A SENSITIVITY-ANALYSIS TO INVESTIGATE THE IMPACTS OF OIL AND GAS RESOURCES ON THE ENERGY MARKET

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Abstract:

The aim of this paper is to investigate the impacts of oil and gas resources on the energy supply and demand. In general, energy scenarios about the future world energy system are based on set of broadly accepted assumptions as to, among others, the resources, future energy and environmental policies, energy prices, general macro-economic background, and the techno-economic development of energy technologies. Nevertheless considerable uncertainty remains on these hypotheses and may change the course of world energy development in the next decades.

With respect to resources especially the uncertainties connected to the availability of fossil fuels, namely gas and oil have been moved recently on the top of the political agenda. Therefore, a detailed analysis will be carried out on the impact of the resource estimates for conventional oil and gas. The goal of this analysis is to evaluate the sensitivity of the energy projection according to these uncertainties.

In this paper probabilistic distributions for oil and gas resources are applied to derive a set of scenarios. The probabilistic distributions base on the U.S. Geological Survey World Petroleum Assessment-2000 (USGS 2000). USGS assessment 2000 provides information on the amount of oil and gas recoverable resources and derives probabilistic distributions for certain parameters. These probabilistic distributions are applied on parameters of larger simulation models (like POLES).

The resulting applications enable to carry out a Monte-Carlo-approach. Instead of deriving a single scenario the model calculates a set of sensitivity runs. For each variable it is possible to determine certain significance intervals and different parameter of their distribution.

In the whole, this approach offers the possibility to investigate the relevance of oil and gas resources on the output of aggregated variables of the models.

* The views expressed are purely those of the author and may not in any circumstances be regarded as stating an official position of the European Commission.

1. Introduction

The aim of this paper is to investigate the impacts of oil and gas resources on the energy supply and demand, mainly on the oil price and its effects as well as on the biofuel market. In general, energy scenarios about the future world energy system are based on set of broadly accepted assumptions as to, among others, the resources, future energy and environmental policies, energy prices, general macro-economic background, and the techno-economic development of energy technologies. Nevertheless considerable uncertainty remains on these hypotheses and may change the course of world energy development in the next decades.

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In this paper the methodology to provide quantitative estimates of impacts of high oil prices on the EU-27 economy is described which was mainly developed in the TRIAS and the HOP! project. This analysis is based on an integrated modelling approach that combines the POLES model for the assessment of trends in worldwide energy supply and demand under various assumptions on oil prices, and the ASTRA model, which will be used to estimate the reactions of all economic sectors to high oil prices in the EU-27. The time horizon of the assessment is 2050.

The baseline scenario serves as projection with a moderate oil price which will later-on be used as a reference to which the scenarios with high oil prices are compared to. The baseline is not necessarily the most likely or the most probable development, but rather serves as a projection with more optimistic assumptions on oil resources which lead to a moderate increase of oil prices. Such slow increase allows a gradual adaptation of actors in economy and industry.

In the baseline, the level of conventional oil resources is based on the estimation of USGS 2000 (USGS, 2000), which estimates an amount of ultimate recoverable resources of oil, gas and natural gas liquefied (NGL) amounting to about 3000, 2500 and respectively 300 bboe in the year 2020. Nearly half of such recoverable resources consists of reserve growth and undiscovered resources.

In addition to conventional oil resources, the baseline also assumed that some unconventional oil will be necessary to meet the energy demand at time horizon 2020 and beyond. These comprise e.g. tar sands from Canada, heavy oil from Venezuela and oil shale mainly from the

United States. Tar sands are expected to contribute with the largest amount of unconventional oil in the near future, followed by heavy oil. The contribution of oil shale is expected to remain marginal until 2030 and might increase slightly until 2050 (WETO-H2, 2006).

Energy demand is driven by a number of factors, the most relevant including the development of population, economy, and transport. The development of population in EU Member States is expected to remain stable until 2030 and to decline afterwards. World population is expected to grow at a decreasing rate to 8.9 billions in 2050. After 2030, the population in several regions of the world is decreasing – including China.

The assumed development of GDP in the EU is taken from the European project ADAM (ADAM, 2007). GDP in Europe would nearly triple between 2000 and 2050, which is equivalent to an annual growth rate just above 2 %. GDP outside the EUis based on the projections of WETO-H2 (WETO-H2, 2006): the rate of economic growth in industrialised regions converges to less than 2% per year in the very long-run with growth in Asian emerging economies significantly falling after 2010 and significant acceleration in Africa and the Middle East. Exports and investments are expected to increase significantly stronger than GDP in Europe, reaching a quadrupling.

On the transport side, an increment of personal mobility is assumed throughout the EU. Air is expected to grow more than any other mode, doubling the total number of passengers-km at horizon of the year 2050. A high growth rate is also expected for private cars, while for rail a moderate growth is assumed. Still for Europe the baseline projects that in the year 2050 the amount of tonnes-km will be tripled with respect to the year 2000, with road transport growing faster than any other mode.

Despite stabilisation of the population, the car fleet continues to grow significantly. One major reason is the catching- up of the new EU member states joining the EU in the years 2004 and 2007 in terms of car-ownership. Innovative new diesel technologies led to an improved efficiency of diesel cars and are making them more and more attractive in the context of rising fuel prices. The number of diesel cars is assumed to reach the level of gasoline cars. Biofuel driven vehicles and natural gas vehicles would reach a market share between 5 and 15% around 2030.

Given these trends, primary energy consumption in Europe is expected to increase by around 40% between 2000 and 2050 (WETO-H2, 2006). It is assumed that oil and gas demand will increase until 2020 and will then decrease due to higher prices. Coal use and energy consumption that stem from renewables and nuclear energy are expected to rise instead. Also, the composition of final energy demand by sector is assumed to change: while for the residential sector (including service and agriculture sectors) a growth above 50% is expected between 2000 and 2050 (mainly driven by the growing need of electricity in houses), the increase in the transport and the industrial sector might be much smaller as the impact of increasing transport performance is limited by improvements in fuel efficiency.

The scenarios are used to explore the impact of high oil price. However, the oil price is not directly an exogenous assumption, but it is obtained as a result of other hypotheses concerning energy supply, technologies etc. Tests with the parameters of the model will be carried out in order to ensure that adequately high oil prices are simulated in each scenario.

To identify how high oil prices affect the energy system, the impacts of high oil prices on potential substitutes - and vice versa – have to be investigated.

With reference to conventional oil, the oil price affects the components of oil production cost: exploration (including depletion), production, extra costs (e.g. taxation). The main feedback is the increased investment in R&D and deployment of new technologies due to higher oil prices. In some cases the result might be that some of the oil fields become economically exploitable so that they can increase the oil supply and dampen the oil prices increase. The time delay in producing oil from new facilities should be considered: in upstream sector the times for new capacity can be between five-to-eight years.

As far as alternative sources are concerned, oil prices influence the level of deployment as long as they are directly linked to fossil fuel prices and influence production costs (e.g. for biofuels energy costs account for up to 15%). On the other end, due to high oil prices, alternative energy sources become more competitive in terms of relative prices. However, the time for the construction of the required infrastructure needs to be considered (e.g. production of biofuels could not be increased significantly in some weeks or some months; even if large amount of hydrogen could be produced it could not be distributed or used; even if nuclear energy would become relatively cheap, building new plants would need years, etc.).

For the resulting application, sensitivity runs are conducted varying the level of oil and gas resources and growth of GDP in India and China.

2. Method

The POLES model is a partial equilibrium energy model that can be used for the development of long-term (2050) energy supply and demand scenarios for the different regions of the world. The dynamics of the model correspond to a hierarchical system of interconnected modules and articulates three level of analysis:

- international energy markets;
- regional energy balances;
- national energy demand, new technologies, electricity production, primary energy production systems and CO2 sector emissions.

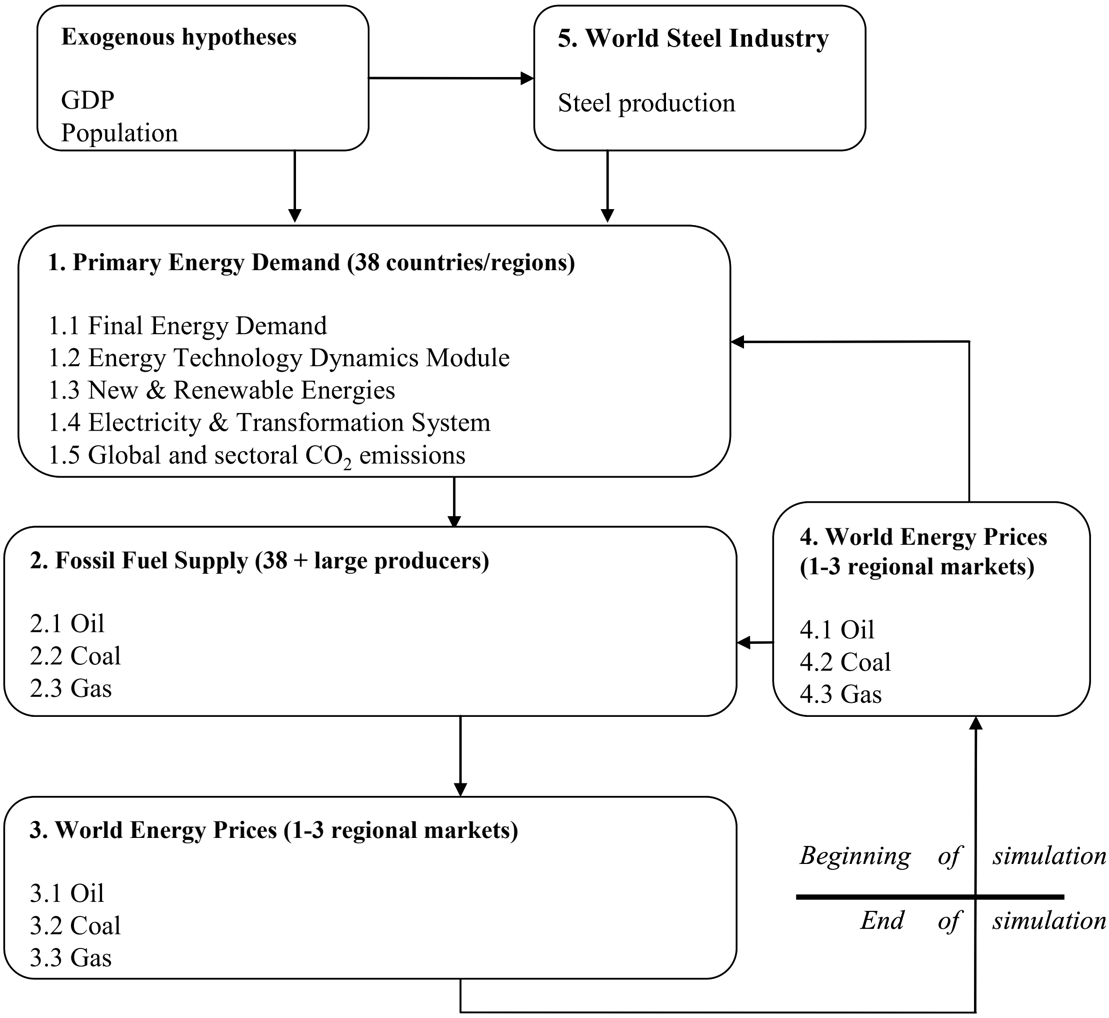
The main exogenous variables are the population and GDP (which are derived iteratively with ASTRA, see below), for each country / region, the price of energy being endogenised in the international energy market modules. The dynamics of the model corresponds to a recursive simulation process, common to most applied models of the international energy markets, in which energy demand and supply in each national / regional module respond with different lag structures to international prices variations in the preceding periods. In each module, behavioural equations take into account the combination of price effects and of techno-economic constraints, time lags or trends.

The ASTRA System Dynamics model has been developed since 1997 with the purpose of strategic assessment of policies in an integrated way i.e. by considering the feedback loops between the transport system and the economic system. The ASTRA model consists of nine modules linked together in manifold ways.

Given the strategic nature of ASTRA, the treatment of the economy is essentially at a macro level. However, some 'micro-economic' concepts are detailed with regard to the role of transport in the interaction with the economy. For instance, expenditures for fuel, revenues from fuel taxes and value-added-tax (VAT) on fuel consumption are transferred to the macroeconomics module and provide input to the economic sectors producing fuel products and to the government model. On the transport side, ASTRA provide a description of the 'supply-side' in terms of infrastructures and of vehicle technologies, while transport demand

is described in terms of aggregated OD-trip matrices and mode split. Additional modules use input from the transport and the economic variables in order to compute environmental effects (emissions from transport, accidents) and other social indicators.
The POLES model is a simulation model for the development of long-term (2050) energy supply and demand scenarios for the different regions of the world (Figure 1). The version of POLES which will be applied bases originally on the WETO-H2 project (WETO-H2, 2006) plus some updates and adaptations which were made within the TRIAS project.

Figure 1: POLES modules and simulation process



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Zoning system

In POLES, the world is divided into fourteen main regions: North America, Central America, South America, European Community, Rest of Western Europe, Former Soviet Union, Central Europe, North Africa, Middle-East, Africa South of Sahara, South Asia, South East Asia, Continental Asia, Pacific OECD.

In most of these regions the larger countries are identified and treated, as concerns energy demand, with a detailed model. In this version these countries are the G7 countries plus the countries of the rest of the European Union and five key developing countries: Mexico, Brazil, India, South Korea and China. The countries forming the rest of the 14 above-mentioned regions are dealt with more compact but homogeneous models.

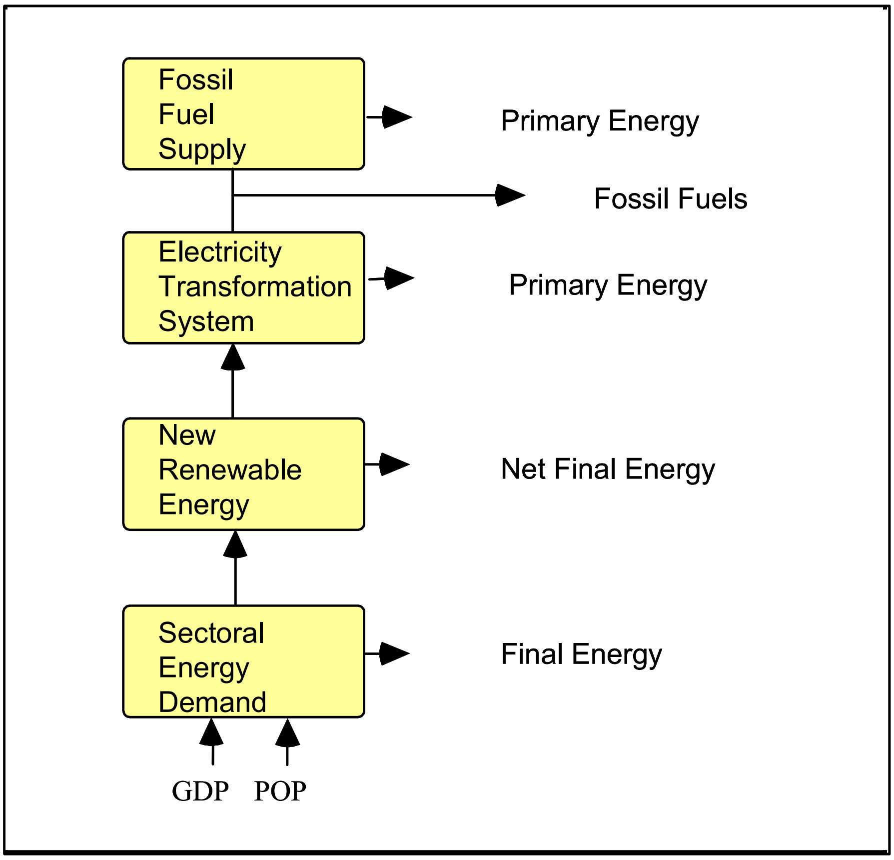
Vertical integration

For each region, the model articulates four main modules dealing with:

- Final Energy Demand by main sectors;
- New and Renewable Energy technologies;
- The Electricity and conventional energy and Transformation System;
- The Primary Energy Supply.

As indicated in Figure 2, this structure allows for the simulation of a complete energy balance for each region.

Figure 2: POLES vertical integration



Horizontal integration

While the simulation of the different energy balances allows for the calculation of import demand / export capacities by region, the horizontal integration is ensured in the energy markets module of which the main inputs are the import demands and export capacities of the different regions. Only one world market is considered for the oil market (the "one great pool" concept), while three regional markets (America, Europe, Asia) are distinguished for coal and gas, in order to take into account for different cost, market and technical structures.

According to the principle of recursive simulation, the comparison of imports and exports capacities for each market allows for the determination of the variation of the price for the following period of the model. Combined with the different lag structure of demand and supply in the regional modules, this feature of the model allows for the simulation of under- or over-capacity situations, with the possibility of price shocks or counter-shocks similar to those that occurred on the oil market in the seventies and eighties.

In the final energy demand module, the consumption of energy is divided into 11 different sectors, which are homogenous from the point of view of prices, activity variables, consumer behaviour and technological change. This is applied in each main country or region. The Industry, Transport and Residential-Tertiary-Agriculture blocks respectively incorporate 4, 4 and 3 such sectors as reported in Table 5.

In each sector, the energy consumption is calculated separately for substitutable technologies and for electricity, with a taking into account of specific energy consumption (electricity in electrical processes and coke for the other processes in the steel-making, feedstock in the chemical sector, electricity for heat and for specific uses in the residential and service sectors).

Table 1 POLES demand breakdown by main sectors

Industry	Steel Industry Chemical industry (+feedstock) Non metallic mineral industry Other industries (+non energy use)	STI CHI (CHF) NMM OIN (ONE)
Transport	Road transport Rail transport Air transport Other transports	ROT RAT ART OTT
RAS	Residential sector Service sector Agriculture	RES SER AGR

2.2.2 The Oil production in POLES

The POLES model calculates oil production for every key producing country or region, based on oil reserves. This is performed in three steps. Firstly, the model estimates the cumulative amount of oil discovered as a function of the Ultimate Recoverable Resources and the cumulative drilling effort in each region. The amount of URR is not held constant but is calculated by revising the value for the base year, as estimated by the USGS (USGS, 2000), based on a recovery ratio that improves over time and increases with the price of the resource. According to WETO-H2 (WETO-H2, 2006), while the recovery rate is differentiated across regions, the world average accounts for 35% today and, due to the price-driven technology improvements, increases to around 50% in 2050.

Secondly, the model calculates remaining reserves as equal to the difference between the cumulative discoveries and the cumulative production for the previous period. The accounting is described by the formula: $R_{t+1} = R_t + DIS_t - P_t$ (where R = reserves, DIS = discoveries, P = production, subscript t = year of account)

Finally, the model calculates the production, which differs among regions of the world. In the “price-taker” regions (i.e. Non-OPEC) it is resulting from an endogenous Reserves-to-Production ratio that decreases over time and the calculated remaining reserves in the region; the production from “swing-producers”(i.e. OPEC) is assumed to be that amount needed to balance the world oil market (OPEC total oil production= total oil demand – Non-OPEC total oil production). Thus, the model calculates a single world price, which depends in the short-term on variations in the rate of utilisation of capacity in the OPEC Gulf countries and in the medium and long-term on the world R/P ratio (including unconventional oil).

The unconventional oil enters in the composition of the world oil supply when the oil international price makes it competitive against the conventional oil, that is when the world oil price exceeds the cost of an unconventional source of oil (IEA, 2005).

2.2.3 The Gas production in POLES

The gas discoveries and reserves dynamics are modelled in a way that is similar to that used for oil; whereas the gas trade and production are simulated in a more complex process that accounts for the constraints introduced by gas transport routes to the different markets; The production of gas in each key producing country is derived from the combination of the demand forecast and of the projected supply infrastructures in each region (pipelines and LNG facilities).

Three main regional markets are considered for gas price determination, but the gas trade flows are studied with more detail for 14 sub-regional markets, 18 key exporters and a set of smaller gas producers.

The price of gas is calculated for each regional market; the price depends on the demand, domestic production and supply capacity in each market. There is some linkage to oil prices in the short-term, but in the long-term, the main driver of price is the variation in the average Reserve-to-Production ratio of the core suppliers of each main regional market. As this ratio decreases for natural gas as well as for oil, gas prices follow an upward trend that is similar in the long-term to that of oil (WETO-H2, 2006).

2.2.4 The Biofuels Model

The biofuels model has been developed for the PREMIA (Wiesenthal et al., 2007) and the TRIAS project (Krail et al., 2007). It has improved the capability of POLES to deal with a potentially relevant alternative source of energy for the transport sector. The biofuels model is based on recursive year by year simulation of biofuels demand and supply until 2050. For each set of exogenously given parameters an equilibrium point is calculated at which the costs of biofuels equal those of the fossil alternative they substitute, taking into account the feedback loops of the agricultural market and restrictions in the annual growth rates of capacity. This equilibrium point is envisaged by market participants but not necessarily reached in each year. Increasing production of biofuels and a subsequent rise in feedstock demand has an impact on the prices of biofuels feedstock, which in turn affects biofuels production through a feedback loop.

Figure 3: Interaction of factors simulated in the biofuels model

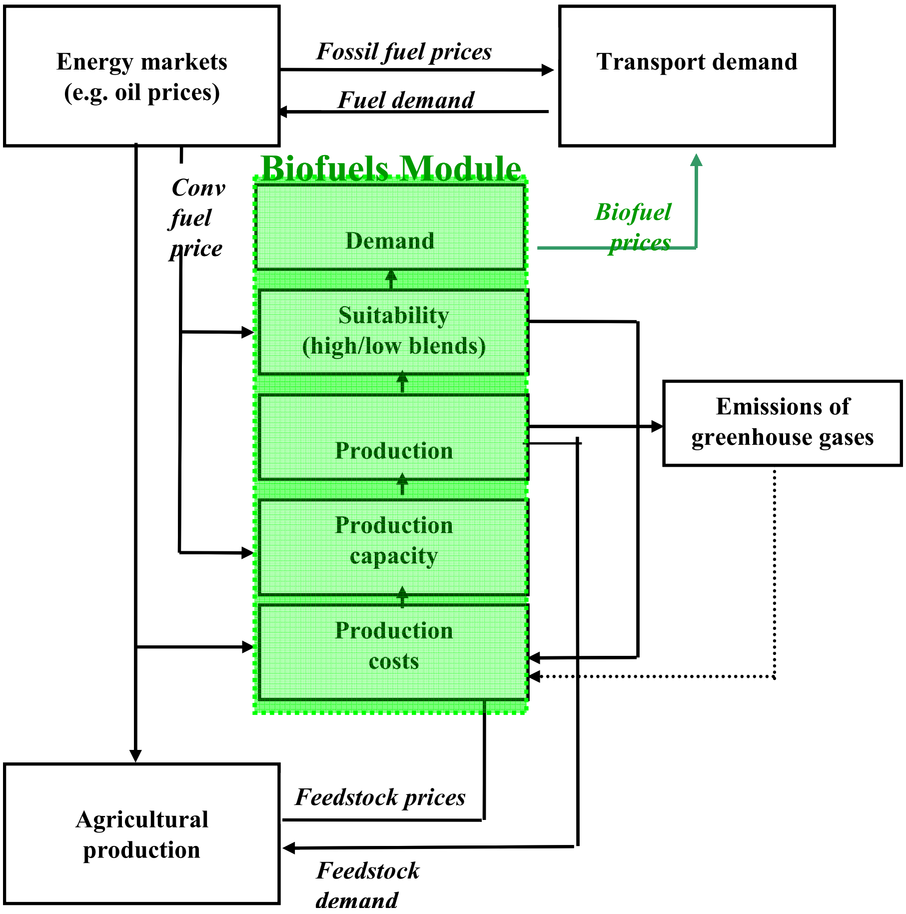


Figure 3 summarises the way the different factors interact. Impacts are traced in the various sectors. The chart is restricted to the EU domestic biofuels market. Regarding imports, biofuels prices are given as exogenous variables as well as their maximum penetration levels. Other main exogenous parameters include

- Selection of biofuels production pathways;
- Production costs and maturity factors (learning of new production technologies);
- Well-to-wheel emissions of greenhouse gases;
- Development of oil prices and subsequently the fossil fuel prices;
- Elasticities of the raw material prices;
- Transport fuel demand.

The model determines the penetration of biofuels as a function of final price of biofuels relative to the pump price of fossil fuels. These are affected by the prices of oil and raw materials as well as the production costs that each alternative pathway entails (depending on capital costs, feedstock prices, load factors etc.). The main factors that determine the equilibrium point via influencing the cost ratio of biofuels and fossil fuels are oil prices, distribution costs and feedstock prices.

2.3 Sensitivity analysis with POLES and ASTRA

The scenarios developed are based on a set of assumptions, some of which can be considered as uncertain. To get an impression of how uncertainties can affect the outcome a sensitivity analysis was carried out. The sensitivity analysis could not examine every potential source of uncertainty but focussed on a limited set of variables that might have a major impact on the results.

We have developed a sensitivity analysis for the coupled three models POLES-BIOFUEL and ASTRA. This seems to us quite a novelty, at least we were not aware of a similar attempt, so far. The first two models function in close cooperation for this test and thus their results are explained together in one section. The basic concept of this coupled sensitivity analysis is: in a first step POLES-BIOFUEL are running their sensitivity analyses generating ranges of results for a number of variables that are used as inputs to ASTRA. These ranges then provide the input ranges for the sensitivity analysis of ASTRA. Second, there is also one parameter that is exogenous to both models (GDP growth of China and India), and which is then varied by the same range in the two separate sensitivity analyses in POLES-BIOFUEL and ASTRA, respectively. The outcome of the joint sensitivity analysis is then ranges of results for all indicators that can be provided by the three models.

As Figure 4 shows, first POLES runs its sensitivity analysis with ranges of the fossil fuel reserves and ranges of the GDP growth for China and India. The outcome are ranges of fossil fuel trade i.e. imports of fossil fuel of EU27 countries and ranges of fossil fuel prices. Second, BIOFUEL runs its sensitivity analysis using the ranges of fossil fuel prices of POLES as inputs and generates as output ranges of biofuels fuel prices. Finally, ASTRA takes (1) the ranges of GDP of China and India, (2) the ranges of fossil fuel trade and (3) the ranges of fossil fuel prices from POLES as well as (4) the ranges of biofuel fuel prices from BIOFUEL and uses these as input for its sensitivity analysis. The outcome of the ASTRA analysis is then ranges of economic, transport and environment indicators. Of interest, in particular, are results for GDP, the vehicle fleet composition and CO_2 emissions from transport.

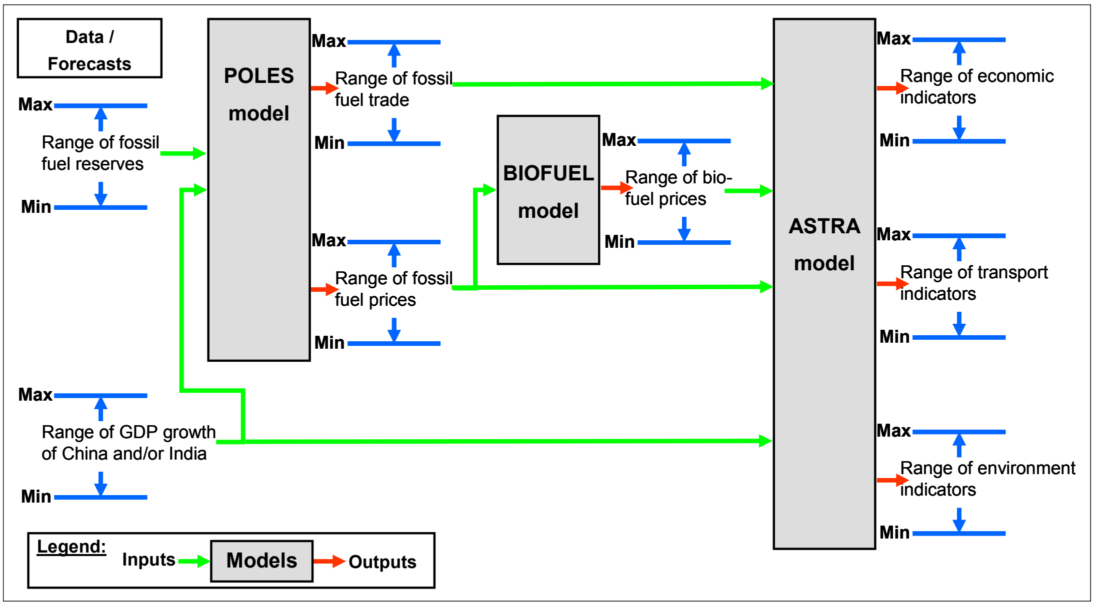


Figure 4: Overview on structure of POLES-BIOFUEL-ASTRA sensitivity analysis

This section consists of five parts: (1) the parameter ranges used for the first part of the sensitivity analysis made by POLES are substantiated, (2) the results of the sensitivity analysis from POLES-BIOFUEL are presented, (3) the transfer of POLES ranges of results as inputs to ASTRA is described, (4) the results of the sensitivity analysis from ASTRA are presented, and (5) a brief synthesis on noticeable results of the sensitivity analyses is given.

2.3.2 Parameters of the Sensitivity Analysis of POLES-BIOFUELS

The first step in the sensitivity analysis was to identify the main parameters of POLES-BIOFUELS that have to be varied. We decided to look at the main variables that might have an impact on the energy supply and the energy demand. With respect to energy supply, the highest uncertainty is most probably due to the unknown amount of oil reserves. For energy demand, the development of GDP until 2050, in particular of the large and booming countries China and India, seems to be the most important factor.

2.3.3 Assumptions about oil reserves in the sensitivity analysis

Therefore, a sensitivity analysis was undertaken, varying the amount of oil reserves during the time horizon of the scenarios. Data about the amount of oil reserves come originally from the USGS assessment (USGS 2000) and were used to calibrate the POLES-BIOFUELS model. The USGS assessment quantifies the total of ultimate recoverable resources. These are calculated using information of the remaining ("proved") reserves, the reserve growth plus "undiscovered" resources and cumulative production.

Figure 6 shows the values of cumulative production, remaining reserves, reserve growth and undiscovered resources of the World-excluding-USA (WEU) and USA. USGS estimates an amount of ultimate recoverable resources of oil of about 3000 bboe of the world for the year 2020. Nearly half consists of reserve growth and undiscovered resources.

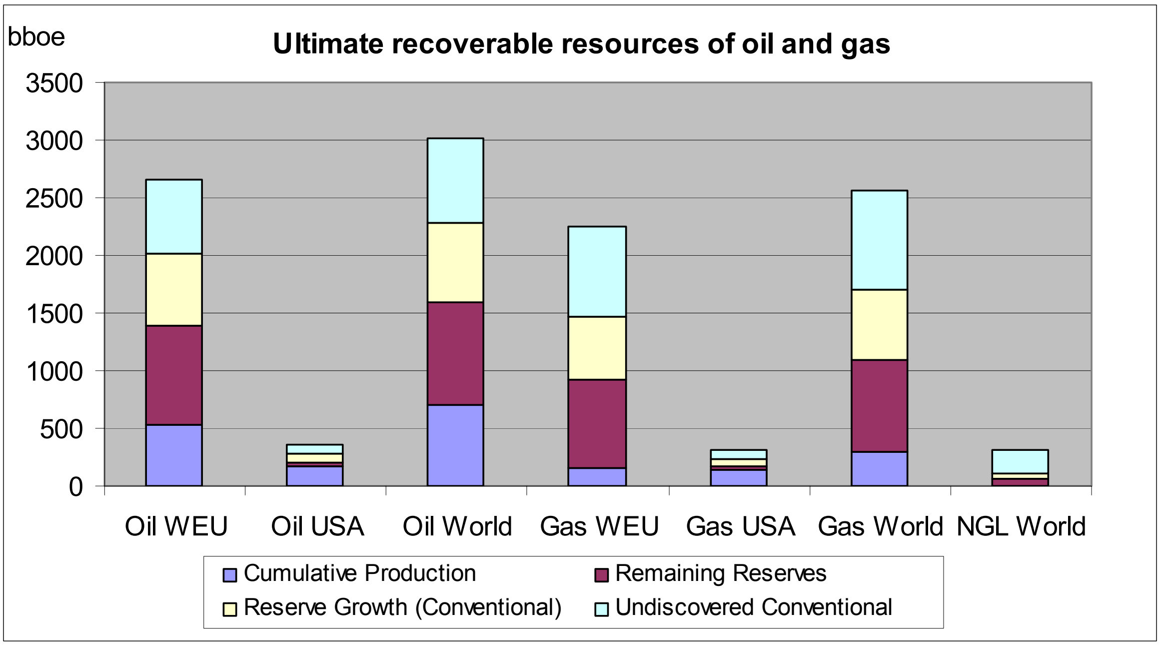


Figure 5: Oil and gas resources of World-excluding-USA (WEU) and USA in 2020 (USGS, 2000)

For gas the cumulative production is much lower than for oil. But the remaining reserves, the reserve growth and the undiscovered resources reach a similar level.

USGS (2000) focuses on the estimation of reserve growth and undiscovered conventional oil and gas fields. In the USA, oil companies have to report annually the field size of their resources. Therefore, historical data are available over long time spans. In general, most recent data on fields refer to the year 1995. The age structure (years after discovery) of each field was taken into account. A reserve growth function was applied on all oil and gas fields.

The reserve growth function was then adopted for oil, gas and natural gas liquids (NGL) fields of the WEU. Applying the USA reserve growth function to the rest of the world (WEU), USGS derives estimates of total grown volumes and total known volumes for 2025. The difference between these volumes yields the reserve growth. USGS mentions several reasons that this approach might underestimate reserve growth of WEU:

- Oil and gas fields of WEU might be younger and have therefore significantly higher reserve growth potential.
- Technological developments might be stronger compared to the technical developments which had an impact on the USA historical reserve growth record.
- Shortages might accelerate developments to expand the exploitation of existing resources.

On the other hand, arguments can be mentioned that this approach overestimates the reserve growth of WEU:

- In WEU the criteria for reporting reserves of oil and gas fields might be less restrictive.
- Reported reserves might be overestimated which reduces their reserve growth potential.

- The initial field-size estimates might be more accurate in recent time periods which would reduce the reserve growth potential of WEU.

Following these arguments, USGS states that the impact of these USA effects on world reserve growth is unclear and thus provides a probabilistic distribution for reserve growth of WEU. A triangular distribution is assigned. The most likely value of the triangular distribution is the estimation of the reserve growth of WEU by applying the reserve growth function of USA. The minimum value of the triangular distribution is set to zero. The maximum value is set to 1224 bboe (1224 bboe for WEU; 84 bboe USA)which is exactly twice as much as the most likely value (612 bboe for WEU; 42 bboe USA). The resulting triangular distribution is symmetric as shown in Figure 6.

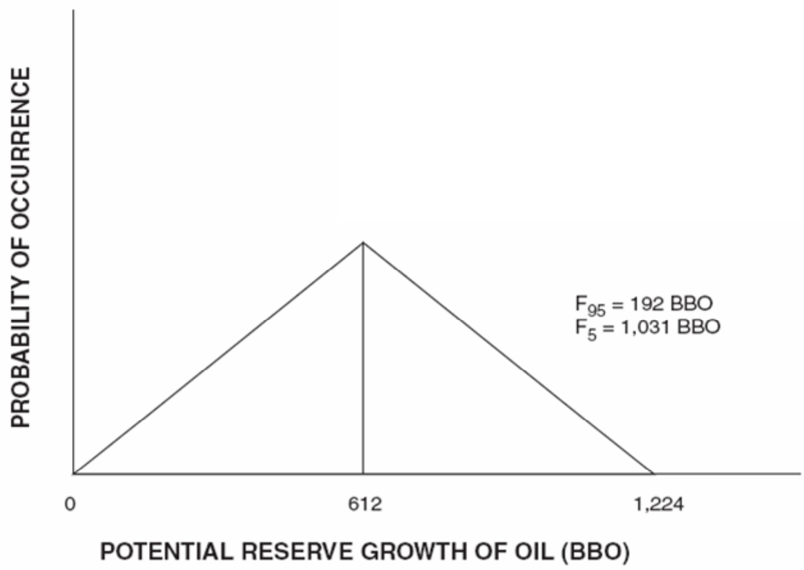


Figure 6: Reserve growth of oil of WEU (USGS, 2000)

Probabilistic distributions were estimated by USGS for the undiscovered resources as well as for the reserve growth. Undiscovered resources are those resources postulated from geological knowledge and theory to exist outside of known fields. The undiscovered resources are assessed via a geology-based proprietary USGS method. All assessments were made at the assessment unit level (AU). On a regional level it was assumed that all AU have a perfect positive correlation with geological and non-geological factors. Finally, USGS estimated probabilistic distributions for 8 regions. For each of them oil, gas and natural gas liquids (NGL) resources were considered for WEU.

The probability distributions for some input parameters represent the uncertainty of a fixed value such as the probability distribution for number of undiscovered fields. In other cases, input probability distributions represent values that are inherently variable such as the probability distribution for sizes of undiscovered fields.

This approach results in a curve showing the probability of the existence of undiscovered oil, gas and NGL resources. The results for oil resources are shown in Figure 7.

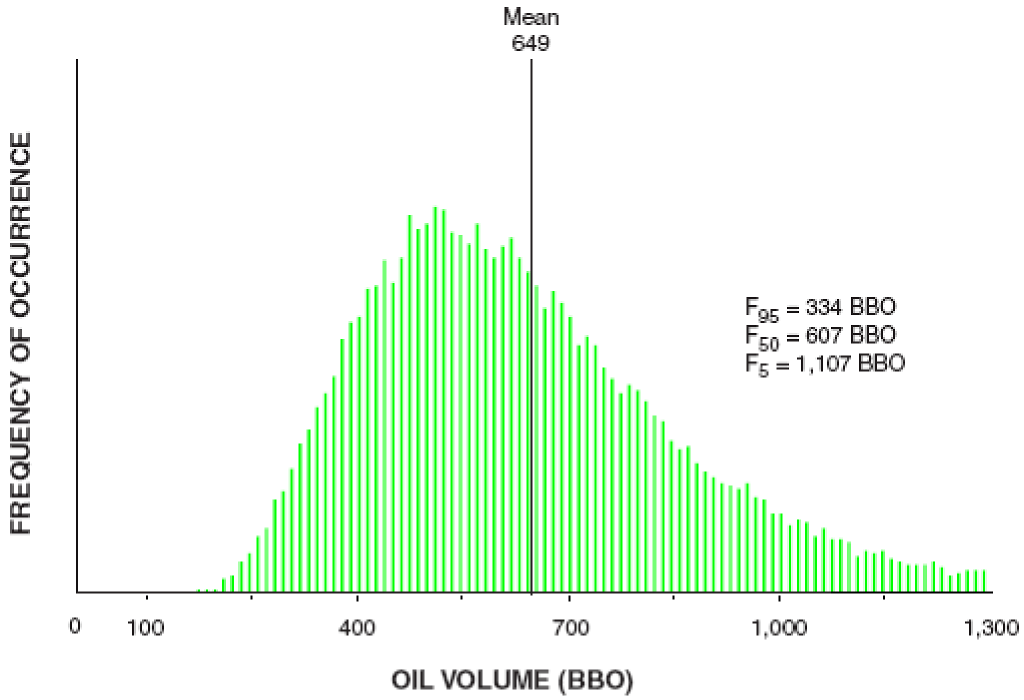


Figure 7: Probabilistic distribution of oil resources of WEU (USGS, 2000)

The distribution of oil resources is assumed to be a log-normal distribution. A log-normal distribution is adopted generally for parameters such as size etc. The log-normal distribution is symmetric but the distribution of resources turns into an asymmetric distribution.

USGS derives the median value of 607 bbo for oil resources and a mean value of 649 bbo. Concerning gas and NGL the median values are 722 bboe and 189 bboe respectively 778 bboe and 207 bboe for the mean value.

Table 2: Scenarios varying assumptions about world (WEU and USA) oil reserves

Scenario name	Number of simulation	Scenario name	Oil reserve growth [bboe]	Oil reserve growth distribution	Oil discovery [bboe]	Oil discovery Distribution
Low oil reserve scenario	1	Low oil reserve scenario	0	Single point	185	Single point
High oil reserve scenario	1	High oil reserve scenario	1308	Single point	3660	Single point
Oil reserve sensitivity run	200	Oil reserve sensitivity run	0 - 1308	Triangular distribution	185 - 3660	Log-normal distribution

Source: based on TRIAS assumptions

Two scenario runs were conducted with lowest and the highest values for reserve growth and discovery of fields. A sensitivity run with 200 simulations was also undertaken. In the sensitivity run oil reserve growth and oil discovery varies from the minimum value to the maximum value. In the case of oil reserve growth a triangular distribution and in the case of oil discovery a log-normal distribution was applied (as in USGS 2000).

2.3.4 Assumptions about GDP in the sensitivity analysis

Varying the assumptions about the development of GDP in all countries would be a major increase in the extent of the analysis. Therefore, the sensitivity analysis focuses on only two countries. The countries were chosen due to their possible impact on global energy demand for the time horizon 2050. In the past, projections of energy demand have often been revised due to underestimated development of GDP of countries like China.

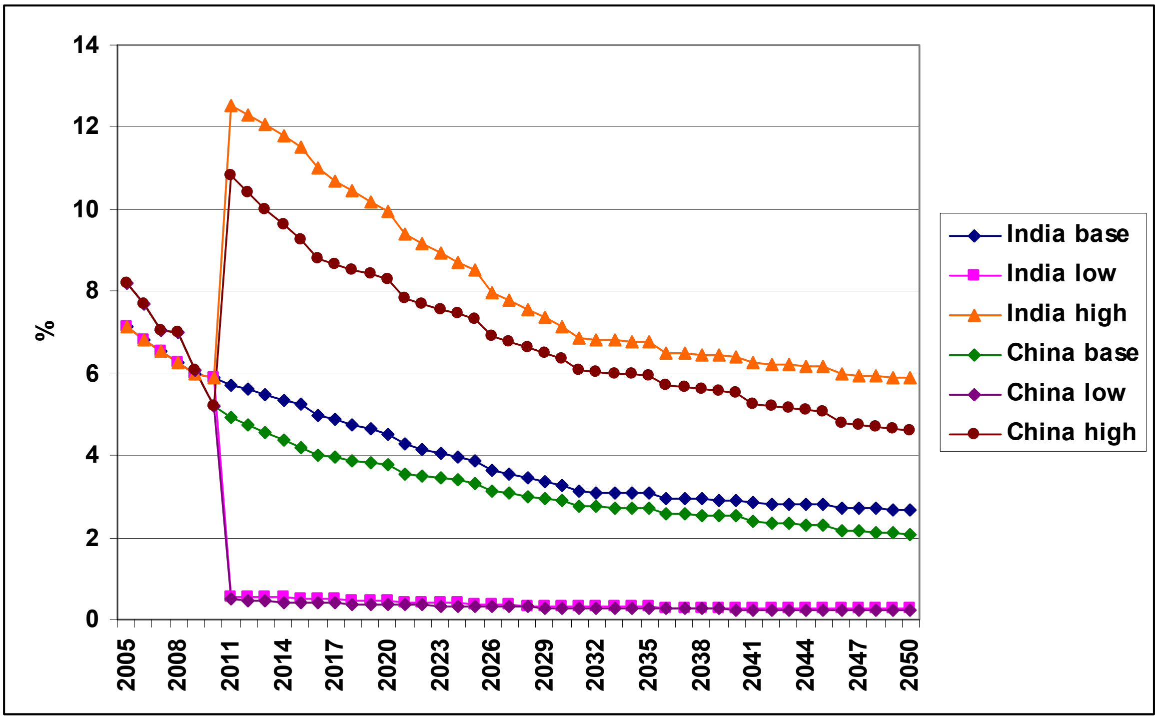


Figure 8: Growth of GDP of China and India

Hence, we have chosen China and India as countries where the development of GDP varies. To vary their development of GDP we vary the base run assumed growth of GDP by a factor between 0.1 and 2.5. According to this the growth rates of GDP for China and India are in the range of 4 to 13% in the high growth scenario and below 1% in the low growth scenario instead of the range 2 to 8% in the base run (Figure 8).

Table 3: Scenarios varying assumptions about GDP of India and China

Scenario name	Number of simulation	Growth rate GDP India from 2010 to 2050	Growth rate GDP China from 2010 to 2050	Multiplication factor
Low GDP scenario	1	0-1%	0-1%	0.1
High GDP scenario	1	5-13%	4-11%	2.5
GDP sensitivity run	625	0-13%	0-11%	0.1 – 2.5 (equal distribution)

Source: based on TRIAS assumptions

These extreme values were used to develop single runs (Table 3). A further analysis was conducted with a set of scenarios. In the case of GDP a sensitivity analysis with 625 runs was carried out. The runs vary stepwise the multiplication factor from 0.1 to 2.5. That means also that the growth rates of India and China are treated independently in the sensitivity run so that there might be runs in which e.g. a low growth rate of GDP of India will be overcompensated by a high growth rate of GDP of China.

3. Results

At the present stage only a few results can be highlighted. The results concern the biofuel market of the POLES-BIOFUEL application and GDP and other macro-economic indicators for the POLES-BIOFUELS-ASTRA application.

3.1 Results of Sensitivity Analysis of POLES-BIOFUEL

3.1.1 Single runs with extreme values of oil reserves and prices

Firstly, we investigate the scenario with extreme low oil reserves further. If oil reserves are very low and, therefore, the oil price is very high, the prices for fossil fuels increase. As the production costs of biofuels decline they fall below market prices by 2025. Around this year, the 1st generation of biofuel and ligno-cellulosic ethanol have lower prices in the market than fossil fuels. Therefore, they extend their market share above the values set by the quota of the base scenario (around 4%).

Secondly, the scenario with extreme high oil reserves does not differ much from the baseline. If oil reserves are very high and, therefore, the oil price is low, the prices for fossil fuels decline. Therefore, the market position of biofuels is worse than in the baseline. They only enter the market according to the applied quota.

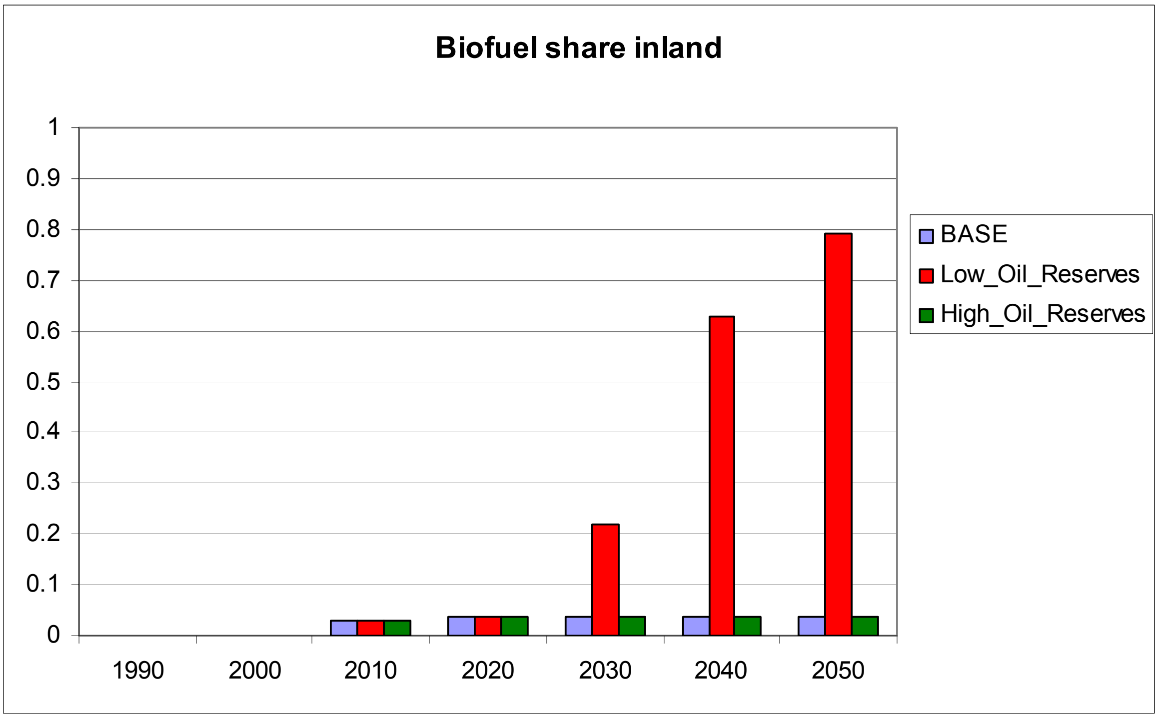


Figure 9: Share of inland produced biofuels varying the amount of oil reserves

Looking at the scenario with extremely low oil reserves we obtain the following results (Figure 9 and Figure 10). The rise of feedstock costs of the 1st generation of biofuels limits their diffusion. For ligno-cellulosic ethanol feedstock costs rise to a much lesser extent. Therefore, ligno-cellulosic ethanol can gain a higher market share than the 1st generation of biofuels. So far, it looks very similar to the development in previous scenarios.

But differences occur for BTL. If oil reserves are very low, high market prices of fossil fuels lead to the situation that BTL falls below the market price of fossil fuels. Therefore, BTL enters the market for transport fuels in 2030. In the scenario with extremely low oil reserves BTL can attain even higher production levels than the sum of the other biofuels within one decade. The reason behind this is that feedstock costs of BTL rise to a much lesser extent than biofuels of the 1st generation. Compared to ligno-cellulosic ethanol the rise of feedstock costs is the same, since the same elasticity between production level and feedstock costs is applied. However, we observed a shift from gasoline to diesel in the transport system. Based on this shift diesel demand is much higher than gasoline demand in 2050.

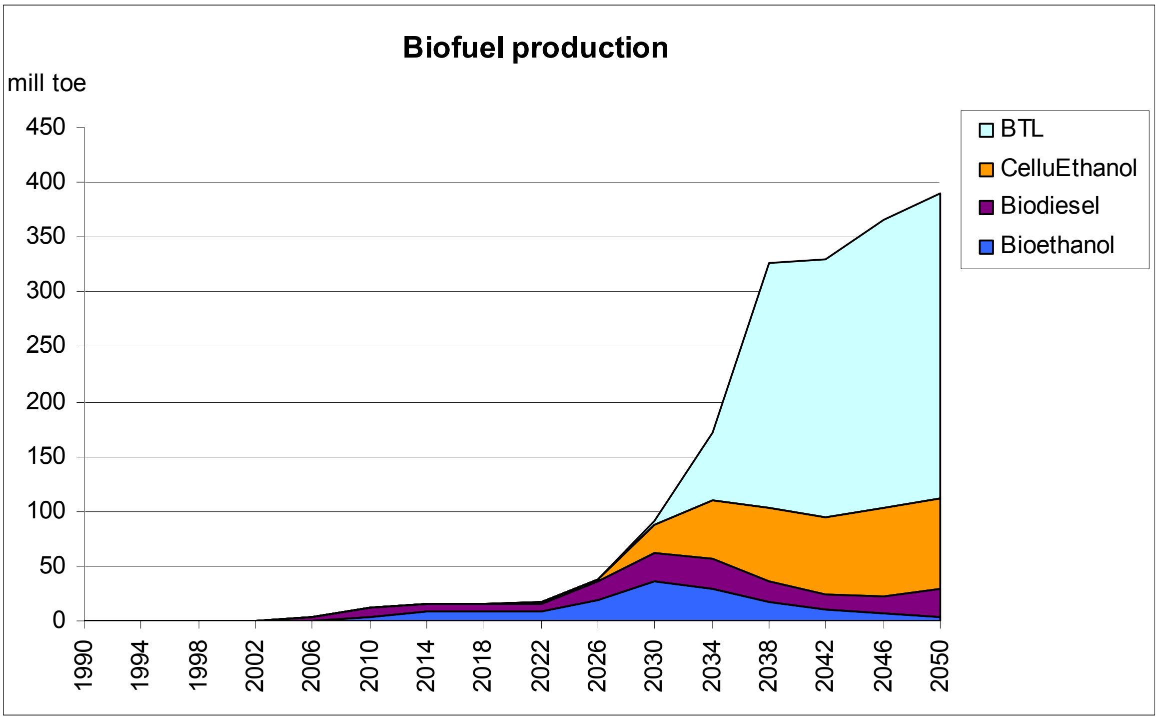


Figure 10: Biofuel production

If we compare shares we can derive that ligno-cellulosic ethanol and BTL have a similar share of about 75% in gasoline demand and diesel demand, respectively. This demonstrates that the higher production level of BTL compared to ligno-cellulosic ethanol stems from the higher diesel demand compared to gasoline demand (and not from a better market position of BTL to ligno-cellulosic ethanol).

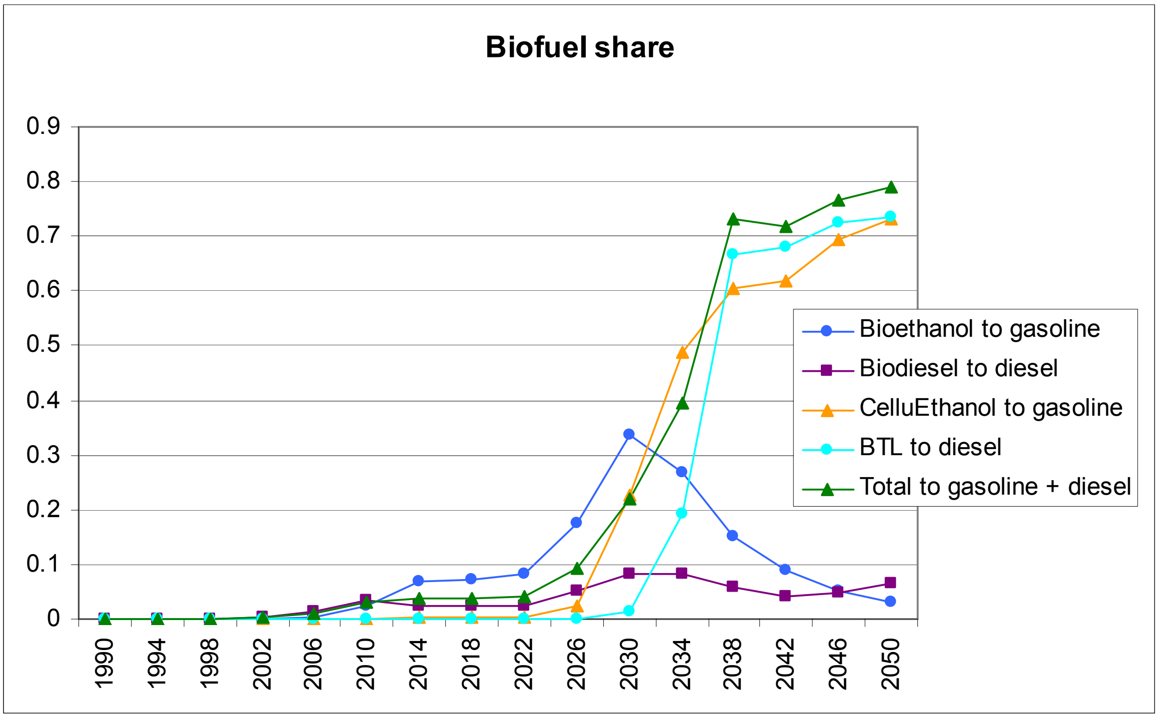


Figure 11: Biofuel share

The resulting market shares for biofuels of 2nd generation biofuels are very high. As fossil fuel prices increase in the case of low oil reserves, they exceed the production costs of 2nd generation biofuels which the enter the market. When entering the market rising production has only a small effect on production costs.

In general, the reaction of the agricultural markets thus influences the production costs of biofuels and, subsequently, the level of biofuel supply. The assumed elasticities for wheat, sugar beet, rapeseed, sunflower, lignocellulosic and biomass feedstock are 0.1, 0.1, 0.25, 0.2, 0.04, 0.04, respectively[1]. Hence the production costs of 2nd generation biofuels increase to a much lesser extent than 1st generation biofuels.

The feedback elasticities are based on information in the ESIM model simulation results of DG Agriculture. They are econometrically estimated, but some uncertainties remain as in the past production levels rose much less than in the forecasts. As the feedstock elasticity for 2nd generation biofuels strongly influences the model results by 2030, the results in the extreme scenarios after 2030 must be seen as less robust in absolute terms.

However, the scenarios demonstrate that the production of biofuels is strongly affected by low amounts of oil reserves. Furthermore, 2nd generation biofuels including BTL might enter the market to a major extent if oil prices increase strongly.

3.1.2 Sensitivity runs varying the amount of oil reserves

The sensitivity analysis sheds light on the role of some variables on the outcome of the analysis. We determined that the oil price entails uncertainty on the development of biofuel production. The analysis shows that a high oil price can change the relation between market prices of fossil fuels and production costs of biofuels which appears to be crucial. Of course,

[1] Please note that with the high volumes of demand that are likely to be achieved in some of the scenarios, dynamic elasticities would have been more appropriate. However, these could not be determined with the currently available information.

similar uncertainties occur due to the difficulty in predicting the development of production costs of 2nd generation biofuels. In case of breakthroughs in technology for the production of BTL and, therefore, huge drops of production costs, BTL might gain high market shares very rapidly.

In a further sensitivity analysis we do not look only at scenarios with extreme high or low oil reserves. In the sensitivity runs we conduct 200 simulations within the range of extreme low and high oil reserves and, therefore, low and high oil prices. Oil prices lie in the range of 45 to 130 $€_{2005}$.

The results show that projections of 1st generation biofuels are robust in 2030 (Table 4) and 2050 (Table 5). The mean values of their production lie in the range of 8 to 10 mtoe and the standard deviations of the normal distribution are between 0.2 and 0.3. Large differences are found for the 2nd generation of biofuels. In 2030 their production values are quite low and in the range between 0 and 8 mtoe. The standard deviations of the normal distribution are between 1.3 and 2.0 which are quite high but can be explained by the low production values. As production values are very low small changes have a huge impact on the results.

Table 4: Biofuel production in absolute and relative terms in 2030

Variable	Subscript	Min	Max	Mean	Median	StDev	Norm
Biofuel Production [mtoe]	Bioethanol	7.3	21.6	9.8	8.6	3.1	0.3
	Biodiesel	6.7	15.5	8.0	7.4	1.8	0.2
	CelluEthanol	0.3	7.7	1.2	0.4	1.5	1.3
	BTL	0.0	2.0	0.1	0.1	0.3	2.0
Biofuel Share [%]	Bioethanol in gasoline	6.7	19.8	9.0	7.8	2.9	0.3
	Biodiesel in diesel	2.2	5.0	2.6	2.4	0.6	0.2
	CelluEthanol in gasoline	0.3	7.1	1.1	0.4	1.4	1.3
	BTL in diesel	0.0	0.6	0.0	0.0	0.1	2.0
	Biofuels in Fossil Fuels	3.7	11.2	4.6	3.8	1.6	0.3

Source: POLES, BIOFUEL results

Table 5: Biofuel production in absolute and relative terms in 2050

Variable	Subscript	Min	Max	Mean	Median	StDev	Norm
Biofuel Production [mtoe]	Bioethanol	5.1	13.0	8.8	7.9	2.6	0.3
	Biodiesel	7.0	15.5	9.9	8.1	2.8	0.3
	CelluEthanol	2.4	64.7	25.0	10.1	23.6	0.9
	BTL	0.0	251.2	48.7	0.1	83.2	1.7
Biofuel Share [%]	Bioethanol in gasoline	4.5	11.6	7.8	7.0	2.3	0.3
	Biodiesel in diesel	1.8	4.1	2.6	2.1	0.7	0.3
	CelluEthanol in gasoline	2.1	57.3	22.1	8.9	21.0	0.9
	BTL in diesel	0.0	66.1	12.8	0.0	21.9	1.7
	Biofuels in Fossil Fuels	3.7	68.5	18.7	5.2	21.9	1.2

Source: POLES, BIOFUEL results

However, the range of values for the production of 2nd generation biofuels increases out to 2050. The production of ligno-cellulosic ethanol is expected to be in the range of 2.4 to 64.7 mtoe (instead of 0.3 to 7.7 mtoe). For BTL the maximum increases from 2 mtoe in 2030 to 251 mtoe in 2050 (the lower bound is in both cases zero).

These results underpin the outcome that the market success of 2nd generation of biofuels is quite sensitive to the oil price which itself strongly depends on the oil reserves. The sensitivity increases towards the end of the time horizon.

In the majority of the simulations ligno-cellulosic ethanol slightly exceeds the production of bioethanol and also of biodiesel (median values). But with high oil prices it can outstrip 1st generation of biofuels by factors of up to 4 (max values). In the majority of the simulations BTL gains only marginal market shares (median value of 0.1). But with high oil prices it can suddenly have a huge market success and can outstrip 1st generation biofuels by even higher factors than in the case of ligno-cellulosic ethanol.

3.1.3 Low GDP growth and high GDP growth scenarios

Firstly, we investigate the scenario with extremely high growth in China and India. If economic growth is very high and, therefore, the energy and hence oil demand is very high, the prices for fossil fuels increase up to 104 $€_{2005}$. As production costs of biofuels decline they fall below market prices in 2040. Therefore, they extend their market share above the values set by the quota of the base scenario (around 4%).

Secondly, the scenario with extremely low growth in China and India does not differ much from the baseline. If economic growth is very low and, therefore, the energy respectively oil demand is low, the prices for fossil fuels decline to 64 $€_{2005}$. Therefore, the market position of biofuels is worse than in the baseline. They only enter the market according to the applied quota.

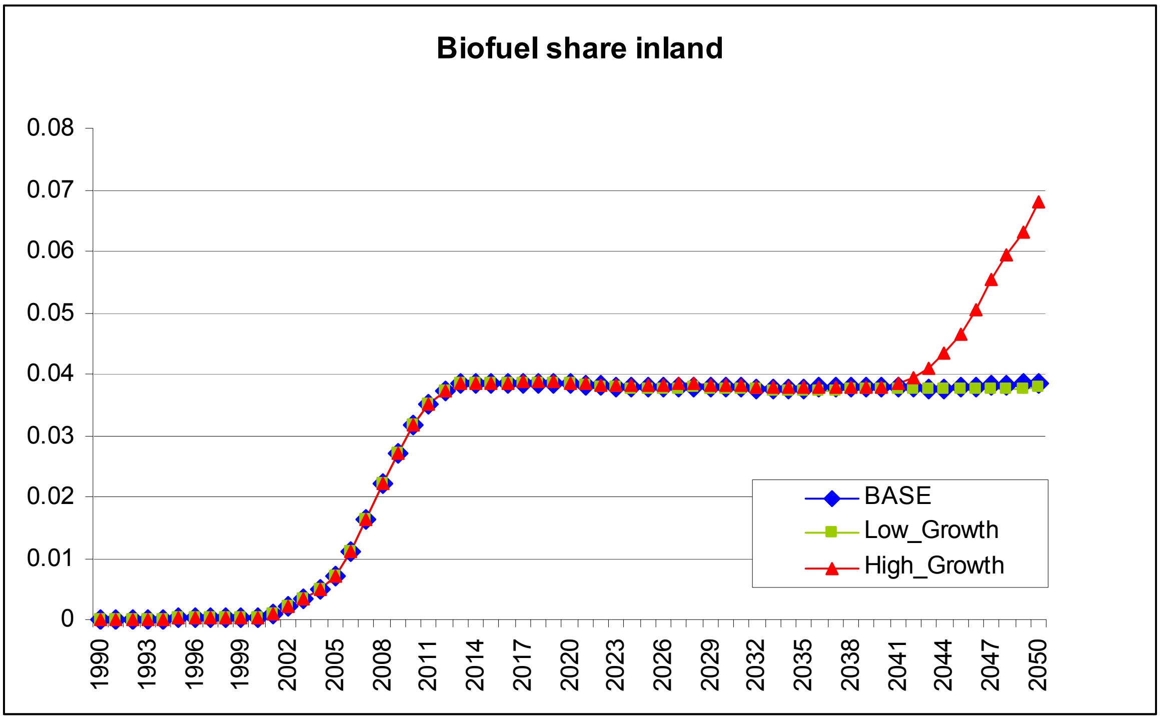


Figure 12: Share of inland produced biofuels varying growth of GDP of China and India

Up to 2040 biofuel production in the scenario with high growth rates in China and India is very similar to the baseline. Their competitiveness is lightly improved due to the fact that fossil fuel prices are higher. But it does not lead to an increase of production as their production costs are still higher than fossil fuel prices. The situation changes in 2040. Then, production costs of bioethanol and ligno-cellulosic ethanol become lower than fossil fuels, which leads to an increased production of bioethanol and to a market entry of ligno-cellulosic ethanol on a major scale.

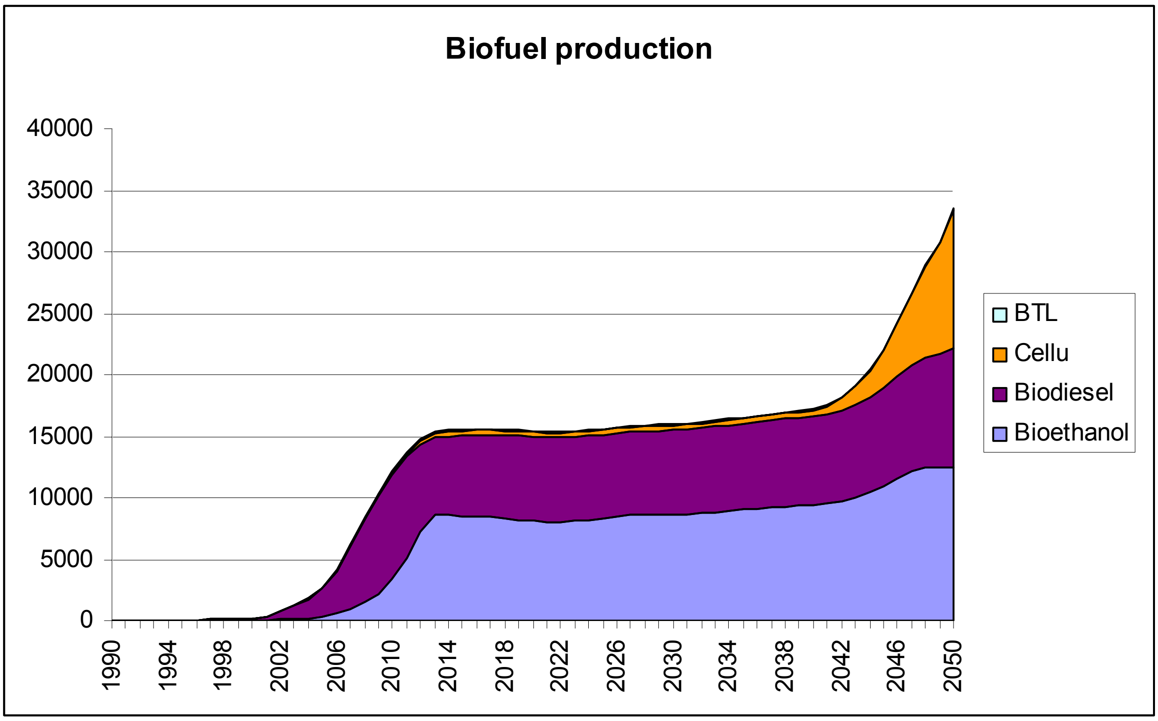


Figure 13: Biofuel production

To investigate the robustness of the results a sensitivity analysis was carried out varying GDP of China and India. 625 runs were conducted between taking low growth and high growth as the lower and upper range of the sensitivity runs.

Table 6: Biofuel production in absolute and relative terms in 2030

Variable	Subscript	Min	Max	Mean	Median	StDev	Norm
Biofuel Production [mtoe]	Bioethanol	5.1	6.2	5.4	5.4	0.18	0.03
	Biodiesel	7.2	7.7	7.4	7.4	0.10	0.01
	CelluEthanol	5.9	7.8	6.6	6.6	0.28	0.04
	BTL	0.1	0.1	0.1	0.1	0.00	0.06
Biofuel Share [%]	Bioethanol to gasoline	4.5	5.5	4.8	4.8	0.16	0.03
	Biodiesel to diesel	1.9	2.0	2.0	2.0	0.03	0.01
	CelluEthanol to gasoline	5.3	6.9	5.9	5.8	0.25	0.04
	BTL to diesel	0.0	0.0	0.0	0.0	0.00	0.06
	Biofuels to Fossil Fuels	3.8	4.3	4.0	4.0	0.08	0.02

Source: POLES, BIOFUEL results

Looking at the biofuel production the results are very robust (Table 6). Bioethanol, biodiesel and ligno-cellulosic ethanol will be produced in a range of 5 to 8 mtoe each. BTL enters the market only marginally. The standard deviation of the normal distribution is below 0.1 for all types of biofuels.

Overall, the extreme scenarios and the sensitivity analysis show that the production of biofuels is very robust to changes in the growth rates of GDP in China and India.

Much larger effects can be expected when the oil reserves are very low and oil prices are very high. In these cases the results can differ significantly from the results of the base run. High differences can be expected for the production of 2nd generation of biofuels, in particular BTL.

3.2 Parameters of the Sensitivity Analysis of ASTRA

The sensitivity analysis in ASTRA is based on the variation of four parameters:

- GDP growth of China and India (the same as in POLES sensitivity analysis),
- Imports of fossil fuels into the EU27 in monetary terms,
- Prices of fossil fuels (gasoline, diesel, CNG), and
- Prices of biofuels (biodiesel, bioethanol, differentiation into 1st and 2nd generation by BIOFUEL model).

These parameters were varied starting from the baseline scenario of ASTRA, which suppresses the introduction of hydrogen vehicles by definition due to the results of other projects like HyWays (2006), which conclude that hydrogen only enters the market induced by strong policy support during market entry.

The ranges of the parameters as applied in the sensitivity analysis of the ASTRA model are presented in Table 7. The values indicate factors by which the respective parameter is multiplied to produce a range of values for it. E.g. the GDP growth of China and India is tested for the range of -80% below the baseline scenario assumption (factor 0.2 as minimum) until +120% of the baseline scenario (factor 2.2 as maximum). The choice of the step for the variations (the 4th column) of 0.4 means that 6 iterations are needed for this parameter (i.e. 0.2, 0.6, 1, 1.4, 1.8, 2.2). The ranges of the different parameters come from different sources: range of GDP growth of China and India is taken as exogenous assumption that is coherent with the assumptions in the corresponding sensitivity analysis of POLES. The range for the fossil fuel imports and the fossil fuel prices are taken as output from the POLES sensitivity analysis and the range of biofuels fuel prices are derived as output from the BIOFUEL sensitivity analysis. Multiplying the number of iterations of each parameter together reveals that the ASTRA sensitivity analysis requires 1176 runs to be made with ASTRA model. This is feasible since the applied Vensim software used for ASTRA implementation offers comfortable features to run such sensitivity analyses.

Table 7: Parameter ranges of the ASTRA sensitivity analysis linked with POLES

Parameter	Min	Max	Step	Iterations	Source
GDP growth of China and India	*0.2*	*2.2*	*0.4*	*6*	Assumption
Import fossil fuels	0.5	3.5	0.5	7	POLES
Fossil fuel prices	0.5	2	0.25	7	POLES
Biofuels prices	*0.80*	*1.40*	*0.20*	*4*	BIOFUEL
Total iterations				1176	

3.2.2 Single runs with extreme values of fuel trade and fuel prices

In the main sensitivity analysis with the linked POLES-BIOFUEL-ASTRA combination of models the influence of several parameters is mixed. Hence, before presenting the results of this combined analysis selected results for variations of only one parameter are described in this section to get a better understanding of the mechanisms. We concentrate on the impacts of the two more influential parameters: fossil fuel prices and oil imports. Figure 14 shows the impacts of the extreme values of these two parameters on GDP in the EU27. Reduced oil imports (in monetary terms) reveal a slightly positive impact while increasing oil imports have a negligible impacts. It seems that some dampening mechanisms in ASTRA act too strongly in this case mitigating the negative impact on the trade balance of the energy sector. In the case of the influence of fossil fuel price changes we observe the expected trend that low fuel prices would increase GDP. But, also increases of fuel prices are able to drive GDP after an initial phase of about 6 years in which GDP is reduced. This curve reacts to changes in car purchase behaviour, which is reduced for an intermediate period, and to changes in investment behaviour into alternative modes. With higher fuel prices such modes, in particular rail, becomes more competitive, increases their modal-share and thus to satisfy their demand investments into these modes increase and stimulate GDP in the longer term.

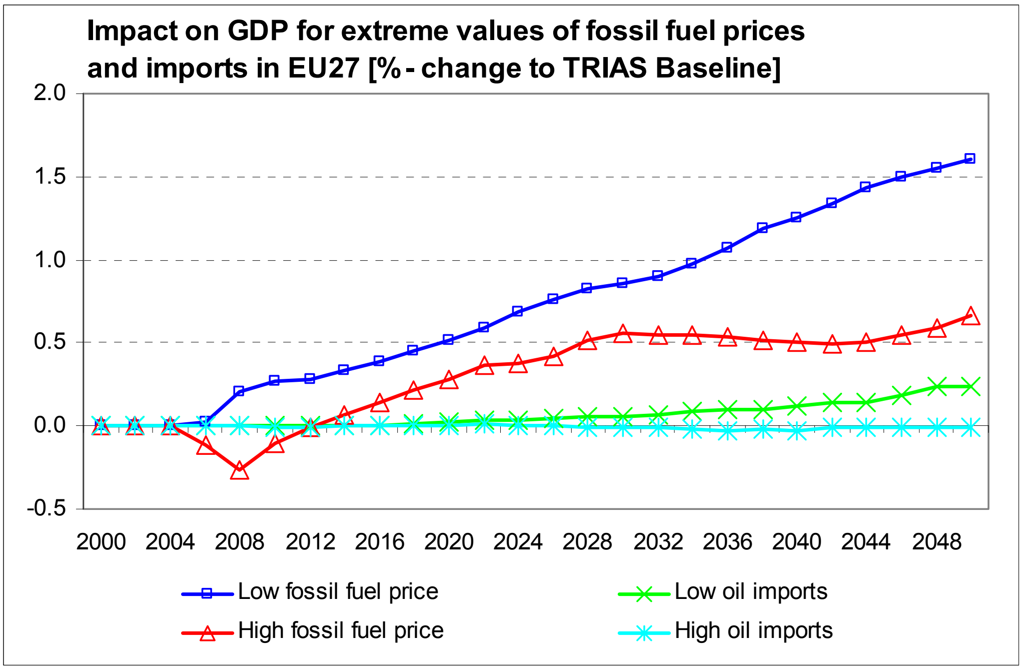


Figure 14: Sensitivity of GDP to extreme values in the EU27 of fuel price and trade

Figure 15 presents the investment impacts in more detail. Low fossil fuel prices directly stimulate investments into cars for a few years. This is sufficient to raise GDP above the baseline such that due to second round effects investments in other sectors are increased. For high fossil fuel prices we observe first the decrease of investment into cars, followed by the increase of investment into other modes and then around 2020 this influence levels off. Investment increase in later years in this case is also due to second round effects of the increased GDP due to the first round effects.

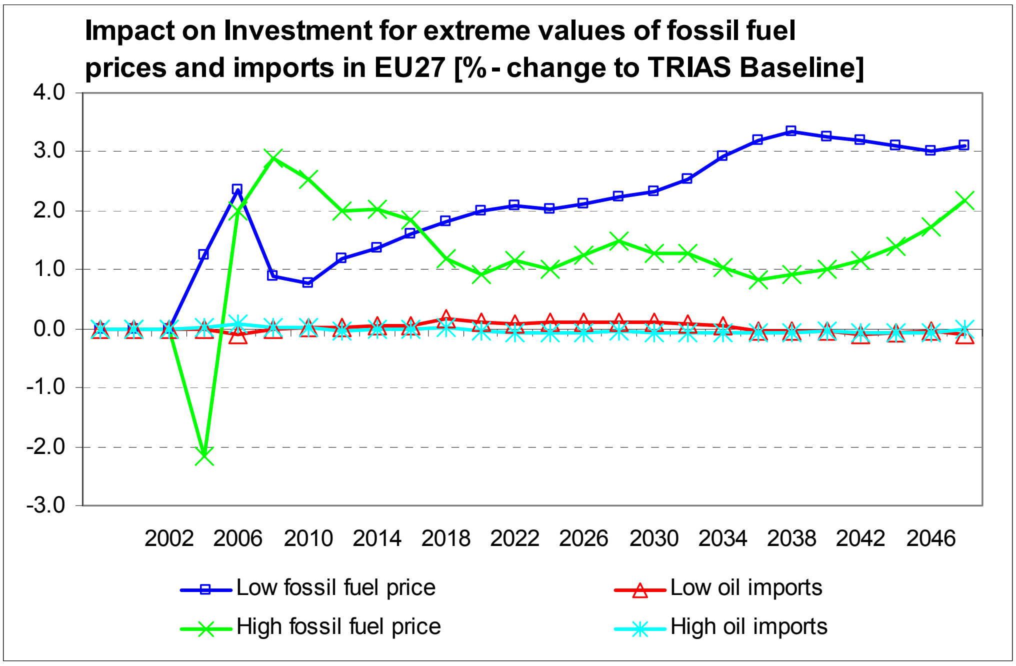


Figure 15: Sensitivity of Investment to extreme values in the EU27 of fuel price and trade

4. Synthesis of sensitivity analyses with POLES-BIOFUEL, and ASTRA

The results of the joint sensitivity analysis as well as the sensitivity analyses of extreme values reveal that going beyond the moderate policies would for some indicator lead to significantly different results. However, in particular high fuel prices could cause strong impacts that would alter strongly the results. This can be especially seen if you compare the results for mean values with the max and min values.

In the majority of the simulations ligno-cellulosic ethanol slightly exceeds the production of bioethanol and also of biodiesel (median values). But with high oil prices it can outstrip 1st generation of biofuels by factors of up to 4 (max values). In the majority of the simulations BTL gains only marginal market shares (median value of 0.1). But with high oil prices it can suddenly have a huge market success and can outstrip 1st generation biofuels by even higher factors than in the case of ligno-cellulosic ethanol.

Overall, the extreme scenarios and the sensitivity analysis show that the production of biofuels is very robust to changes in the growth rates of GDP in China and India. Much larger effects can be expected when the oil reserves are very low and oil prices are very high. In these cases the results can differ significantly from the results of the base run. High differences can be expected for the production of 2nd generation of biofuels, in particular BTL.

An extended analysis should reflect also the changes induced by the high fossil fuel prices in other sectors, in particular the energy sector, which then would cause additional effects e.g. on household expenditures for heating and investments into efficient heating systems, on the cost of energy inputs of industry sectors.

Such an analysis is undertaken in the ongoing HOP! project, which is also a 6th Research Framework Project funded by the EU and that builds on results of the TRIAS project.

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