure 7: Learning curve for Ligno-cellulosic ethanol
Source: Own calculation based on data from IEA/OECD, biofueldigest, company information

With respect to BTL we have 11 data points (see Figure 8). We estimated an elasticity of learning of -0.14 which equals a learning rate of 0.09. In the case of DME the estimation is based on only 2 data points (see Figure 9). We derived an elasticity of learning of -0.26 which equals a learning rate of 0.17.

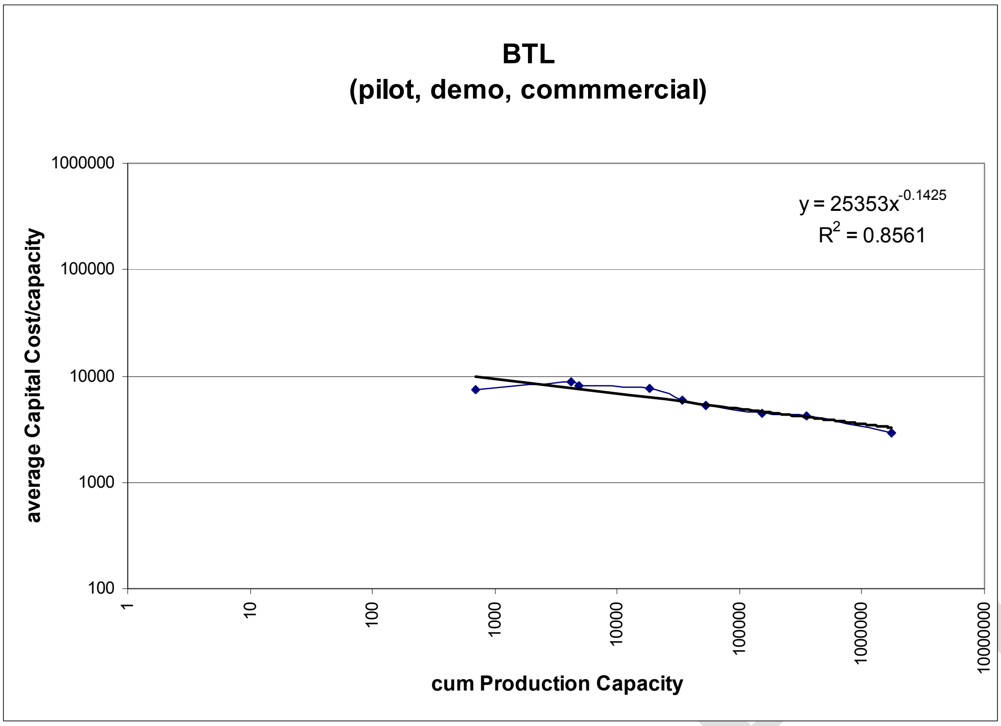


Figure 8: Learning curve for BTL
Source: Own calculation based on data from IEA/OECD, biofueldigest, company information

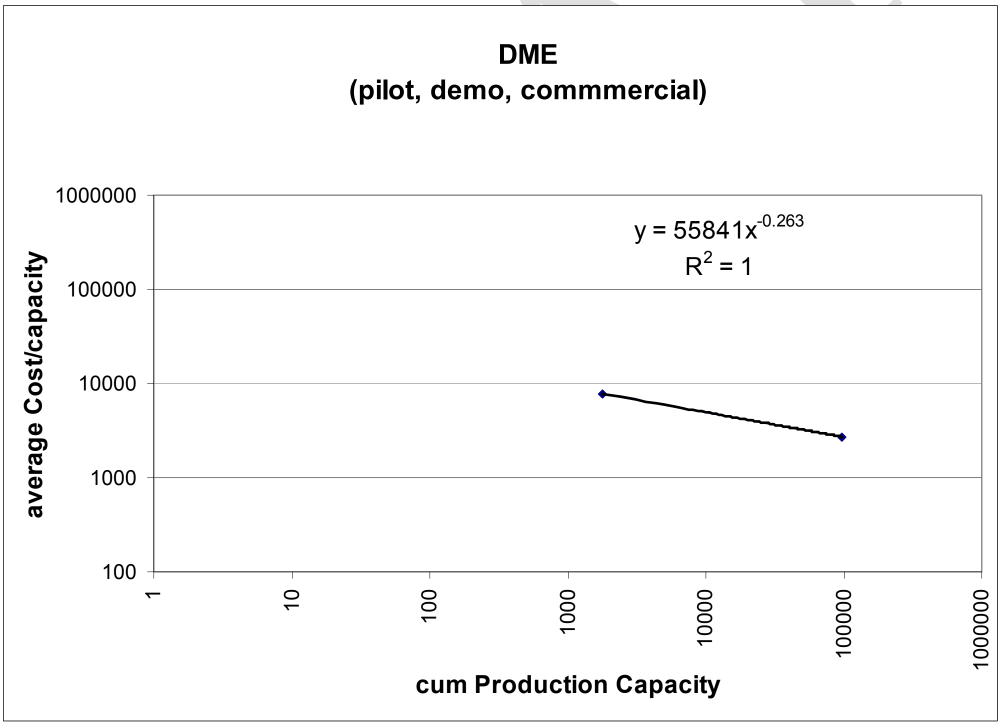


Figure 9: Learning curve for DME
Source: Own calculation based on data from IEA/OECD, biofueldigest, company information

However, estimating the factors that drive the learning of a given technology is a multi-dimensional problem (for wider discussion see Wiesenthal et al. 2010). In general, several factors like spillover effects, scaling, cost of material inputs and data availability incur some uncertainties. In this very specific estimation with the exception of ligno-cellulosic ethanol the number of data points is low and that the time series are rather short (2003-2014) to estimate a learning curve with three estimated parameters. Especially in the case of DME one might argue that the cost decrease most probably rather reflect scale effects than learning effects as we have here only two data points which differ significantly in the capacity of the DME plants. Furthermore, the investments in pilot plants form only one part of the RD investment. E.g. RD investment undertaken at universities undertaken with public funding are not considered. In addition, some of the cost information refers to biofuel production plants which are under construction and cost figures might change until the construction is finished.

Table 3: Overview on learning rates for biofuels

Measure	Learning rate	Dependent variable	Independent variable	Area	Source
Bioethanol	0.13 – 0.22	Sales price	Cumulative production	Brazil, USA (1975 – 2005)	Goldemberg (1996), Van den Wall Bake (2009), Hettinga (2009), de Wit (2010)
	0.07			Brazil, (1980 – 1985)	Goldemberg (2004)
	0.29			Brazil, (1985 – 2002)	Goldemberg (2004
Biodiesel	0.10	Investment/ operating cost	Cumulative production	EU25 (1993 – 2004)	De Wit (2010)
Ligno-cellulosic	0.10			assumption	IEA (2008)
	0.22	Investment cost	Cumulative production capacity (all plants)	World (2003 – 2014)	Own estimate
BTL	0.10			assumption	IEA (2008)
	0.09	Investment cost	Cumulative production capacity	World (2003 – 2014)	Own estimate
DME	0.17	Investment cost	Cumulative production capacity	World (2003 – 2014)	Own estimate
Biogas	0.12	Investment cost	Cumulative production capacity	Denmark (1984 – 2001)	Junginger (2006)
	0.15	Biogas production cost		(1984 – 1990)	
	0.00			(1991 – 2001)	

Source: Own calculation and various studies

However, the estimated are broadly in line with learning rates of other studies (see Table 3). Several studies investigated the learning rates of 1st generation bioethanol and biodiesel which were in the range of 0.07 to 0.29, the learning rates for bioethanol being at the higher end of the range.

With respect to 2nd generation biofuels, the IEA assumed learning rates of 0.10 for ligno-cellulosic ethanol and BTL. Junginger (2006) derived learning rates for biogas in the range of 0 and 0.15 depending on the time span and cost function.

As main outcome we receive learning rates for ligno-cellulosic ethanol and BTL of 0.22 and 0.09 respectively applying a One-Factor-Learning-Curve approach. The range of the learning rate is in line with the estimations and/or assumptions of other studies. The learning rate of ligno-cellulosic ethanol is higher than of BTL which is supported by the higher activity (number of projects) in this sector.

The implementation of learning leads to a new feedback loop. Feedback loop 8, which is a positive feedback loop, is illustrated in Figure 10. Rising biofuel production capacity leads to an increase of the cumulative production capacity, which in turn reduces the biofuel capital costs. Lower biofuel production cost lead to lower biofuel market prices and higher biofuel demand. Higher biofuel demand leads to an increase of biofuel production capacity.

Feedback loop 8 is reinforcing feedback. It means on one hand, ones a certain biofuel type overcomes market barriers and enters the market, it will further reduce its production cost and, therefore, will come into the market even stronger. On the other hand, it hints, that if a certain biofuel type doesn't enter the market, the production cost won't change and it might never enter the market. As most of the feedback loops were dampening the impact of the reinforcing feedback loop is limited.

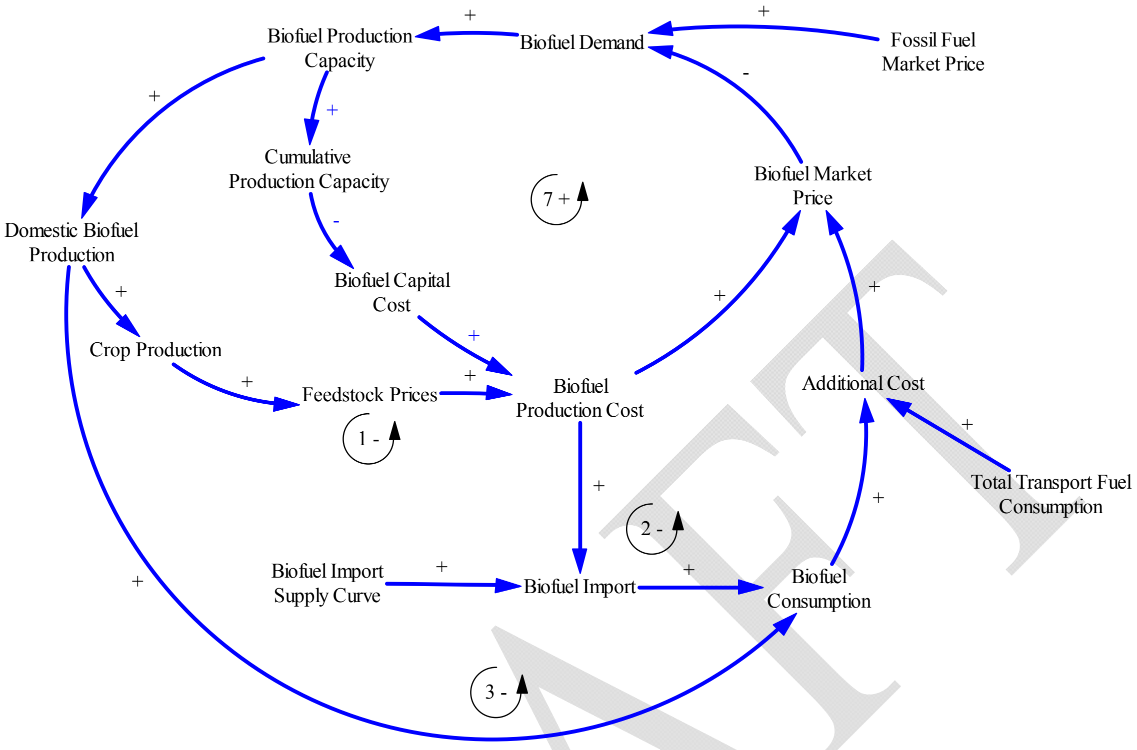


Figure 10: Implementation of learning rates

2.6. Interlinkages with other models

In GHG TransPoRD BIOPOL was applied together with a set of models. During the simulation BIOPOL was interlinked with the energy model POLES and the transport model ASTRA. ASTRA (Assessment of Transport Strategies) is applied for Integrated Assessment of policy strategies. The model is implemented as System Dynamics model. The ASTRA model has been developed and applied in a sequence of European research and consultancy projects for more than 10 years now by three Institutions: Fraunhofer-ISI, IWW and TRT. Applications included analysis of transport policy (e.g. TIPMAC, TRIAS), climate policy (e.g. ADAM project) or renewables policy (e.g. Employ-RES project). The ASTRA model consists of nine modules that are all implemented within one Vensim© system dynamics software file.

The POLES (Prospective Outlook for the Long term Energy System) model is a global sectoral simulation model for the development of energy scenarios until 2050. POLES has been developed and applied in a variety of EU projects, e.g. the WETO, WETO-H2, TRIAS, HOP! and GRP project. The dynamics of the model is based on a recursive (year by year) simulation process of energy demand and supply with lagged adjustments to prices and a feedback loop through international energy price.

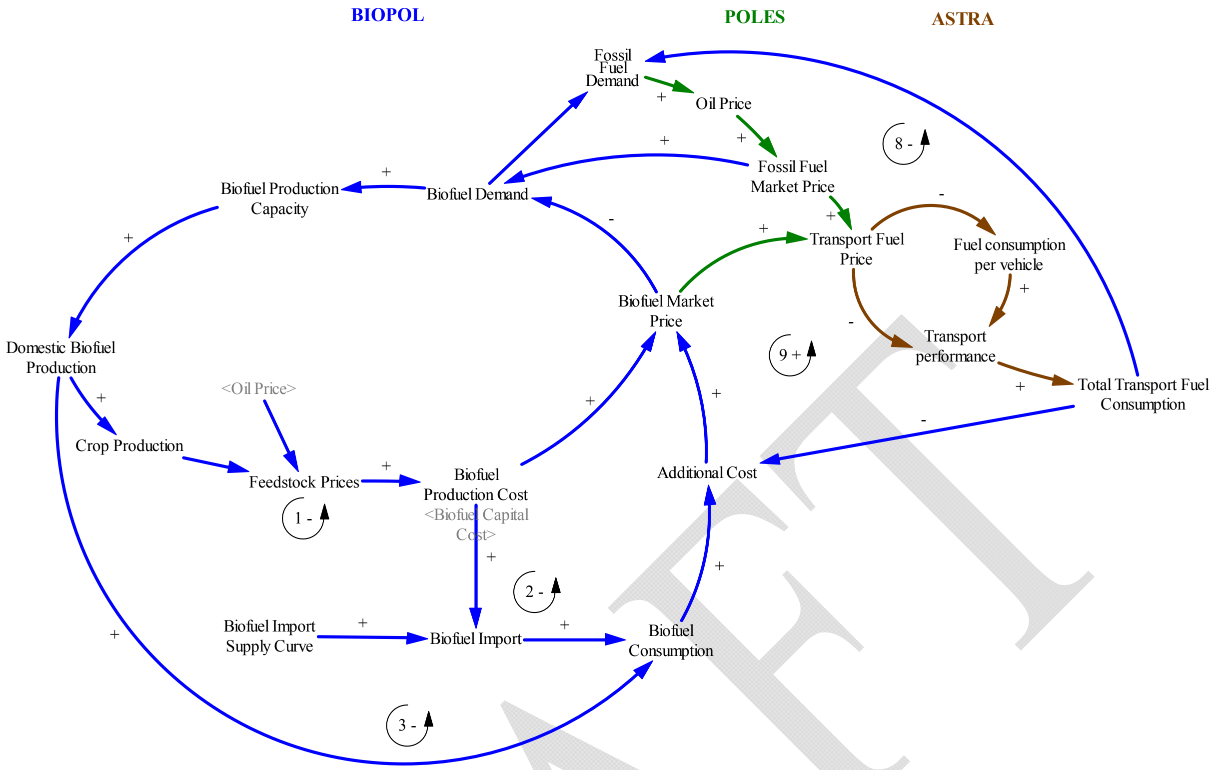


Figure 11: Feedback loops including linkages between the models BioPOL, POLES and ASTRA

The connection establishes a feedback (8) on the oil price (determined in POLES) and the transport fuel consumption (determined in ASTRA). Rising biofuel demand reduces fossil fuel demand, which in turn reduces oil prices and transport fuel demand including fossil fuel and biofuel demand.

A positive feedback loop (9) is established related to the additional costs (vehicle adaptation) by linking the models. Rising biofuel market prices lead to higher transport prices and to a lower transport performance and lower transport fuel demand. This affects the biofuel share and the increases the blending of biofuels in transport fuel, which has an impact on the required vehicle adaptations to run transport vehicles with higher blends.

Both, POLES and ASTRA, contain a number of further feedback loops like e.g. on the biomass potential, which are not further described in this article.

3. SCENARIOS

3.1. Reference Scenario

The Reference Scenario is the scenario against which the GHG emission reduction scenarios were tested in GHG TransPoRD. The Reference Scenario includes assumptions about exogenous trends (e.g. economic growth) but also about the endogenous variables in GHG-TransPoRD such as e.g. transport demand, energy supply and demand, transport emissions. Furthermore, the reference scenario includes some transport policies.

The GHG-TransPoRD Reference Scenario is based on two main sources:

- Until 2030 the Reference Scenario is taken from the PRIMES as defined in the document "EU energy trends to 2030 — UPDATE 2009" (EC, 2010). This reference scenario is the one used for assessment of the White Paper of the European Commission
- From 2030 to 2050 the Reference Scenario is extended using the ADAM reference scenario.

Despite the PRIMES reference scenario can be considered a sort of forecasting exercise trying to anticipate a possible future, the role of the GHG-TransPoRD Reference Scenario is just to provide a benchmark. It does not imply any strong belief on the future development of the economy or of the transport demand or of the energy sector.

3.1.1. Socioeconomic assumptions in the Reference Scenario

The PRIMES reference scenario assumes that the economic crisis has long lasting effects leading to a permanent loss in GDP. At the same time, while the average EU-27 growth rate for the period 2000-2010 is only 1.2% per year, the projected rate for 2010-2020 is recovering to 2.2%, similar to the historical average growth rate between 1990 and 2000. This assumption is challenged by the economic trend registered in 2010 and 2011. Short term forecasts (e.g. OECD 2011) for the incoming years are also quite below 2% per year. Therefore, the PRIMES scenario can be considered on the optimistic side. Between 2020-2030 the growth rate is slightly reduced to about 2% per year. Between 2030 and 2050 the growth rate, taken from the ADAM reference scenario, is further lowered to 1.8%.

The population projections for EU27 are based on the EUROPOP2008 convergence scenario (EUROpean POpulation Projections, base year 2008) from Eurostat. The demographic projection includes a dynamic immigration trend which helps keeping positive growth rates but is not sufficient to sustain higher growth. Both total population and active population are assumed to grow at positive, albeit very low, growth rates over the entire projection period; this contrasts past scenarios.

The assumptions concerning the energy prices trend was taken from POLES rather than from the PRIMES scenario (also to get a consistent picture until 2050), however the two projections are quite similar until 2030 as far as oil price is concerned. There is a general consensus among the experts that the rise of energy prices should be regarded as a structural condition due to the foreseeable trend of demand and supply. The rising demand from fast developing regions and uncertainty about the future availability of cheap resources suggest that crude oil prices will not fall back to the low levels observed before 2007. It was therefore assumed that they rise from present prices and then remain at high levels at around 80 €2005/bbl in 2020, almost 90 €2005/bbl in 2030 and nearly 110 €2005/bbl in 2050. Gas prices are assumed to increase in a similar pattern but at a slower pace, reflecting the dynamics of the inter-fuel competition and the rising supply costs. Coal prices increase by only one third due to the ample reserves.

3.1.2. Policy content of the Reference Scenario

The PRIMES reference scenario includes assumptions on the policy content. Measures implemented in the Member States by April 2009 and legislative provisions adopted by April 2009 that are defined in such a way that there is almost no uncertainty how they should be implemented in the future are within this scenario. As far as the transport sector is concerned, the main measures considered are:

- Regulation on CO2 from cars 2009/443/EC (binding CO2 emission targets for cars: 135 g CO2/km in 2015; 115 g CO2/km in 2020; 95 g CO2/km in 2025).
- Labelling regulation for tyres 2009/1222/EC
- Regulation Euro VI for heavy duty vehicles 2009/595/EC
- RES directive 2009/28/EC on the promotion of the use of energy from renewable sources; 10% target for renewables in transport is achieved for EU27

With respect to biofuels we considered the Communication from the Commission on the practical implementation of the EU biofuels, which sets minimum GHG emission savings for biofuels (EC 2010). The communication requires a greenhouse gas emission saving of 35 % (rising to 50 % in January 2017, and 60 % in January 2018 for installations in which production started from 2017 onwards). It is assumed that biofuel plants will be replaced successively after a lifetime of 12 years. This means that after 2030 all biofuel plants will fulfill the greenhouse gas emission savings of 60%.

3.1.3. Reference trends for endogenous variables

The Reference Scenario includes forecasts for several variables which are endogenous in GHG-TransPoRD, e.g. transport demand, energy consumption in the transport sector and transport emissions. For these variables the Reference Scenario is actually a reference, i.e. a comparison term for the modelling results. Therefore models calibration was revised to be consistent with the reference trends before to apply policy input.

Table 4 summarises the key trends of the Reference Scenario. In PRIMES transport demand is expected to growth until the year 2030 but less than the GDP. Passenger and freight are expected to have a very similar trend. In the ADAM projections, after 2030 passenger demand is expected to decline slightly (at least partially for demographic reasons) while freight traffic should continue its growth although at slower pace. The energy consumption in the transport sector is stagnating for the whole period, while CO2 emissions from transport are expected to decrease slowly until 2030 and restart a slight increase beyond that time. The transport sector should perform worse than other sectors in terms of emissions reductions as in overall terms the PRIMES scenario assumes that CO2 emissions are reduced faster (even if not so fast in absolute terms).

Table 4: Summary of key trends of endogenous variables in the reference scenario

Variable	**Average growth rates per year (%)**	
	2010-2030	**2030-2050**
Passengers-km	1.2	-0.2
Tonnes-km (maritime excluded)	1.3	1.0
Energy demand (transport)	0.1	0.0
CO_2 Emissions (transport, tank to wheel))	-0.2	0.2
CO2 Emissions (total)	-0.8	

Source: EU energy trends to 2030 — UPDATE 2009, ADAM project

In summary, in the Reference Scenario the transport sector is very far from any emissions reduction target. Despite some gains in energy efficiency, which allows stopping the growth of transport energy demand, CO2 emissions in the year 2050 are above the 1990 level.

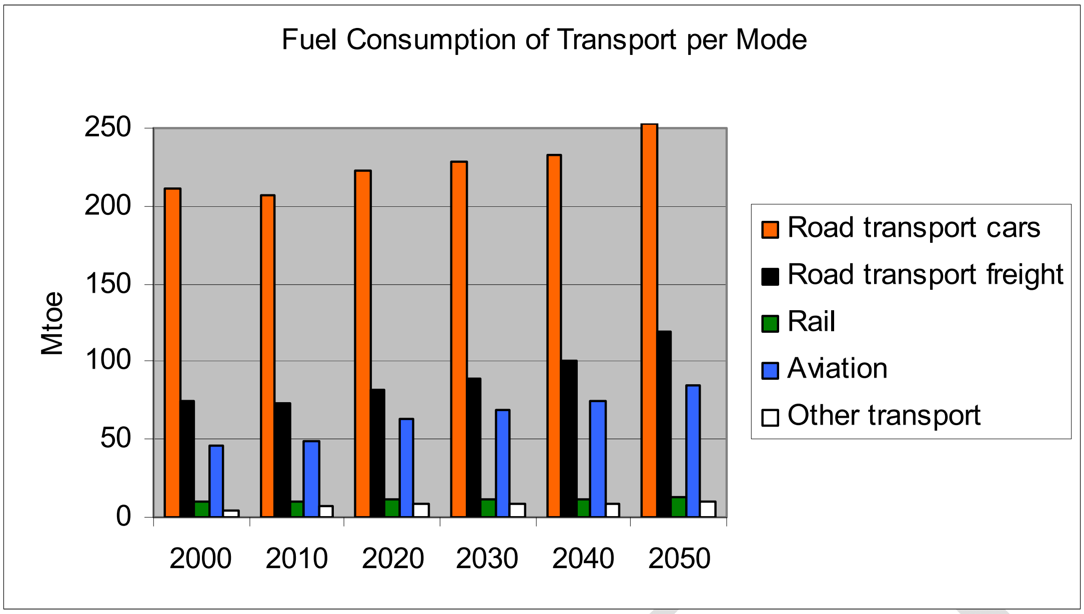
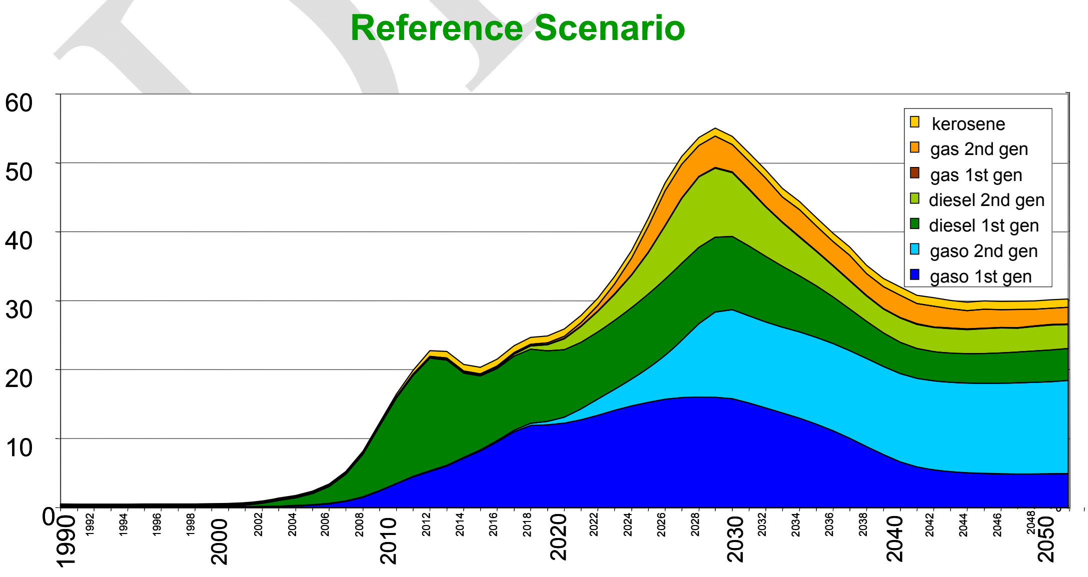


Figure 12: Fuel consumption per transport mode

With respect to fuel consumption, we identified strong growth of fuel consumption for aviation and road freight, while only moderate growth is projected for road passenger and rail transport.

3.1.4. Biofuel production, consumption and share

The biofuel consumption is expected to increase over time reaching a share of somewhat 7.5% in 2020. From the beginning until 2015 biodiesel is expected to have the highest share in biofuel consumption, while bioethanol is becoming the dominant biofuel afterwards. 2nd generation biofuels enter the market around 2020. 1st generation bioethanol reaches the highest share of biofuels in 2030 and declines thereafter. After 2030 2nd generation bioethanol reaches the highest share and keeps its level until 2050. The highest peak in the biofuel production is around 2030, due to the required GHG emission reductions savings of 60%. It is assumed that biofuel plants will be replaced successively after a lifetime of 12 years. This means that after 2030 all biofuel plants will fulfill the greenhouse gas emission savings of 60%.



Source: GHG transPoRD, BIOPOL

Figure 13: Biofuel consumption in the reference scenario *Source*: GHG TransPoRD

3.2. GHG emission reduction scenarios

Each scenario consists of a different bundle of measures, either technological or policies or both. When packages of policies are defined, two main approaches can be used. One approach is to select measures according to some criteria (e.g. by transport mode, by technological content, etc.) and then measuring their impact. An alternative approach is to set impact targets and put together measures potentially capable to meet the targets. This second approach – backcasting approach – has been followed in GHG-TransPoRD.

Ambitious greenhouse gas reduction targets have been the guiding principle as this is in line with the higher policy framework (e.g. the White Paper mentioning a 60% reduction as a goal of European policy). Among all the measures analysed in the previous packages, the selection has been made based on their effectiveness (potential amount of reduction provided) and efficiency (potential abatement cost per tonne).

A first set of scenarios has been defined to make initial modelling simulations and analyse the forecasted impacts in comparison to theoretical potential and abatement costs appraised previously. Three main scenarios have been considered in this initial phase. The first was a "Maximum Technology" scenario where basically all the technological measures are included. The second scenario picked up a selection of technical measures which, according to the estimated potential, are able to reduce greenhouse gas emissions by 60% at the horizon of the year 2050. The third scenario added some policy measures – both universal and urban ones – still aiming at the same reduction targets.

The results of the simulation of such scenarios and their discussion with stakeholder in a public workshop provided some useful indications, namely:

- Most of the technological instruments initially selected are needed to meet or get close to emissions reduction targets.
- Market penetration of innovative vehicles can be crowded out by efficiency improvements of conventional vehicles.
- A noticeable rebound effect on transport demand can be expected as result of significantly more energy-efficient vehicles.
- Ambitious targets for renewable energy sources are needed in addition to emissions reduction targets.
- Policy measures should be very strong to be effective and should change behavioural habits.

These indications have been used to define the final set of scenarios for the techno-economic assessment in WP4:

a) MAX_E&M: Maximum Efficiency at Market conditions. This scenario includes most of the technological measures for all modes, including both conventional and innovative cars. Neither the latter nor biofuels are supported by dedicated policy to promote their penetration in the market.
b) EV: Electric Vehicles. In this scenario the technological effort is concentrated on Electric Vehicles (although some technological development is assumed also for conventional road vehicles and other modes). Furthermore, additional supporting policies for Electric Vehicles (e.g. feebate schemes) are supposed to be in place to promote the diffusion of Electric vehicles.
c) HFC: Hydrogen Fuel Cells vehicles. This scenario follows the same approach of the EV scenario, but the technological effort and the supporting policies is concentrated on Hydrogen Fuel Cell vehicles.
d) EV+HFC. This scenario is the combination of the EV and HFC scenarios. In particular, supporting policies do not select in advance one of the two technologies, but are applied to promote both (roughly with the same amount of resources split between the two).

e) AMB_TP: Ambitious Technology and Policy. This scenario shares the same technological measures as in the MAX_E&M scenario plus the additional supporting policies for Electric and Hydrogen Fuel Cells vehicles. Additionally other policy instruments are assumed at urban and universal level (including urban charges, promotion of walking and cycling, promotion of efficient logistics. Last but not least, a huge increase of fuel taxation (on average up to +200% with respect to 2010 value) is assumed in order to contrast demand rebound effect and offset fuel taxation revenues loss determined by more efficient vehicles.

Table 5 provides a summary of the scenarios and of their content.

Table 5: Summary of scenarios tested by GHG-TransPoRD

Policy bundles	**MAX_E&M**	**EV**	**HFC**	**EV+HFC**	**AMB_TP**
Technologies					
Conventional road	X	x	x	x	X
Electric vehicles	X	X		X	X
Fuel cells vehicles	X		X	X	X
Non road	X	x	x	x	X
Policies					
Universal					X
Urban					X
Support innovative vehicles		X	X	X	X
Drastic fuel taxes				X	X
Biofuels	X	X	X	X	X
Renewables	X	X	X	X	X

With respect to biofuels only a specific set of biofuels are supported by investment programs. The choice of the biofuels being supported depends on the definition of the scenario. In the scenarios with fuel cell vehicles, biogas production is supported

Table 6: Biofuel policies in the GHG emission reduction scenarios of GHG-TransPoRD

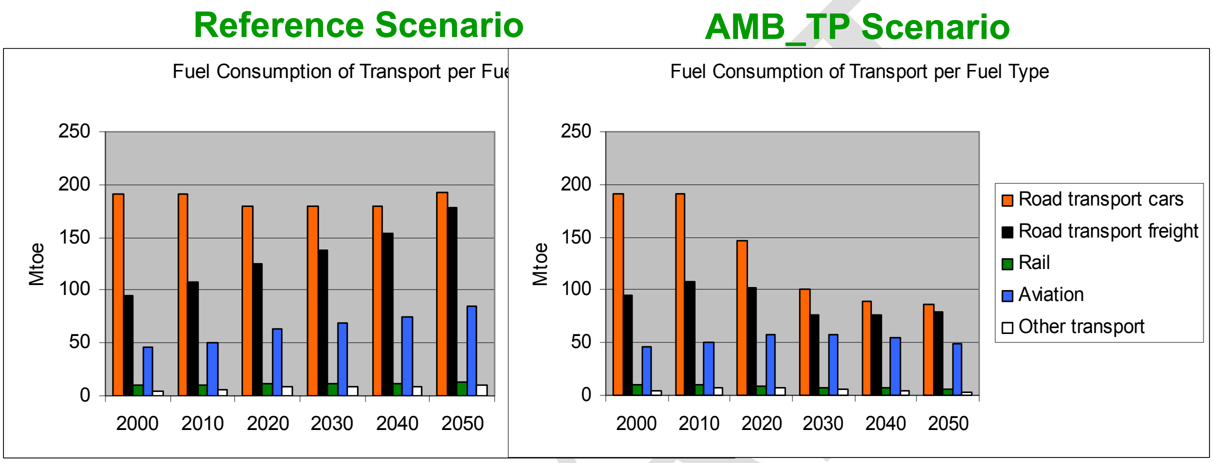
Policy bundles	**MAX_E&M**	**EV**	**HFC**	**EV+HFC**	**AMB_TP**
Biofuel technologies					
Biogas			X	X	X
BTL		X		X	X
HVO		X		X	X

4. RESULTS

The section on results is separated in a comparison of results where we compared the reference scenario with a specific GHG emission scenario and section in which we compare all scenarios. For the specific comparison we have chosen the AMB_TP scenario out of the GHG emission scenarios.

4.1. Transport energy demand in the Reference and AMB_TP scenarios

In the GHG scenarios we derive a break in trend for the energy demand of road passenger transport and road freight transport. After a strong reduction until 2030 the development of energy demand remains stable around 125 mtoe and 40 mtoe respectively. Energy demand of aviation is curbed and remains at a level of 50 mtoe, while it was experiencing strong growth in the reference scenario. Energy demand of rail transport is quite similar in all scenarios.


Reference Scenario

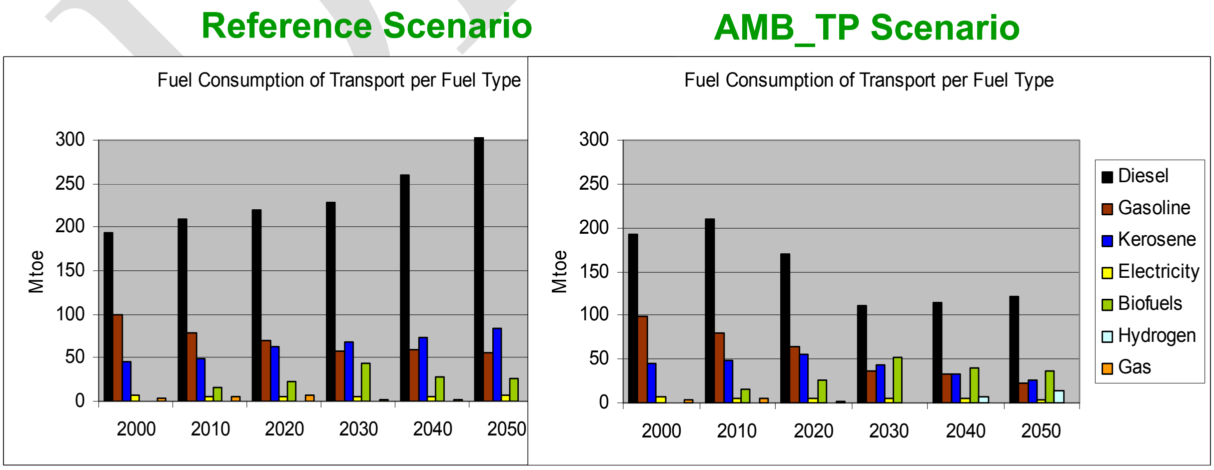
AMB_TP Scenario

Source: GHG TransPoRD

Figure 14: Fuel consumption per transport mode

4.2. Fuel consumption in the Reference and the AMB_TP scenario

This affects of course the development of fuel consumption. While we were determining a strong increase of diesel consumption in the reference scenario, diesel consumption remains at a level of around 100 mtoe. Gasoline consumption drops to around 25 mtoe, while we derive an increase of hydrogen consumption to about 20 mtoe.

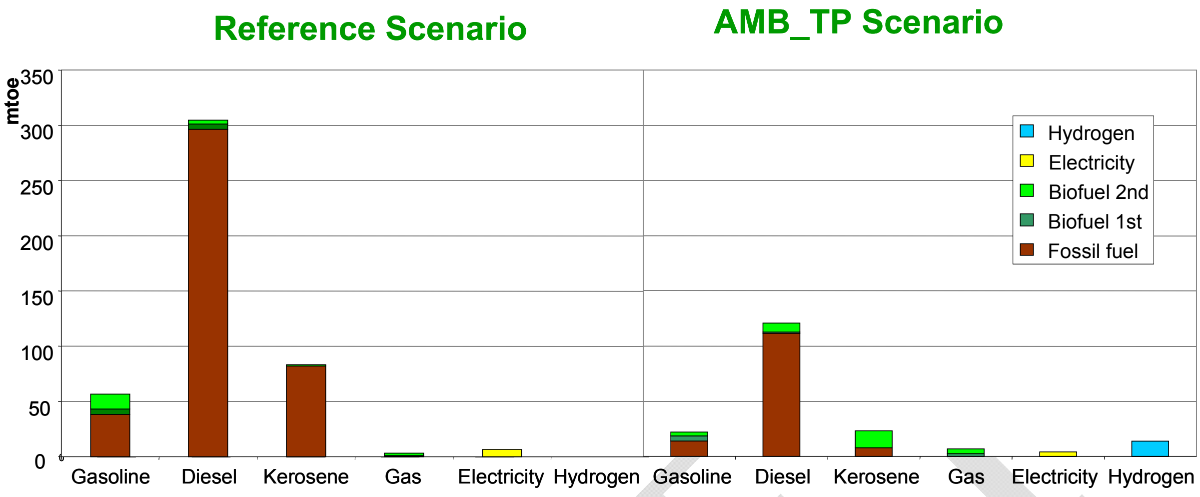

Reference Scenario

AMB_TP Scenario

Source: GHG TransPoRD

Figure 15: Fuel consumption per Fuel Type

If we assign the biofuels to the fuel types they are blended with we receive Figure 16. While we have in the reference scenario in 2050 mostly bioethanol, there is almost no bio-kerosene and only very little biodiesel.



Source: GHG TransPoRD

Figure 16: Fuel consumption with biofuel blends in 2050

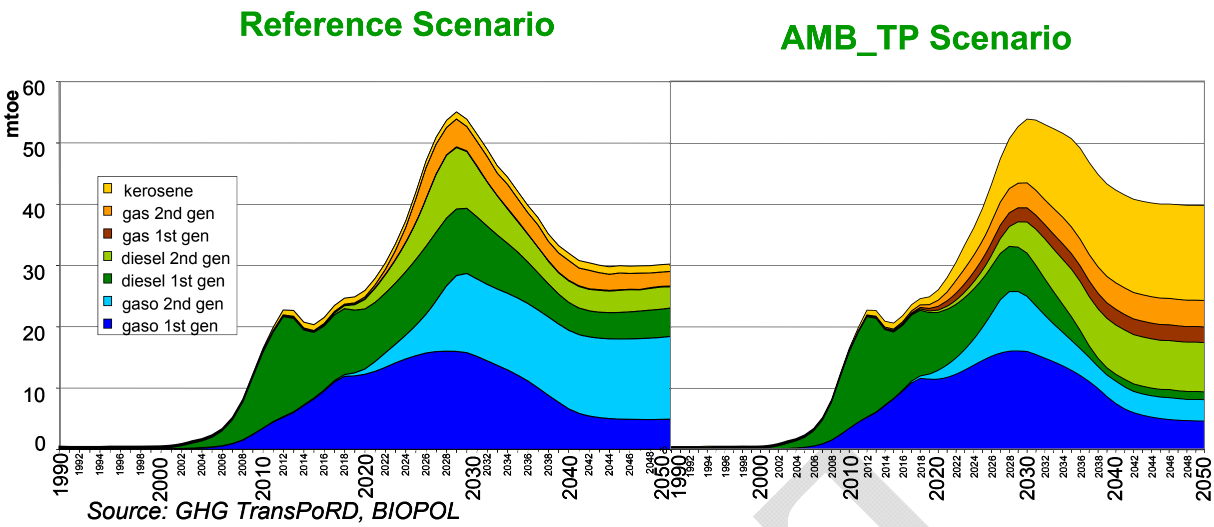
The picture is completely different for the AMB_TP scenario. The share of bioethanol and of biogas is limited by the blending limits of vehicles 20% for gasoline; 80% for gas). In principle, it would be possible to produce more bioethanol and biogas at competitive costs, but the limitation is here on the demand side.

For biodiesel and bio-kerosene we have a different picture. Both only marginally entered the market in the reference scenario. And as they didn't enter the market, they also didn't experience strong cost reductions due to learning. But in the AMB_TP scenario they received an investment incentive at the beginning of the simulation. Based on this they enter the market and experience cost reductions which pushes them further into the market until higher biodiesel and bio-kerosene demand lead to an increase of feedstock costs. The rise in feedstock cost limits the further market diffusion of biodiesel and bio-kerosene. Both could be used with higher blends: for biodiesel in passenger cars we assume a blending of 7% and for trucks with 20%. In aviation the blending could be significant higher at about 80%.

From this result we derive that bioethanol and biogas is limited from the demand side, while biodiesel and bio-kerosene are limited from the supply side.

4.3. 1st and 2nd generation biofuels in the reference and the AMB_TP scenario

Figure 17 provides a more detailed view on the development of specific biofuel pathways (see description of reference scenario in 3.1.4). It shows that until 2020 the most important biofuels are the 1st generation biofuels. Biodiesel reaches its peak before 2015 and remains at this level, while bioethanol picks up fast until 2020, followed by a lower increase until 2030. 2nd generation biodiesel, bioethanol and biogas enter the market around 2020 in both scenarios. Overall biofuel consumption reaches its peak at around 2030, but the biofuel consumption decreases thereafter due to the requirements of a certain level of GHG emission savings.



Source: GHG TransPoRD, BIOPOL

Figure 17: 1st and 2nd generation biofuels in the reference and the AMB_TP scenario

However, Figure 17 reveals also a number of differences: overall biofuel consumption remains on a level of around 40 mtoe (AMB_TP) instead of 30 mtoe (reference). The biofuel consumption of 2^{nd} generation biodiesel and biokerosene is much higher in the AMB_TP scenario, while 2^{nd} generation bioethanol is much lower. The main reason for this is that the reduction of gasoline demand limits the consumption of 2^{nd} generation bioethanol. Diesel demand remains at quite high levels and as in AMB_TP bio-kerosene and 2^{nd} generation biodiesel are fostered they enter the market and substitute diesel and kerosene. Furthermore, the AMB_TP scenario reaches a higher level of 1^{st} and 2^{nd} generation biogas due to the fact that in AMB_TP more gas vehicles diffuse into the market. In combination with the support of biogas this leads to an elevated level of biogas consumption.

4.4. Overview on all GHG emission reduction scenarios

The comparison of the final energy demand per transport sector reveals that there are only minor differences between the scenarios in the year 2020. In 2030, substantial differences between the reference and the GHG emission reduction scenarios emerge. In the reference scenario the overall final demand is around 480 mtoe. In the set of GHG emission reduction scenarios with only technical measures, the final demand ranges between 260 and 340 mtoe. If further policies are applied, the final energy demand could decrease to 180-220 mtoe.
Looking at the variation in consumption of different fuel types, the finding are that electricity and hydrogen differ strongly between the scenarios as some of the scenarios bring electric vehicles or hydrogen vehicles strongly in to the market. In contrast to this the biofuel consumption looks rather similar and stays within a range of 26 to 37 mtoe. However, the Table 7 has to be interpreted with care, when discussing the results on diesel, gasoline and kerosene. The indicated energy demand for diesel, gasoline, gas and kerosene refers to pure amount of these fuel types and does not reflect any blending. This means, to give a correct picture biofuels have to be split into bioethanol, biodiesel, biogas and biokerosene and to be added on the fossil fuel demand they refer to.

Table 7: Final energy demand in the reference scenario and the GHG emission reduction scenarios (source: POLES)

Final energy demand… [mtoe]	REF	MAX_ E&M	EV	HFC	EV+HFC	AMB_TP	AMB REG	REF	MAX_ E&M	EV	HFC	EV+HFC	AMB_TP	AMB REG

	2020							2050						
…per fuel	388	329	365	374	365	322	320	478	265	313	340	297	224	185
Diesel	219	178	205	209	203	170	168	305	152	196	169	131	121	44
Gasoline	70	65	69	73	72	64	63	57	23	28	21	16	22	8
Kerosene	62	56	55	56	55	55	55	83	45	25	47	25	26	26
Electricity	5	5	8	5	7	5	6	6	4	21	6	16	4	23
Biofuels	23	21	24	23	26	25	25	26	31	35	33	35	37	32
Hydrogen	0	0	0	0	0	0	0	0	9	6	63	74	14	51
Gas	7	4	4	7	2	2	2	1	1	2	1	0	0	0
…by mean	388	329	365	374	365	322	320	478	265	313	340	297	224	185
Road transport cars	180	151	171	176	171	146	145	193	109	129	142	120	86	65
Road transport freight	125	105	119	123	119	102	101	178	100	119	131	111	80	60
Rail	11	8	9	10	10	9	9	13	6	10	10	10	6	7
Aviation	63	57	57	57	57	57	57	84	47	47	48	48	49	49
Other transport	8	8	8	8	9	8	8	9	3	8	8	8	3	3

Table 8 illustrates the biofuel consumption per biofuel type. While in 2020 overall biofuel consumption and consumption per biofuel type is quite similar, the picture changes when looking at different biofuel types in 2050.

The main difference between the scenarios is whether 2nd generation biodiesel and bio-kerosene enters the market or not. If these two biofuel types enter the market and become competitive then they might reach together a level of around 23 mtoe or around 2/3 of the overall biofuel consumption. In those scenarios the 2nd generation bioethanol consumption is reduced as 2nd generation biodiesel and bioethanol are produced with the same feedstock.

A high variation of biofuel consumption can be identified for biogas. Main important factor for the variation of biogas is the diffusion of gas vehicles into the market.

The avoided GHG emission reduction could be in the range of 80 to 110 mt CO2 eq. The avoided GHG emission considers the GHG emission savings per biofuel type, but do not take into account the effects of indirect land use changes (see discussion in section 2.4).

Table 8: Comparison of biofuel consumption per biofuel type in the reference scenario and the GHG emission reduction scenarios (source: BioPOL)

Biofuel consumption [mtoe]	REF	MAX_ E&M	EV	HFC	EV+HFC	AMB_TP	AMB REG	REF	MAX_ E&M	EV	HFC	EV+HFC	AMB_TP	AMB REG
	2020							2050						
1st gen bioethanol	12	11	11	11	12	12	12	5	6	5	6	5	5	5
2nd gen bioethanol	1	1	2	1	2	1	1	13	15	5	12	4	3	4
1st gen biodiesel	10	9	9	9	10	9	9	5	5	1	5	1	1	1
2nd gen biodiesel	0	0	0	0	0	0	0	0	0	8	0	8	8	8
Biokerosene	1	1	2	1	2	2	2	1	2	15	2	15	15	15
1st gen	0	0	0	1	1	1	1	0	0	2	3	1	2	0

biogas														
2nd gen biogas	0	0	0	1	1	1	1	2	4	0	6	2	3	0
Biofuels	24	22	25	24	27	26	26	27	32	36	34	36	38	34
Avoided CO2 emission [mt CO2eq]	53	48	58	55	63	61	61	77	90	111	102	103	109	93

5. CONCLUSIONS

The paper described the model BioPOL, a set of scenarios that were developed and their results with respect to energy demand, fuel consumption and biofuel consumption per biofuel type.

The BioPOL model is a recursive dynamic model that is constructed in the VENSIM modelling platform. It is based on a year-by-year simulation of biofuel production, production cost and biofuel demand until 2030. The model delivers detailed outcomes for the types of biofuels considered with regard to production capacity and produced volumes, costs and well-to-wheel emissions of greenhouse gases. The description of the BioPOL model focuses on the feedback structure were we identified seven feedbackloops, three of them with a mayor impact on the development of biofuel production and consumption.

An important issue of BioPOL is the improved way in which learning for 2nd generation is considered. Based on a database on biofuel plants learning rates for 2nd generation biofuels (Ligno-cellulosic ethanol, BTL, DME) were estimated. The resulting learning rates are considered in the BioPOL model, which means that the cumulative production of 2nd generation bioethanol, biodiesel, biogas and HVO affects their production costs. The decrease of capital cost due to learning leads to a further increase of these biofuel types and shifts their consumption on a higher level.

A Reference Scenario has been developed. It is the scenario against which the GHG emission reduction scenarios were tested in GHG TransPoRD. The Reference Scenario includes assumptions about exogenous trends (e.g. economic growth) but also about the endogenous variables in GHG-TransPoRD such as e.g. transport demand, energy supply and demand, transport emissions. Furthermore, the reference scenario includes some transport policies.

A set of GHG emission reduction scenarios were developed varying the technical measures to reduce GHG emissions. The technical measures refer to all transport modes including new vehicle technologies like electric vehicles and hydrogen vehicles. In addition, different biofuel types were pushed into the market according to the definition of the GHG emission reduction scenarios.

As result we derive a break in trend for the energy demand of road passenger transport and road freight transport. After a strong reduction until 2030 the development of energy demand remains stable around 125 mtoe and 40 mtoe respectively. Energy demand of aviation is curbed and remains at a level of 50 mtoe, while it was experiencing strong growth in the reference scenario.

With respect to fuel types we identify an increase of alternative fuel types like hydrogen depending on the definition of the scenarios. For biofuels we derive that overall biofuel consumption and consumption per biofuel type is quite similar in 2020, but the picture changes when looking at different biofuel types in 2050.

The main difference between the scenarios is whether 2nd generation biodiesel and bio-kerosene enters the market or not. If these two biofuel types enter the market and become competitive then they might reach together a level of around 23 mtoe or around 2/3 of the overall biofuel consumption. In those scenarios the 2nd generation bioethanol consumption is reduced as 2nd generation biodiesel and bioethanol are produced with the same feedstock.

A high variation of biofuel consumption can be identified for biogas. Main important factor for the variation of biogas is the diffusion of gas vehicles into the market.

The avoided GHG emission reduction could be in the range of 80 to 110 mt CO2 eq. The avoided GHG emission considers the GHG emission savings per biofuel type, but do not take into account the effects of indirect land use changes.

One of the outcomes is that bioethanol and biogas is limited by the blending limits of vehicles (20% for gasoline; 80% for gas). In principle, it would be possible to produce more bioethanol and biogas at competitive costs, but the limitation is here on the demand side. In contrast to this, higher biodiesel and bio-kerosene demand lead to an increase of feedstock costs. The rise in feedstock cost limits the further market diffusion of biodiesel and bio-kerosene. Both could be used with higher blends in road fright transport and aviation. From this result we derive that bioethanol and biogas is limited from the demand side, while biodiesel and bio-kerosene are limited from the supply side.

6. REFERENCES

EC (2010): Communication from the Commission on the practical implementation of the EU biofuels and bioliquids sustainability scheme and on counting rules for biofuels. COM(2010/C 160/02).

EU (2003): Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport.

EU (2009): Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/ECber States' Reports in the frame of Directive 2003/30/EC, 2004, 2005 and 2006 reports.

EurObserv'ER (2008): Biofuels Barometer June 2008.

EurObserv'ER (2009): Biofuels Barometer July 2009.

IEA (2008a): Energy Technology Perspectives 2008. IEA/OECD, Paris.

IEA (2008b): From 1st to 2nd generation biofuel technologies. An Overview of current industry and RD&D activities. IEA and IEA Bioenergy. IEA/OECD, Paris.

JEC (JRC, EUCAR, CONCAWE) (2007): Well-to-Wheels analysis of future automotive fuels and powertrains in the European context WELL-TO-WHEELS Report Version 2c.

JEC (2008): Well-to-Wheels analysis of future automotive fuels and powertrains in the European context. WELL-TO-TANK Report Version 3.0 November 2009. WTT App.2 - Description and detailed energy and GHG balance of individual pathways

Resch, G., Ragwitz, M., Panzer, C., Faber, T., Toro, F., Held, A., Hass, R. (2009): Beyond 2020 - Characterization of Alternative Renewable Energy Scenarios for the EU. Final report of a project contracted by JRC IPTS. Unpublished.

Schade B., Casamassima, G., Fiorello, D., Martino, A., Schade W., Walz, R. (2007): High Oil Prices: Scenarios assumptions and model interfaces. Deliverable 2 of HOP! (Macro-economic impact of high oil price in Europe). Funded by European Commission 6th RTD Programme. Seville, Spain.

Schade, B., Wiesenthal, T. (2011): Biofuels: a model based assessment under uncertainty applying the Monte Carlo method. *Journal of Policy Modeling*, Vol. 33, No. 1, pp. 92-126.

Schade, W., Fiorello, D., Köhler, J., Krail, M., Martino, A., Schade, B., Wiesenthal, T. (2008): *Final Report of the TRIAS Project: SIA of Strategies Integrating Transport, Technology and EnergyScenarios*. Deliverable 5 of TRIAS. Funded by European Commission 6th RTD Programme. Karlsruhe.

Schade, W., Krail, M., Fiorello, D., Helfrich, N., Köhler, J., Kraft, M., Maurer, H., Meijeren, J., Newton, S., Purwanto, J., Schade, B., Szimba, E. (2010): *The iTREN-2030 Integrated Scenario until 2030*. Deliverable 5 of iTREN-2030. Project co-funded by European Commission 6th RTD Programme. Fraunhofer-ISI, Karlsruhe.

Wiesenthal, T., Leduc, G., Christidis, P., Schade, B., Pelkmans, L., Govaerts, L., Georgopoulos, P. (2009): Biofuel Support Policies in Europe: Lessons Learnt for the Long Way Ahead. Renewable and Sustainable Energy Reviews 13 (4); 2009, 789-800.