	HOP! research project **Macro-economic impact of high oil price in Europe**

Deliverable 3

High Oil Prices: Quantification of direct and indirect impacts for the EU

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Executive Summary

The HOP! project addresses the impacts of high oil prices on the European economy. The assessment is performed on a model-based analysis of various scenarios corresponding to oil price shocks with a range of 150 $€_{2000}$/barrel to 800 $€_{2000}$/barrel by the year 2020. The emphasis of the analysis is on assessing the impact of such high oil prices under different characteristics varying the height, the lead time and the steepness of the oil price shock; it is not on estimating the probability of such an oil price being reached or on forecasting the oil price in the future. In particular, the extraordinary oil price shocks are assumptions developed for analytic purposes and should not be considered as forecasts of a likely oil price development.

The overall conclusion is that high oil prices have a significant economic impact in the short-term and may have a limited impact in the medium- and long-term. In general, the impact on employment is more severe than that on GDP. The effects on investments are critical in shaping the final macroeconomic outcome. In the first instance, a high oil price will have a negative effect due to cost increases in many areas of the economy, but this can be offset by the boost of investment induced by the search for alternatives to fossil fuels and for efficiency technologies.

The key messages that can be derived from the HOP! scenario analyses can be summarized as:

- GDP and employment are negatively affected during the peak period of the oil price increase, employment will be reduced significantly more.

- The impact after the peak period of oil price increase strongly depends on the mechanisms kicked-off by the price increase. Mitigating the impacts by investing into energy efficiency and alternatives could even lead to a positive economic impact in the medium to long-term, while a world recession or a situation with insufficient energy supply could multiply the negative impacts by factors of 5 to 10.

- A rapid price increase over a few years would have different effects in the short and the medium-term. In the short term, the lack of response time due to high inertia of the industry hampers the mobilisation of alternative sources, leading to a more profound impact on GDP growth. In the medium term, a rapid price increase, if not reaching the extreme levels of 600-800 $€_{2000}$/barrel, would be advantageous compared with a smooth price increase since the shock most effectively triggers the compensating mechanisms in particular the investments into energy efficiency and alternatives. This presupposes that investors expect a sustained oil price increase and not a temporary one, and that governments do not take actions to lower the fossil fuel prices artificially distorting the price signal.

- The most relevant actions to counterbalance the negative impact of high oil prices are investments into energy efficiency and alternatives. As first, they directly provide a positive stimulus for the economy as part of final demand. As second, they indirectly help to reduce the vulnerability of the economy to oil price increases by reducing energy demand, energy cost and imports of fossil energy.

- In terms of impacts on employment, the most important issue is how the energy sector can forward the price increase to other sectors. Full forwarding of the price increase causes the strong losses observed for employment and boosts the profits of the vertically integrated large energy companies. Limiting price forwarding would strongly reduce the negative impacts on employment, either indirectly by the energy companies reinvesting their profits into efficiency technologies and alternatives that are produced domestically in the EU or directly by the government taxing the profits and creating investment incentives into efficiency technologies and alternatives by subsidies.

On the most aggregated level, the oil price increase negatively affects GDP growth of EU27. The assumed doubling of the oil price in 2020 would lower Europe's GDP by -1.5% percent compared with the reference scenario. A further oil price increase such as a tripling from reference levels would result in further reductions of GDP to be some -2.2% below the reference by 2020. However, only oil prices in the extreme scenarios would lead close to stagnation of GDP (and only for a limited time period). Decline of GDP would only be expected when two further external factors become true: a world recession and/or a physical shortage of energy supply. The corresponding impacts on employment are roughly three times larger. The doubling of the oil price by 2020 would reduce employment by -5%, a tripling by close to -8%. This would shift the peak of European employment from 2017, as it is expected in the reference scenario, to about 3 to 5 years earlier. The extreme cases would cause dramatic losses of employment of up to -30%, presupposing that no specific counterbalancing policies to stabilize employment are taken or significant wage reductions are expected.

Amongst the many mechanisms by which the high oil-price would limit GDP growth, we may underline the shift of consumption from non-energy sectors to the energy sector and the reduction in transport activity. The latter is particularly pronounced for passenger transport activity (some -14% points by a doubling of oil price and some -17% points by a tripling), but can also be observed for the transport of goods (some -11%). The high oil price would also reduce the dominance of road transport in the modal split, even if it still remains the most important mode. As a result of the decreasing activity but also due to the introduction of energy efficiency measures, final energy consumption in the energy sector would reduce by around 16% by 2030 (compared to the reference trend) for a doubling of the oil price, and around 26% at a tripling.

The impact of high oil prices can be separated into four impulses triggering the economy:

- Energy price impulse: is the direct impact of high oil prices on prices of goods and services leading to the budget effect and the substitution effect for household consumption and structural change of the monetary flows in the input-output tables.

- Investment impulse: is induced by the response of the energy system to adapt its facilities and appliances by investing in alternative and more efficient technologies as well as by the changes of investment patterns due to the structural change of household consumption and exports.

- Energy import impulse: occurs by the increased value of imports of fossil fuels due to the price increase and affects the trade balance as well as value-added of the energy sector.

- Inflation impulse: is the additional inflation that a strong price increase of energy would cause thus reducing disposable income of households as well as consumption.

The HOP! analysis has revealed that the strongest impulse for both GDP and employment comes from the energy price impulse, while the inflation impulse would be the least important one. The investment impulse would be the second most important one in terms of strength of impact but also because it can partially offset the negative impact of the energy price impulse.

The HOP! conclusion is that the expected GDP response to an oil price shock would be less pronounced than that observed for the oil price shocks in the 1970s and 80s. This is due to the changed economic framework and technical progress achieved since then that provide for a large variety of dampening effects on both the oil price and its economic impact. Compared to past oil price outbursts, the oil intensity of the European economy has halved and the service sectors have increased their importance at the expense of the more energy-intensive industrial sectors.

A broad variety of improved and alternative energy technologies contributed to this reduction of energy intensity and further technologies become competitive at the oil prices assumed. Thus, the share of renewable energy in primary energy demand would increase considerably. Biofuels, both stemming from first and second generation technologies, exploiting imported and domestic raw resources would experience a significant increase within the transportation sector. They could deliver some 20% of the total transport fuel demand by 2030 as a result of the oil price doubling in 2020, increasing even much further afterwards. Also the composition of the vehicles fleet would change in favour of flexi-fuel vehicles and hydrogen- and gas-fuelled cars.

Yet, all these changes to the energy and transport system require the availability not only of technologies but also of investment. If the level of investments was constrained, the deployment of alternative fuels such as biofuels and the improvement of energy efficiency would rather remain at reference levels. Limited investments would thus significantly restrict the adaptation process of the energy and transport sectors, implying a stronger oil price induced GDP reduction. In the long run this would lead to the most negative scenario – even more negative than the extreme oil price scenarios, in which the energy system responds through extensive adaptation through investments.

In the short-run a somehow similar effect could be observed if the oil price peak happened suddenly (e.g. at 2010), instead of following a long smooth increase as assumed as default. In the case of a sudden and early step, the lack of response time due to high inertia of the industry hampers the mobilisation of alternative sources, leading to a more profound impact on GDP growth. But this is only valid in the short-term. In the medium-term a shock provides a more effective stimulus for investments in energy efficiency and alternative energy than a smooth price increase. Thus the stronger investment stimulus and the resulting decrease of energy demand and fossil energy imports as well as the larger share of domestic energy production (in particular from renewables) makes this scenario with a steep increase towards 150 $€_{2000}$/bbl until 2013 the most economically positive scenario in the medium- to long-term.

Obviously, investments in alternative energies, fuels and powertrains can bring important co-benefits. Domestic energy production would increase by some 10 percentage points, thus enhancing energy security and redirecting demand from imported energy goods and services to domestically produced ones. Furthermore, energy-related greenhouse gas emissions could be reduced considerably.

These results were obtained by an integrated simulation with the ASTRA and POLES models, in which POLES/BioPOL estimates the impacts in the energy system and ASTRA in the transport and economic systems. Thus some conceptual and model constraints shall be mentioned that may influence the project results. Firstly, the models broadly assume that market mechanisms work i.e. when new technologies become cost competitive there will be investors that invest in these technologies. As the models close the economic system by increasing the energy cost to finance the investment, it can reasonably be assumed that such investors exist. Secondly, the limitation of two of the models to the EU implies that global effects can hardly be illustrated in their full variety. These effects could act both in a dampening (e.g. if an increasing global demand for alternative energy technologies would benefit the EU's renewable energy industry) and a reinforcing way (e.g. if overall exports from the EU were reduced due to a world recession). Thus the latter effect was approximated in sensitivity tests showing that this would considerably lower the economic growth.

Given the unambiguous result that investments into energy efficiency and into alternative energies constitute the most effective instrument to tackle high oil prices it is obvious that policy interventions should provide incentives to stimulate investments that would reduce the fossil energy use instead of subsidizing the continued fossil energy use (e.g. by tax reductions or direct transfers). The latter will in particular worsen the effects in the medium-term because the economy will then not be prepared to shift away from fossil fuels and as the government budget is already under pressure due to higher unemployment payments and lower fuel tax revenues it will amplify the negative development of the government budget.

Timing of investment was identified as a crucial issue. Given the very high probability that oil prices will remain high as well as the significant probability that they will increase further in the next 5-10 years any investment made today in energy efficiency and close to marketable alternative energies will dampen the negative impact of high oil prices. Any delay will increase it. In this respect, some renewable technologies (e.g. wind energy) may offer the more advantageous option to cope with the timing requirement: At the capacity of large-fossil or nuclear-power plants, they can be installed within a few years considering planning and construction compared to more than a decade for a nuclear power plant.

Overall, the conclusion is that oil scarcity and oil price shocks can have significant negative impacts on the EU – but they need not, if the EU prepares itself adequately. Looking at the fast decreasing mid-term oil production forecast, the EU should have enough reasons to prepare.

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List of abbreviations

ASPO = Association for the Study of Peak Oil&Gas

ASTRA = Assessment of Transport Strategies

BTL = Biomass-to-Liquid

CA = Carbon Abatement

CDM = Clean Development Mechanisms

CER = Certified Emission Reduction

CHP = Combined heat and power

CIS = Community of Independent States

CNG = Compressed Natural Gas

CTL = Coal-to-Liquid

EIA = Energy Information Administration of the United States Department of Energy

EEA = European Environment Agency

EU = European Union

EU27 = EU member states (27 countries as of today)

EU15 = EU member states (15 countries) before May 2004

GDP = Gross Domestic Product

GHG = Greenhouse Gas emission

GTCC = Gas Turbine Combined Cycle

GTL = Gas-to-Liquid

Gtoe = Billion of tons oil equivalent

GWP = Global Warming Potential

HFC= Hydrogen/Fuel Cells

IEA = International Energy Agency

IEPE = Institute of Energy Policy and Economics

IET = International Emission Trading

ICE = Internal Combustion Engine

IGCC = Integrated coal gasification combined cycle

IIASA = International Institute for Applied System Analysis

IMF = International Monetary Fund

IOC = International Oil Companies

IPCC = Intergovernmental Panel on Climate Change

LNG = Liquefied Natural Gas

MMBD = Million Barrel per day

Mtoe = Million ton oil equivalent

NOC = National Oil Companies

NGL = Natural Gas Liquids

OD = Origin – Destination (- matrix)

OECD = Organisation for Economic Cooperation and Development

OPEC = Organisation of Petroleum Exporting Countries

PEM = Proton Exchange Membrane

PKM = Passenger kilometres - – transport of one person over one kilometre

POLES = Prospective On Long Term Energy Systems

PPP = Purchasing Power Parities

R&D = Research and Development

SAGD = steam-assisted gravity drainage

SFC = Solid oxide Fuel Cell

TKM = Ton kilometres – transport of one ton over one kilometre

TOE = Ton of oil equivalent

TWh = Billion kWh

UAE = United Arab Emirates

UN = United Nations

UNFCCC = United Nations Framework Convention on Climate Change

URR = Ultimate Recoverable Resources

US-DOE = US Department of Energy

WBCSD = World Business Council for Sustainable Development

WEC = World Energy Council

WETO = World Energy, Technology and Climate Policy Outlook

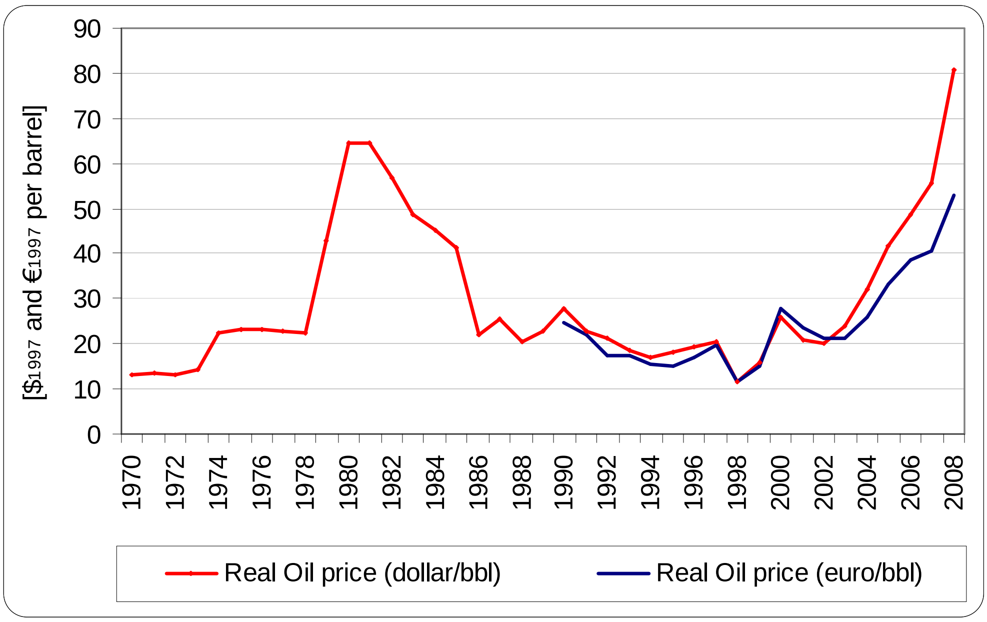
1 Introduction

1.1 The high prices of oil

After more than a decade of cheap oil around 20 US$/barrel, prices have steeply risen lately. Today's oil prices of more than 120 US$/barrel reflect the increasing demand from fast-growing economies like China and India as well as supply shortages originating from geopolitical tensions and short-term market speculative movements. The reduction of oil production from OECD countries, as well as political instability in the Gulf region, Nigeria, and Venezuela contributed as well to higher oil prices. The prices for natural gas followed the oil price trends in general.

Further, major oil exporting countries experience strong economic growth and in parallel subsidize their local oil demand such that the available oil exported to the world market is reduced by the growth of domestic demand. All these developments have strongly driven the oil prices since about 2003 (see Figure 1), though the understanding of the HOP! project is that the two major drivers are the growth in demand in particular from China and India as well as the capacity and geological limitations that hinder to extract more oil from wells.

Figure 1 Development of oil prices in real terms



Source: own elaboration on Swivel[1] and IMF data

[1] http://www.swivel.com/data_sets/show/1003291

The HOP! project deals with the impact of high oil price on the EU economy. As Figure 1 shows, we are currently facing the highest oil prices since 1970 i.e. even higher than during the oil crises in the 1970ies and 1980ies. However, past experiences can provide some indications about likely impacts, but differences exist between the current and the past situation, and the future can be expected to be even different from the time being. Thus the following section provides an overview of some key differences between the past, current and future situation with respect to oil price growth.

1.2 The differences with previous oil crisis

Even if the steeply increasing oil prices in 2007 and the first half of 2008 have some similarities to the oil price crises in the 1970s, today's oil price peaks are based on different grounds than previous ones; furthermore, economies and institutional settings developed substantially since the 1970s. For this reason it does not come as a surprise that the more recent oil price shocks (1999, 2002 and today) did not lead to similar effects on GDP and employment as those of the 1970.

A better understanding of the factors making out the difference may help in approaching the effects of future oil price peaks. An incomprehensive overview is shown in Table 1; some main items shall also be explained in the following.

- Current oil price highs reflect a demand-supply gap to a much larger extent than previous oil price shocks, notwithstanding the influence of speculation. On the one hand, demand for oil has been rising rapidly. Between 2002 and 2007, China more than doubled its oil imports and imports in India rose by more than 50%, leading to China and India accounting for some 12% of the global oil consumption by 2006 compared to less than 10% in 2002. On the other hand, supply has been rising at a lower pace influenced by spare production and refining capacities. It is likely to assume that future oil price shocks will also tend to reflect resource scarcities to a larger extent than the shocks of the 1970s (see e.g. Zittel and Schindler, 2007).

- The oil intensity of the economy halved over the past 30 years in developed countries on average, and was reduced by one third in developing countries (IMF, 2005).

- More flexible labour markets (and with this, less rigid wages) have contributed to dampen the effect of oil price shocks in the late 1990s compared to the 1970s (Blanchard and Gali, 2007). However, with regard to future oil price shocks, it remains questionable whether this factor will have a dampening or reinforcing effect, depending on e.g. the reactions of the unions.

- Monetary policy has learned from previous experience. In general, central banks primarily focused on keeping inflation at low levels during the recent oil price peaks (Blanchard and Gali, 2007).

- Oil substitutes such as electrical vehicles or biofuels, and fossil fuel substitutes in general (such as renewable energy carriers) have experienced important cost reductions together with major technical improvements over the past decades.

Table 1: Major differences between oil price crises over time

Past oil price crises	Current oil price crisis	Future oil price crisis
Nature of the oil price shock		
Supply shock (also sudden)	Demand shock (rather incremental, thus less of a crisis)	Demand and supply shock (incremental)
Expectation of short-term price hype because of:	Expectation of sustained price increase because of:	Sustained price increase because of:
- No resource constraint;	- Looming resource constraint;	- Obvious resource constraint
- Reserve/Production Ratio high;	- Reserve/Production ratio shorter (especially for crucial Non-OPEC players like Russia);	- Reserve/Production ratio shorter (especially for crucial Non-OPEC players like Russia),
- Prospects of availability of undiscovered resources at low extractions cost	- Some signs of exhaustion of cheap resources.	- Exhaustion of cheap resources
	- Low availability of non-conventional resources, with high extraction costs;	- Higher availability of non-conventional resources, with high extraction costs,
- Sufficient spare production capacity	- little spare production capacities;	
Economic environment		
Weak world economy	Booming world economy	Lower growth world economy e.g. population growth reduced
OPEC supply cut + price increase	China + India economic boom	China/India/Brazil/Russia important growing economies
Strong unions making pressure on wages	Weak unions due to globalisation, micro- and macroeconomic policies	Power of unions unclear
Monetary policies enforce inflation	Monetary policy devoted to avoid inflation in EU	Monetary policy careful in order to pass on price signal.
	Expansive deficit spending and monetary policy in USA	USA economic imbalances may prove to be unsustainable
	Cheap production in China and India led to deflation.	Deflationary effect of China, India will change in the future
Cold War hindered joint activities	G8 and UN help aligning activities, US dominates choice of inter-national agencies	G8 and UN helps aligning activities, China emerges as new world power
=> Weak institutional setting	=> Experienced institutional setting	=> Experienced institutional setting
Technology and Energy use		
Lock-in into fossil fuel energy technology	Availability of alternative technologies	Increased availability of alternative technologies, their competitiveness increases with oil price
High oil intensity (Euro Area in 1973: 0.15 kg oil per unit PPP-adjusted GDP, IMF 2005)	Oil intensity halved compared to 1973 (Euro-Area in 2002: 0.075 kg oil per PPP-adjusted GDP)	Oil intensity probably further decreasing.

Transport close to 100% dependent on oil	Transport in EU depends to 95% on oil	Significantly reduced dependence of transport on oil

1.3 The HOP! research project

The objective of the HOP! research project is to provide quantitative and qualitative analysis of direct and indirect impacts on the European economy of long term oil price escalation. The project approach, which focuses in particular to impacts on energy and transport sectors and employment, is based on the use of System Dynamics Modelling in order to capture the systemic effects, including feedbacks, that are determined by the modifications of oil and energy prices in our economies and societies.

The HOP! research project is co-funded by the European Commission DG Research and is undertaken by three partners, with TRT Trasporti e Territorio taking the lead and collaborating with Fraunhofer Institute Systems and Innovation research (ISI) and the Institute for Prospective Technological Studies of the European Commission DG JRC (IPTS).

In order to quantify direct and indirect impacts on the transport, energy and economic systems, the system dynamics modelling approach combines the global partial equilibrium energy model POLES (in a designated HOP! version) with the ASTRA model. The latter has been developed over the last decade as a strategic tool for the analysis of the interaction between transport, economy and environment. According to an already tested methodology, the two models are used in an interlinked way to run alternative scenarios corresponding to different sets of assumptions about cost of oil and alternative energy and transport technologies, making reference to the time horizon of the year 2050. The interaction of the two models allows a consistent assessment of reactions in the energy and transport sectors and the economy as a whole. For example, the link ensures that the contribution of the European transport sector on the global demand of energy is considered in detail, whilst at the same time the energy market conditions influence the evolution of transport demand.

The model-based quantitative analysis is combined with expert opinions, which were obtained primarily through two scientific events: the first workshop in November 2007, which focused on model assumptions and project methodology, and the final conference on 5th June 2008 during which the project results were discussed. Detailed summaries of the outcomes of these events are available on the HOP! project website www.hop-project.eu.

The HOP! project started with a thorough analysis of relevant studies and scenarios within the EU and internationally (in WP1). The aim was to create the basis for designing plausible scenarios and to stress the relationships between high-energy prices and consequences on the macroeconomic variables such as GDP. Several scenario studies prepared by major institutions active in the energy and transport field were selected for in-depth analysis. Their findings concerning world energy supply, energy demand, economic development and potential technological development were taken into account to develop the HOP! scenario framework.

The designing of a set of plausible scenarios for HOP! was the next step (WP2), which led also to the refinement of the models linkages. The scenarios were further revised on the basis of the outcome of the first project workshop, held on 8th November 2007. These scenarios differ mainly in terms of four main dimensions: **oil price** increase, **timing** and **steepness of**

the increment, **policy reaction** through taxation and through investment in alternative transport fuels and/or accelerated energy efficiency improvements.

1.4 The structure of the Deliverable

The report is divided into 6 sections, followed by an annex providing more details on the quantitative results, by references, a glossary, and a list of abbreviations.

- **Section 1** delivers an introduction to the global framework of high oil prices as well as to the HOP! project, and describes the outline of the report.

- **Section 2** provides a brief overview of the modelling approach: the basic functionality of the ASTRA model and the POLES/BioPOL model as well as the linkage between the two models.

- **Section 3** recalls the main impacts of high oil prices and explains how such impacts are modelled using the HOP! modelling tools and which impact chains are covered by the models and where further qualitative reasoning is required to come to conclusions.

- **Section 4** introduces the scenarios, presents the reference scenarios, provides an overview across the scenario results and afterwards focuses on specific impacts and results for energy, transport and economic system.

- **Section 5** adds qualitative assessment to the quantitative results obtained from the models and thus develops policy suggestions.

- Lastly, **section 6** provides the main conclusions from the assessment of the impacts of high oil prices on the EU economy.

2 The modelling approach

2.1 The use of the simulation models and their interaction

The HOP! project applies a combination of energy and transport-environment-economy models. Besides the exchange with scientists and stakeholders, the central part of the study consists of a model-based assessment of alternative future scenarios of high oil prices in order to quantify direct and indirect impacts on the transport, energy and economic systems.

The complexity of the real world often requires specialised models to be used for providing a simplified but detailed enough representation of key variables and relationships. For this reason, two models have been used in HOP!: the worldwide energy supply POLES model with its biofuel-focused extension BioPOL and the ASTRA model, developed as a strategic tool for the analysis of the interaction between transport, economy and environment.

In this chapter, the modelling tools are described.

2.2 The POLES model

The POLES (Prospective Outlook for the Long term Energy System) model[2] is a global sectoral simulation model for the development of energy scenarios until 2050. The dynamics of the model are 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 prices

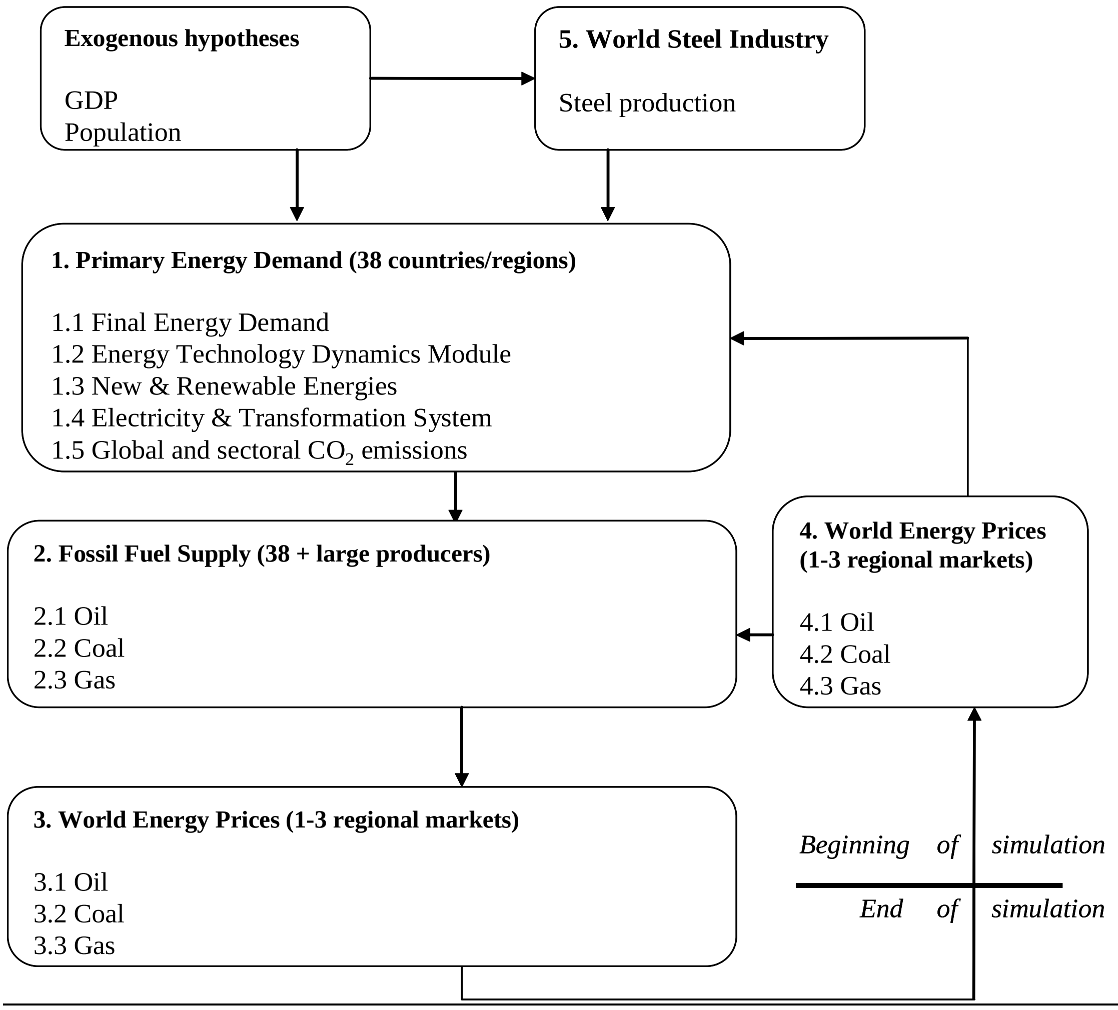
The model is developed within the framework of a hierarchical structure of interconnected modules at the international, regional and national level. It contains technologically-detailed modules for energy-intensive sectors, including power generation, production of iron and steel, aluminium and cement, as well as modal transportation sectors.

In each sector, energy consumption is calculated both for substitutable fuels and for electricity. Each demand equation contains an income or activity variable elasticity, a price elasticity, captures technological trends and, when appropriate, saturation effects. Particular attention is paid to the treatment of price effects.

In POLES, the world is divided into 47 regions/countries, for which the model delivers detailed energy balances. These can be aggregated to main regions: North America, Central America, South America, European Union, 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.

[2] The POLES model is continuously being updated and enhanced with more detail. For the HOP! analysis, a dedicated model version was developed that builds on the POLES version used in the World Energy Technology outlook until 2050 and the TRIAS project, but includes additional details on e.g. oil production.

Figure 2 POLES modules and simulation process



The model structure corresponds 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 CO_2 sector emissions.

The main exogenous variables are the population and GDP (which are derived iteratively with ASTRA in the HOP! project, see below), for each country / region, the price of energy being endogenised in the international energy market modules. 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. 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.

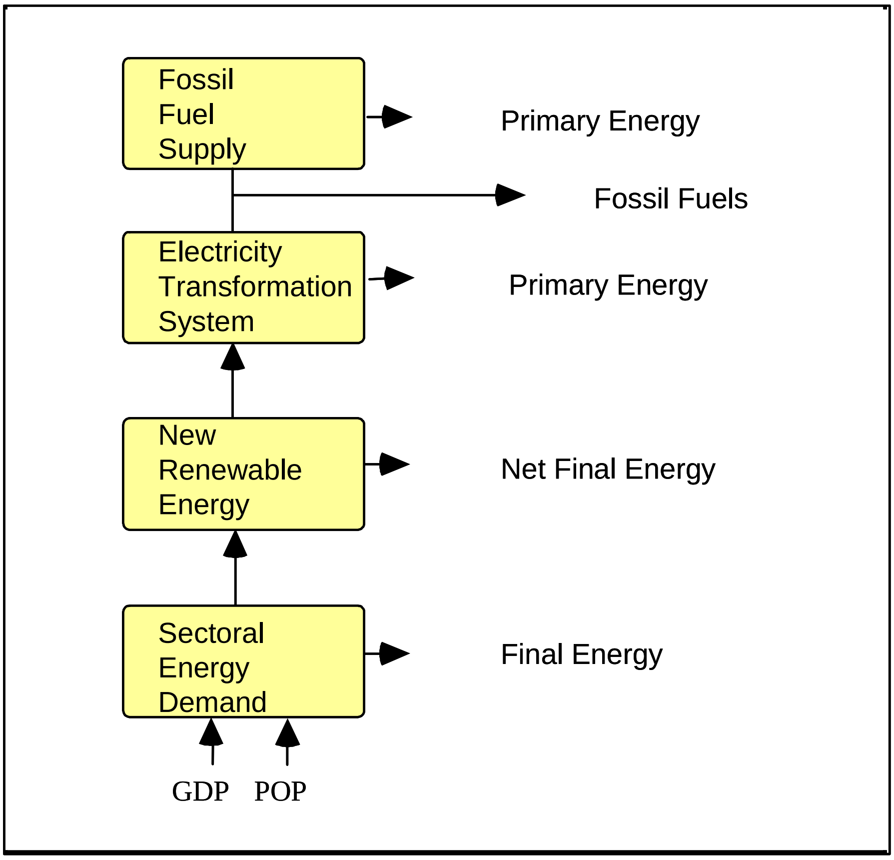
2.2.1 Vertical integration

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

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

As indicated in Figure 3, this structure allows for the simulation of a complete energy balance for each region.

Figure 3 POLES vertical integration



2.2.2 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. A single world oil market is assumed (the "one great pool" concept), while three regional markets (America, Europe and Asia) are identified for coal, in order to take into account different cost, market and technical structures. Natural gas production and trade flows are modelled on a bilateral trade basis, thus allowing for the identification of a large number of geographical specificities and the nature of different export routes.

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 2.

In each sector, the energy consumption is calculated separately for substitutable technologies and for electricity, taking into account the 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 2 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

2.2.3 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 (URR) 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. 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, i.e. when the world oil price exceeds the cost of an unconventional source of oil (IEA, 2005).

Oil prices in the long term depend primarily on the relative scarcity of oil reserves (i.e. the reserves-to-production ratio). In the short run, the oil price is mainly influenced by spare production capacities of large oil producing countries. Furthermore, in the HOP! version a 'market power' price add-on is simulated in dependence of the geographical distribution of oil reserves. It must be noted that the endogenous price forming mechanism cannot model the price volatility induced by short term market expectations.

2.2.4 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).

2.2.5 The Biofuels Model; BioPOL

The biofuels model (BioPOL), developed for previous projects like PREMIA (Wiesenthal et al., 2007) and the TRIAS project (Krail et al., 2007), 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 in the EU-27 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 4 Interaction of factors simulated in the biofuels model BioPOL

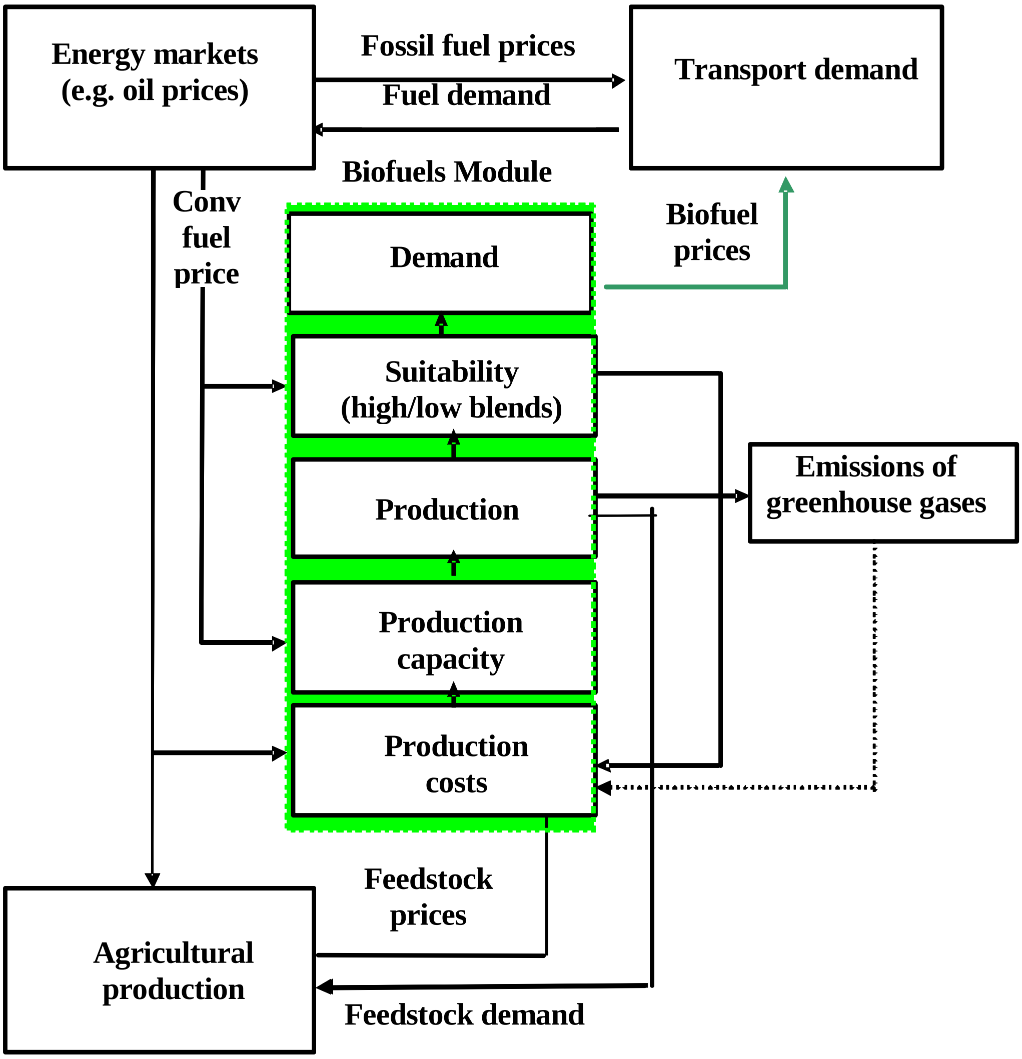


Figure 4 summarises the way the different factors interact. Impacts are traced in the various sectors. The chart is restricted to the EU domestic biofuels market. Regarding imports, biofuels prices are given as exogenous variables as well as their maximum penetration levels. Other main exogenous parameters 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 The ASTRA model

ASTRA stands for Assessment of Transport Strategies. The model is 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 model is based on the System Dynamics methodology, which similar as the POLES approach can be seen as a recursive simulation approach, and follows system analytic concepts, which assume that the implemented real systems can be conceived as a number of feedback loops that are interacting with each other. These feedback loops are implemented in ASTRA and the model is calibrated for key variables for the period 1990 until 2003. The spatial coverage extends over the EU27 countries plus Norway and Switzerland. Each country is further disaggregated into at maximum four functional spatial zones classified by their settlement characteristics. A detailed description of ASTRA can be found in Schade (2005) with extensions described in Krail et al. (2007).

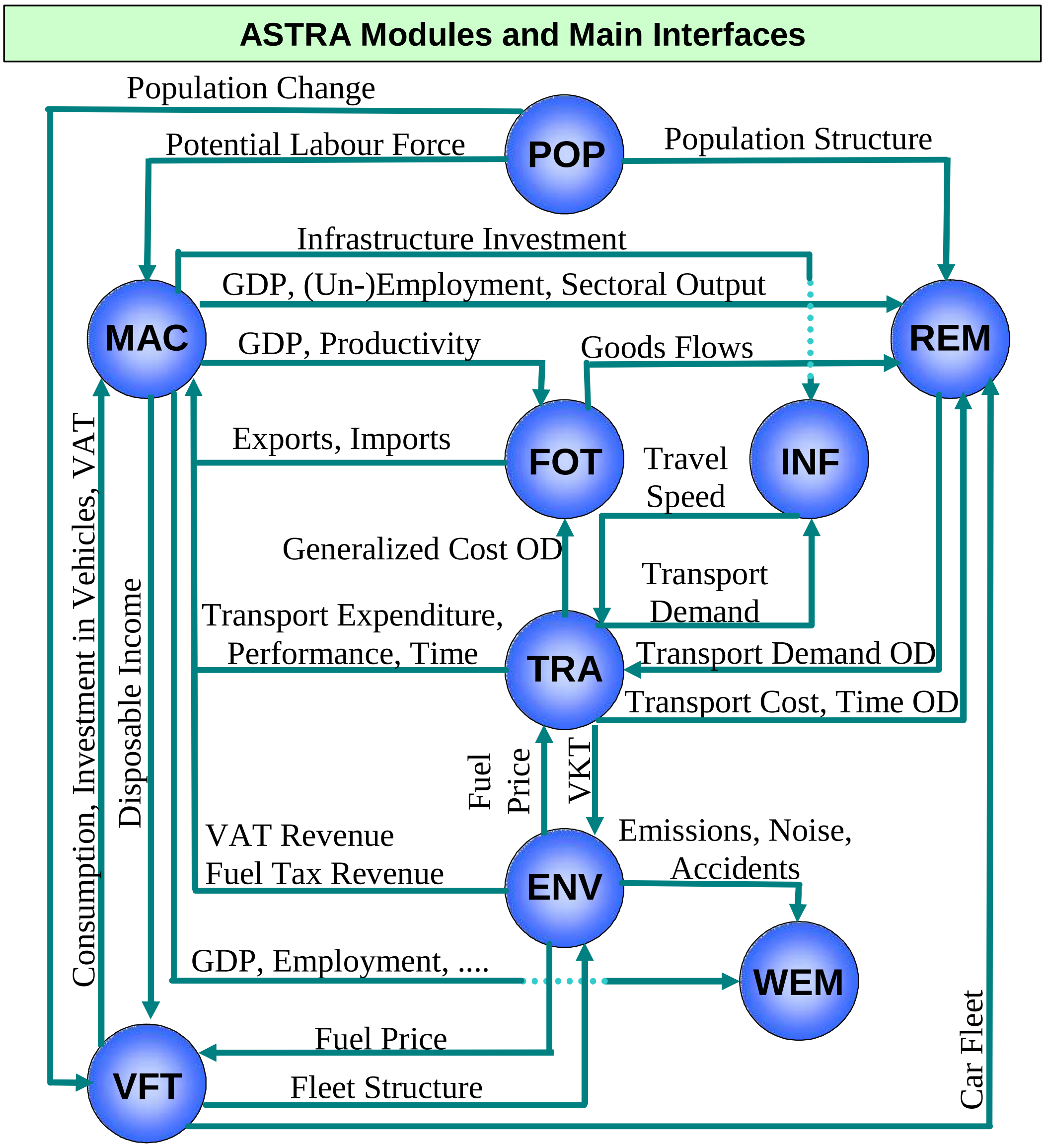
2.3.1 Overview on Modules of ASTRA

The ASTRA model consists of nine modules that are all implemented within one Vensim system dynamics software file:

- Population module (POP),
- Macro-economic module (MAC),
- Regional economic module (REM),
- Foreign trade module (FOT),
- Infrastructure module (INF),
- Transport module (TRA),
- Environment module (ENV),
- Vehicle fleet module (VFT) and
- Welfare measurement module (WEM).

An overview on the nine modules and their main interfaces is presented in Figure 5. From the figure, it is apparent that modules are not independent, but linked together in manifold ways. A short description of the modules and of their main linkages is provided below.

Figure 5 Overview on the structure of the ASTRA modules



Abbreviations:

POP = Population Module
MAC = Macroeconomics Module
REM = Regional Economics Module
FOT = Foreign Trade Module
INF = Infrastructure Module
TRA = Transport Module
ENV = Environment Module
VFT = Vehicle Fleet Module
WEM = Welfare Measurement Module

2.3.2 Transport

On the transport side, ASTRA provides 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. Four modules are involved as described below.

2.3.2.1 Transport Technology and Infrastructure

The Infrastructure Module (INF) provides the network capacity for the different transport modes. Infrastructure investments derived both from the economic development provided by the MAC and from infrastructure investment policies alter the infrastructure capacity. Using speed flow curves for the different infrastructure types and aggregate transport demand the changes of average travel speeds over time are estimated and transferred to the TRA where they affect the modal choice.

The Vehicle Fleet Module (VFT) describes the vehicle fleet composition for all road modes. Vehicle fleets are differentiated into different age classes based on one-year-age cohorts and into different emission standard categories. The car vehicle fleet is developing according to income changes, development of population, fuel prices, fuel taxes, maintenance and purchase cost of vehicles, mileage and the density of filling stations for the different type of fuels. Vehicle fleet composition of buses, light-duty vehicles and heavy-duty vehicles mainly depends on travelled kilometres and the development of average annual mileages per vehicle of these modes. The purchase of vehicles is translated into value terms and forms an input of the economic sectors in the MAC that cover the vehicle production.

2.3.2.2 Transport Demand

The Regional Economic Module (REM) mainly calculates the generation and spatial distribution of freight transport volume and passenger trips. The number of passenger trips is driven by employment situation, car-ownership development and number of people in different age classes using trip rates for each group. Trip rates are fixed over time (i.e. individuals belonging to a given group always make the same number of trips). This is consistent to some evidence when all trips (i.e. including short non-motorised trips) are considered. The growth of overall mobility is therefore depending on the growth of population, the shift of individuals to groups with higher mobility habits (e.g. from non-motorised to motorised) and to larger distances. Trip generation is performed individually for each of the 71 zones of the ASTRA model Distribution splits trips of each zone into three distance categories of trips that remain within the zone and two distance categories crossing the zone borders and generating OD-trip matrices with 71x71 elements for three trip purposes.

Freight transport is driven by two mechanisms: Firstly, national transport depends on sector production value of the 15 goods producing sectors where the monetary output of the input-output table calculations are transferred into volume of tons by means of value-to-volume ratios. For freight distribution and the further calculations in the transport module the 15 goods sectors are aggregated into three goods categories. Secondly, international freight transport i.e. freight transport flows that are crossing national borders are generated from monetary Intra-European trade flows of the 15 goods producing sectors. Again transfer into volume of tons is performed by applying value-to-volume ratios that are different from the ones applied for domestic transport. In that sense the export model provides generation and distribution of international transport flows within one step on the base of monetary flows.

The matrices estimated in the REM module are the major input of the Transport Module (TRA). Using transport cost and transport time matrices the transport module performs the modal-split for five passenger modes and three freight modes. The cost and time matrices depend on influencing factors like infrastructure capacity and travel speeds both coming from the INF module, structure of vehicle fleets, transport charges, fuel price or fuel tax changes.

Depending on the modal choices, transport expenditures are calculated and provided to the macroeconomics module. Changes in transport times are also transferred to the macroeconomics module such that they can influence total factor productivity. Considering load factors and occupancy rates respectively, vehicle-km are calculated.

2.3.3 Economy

The economic models implemented in ASTRA reflect the view of the economy as being built out of several interacting feedback loops (e.g. income – consumption – investment – final demand – income loop, the trade – GDP – trade loop etc.). These feedback loops are built out of separate models, without making reference to one specific economic theory, only. Investments are partially driven by consumption following Keynesian thought, but exports are added as second driver of investment. Neoclassic production functions are used to calculate the production potential of the 29 economies. Total factor productivity (TFP) is endogenised following endogenous growth theory by considering sectoral investment and freight travel times as drivers of TFP.

The purpose of the model is to analyse long-term and strategic developments. Thus the model concentrates on describing the real economy and to a large extent neglects the short-term oscillations caused by the financial system. Two effects related to the financial markets are considered in ASTRA: (1) crowding out of private investment due to increased government debt and thus increased interest rate, and (2) dampening impact of inflation on disposable income induced by the higher energy prices.

ASTRA itself incorporates the micro-macro-bridges from the bottom-up transport system models to the economy. For the HOP! project also the micro-macro-bridges from the bottom-up energy system model, which is provided by POLES, to the economy have to be established. These linkages and their further take-up in the economic models of ASTRA are presented in Figure 6.

Broadly spoken the impacts from the energy system can be divided into those on (1) the consumers demand, (2) on the production of goods and services, and on (3) the trade balance of the 29 economies. Consumers demand is directly affected by the higher energy prices via the budget effect (more money spent for energy demand and thus less money for other sectors) and the substitution effect (prices of goods and services change different as a reaction to higher energy prices and depending on energy content and elasticities the sectoral consumer demand will be restructured i.e. broadly spoken more energy intensive goods and services will be substituted by less energy intensive ones).

The production of goods and services reacts in two ways: first, adaptation of the energy system estimated by POLES leads to both additional investments in alternative energy technologies and efficiency and avoided investments into conventional energy technologies. Second, changes of energy prices, and thus also transport cost, affect the exchange of intermediate goods in the input-output-table. The latter impact then affects the value-added of each sector, the employment and finally the GDP from the supply side, while the direct impacts on the consumer side rather affect the GDP on the demand side.

Thirdly the impact on the trade balance enters the model via the imports of energy in the energy sector leading to a negative impact on the demand side of GDP, as well as via a reduction of the value-added of the energy sector.

Figure 6 Feeding the influences of energy system changes into the economy in ASTRA

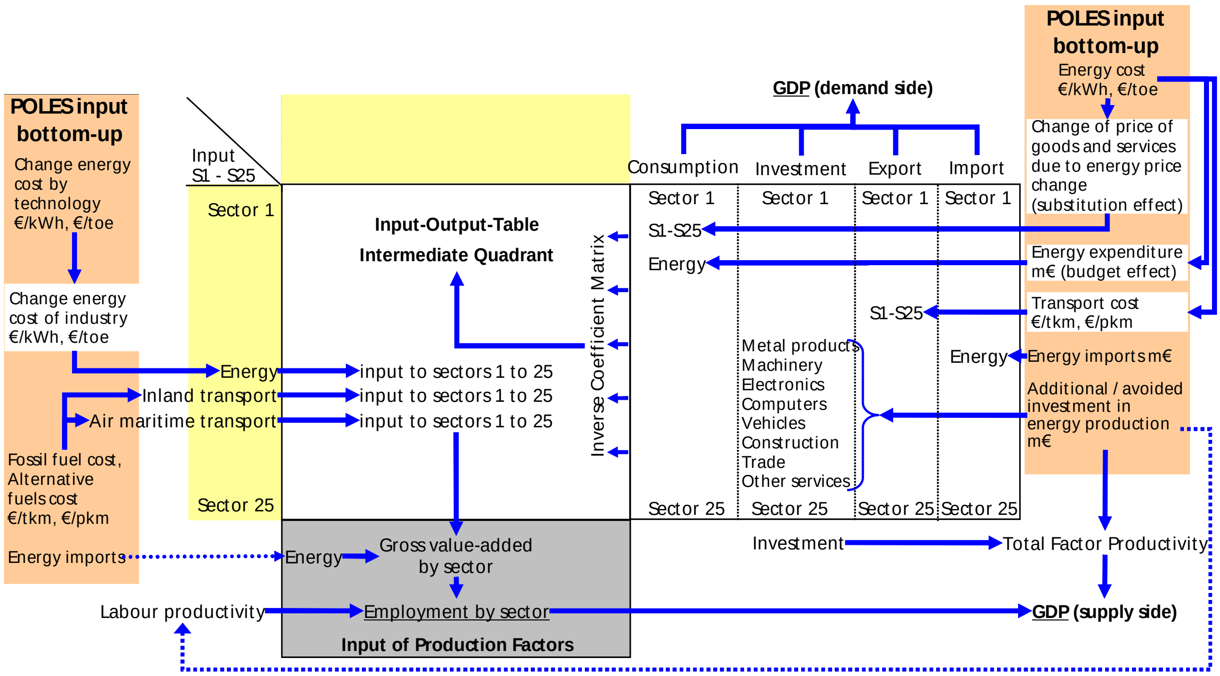


Figure 6 concentrates on showing the bottom-up inputs from the energy sector from POLES. Further, but similar effects emerge from inputs from the transport sector that come from the ASTRA transport module, but are not shown in the figure.

The following three sections briefly describe the modules relevant for the economic analysis applying ASTRA in HOP!.

2.3.3.1 Households

The Population Module (POP) provides the population development for the 29 European countries with one-year age cohorts. The model depends on fertility rates, death rates and immigration of the EU29 countries. Based on the age structure, given by the one-year-age cohorts, important information is provided for other modules like the number of persons in the working age or the number of persons in age classes that permit to acquire a driving licence. POP is calibrated to EUROSTAT population predictions. Of relevance for the economic models are in particular the potential labour force, i.e. the number of persons in the age class of 18 to 65 years, the number of retired persons as this affects the social transfer payments (i.e. the payments of pensions) and the number of children as this also affects the social transfer payments (i.e. the payment of child allowances). However, these are not changing between the HOP! scenarios.

2.3.3.2 Macro-economy

The MAC module provides the national macro-economic framework. Six major elements constitute the functionality of the macroeconomics module. The first is the sector interchange model that reflects the economic interactions between 25 economic sectors of the 29 national economies. Demand-supply interactions are considered by the second and third element. The second element, the demand side model depicts the four major components of final demand: consumption, investments, exports-imports and the government consumption.

The supply side model reflects influences of three production factors: capital stock, labour and natural resources as well as the influence of technological progress that is modelled as total factor productivity. Endogenised Total Factor Productivity (TFP) depends on sectoral investments, freight transport times and sectoral labour productivity changes. Investments are affected by a major positive loop as investment increase capital stock and total factor productivity (TFP) of an economy leading to growing potential output and GDP that drives income and consumption feeding back to an increase of investments. However, this loop could also be influenced by other interfering loops that would break the growth tendency (Figure 7):

1. In ASTRA it is accepted the existence of the ‘crowding out’ effect, therefore increasing government debt could provide a negative impact on investment.

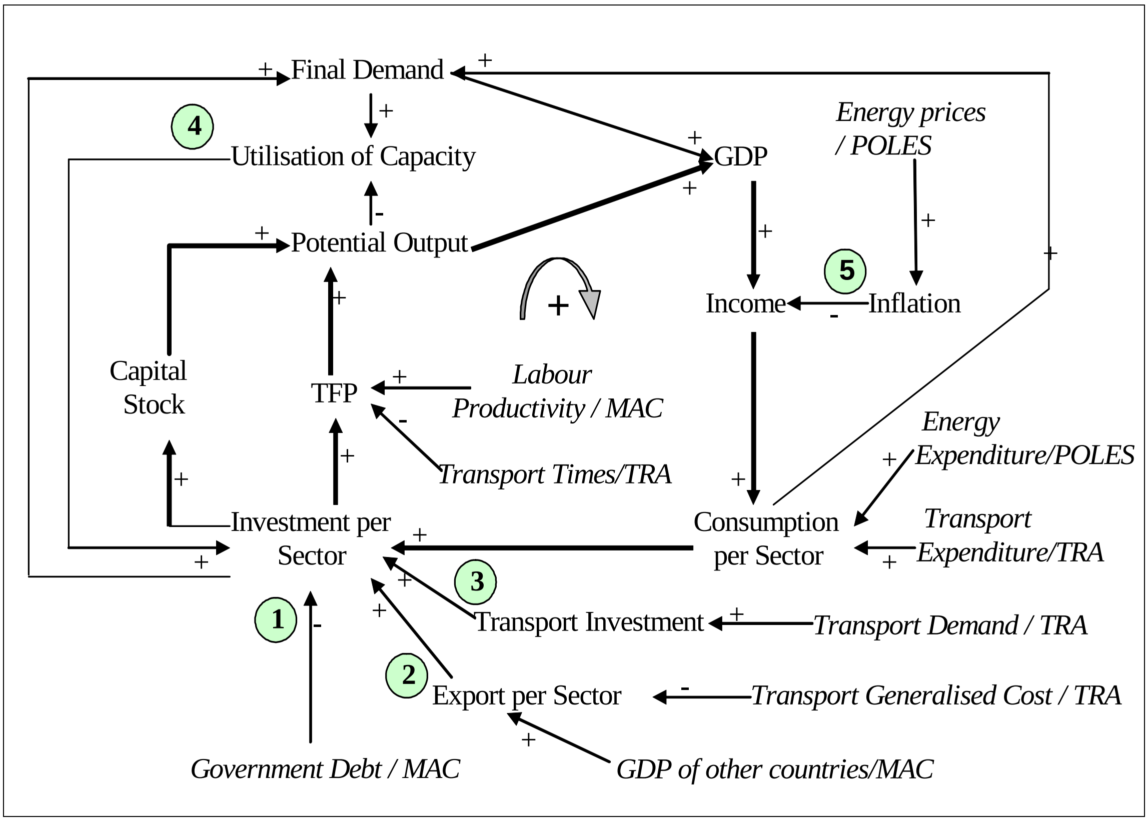
2. Also exports e.g. influenced by growing transport cost could decrease, which in turn would reduce investments.

3. Changes in transport demand e.g. modal-shifts due to policies that would shift demand from modes with high investment needs to modes with low investment needs per unit of demand would reduce investments.

4. Different growth rates between the supply side (potential output) of an economy and the demand side (final demand) change the utilisation of capacity. In case of demand growing slower than supply utilisation would be reduced affecting also the investment decisions. Finally that would also decrease investments.

5. Substantial changes of energy prices could cause inflation, thus reducing disposable income.

Figure 7 The investment feedback loop in ASTRA



The fourth element of MAC is constituted by the employment model that is based on value-added as output from input-output table calculations and labour productivity. The fifth element of MAC describes government behaviour. As far as possible government revenues and expenditures are differentiated into categories that can be modelled endogenously by ASTRA and one category covering other revenues or other expenditures. Categories that are endogenised comprise VAT and fuel tax revenues, direct taxes, import taxes, social contributions and revenues of transport charges on the revenue side as well as unemployment payments, transfers to retired and children, transport investments, interest payments for government debt and government consumption on the expenditure side.

Sixth and final of the elements constituting the MAC are the micro-macro bridges. These link micro- and meso-level models, for instance the transport module or the vehicle fleet module to components of the macro-economics module. That means, that expenditures for bus transport or rail transport of one origin-destination pair (OD) become part of final demand of the economic sector for inland transport within the sectoral interchange model.

2.3.3.3 Trade

The Foreign Trade Module (FOT) is divided into two parts: trade between the EU29 European countries (INTRA-EU model) and trade between the EU29 European countries and the rest-of-the world (RoW) that is divided into nine regions (EU-RoW model with Oceania, China, East Asia, India, Japan, Latin America, North America, Turkey, Rest-of-the-World). Both models are differentiated into bilateral relationships by country pair by sector.

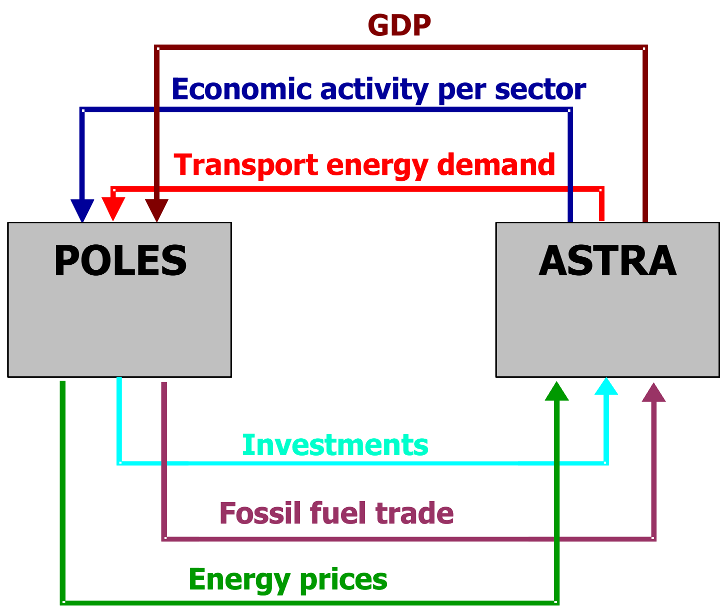
The INTRA-EU trade model depends on three endogenous and one exogenous factor. World GDP growth exerts an exogenous influence on trade. Endogenous influences are provided by: GDP growth of the importing country of each country pair relation, relative change of sector labour productivity between the countries and averaged generalised cost of passenger and freight transport between the countries. The latter is chosen to represent an accessibility indicator for transport between the countries.

The EU-RoW trade model is mainly driven by relative productivity between the European countries and the rest-of-the-world regions. Productivity changes together with GDP growth of the importing RoW-country and world GDP growth drive the export-import relationships between the countries. Since, transport cost and time are not modelled for transport relations outside EU29 transport is not considered in the EU-RoW model. The resulting sector export-import flows of the two trade models are fed back into the macroeconomics module as part of final demand and national final use, respectively. Secondly, the INTRA-EU model provides the input for international freight generation and distribution within the REM module.

2.4 Interaction between ASTRA and POLES models

In HOP!, the quantitative analysis of the scenarios required an integrated use of both POLES and ASTRA. As explained in the previous sections, POLES covers the energy field with supply of energy resources on world level, energy demand and development of energy prices with an exogenously given economic development, while ASTRA covers the transport field with infrastructure supply and transport demand as well as a macro-economic model that endogenously forecasts economic development under varying policy conditions.

Figure 8 Links between POLES and ASTRA



The two models have been linked as summarised in Figure 8:

- ASTRA received from POLES: fuel and energy prices, the value of investments for developing alternative energy sources and for improving efficiency, the overall energy demand and domestic energy production as well as the import of fossil fuels;

- POLES received GDP development, energy demand for the transport sector and the economic activity per sector from ASTRA.

The simulation of scenarios was an iterative process. POLES started the simulation to provide starting results for ASTRA, whose interface results were transferred to POLES. A new scenario run was then replicated in POLES to produce updated outcomes for ASTRA and so on. At the end of each iteration, results were compared with those of the previous iteration and the process was stopped when in both models differences between the two scenario simulations were sufficiently small.

It is worth to note that the exchange of variables between ASTRA and POLES consists of two major parts: (1) an iterative process involving the evolution of fuel price and transport demand, and in parallel (2) an iterative process involving economic activity, energy demand and investments in the energy system. In HOP!, taking fuel demand from the ASTRA model, POLES computed the fuels price development. In turn, the fuels (resource) price forecast by POLES were used in ASTRA to revise the transport demand forecast, which was again fed into POLES and so on. Similarly, economic activity by sector from ASTRA drove energy demand requiring investment in the energy system, which depends on energy resource prices and technology cost in POLES, which then fed back energy prices and investment into ASTRA to compute a new level of economic activity, and so on.

The first loop allows taking into account the complex relations between oil price, fuels price and transport demand. Indeed, even if there is a clear correlation between oil price and fuels price, it would not be correct to assume that the hypothesis concerning the former could be applied as such to the latter. Actually, historical trends show that fuel price is generally less volatile than oil price and this is very important for a correct simulation of impacts.

Also other variables are exchanged at any iteration and contribute to adapt the model forecasts, even if their impact on the results of the model receiving the inputs is smoother. Additionally, ASTRA and POLES endogenously simulate a common set of variables (e.g. population, GDP growth) which are comparable across the two models.

2.4.1 Linkage for the sensitivity analysis

A special kind of linkage between POLES and ASTRA takes place when a sensitivity analysis is carried out. As the modelling results depend on the iteration between the models, as explained above, the sensitivity analysis has to involve both tools. However, it is unfeasible to perform an iterative process by exchanging distributions of values rather then single values. Therefore, the sensitivity analysis consists of a procedure in three steps:

a) An exogenous distribution is applied to the variables chosen for the analysis in the model where the variables are primarily simulated. For instance, in the TRIAS project, POLES varied the assumed resource base of fossil fuels i.e. the known and assumed reserves of oil, gas and coal (Schade et al. 2008).

b) From the sensitivity analysis a range of values is obtained for the variables to feed into the other model. For instance, in TRIAS a range for the prices of different types of fuels (fossil fuels, hydrogen and biofuels) and also a range of trade of fossil fuels resulted from the analysis.

c) These results are used as input for the sensitivity analysis in the other model.

In HOP!, the scenarios already include a wide variation of prices of fossil energy resources, such that a sensitivity analysis focuses on other issues. In particular, two issues are relevant for a sensitivity analysis:

(1) since world GDP is not endogenously modelled reactions of the world economy have to be fed exogenously into the models. This is done in parallel in ASTRA and POLES, receiving from ASTRA a response of EU GDP to the world GDP changes and from POLES a response of the fuel prices.

(2) Since, in POLES the price signal of the energy prices endogenously causes the energy system to react by adapting technologies and energy demand through changes of investment patterns such that physical energy shortage never occurs such a shortage is tested as a sensitivity analysis in ASTRA, only.

3 Modelling of direct and indirect impacts of oil price growth

This section briefly discusses the major direct and indirect impacts that were expected to be caused by high oil prices and the way how these are considered by the applied models. The notion of **direct** impacts indicates the impact on the usage of oil and other fossil fuels in the energy system and the transport system, i.e. these impacts directly affect the user of fossil fuels. **Indirect** impacts appear first in the economic system as a consequence of the direct impacts in the energy and transport systems. They may affect all sectors (e.g. by higher transport cost, changed consumption patterns) and all agents like households, industry or government. These indirect impacts could either feed back to the energy or transport systems (e.g. by changed demand for energy or transport) or could be carried forward via economic mechanisms over time e.g. lower consumption would lead to lower GDP and thus to lower disposable income in the next period. Such indirect impacts could also be called the second round effects or secondary impacts.

Given the purpose of HOP! and the features of the modelling tools, impacts of high oil prices can be separated into direct effects on the energy system and the transport system as well as indirect effects on the economic system. It is important to take into account that the changes taking place in one system, affects the other system as well. For instance, if alternative transport fuels enter the market to a large extent, the composition of the vehicle fleet and the transport costs of different transport modes are also affected. As a consequence, the increase of transport costs has an impact on the production costs and, hence, on GDP. Feedbacks from the economy also exist too: if GDP, investment and trade would change, energy demand and transport demand will change as well. The following two sections present the major impact chains expected to be relevant for the three domains energy, transport and economy. Together with the discussion of these impact chains strengths and potential gaps of the applied models to consider these impacts are identified.

3.1 Direct impacts of High Oil Prices

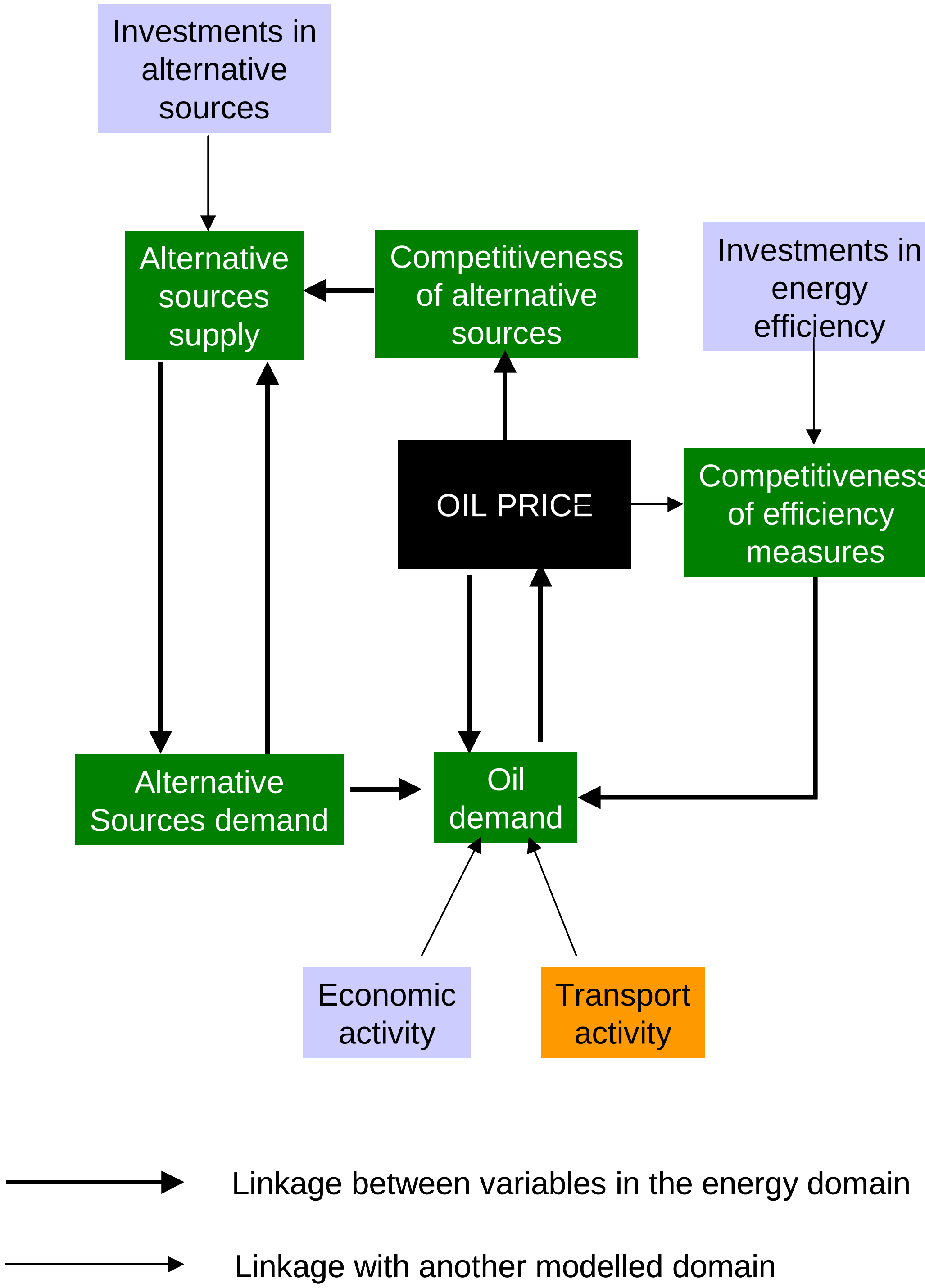
3.1.1 Direct impacts: reactions of energy system

Figure 9 below schematically describes the main impacts of an oil price shock on the energy system:

- First of all, high oil prices would tend to reduce energy consumption through a combination of lower demand for energy services and rising energy efficiency (negative feed-back on demand growth rate). In return, lower energy demand would slow down the oil price increase, providing a stabilising mechanism.
- At the same time, unconventional oil would become more competitive in terms of price and its supply can grow. Also some conventional oil fields that are today not

economically viable might become exploitable at the new oil price. Due to the increasing price, new and more costly oil exploration technologies could become competitive, leading to an increase of the oil supply. These effects would dampen the oil prices increase.

Figure 9 Impacts of high oil prices on the energy system



Also substitutes for the various oil derivates would become more competitive, thus experiencing an increased deployment. For example, biofuels would replace some fossil-based petrol and diesel in the transport sector, households and industry may shift from the use of oil to electricity, which is primarily produced from non-oil carriers. However, as a general principle high oil prices would also push the prices of oil substitutes upwards, depending on the technology (e.g. for biofuels energy costs account for up to 15%). Also the prices of natural gas would experience an increase, leading to a rise in the use of coal, renewable energies and nuclear power in the power sector. In return, the higher demand for those energy sources would drive up their prices.

While all technological options described above tend to counterbalance the oil price shock by reducing demand of conventional oil and thus driving down the prices again, there are important differences between responses on the supply side (i.e. unconventional oil and oil substitutes) and demand side (i.e. lower energy consumption). Energy efficiency consists of providing the same energy services with less energy consumption. Therefore, it implies also less environmental external costs (GHG emissions, land use, air pollution etc.). On the other hand, a number of non-conventional oil resources are expensive also in environmental terms. They exhibit not only increasing marginal private costs, but also increasing marginal external costs. Under this point of view, supply and demand-side measures to counterbalance an oil shock outburst are not equal as supply-side measures tend to be environmentally more harmful than demand-side measures.

Key for realizing the above changes is the availability of investments into energy efficiency measures, unconventional oil and alternative energy sources. Private investments to exploit oil fields and to increase supply of alternative sources of energy can be undertaken provided that they are perceived as profitable and resources are available (see below). If private investors fail to mobilise the required amount of capital investments because of any kind of market failure, public investments can also be undertaken.

Even under the assumption of the required investments becoming available, there will be a delay between the oil price shock and the responses shown above, unless preventive action had been taken. The installation of new capacities in the upstream sector can reach some five to eight years. Production of biofuels could not be increased significantly in some weeks or months. Even if large amount of hydrogen could be produced, the development of the distribution infrastructure will take some time. Planning procedures on the construction of new nuclear plants could take a decade even if nuclear energy would become relatively cost competitive.

In conclusion, the to-be-expected responses of the energy system to a high oil price can be summarized as follows:

- Higher oil prices will provide an incentive to lower oil consumption either through a reduction in demand or through oil or transport fuel substitutes:

- The increasing energy price will initiate additional investments into energy efficiency, therefore lowering the overall demand. Furthermore, consumer may reduce their demand for energy services.

- Alternative energy sources become increasingly competitive in terms of price and are thus likely to gain market shares. However, also the energy costs of alternative transport fuels will rise due to their need of energy as input in the production. On the other hand, increased deployment of alternative energy technologies could bring down the cost due to learning effects.

- The order and the speed of these changes primarily depend on the availability of investments, and the time needed for bringing new technologies into the market.

The change of oil demand due to higher oil prices is modelled in the global energy model POLES (in its HOP! version), with ASTRA providing a more detailed input concerning the demand of the transport sector as well as the growth rate of the economy. POLES simulates the world energy market and the global balance of energy demand and supply. This means that there is a competition between regions to use oil at a given price, yet the model cannot simulate "strategic" behaviour of the oil producer countries to increase their global power. However, in the POLES version used for HOP! a concentration of oil resources in few regions would allow the producers to increase their profit margin, reflecting the higher market power.

The assessment with the POLES model quantifies the following three main effects in the energy sector that results from high oil prices in a consistent way: (1) demand reductions; (2) switch to alternative energy sources; (3) exploitation of unconventional oil resources. The latter two effects are reflected in the model by accelerated investment prompted by the expectations of higher energy prices. Quantitative estimates for the additional investments in these substitutes have been derived with the analytical toolbox used. As far as these additional investments materialise, current energy prices are assumed to rise in order to absorb them accordingly.

The approach chosen has been to estimate demand reductions for the residential and the industrial sector with POLES, while the transport demand reductions (as well as the growth rate of the economy) are calculated in ASTRA, a model with more technological detail in the transport sector(s). Fuel demand is determined considering the development of oil prices and its substitutes. The market penetration of these substitutes (including non-conventional oil) is simulated in POLES and BioPOL (for the EU in the latter). Increasing feedstock prices for rising biofuels production are taken into consideration. For the second generation production technologies of biofuels, unit cost reductions are assumed to be achievable from learning effects and economies of scale.

Note that the quantitative framework used assumes that the required investments will be made available and alternative energies are installed as long as they are competitive (yet with some time constraints reflecting the time needed for permission, planning and construction of installations). It is thus implicitly assumed that all the energy demanded can be produced, such that no physical energy supply shortages occur. The changes of investments and different cost of feedstock to produce energy are reflected in changes of the energy prices such that the changes on the energy supply side (i.e. adapted investments) and the energy demand side (i.e. adapted energy prices) correspond to each other.

In brief, the HOP! modelling tools implicitly assume that market mechanisms and adequate policy plans are able to anticipate the need to change the energy system to manage adaptation of energy supply to high oil prices as well as to demand. Price signals are assumed to work and investments are assumed to be available and effective in a time frame short enough to avoid energy shortage.

3.1.2 Direct impacts: reactions of the transport system

The primary direct impact on the transport system expected from the increment of the oil price is the growth of operating costs of all modes of transport since in EU countries oil is largely the basic source of energy used in the transport sector. Consequently, also user costs (fares) are expected to rise.

The expected impact is different across the various modes. Concerning the weight of the energy cost on the operating costs, there are significant differences across transport modes. An important aspect to be taken into account is the distinction between a short term perspective and a longer term one. In the shorter term, variable costs are the relevant ones (e.g. car drivers do not take into account the amortisation of the vehicle when they decide whether using their car for a trip). Fuel is quite a significant share of variable operating costs for several modes (e.g. air transport). In the longer terms all operating costs are taken into account and therefore the weight of energy or fuel becomes lower. Summing up, it can be expected that the increment of the transport costs hits the modes in a diverse extent:

- Private cars would probably become quite more expensive (unless a compensatory intervention on fuel taxes was put into practice, this possibility is addressed in one HOP! scenario, see section 4.5.4).

- Motorcycles cost would also increase significantly in absolute terms, even though in comparison to private cars they would become more competitive.

- Public road transport should probably adequate tariffs as well to cover the increasing cost of fuel. The public authorities could also decide to support personal mobility by increasing subsidies to road public transport to limit tariffs growth. Of course, this would mean further public expenditure.

- Air tariffs would be increasing, even if the user price structure in the air market is complex and often poorly linked to operating costs. However, on average the increment of tariffs would be unavoidable and low cost airline services should have some more problems than conventional ones[3].

- On the freight modes side, trucks cost would be increased. As the road haulage market is a very competitive one, profits are very low so there is no room to absorb the increment of fuel cost. At the same time, however, given the high level of competition, road hauliers are often price takers, so also transferring higher costs on user tariffs is not straightforward. Thus, rather than higher road transport costs, an indirect economic impact in terms of either higher public expenditure to subsidise hauliers or higher unemployment of hauliers could rise[4]. However, in the end it would be probably unavoidable that truck costs would be increased.

[3] Some symptoms that especially budget air companies are suffering for high oil prices can be found on newspapers at the time this deliverable is being written.

[4] This is actually happening in Italy at the very time this deliverable is being written

- As for passengers, also for rail freight tariffs the direct impact on tariffs would be probably low, even if indirect impacts due to higher labour cost could also contribute to raise tariffs.

- Inland navigation and maritime shipping fares are heavily driven by market conditions but, as for air, an effect of higher fuel cost would become visible on average, even if the impact should be relatively low if compared to the road sector. The largest impact would take place for maritime deep sea transport, which is not addressed in HOP! however.

This primary impact of an increment of transport costs should have a number of further effects within the transport system, namely:

a) Reduction of the personal motorized mobility;

b) Pressure for reducing mobility of goods;

c) Mode shift towards less expensive modes;

d) Pressure on organising transport more efficiently;

e) Pressure on developing more efficient transport means.

The reduction of personal mobility would be realised both in terms of a lower number of motorised trips per person and of shorter distances per trip. Leisure trips would be at the top of the list of the avoided trips, especially relatively long trips in the week-end. Shortening travel distances would also be a reaction to higher transport costs. Concentrating mobility on unavoidable trips (working, etc.) and reducing travel distances could have a large impact especially on air demand whose massive rise occurred in the last years is mainly made of generated traffic caused by the significant fall of air fares. When high oil prices made low cost flights commercially unviable, at least part of this new demand would disappear.

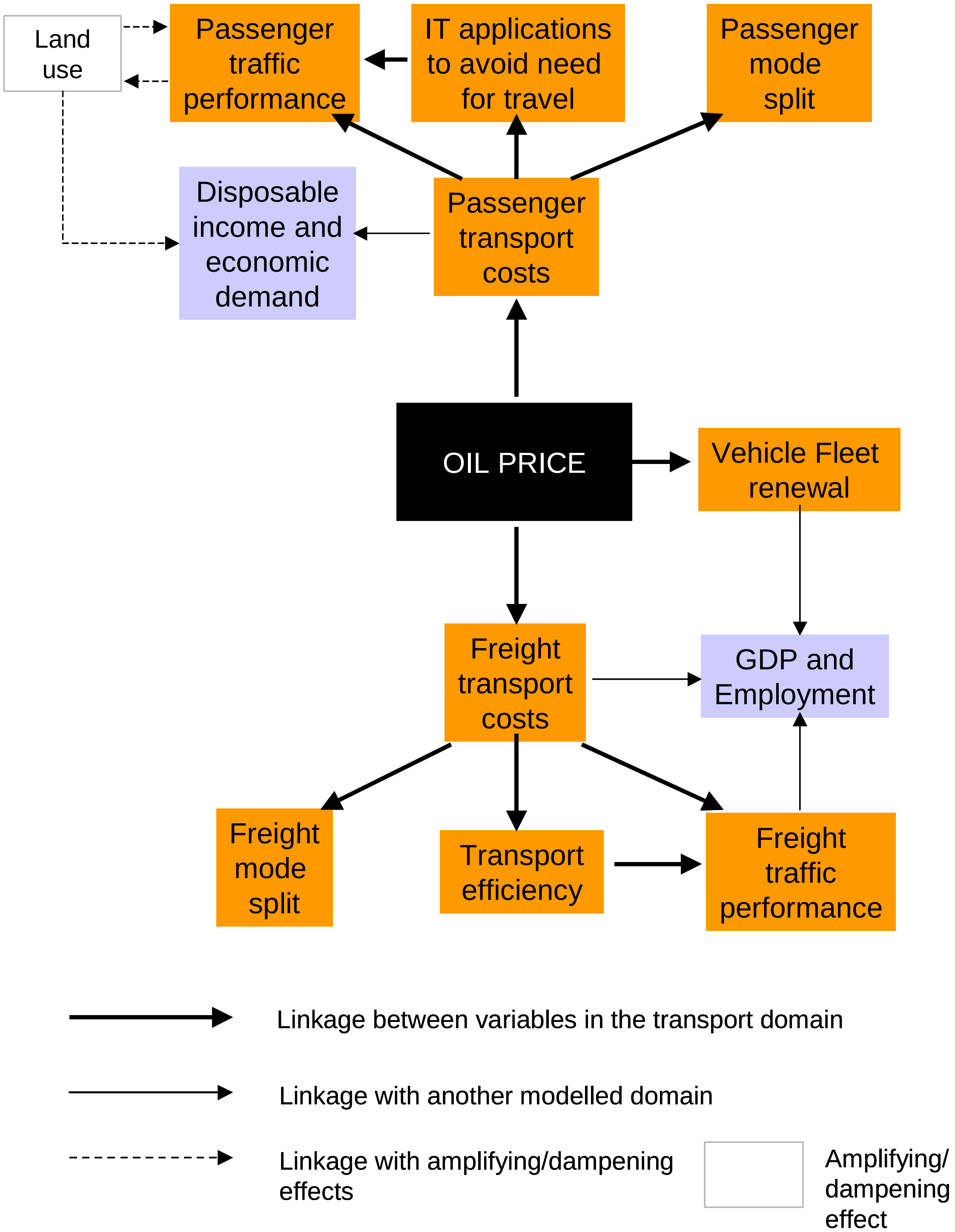
Reducing travel distance would be much more complicated, at least in the shorter terms, for working trips. The only way for commuters to shorten their trips would be to move their residence closer to the workplace. However this solution would not be widely feasible. On the longer terms, there are some strategies that could be put into practice with the aim of reducing the need for travel. The adoption of technologies and organisations that allow individuals to work, shop, manage personal business, etc. from home would be greatly encouraged. However, the potential for this kind of strategies is not unlimited and require time as well as accompanying legal frameworks.

While personal mobility could be at least partially reduced even in the short terms in response to higher transport costs, the impact on mobility of goods is more questionable. The transport of goods is just a segment of a more complex productive and logistics chain, where the relevant variable is total cost. Currently, transport costs often amount to a very low share of total production costs or goods price (see COMPETE, 2006). This is true on the large scale as well as on the medium and short scale, so in the end, the higher transport costs would probably impact on freight transport much less than on personal mobility, at least on the shorter terms[5].

Figure 10 summarises the impacts discussed above also showing what is modelled in HOP!, including indirect impacts in the economic domain (depicted in the grey boxes in the figure). A higher oil price leads to an increase in the costs of travel and transport of goods. As for all other goods and services, transport demand is reduced, both for passenger and freight (less trips, lower distances). The cost of public transport modes would comparatively increase less than private modes. Therefore, some modal shift is expected favouring public transport and less energy-intensive modes. The rapidly growing trend for air transportation could be stopped or slowed down considerably. Motorbikes and bikes could also gain market share. On the freight modes side, trucks cost would be increased substantially. As the road haulage market is a very competitive one, profits are very low so there is no room to absorb the increment of fuel cost, which would be probably transferred almost entirely to the user tariffs, so alternative modes (where energy costs are less relevant) become more competitive.

5 If high oil prices gave rise to severe economic crises, the amount of goods transported could fall significantly, but this would be an indirect economic effect rather than a direct impact of oil price on the transport sector.

Figure 10 Impacts of high oil prices on the transport system



Higher transport costs mean higher prices for several goods and services, even if the share of transport costs on retail price is generally small. At the same time, expenditure for transport requires a larger share of income, reducing the disposable income for purchasing other goods and services, with negative effects on aggregated demand.

On the freight side, higher transport costs foster transport efficiency (e.g. loading factors). Meanwhile, on the passenger side, teleworking and other ways to avoid the need for travel (e.g. teleconferences, home banking, legal validity of electronic documents, etc.) can be encouraged[6].

The pattern and renewal rate of the vehicle fleet would be also affected, less consuming cars and vehicles using alternative technologies can enter the market earlier and faster than with low oil prices.

As in the case of economy, some additional aspects that are able to either increase or reduce the impact on the transport side should be considered. The main one is the feedback with land use. As we noticed above, higher transport costs would prompt individuals to reduce the travelled distance. As far as commuting trips are concerned, this reduction can be obtained only if residences and workplaces are closer. In the last decades, the availability of personal transport at cheap price has led the territorial system towards the expansion of urban and metropolitan areas. High oil prices could reverse this tendency in the long term. In the short term, the geographical patterns of residences and workplaces are inflexible and reductions in commuting through changes in urban development patterns can only be small.

Higher transport costs due to higher oil prices and therefore different mode split are modelled in ASTRA. It should be taken into account that for several transport modes fuel or energy costs are only one part of the overall operating costs or fares, so the responsiveness of demand is smoothed.

Mobility demand can be affected by increasing transportation costs via the number of trips, the average trip distance, and obviously the mode chosen for the trip. The first two mechanism produce a change in the transport volume (vehicle-km or ton-km), whereas the third modifies the fuel intensity (and therefore the costs) of the transport activity, A mechanism to take into account a wider use of technology for teleworking, home shopping, etc. has been implemented for HOP! in the ASTRA model.

The expected impacts on the transport sector discussed above are of different nature. For some of them it is quite easy to identify whether they drive towards e.g. a lower demand or a mode shift, etc. In other case, feed-back effects can invert the direction of the primary impact or more impacts co-exist and it is difficult to identify in advance which one would cause the major influence. In brief, it is difficult to make more specific forecasts without the help of some quantitative tool. The ASTRA model (in combination with POLES) is expected to serve as modelling instrument for providing quantitative forecasts about the impacts of high oil price on transport. Given the features of the model, not all the impacts introduced can be simulated with the same level of detail and/or in a full endogenous way (e.g. impacts on land use changes are not modelled).

3.2 Indirect impacts: reactions of the economy

Impacts of high oil prices on the economy are also manifold and of different nature. The obvious direct impact of high oil prices is that either energy consumption, consumer goods and services become more expensive as nearly all of them incorporate fossil energy and

[6] Although recent trends have indicated that the widespread adoption of IT has increased, rather than decreased, travel demand.

transport services, such that consumers have less money to spent on other consumer goods and services, or that value added of companies is reduced because energy constitutes an intermediate input to them and when they could not pass on price increases of these inputs to their consumers their value-added (the difference between the market price of their goods and the cost of their intermediate inputs) is reduced. However, there exist also a number of compensating mechanisms, which could even lead to a better economic performance with higher oil prices then with low oil prices, such that the final impact of high oil prices on the economy could be in a range from negative to positive results and can not be easily foreseen without at quantitative tool.

The **traditional line of arguments** about the economic impacts of high oil prices argues that "Higher oil prices lead to inflation, increased input costs, reduced non-oil demand and lower investment in net oil-importing countries" and "Overall, an oil-price increase leads to a transfer of income from [oil] importing to exporting countries through a shift in the terms of trade" as formulated by the IEA (2004) and supported by other analyses (Stewart, 1990, Fenton 2004, Arnold et al. 2007). The mechanism works as follows: oil is an input in many goods, leading to a price increase. The overall price increase leads to inflation and thus, given temporarily fixed wages, to less overall consumption. Inflation secondly lowers investment incentives, hitting the firms double because they already have to handle the decrease in demand for goods. Thirdly the value added of the firms decreases because energy as intermediate input becomes more expensive and the energy cost increase cannot be passed on to the customers (Pellény et al. 2008). Overall an increased oil price means a reallocation of given funds towards expenses on oil or oil related goods that decrease the expenses for other goods. Specific focus is here on expenditures for transport, which is currently depending to about 95% on oil, and heating, which largely depends on oil and gas in Europe. Additionally this reallocation is in favour of the oil exporting countries that receive a positive net transfer due to the higher oil price. With this scenario the definite final outcome should be a reduction of GDP of the net oil importing countries.

Since the dependence on oil today is less strong than in previous times and the negative impacts of high oil prices can be mitigated through investments in oil substitutes and energy efficiency there is also a contrasting **alternative line of arguments**. Such investments would have a double benefit: firstly, they would ultimately lower the consumption of (imported) oil and thus tend to dampen the oil price. Secondly, reduced demand would also reduce expenditures for energy imports and thus mitigate the deterioration of the terms of trade. Thirdly, they would occur mainly domestically, therefore creating additional domestic jobs both in the construction of the energy technology and in the maintenance. This alternative point of view is not as well-elaborated as the traditional point of view.

The less sophisticated foundation of this alternative line of arguments is natural as to some extent it depends on circumstances that are only prevailing in the most recent years, but not during earlier periods of high oil prices, such that the potential for direct empirical findings is quite limited. The alternative point of view would not neglect the traditional thinking i.e. of course higher oil prices increase prices of goods and services as well as imports from oil exporting countries in the EU. But these influences have diminished since the oil crises of the 1970ies and 1980ies due to an overall more stable economy and the already mentioned compensation mechanisms. E.g. the response of inflation expectations to an oil price rise has shrunk considerably. In the 1970 a 10% rise of oil prices would have increased inflation expectation by 5%. In the mid eighties this exact same situation would have led to an additional 2% (Blanchard and Gali 2008).

One of these compensation mechanism that is rarely taken into account in the traditional argument consists in the mitigating effect of exports form the oil importing countries towards the oil exporting countries. This trade is biased in favour for European products, so when the income of the exporting countries rises, they will invest part of that rise in European goods and thus partially offset the income transfers away from the oil importing countries (Pellény et al. 2008, Kilian et al. 2007). In HOP! D2 it was shown that since the 1970ies there is a strong correlation between oil price and exports from selected OECD countries to oil exporting countries with a coefficient of determination of between 0.7 and 0.8 (Schade et al. 2007). E.g. the recent numbers for the German exports to Russia, one of the major oil and gas exporters, in the first quarter 2008 confirm this correlation once more: exports have grown by +25%. In a similar range has been the oil and gas dominated imports from Russia to Germany, which have at the same time been growing by +29% (DESTATIS 2008b).

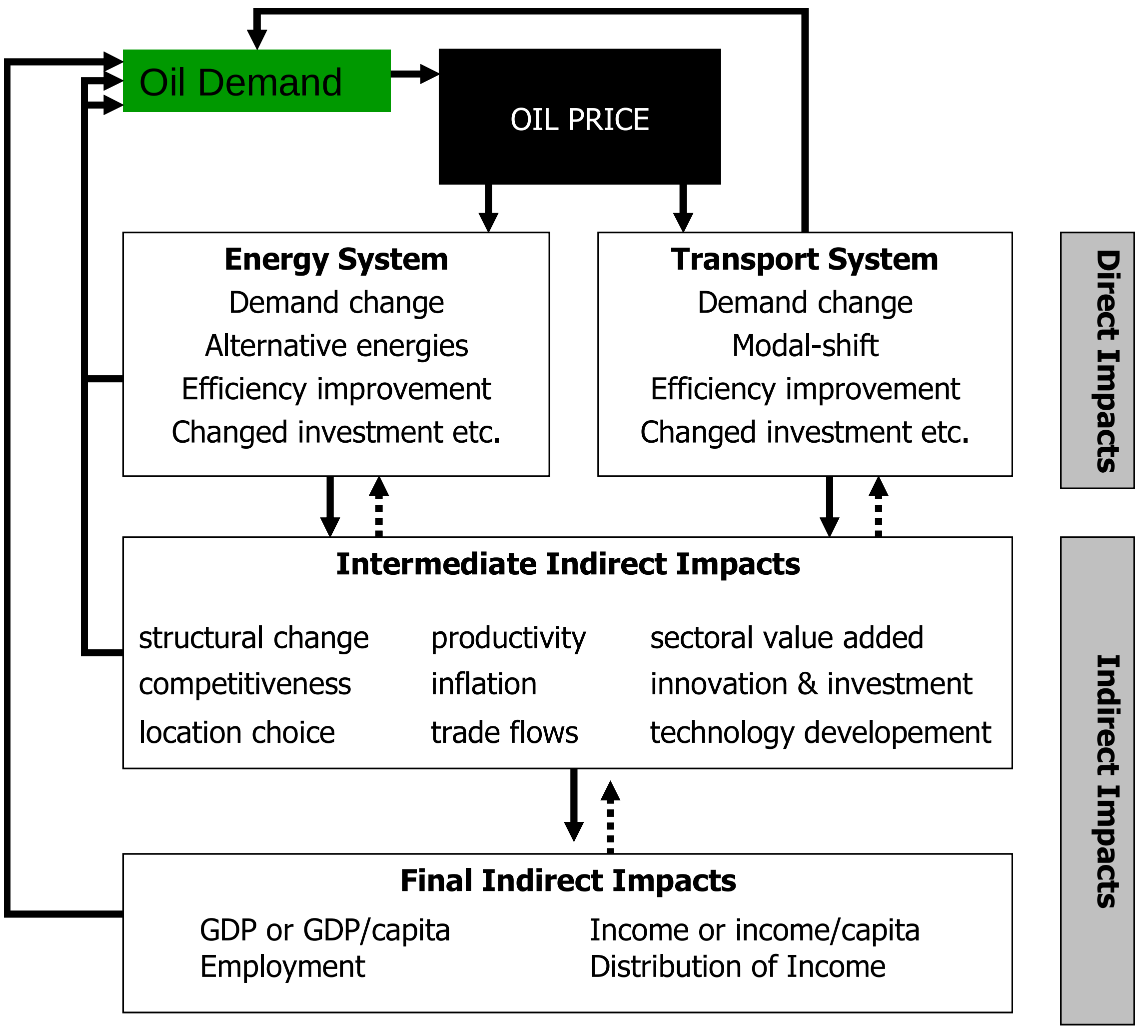
Another main trigger of any reaction of the economy to high oil prices will come from investments. It is clear that high oil prices would stimulate investments into efficiency technologies and into alternative energy technologies, if not the oil price increase is that sharp that it would immediately lead to a recession. We would call such investments **additional investments**. On the other hand it has to be taken into account that due to the shift towards alternative energy technologies investments into conventional technologies would be reduced or avoided. We would call such investments, **avoided investments**. Additional and avoided investments will vary from sector to sector and that way lead to structural changes. This will happen in two ways there will be changes in the sectors that are most oil intensive and there will be overall shifts in between sectors in the economy (Kilian et al. 2007). Both effects have to be taken into account in order to properly estimate the effects of changing oil prices on the economy. One example for sector specific effects offers the domain of supply chain management. In this area the fragmentation of supply chains and the frequent relocation of intermediate products will not be feasible anymore. Also the location of production sites in lower wage countries may have to be recalculated internalizing the increased transportation costs (Pellény et al. 2008). This in turn will lead to new investments into less transport intensive solutions. Investment will contribute to technological progress through widespread research for alternatives to oil. The development of new technologies requires their testing and refining through user-producer interaction in the market, which is why any new technology will need front-up investments. With this in mind the investment into alternatives should be spread across potential technologies as broad as possible as we do not know at the moment which technology or technologies will be dominating the markets in the future.

Investing into alternative technologies to oil now has two further advantages. From the point of view of the EU the development of competitive industries in the production and export of oil replacing technologies may lead to higher employment and in the long term to an overall positive net effect of high oil prices on GDP. Secondly, the high oil prices shorten the optimal lifetime of older investment goods in comparison to more recent less oil intensive technology. Looking at the strong path dependency, e.g. in the energy sector with lifetimes of power plants from 20-40 years, high oil prices could have a mobilization effect on investment leading to energy and oil savings.

Another reason why the reaction to high oil prices may be not as strong as in the past consists in oil intensity. It has been continuously decreasing outside and in particular within the OECD since 1995. This greater independence, however, does not mean that demand has been decreasing as well. In fact the lower oil intensity has contributed to a lower demand growth but did not reverse the overall trend of demand increase mainly driven by the fast growing economies in Asia and the Middle East (IEA 2008; Pellény et al. 2008).

Figure 11 provides an overview of the compensating mechanisms in the economy and the interaction between oil prices – direct impacts – indirect impacts, the latter emerging within the economic system.

Figure 11 Impacts of high oil prices on the economic system



Apart from the endogenous compensation mechanisms of the economy itself there is need for policy intervention to stimulate investments deriving from market imperfections or even market failure in the oil market. If a market fails the state usually intervenes and should intervene to regulate the areas where the failure occurred (Brown 2001). It is possible to identify the long-run security of energy supply as a kind of public good leading to the failure of the market mechanism, in particular when the planning and investment horizons of energy supply facilities are significantly longer than the time horizons in which fossil energy supply and energy prices are changing. This has been the case in the last two years during which prices tripled, while planning and installation of alternatives requires 5 to 10 years, which is at least twice the duration of the price increase. Although the oil intensity has been decreasing in the past years oil is still a critical input for many goods. It is used in almost all sectors, e.g. for furniture, jewellery or data processing. The monetary value of the oil is very low, in many sectors it does not even reach 1% of the produced value (DESTATIS 2008a). The widespread use however shows its physical importance, which seems not necessarily be reflected in the current prices. A similar argument can be found in Jesse/van der Linde (2008) who argue that in the past the oil prices were shaped by a supply-driven price regime, while only recently this shifted to a user-price driven regime i.e. past prices did not represent the market value of oil.

Secondly market participants are incapable of correctly valuing the use of oil today and the use of oil tomorrow. For this reason too much oil will be consumed today, although less extraction today from the remaining oil supplies would allow a smoother phasing out of oil and therefore lower adjustment cost in the long run, e.g. only recently the expectation of shortages in long-term supply of oil has started to translate into futures market prices (Dées 2008), resulting in high adjustment costs for the economy (Pellény et al. 2008). In this respect one could attribute to the long term security of supply of oil the characteristics of a public good that is overused as no coordination exists between the market participants that demand oil now as well as with those in the future, leading to a suboptimal exhaustion.

Thirdly the market for oil is characterized by a few very powerful players that further prevent the market mechanism from working. On the supply side this is OPEC holding 40% of market share and 70% of known oil resources (excluding oil sands, IMF 2005). On the demand side for crude oil one can find a couple of vertically integrated firms that can evade competition through cross subsidization.

With all these market imperfections in mind regulation or redirection of the oil market or more broadly the energy system markets is needed. All policies targeting high oil prices and the response of the energy system, however, have to take into account other overarching policy objectives, such as e.g. the reduction of greenhouse gases (EC COM (2007)2). For this reasons subsidies for oil use are ruled out, because they would prevent adaptive investments and lead to an even higher oil consumption and its adverse effects. Additionally unintended consequences for other sectors through the promotion of alternatives to oil have to be taken into consideration, e.g. could the rise of biofuels lead to adverse effects for land use in agriculture.

At the same time policies to cope with high oil prices should aim at investment into alternatives to oil and not towards subsidization of oil use. As mentioned earlier if investments into alternatives and energy efficiency would be supported by the state this would lead to the development of lead markets and increased competitiveness of the EU (Schade et al. 2007).

Furthermore market intervention cannot replace the taxation of oil as a steering mechanism for consumption. The incentive through taxes still allows individuals to decide on their consumption of the good, leading to an optimal allocation under tax constraints. Market interventions with direct payments to market participants, e.g. through oil subsidies would not allow for individual allocation. Therefore policies should better try to support the market signals from the oil prices, e.g. through investment incentives or labelling.

Discussion Box

"More is better" vs. "Growth, Innovation and Peace" vs. "Egoism and War" as future paradigms

The compensating economic mechanisms will more likely be working provided that a favourable environment exists. Currently the prevailing paradigm consists, as far as EU is concerned, of relative economic growth, technological innovation, as sustainable as possible development and peace. Starting from these relatively positive conditions, alternative developments could become reality, if we foresee changes of the political paradigm of European and Global policy-making.

One possibility is a paradigm that abandons the philosophy of "more is better" i.e. more GDP is better, more monetary income is better, more energy use is better, more tkm or pkm are better. With a stagnating GDP and continuing the improvement of energy intensity we could reduce energy use faster and hence would become faster less dependent from fossil fuel imports, which in turn would lead to less impacts of high oil prices. However, we would expect that this paradigm has some potential to become reality in the very long-term, whereas for the years to come it would be quite unrealistic as, within the dominating economic and politics framework, it does not bear the potential to fund the innovations and investments required to shift the energy and transport system towards a highly efficient non-oil dependent system.

Instead, in an alternative paradigm the choice could be to strengthen the existing egoistic behaviours. Global players would instead of investing in efficiency and alternative energy technologies "invest" more than today in wars or at least in installing governments in oil (and other) resource rich countries to increase their resource base on the expense of other countries. This would for an intermediate period keep their resource base on a level, which might dampen the price increase of oil in their countries, and which reduces the need for innovation and increase of energy efficiency. In the long-term, the outcome of such a policy should be an economy with less innovations and lower productivity growth than for instance compared with the "Growth, Innovation and Peace" paradigm. We would argue that a shift to this paradigm is not very probable because the results would be rather negative on global level, though one has to admit that history shows that this paradigm has been followed in some cases.

3.3 Simulation of the impacts using the HOP! models

The qualitative description of impacts above has shown that even if only the major expected impacts of high oil prices are taken into account, the list of direct and indirect effects includes many items. Furthermore, different impacts may lead the economic system to opposite directions and also feed-back effects exist, such as the final result is hardly predictable in advance and may change over time. In fact, the magnitude and the timing of each impact are the key elements moving the model reactions into one direction or another. For instance, the impact of higher costs of energy and transport are expected to be negative on the economic growth, whereas investments in alternative energy sources are expected to provide a positive contribution. According to which of the two effects is stronger and faster, the economy could react either more positively or more negatively.

The use of the HOP! tools – POLES, BioPOL and ASTRA – provides with scenario forecasts taking all impacts into account, including the feed-back effects and the dynamics of impacts over time. As any other tool, also the HOP! models are a simplified description of the real world based on some theoretical approach and empirical findings. This means that not all impacts are covered at the same level of detail and that various assumptions are used in the structures of the model. Of course, the capability of the models to deal with the various effects and the assumptions they use – implicitly or explicitly as exogenous inputs - play a role to explain the results of the simulations. In the following paragraphs, some impacts identified above are discussed to show whether and how they can be modelled in HOP!.

Preliminarily, it can be anticipated that some relevant aspects affecting the impact of high oil prices, especially on the economic side are not fully modelled in HOP!. One example is the role of the monetary policy. The mission of the European Central Bank is to control inflation, so if oil price growth puts pressure on prices, it can be expected some intervention of the ECB (e.g. a raise of the discount rate) to contrast inflation. In turn, this intervention will impact on economic growth, employment, etc. However, monetary policy is not dealt with in the HOP! models. Another key issue is the economic development outside EU. In chapter 4.5, some sensitivity simulations will be added about how the picture could change if model assumptions were changed.

Table 3 reports a summary of key elements stemming from the previous analysis with respect to their consideration in the modelling. This summary should be taken into account in the perception of the modelling results.

Table 3 Key elements for the simulation of the HOP! scenarios

Item		Modelled	Notes
A	Competition for oil supply	Yes	Only market competition. Military crises/wars are not considered.
B	Physical scarcity of energy supply	No/Indirectly Sensitivity analysis	As market operates to balance demand and supply, the latter cannot be significantly lower than the former (see also C). As military crises are not considered (see A), supply is always available from all producer countries to all import countries. Scarcity impacts are analysed with a sensitivity analyses.
C	Alternative energy sources filling gap of conventional oil supply	Yes	It is assumed that availability of alternative sources depends on price competitiveness, so when oil price grows and alternatives become competitive investments are directed to alternatives and efficiency technologies such that energy is produced in the requested quantity. Government support of investments in response to high oil prices is not anticipated, though the debate on market failure suggests that this would be an option for policy-makers.

	Item	Modelled	Notes
D	Investments in additional oil supply and alternative energy sources	Yes	Changes of energy supply (technology) require investments. These lead to changes of energy costs affecting the consumption split and maintaining the budget constraint of households as well as the input structure of energy in the input-output tables for industry. Thus investments are assumed to be both funded by revenues of energy producers and by redirection of investment flows.
E	Energy price affects prices of other goods and services and therefore aggregate demand	Indirectly	An indirect mechanism to simulate inflation in case of high oil price increases has been implemented thus reducing disposable income and aggregate demand. Further, shifts of transport demand affect aggregate demand due to the different taxation of both the various transport modes and the transport and non-transport consumption.
F	Aggregate demand affects investments and employment	Yes	Investments are affected directly via changed sectoral consumption and indirectly via aggregate effects (i.e. the budget constraint of households reacting to energy price increases and the rough estimation of inflation). Employment reacts to the sectoral changes on the demand side i.e. changes of consumption, investment and exports (see also I)
G	Global trade flows	No / Exogenously	Would be important in order to deduce net impact for EU countries. Trade flows from EU to rest-of-the-world can only be exogenously affected to consider the impact of energy prices on world level (e.g. reduced world GDP growth -> reduced trade, increased exports to oil exporting countries),
H	Monetary and macroeconomic policy	No / Partially	It affects exchange rates, wages and therefore export, internal demand, etc. Varying exchange rates are not part of the models. Increases of government debt over Maastricht criteria levels reduce investments (crowding out).
I	Sectoral economic structure	Yes	Higher energy prices and transport cost affect directly the sectoral consumption and sectoral exports as well as indirectly the sectoral investment. Thus the sectoral structure of the economies are adapted by the higher energy prices.
J	Impacts on different income / person groups	No	High energy cost are expected to hit hardest the less well-off income / person groups. The models do not consider different impacts on different income groups and thus neglect this negative impact.

The aspects reported in Table 3 play a critical role in the modelling of the HOP! scenarios and affect the results. As a whole, they describe a world where market is able to find a peaceful equilibrium and where investments ensure economic growth and energy supply. Some of these assumptions have been tempered to simulate the case of no investments and to take into account of a (small) impact on purchasing power, but still the results of the scenarios are dependent on this “market-perspective”. If this perspective was not confirmed, i.e. if some of the assumptions adopted were not representative of the real world, high oil prices could give rise to different results. This was taken into account by a number of sensitivity analyses (see in particular sections 4.5.1, 4.5.5, and 4.5.6).

4 Modelling results

This main section presents the results and conclusions that can be drawn from the simulation of the scenarios with the ASTRA and POLES models.

The section commences with a description of the ten major High Oil Price scenarios that have been analysed. The main criteria to differentiate these scenarios is the crude oil price achieved in the year **2020** given in **constant EUROs of the year 2000**. These prices range between 150 $€_{2000}$/bbl and 800 $€_{2000}$/bbl by 2020 with further increases thereafter, while in the HOP! Reference Scenario only moderate growth is foreseen leading to 70 $€_{2000}$/bbl. It is important to note that even in this Reference Scenario a further growth of oil prices is included.

The second section describes the Reference Scenario. This is important as many of the later impacts can best be presented by comparing the scenario results with the development in the Reference Scenario. The third section provides an overview on major indicators in the energy, transport and economic domains across all scenarios, which is then followed by a section that presents major results separately for each domain in the fourth section.

The final section of this chapter goes into details of specific impacts assessed focussing on those impacts that are of particular importance for policy making in response to high oil prices. Further, this section provides sensitivity analyses for aspects that have been outside the framework of the model based scenario analysis, e.g. the impact of a world recession or the impact of insufficient energy supply.

4.1 The High Oil Price Scenarios

To derive a comprehensive picture of the economic impacts of high oil prices a series of scenarios have been defined and compared with a reference projection of the HOP! project. The following Table 4 provides an overview on the ten major HOP! scenarios. Additional to these scenarios specific analyses have been undertaken that required further scenario analyses e.g. to identify the sensitivity of the results to variations of the parameters or to considered impact chains responding to the high oil prices.

It should be noted that in all scenarios, oil prices are expressed in $Euros_{2000}$ per barrel rather than in Dollars per barrel. This choice does not imply any assumption concerning the use of Euro as intentional oil trading currency. It is just the simplest way to focus the attention on the key aspect to be investigated in HOP!: how much oil will cost for the EU and what this will mean for the EU economy.

Table 4: the ten major HOP! modeling scenarios

Scenario name	Oil price in 2020 (€$_{2000}$/bbl)	Investment size	Investment target	Fuel taxes	Price growth path
Ref 70	70	Low	Efficiency & New Sources	EU directives	Stable
150 Smooth	150	High	Efficiency & New Sources	EU directives	Smooth rise
150 Smooth no invest	150	**Low**	**Neither**	EU directives	Smooth rise
150 Smooth reduced tax	150	High	Efficiency & New Sources	**Reduced Tax**	Smooth rise
150 Smooth carbon tax	150	High	Efficiency & New Sources	**Carbon Tax**	Smooth rise
150 Early	150	High	Efficiency & New Sources	EU directives	**Early Step**
150 Late	150	High	Efficiency & New Sources	EU directives	**Late Step**
220 Smooth	**220**	Very High	Efficiency & New Sources	EU directives	Smooth rise
600 Early	**600**	High	Efficiency & New Sources	EU directives	**Early Step**
800 Early	**800**	High	Efficiency & New Sources	EU directives	**Early Step**

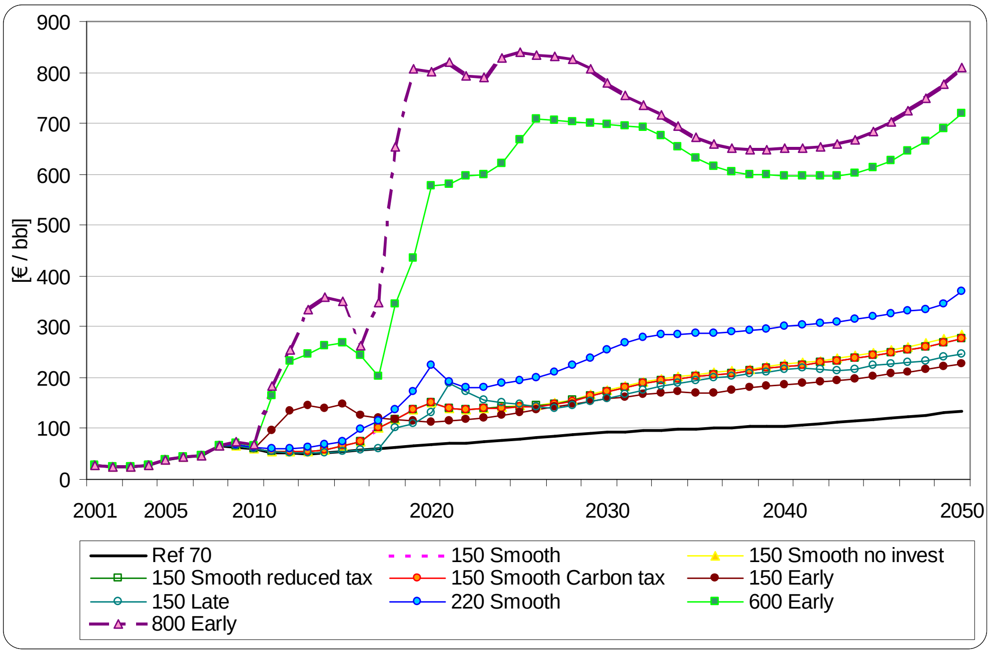
Source: up-front definition of HOP! scenarios

- The scenario *Ref 70* (Reference Scenario) assumes high amounts of oil reserves and can be seen as an optimistic scenario. It reaches an oil price of about 70 €$_{2000}$/bbl in 2020, smoothly rising to 140 €$_{2000}$/bbl by 2050. Investment in energy efficiency and alternative energy sources follows common trend. Taxation takes the current excise duties plus the changes through the diesel directive into account. A carbon dioxide value rising from 5 €/t CO_2 to 30 €/t CO_2 is taken into consideration.
- The scenario *150 Smooth* assumes a smoothly increasing oil price which reaches a level of 150 €$_{2000}$/bbl in 2020. This leads to increased investment in energy efficiency as well as in alternative sources. The other HOP! scenarios vary one or more parameters to investigate the impacts of specific economic responses to high oil prices: the scenario *150 Smooth no invest* assumes that the level of investments remain more or less the same as in the reference scenario (*Ref 70*).
- *150 Smooth reduced tax* and *150 Smooth carbon tax* vary the taxation level: they simulate a tax reduction with the purpose to limit the increase of transport costs and a carbon taxation additional to Ref 70 scenario aiming at higher tax revenues to compensate higher governmental investments.
- *150 Early* and *150 Late* vary the way oil prices increase: this could happen either in an early step between 2010-2013, which enables to look at the impacts of a short-term steep rise of high oil prices, and with a late step to look at the impacts if we assume a moderate oil price development, which suddenly turns out to be false.
- *220 Smooth* investigates a higher oil price than *150 Smooth* (> 220 €/bbl in 2020).
- Two variants of scenario *150 Early* explore the impacts of extraordinarily high oil prices reached with a step in the year 2020. *600 Early* assumes a price of 600 €/bbl in 2020, while *800 Early* assumes a price of 800 €/bbl in 2020.

Oil price development in the HOP! project scenarios is not an exogenous input of the modelling tools, but it is endogenously calculated depending on reserve-to-production ratio, spare production capacities of large oil producing countries and by the impact of 'market power' of a few oil producing countries. While spare production capacities of large oil producing countries affects the oil price only in the short run, the other two factors determine the long-term development. The reserve-to-production-ration entails a feedback loop. Increasing oil prices caused by a low reserve-to-production ratio lead to further search for oil fields and enhanced recovery in existing oil fields, which in turn lowers the oil price. In Figure 12 we can see a low decline in the period between 2010 and 2015 (*Ref 70*, *150 Smooth* etc.) and between 2020 and 2025 (*150 Smooth*) due to this feedback. With oil prices around 150 €$_{2000}$/bbl the decline between 2020 and 2025 is even stronger pronounced as unconventional oil is expected to become competitive around 2020. A similar pattern can be identified for the scenarios with an early rise of oil prices (*150 early*, *600 early*, and *800 early*). After a price peak around 2014, the oil price declines for a couple of years (pattern of overshoot and decline).

It should be clear: the HOP! project did not aim at assessing the oil reserves but focuses on the assessment of the impacts of high oil prices, in case availability of oil is scarce and prices would soar. For this reason, a set of elevated oil price levels were defined up-front for the year 2020, and reserves and other parameters were then adjusted so as to reach those levels.

Figure 12 Trend of oil price in various scenarios (Euro$_{2000}$/barrel)



Source: POLES calculations in HOP!

Two additional aspects should be considered looking at the scenarios: First, given the difficulty about developing assumptions on the exchange rate between $ and €, a reasonable value was selected and fixed throughout the simulations. Second, of course not only the oil price reacts in the scenarios, but also the prices of other energy carriers like gas or coal are influenced by the oil price changes.

4.2 The Reference Scenario

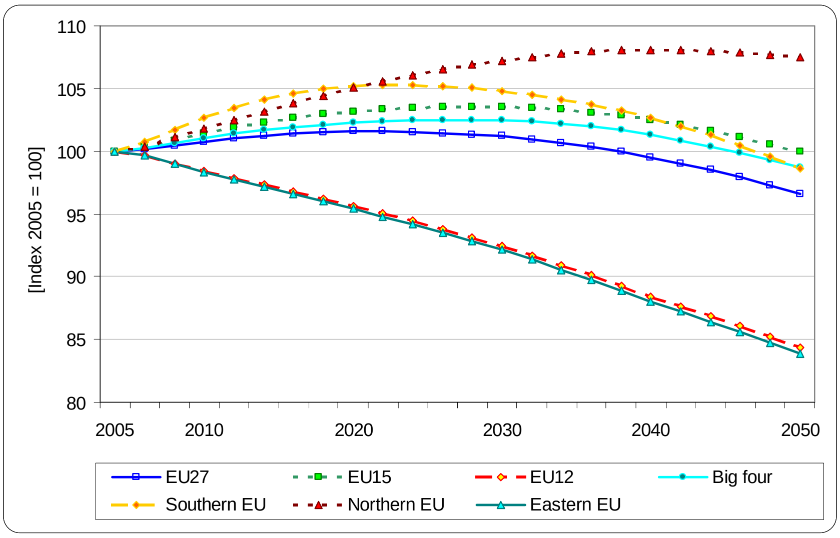
This section provides an overview of the HOP! Reference Scenario (*REF-70*), with focus on the key variables in the main domains, namely:

- Demographic development,
- Economic development,
- Energy system
- Transport system
- Fleet technology

4.2.1 Demographic developments

Looking at the long-term time horizon of the HOP! project the reference scenario has to consider the expected developments of the European population (see Figure 13). For the EU27 it is expected that the population as a whole will grow until about 2020 and then shrink slowly, such that in 2050 the population is about 4% smaller than in 2010. The reduction of population is much more pronounced in the new member states (EU12), who continuously loose population until 2050 experiencing in total a loss of -14%. Only the Northern European countries would be able to maintain a growing population with an increase of about +5% until 2050.

Figure 13 Reference scenario: Trend of population

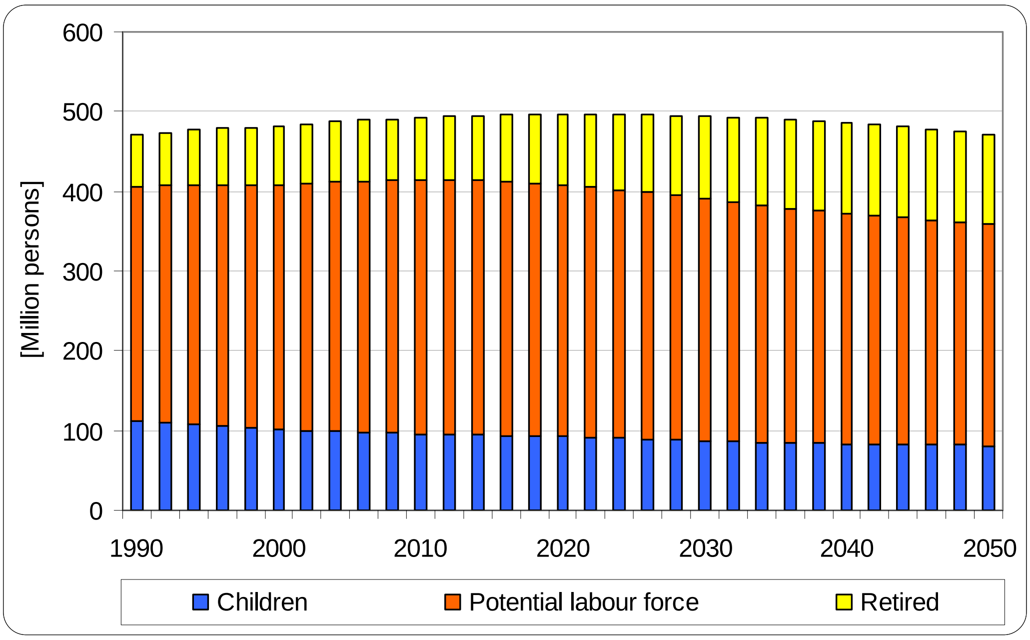


	Growth 2010 to 2050 [%]	
Country group	total	aver. annual
EU27	-4.2	-0.1
EU15	-1.7	-0.0
EU12	-14.1	-0.4
Big four	-2.5	-0.1
Southern EU	-4.3	-0.1
Northern EU	5.2	0.1
Eastern EU	-14.5	-0.4

Source: ASTRA calculations in HOP!

The changes are more drastic looking at the development of the different age classes (see Figure 14). The number of children is continuously reduced over the whole period and the potential labour force decreases after about 2015 reducing its share on the total population by about 6%.[7] The strongest change is expected for the retired persons whose share on the total population will increase by 10% amounting to about one quarter of the whole population in 2050.

Figure 14 Reference scenario: Change of the demographic structure in EU27



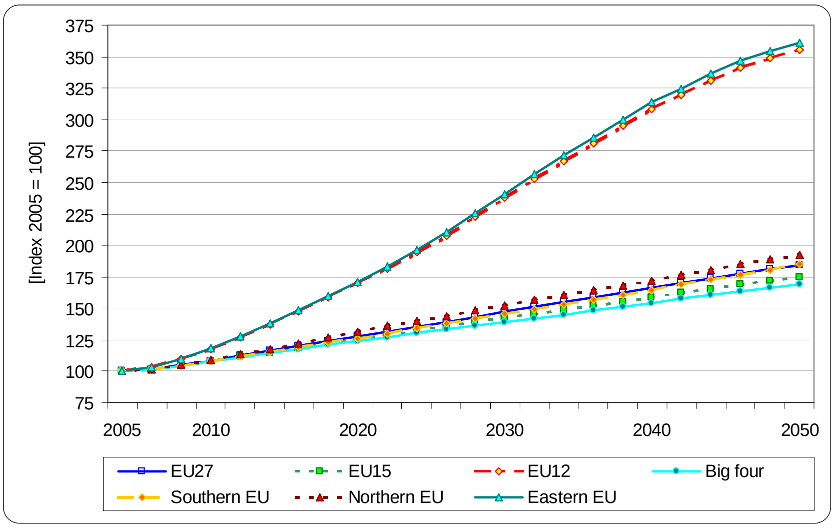
Source: ASTRA calculations in HOP!

4.2.2 Economic developments

It is expected that the European economy continues to grow in the coming decades, where growth is measured as the growth of GDP in constant prices. The relative growth rate is expected to be much stronger for the new member states than for the member states before the year 2004 (EU15). For the new member states an average annual growth of about +2.7% is expected, while the EU15 grows by less than half of this speed with about +1.2%. This implies that some of the new member states like Slovenia or the Czech Republic manage to catch-up in terms of GDP per capita.

[7] The potential labour force is defined as the number of persons in the age class between 18 and 65. Some countries intend to increase the potential labour forces by shifting the retirement age from 65 to older ages, which is not considered here.

Figure 15 Reference scenario: Trend of GDP in constant prices

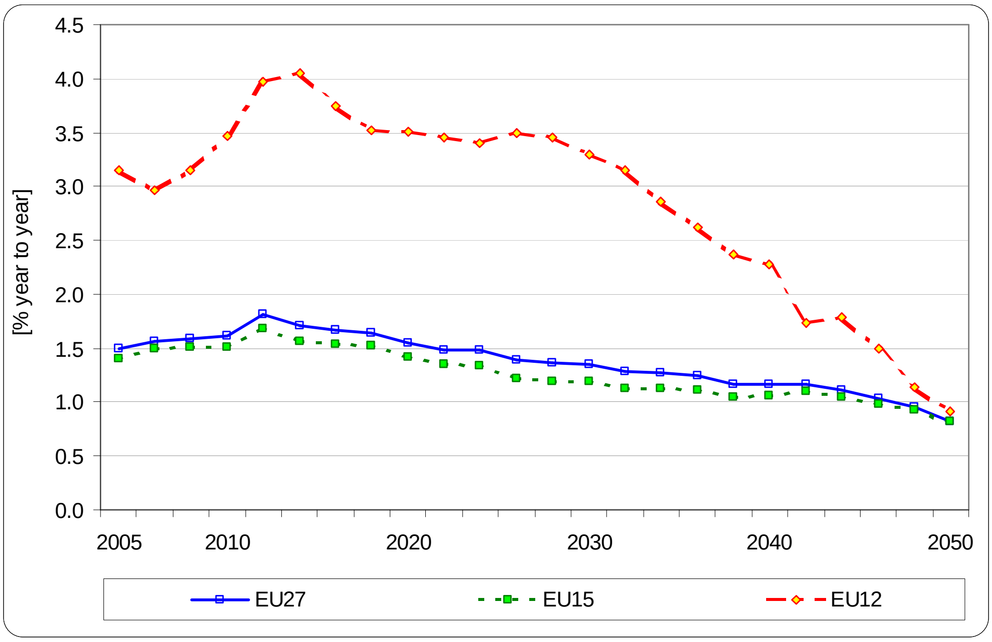


	Growth 2010 to 2050 [%]	
Country group	total	aver. annual
EU27	67	1.3
EU15	60	1.2
EU12	193	2.7
Big four	54	1.1
Southern EU	69	1.3
Northern EU	74	1.4
Eastern EU	197	2.8

Source: ASTRA calculations in HOP!

Over time it can be observed that the growth rates fall for all European regions (see Figure 16), which reflects both fundamental reasons, like the decline of population and in particular of potential labour force in the last two decades, and mathematical reasons (i.e. the base values from which percentage changes are calculated grows over time).

Figure 16 Reference scenario: Annual growth rates of GDP

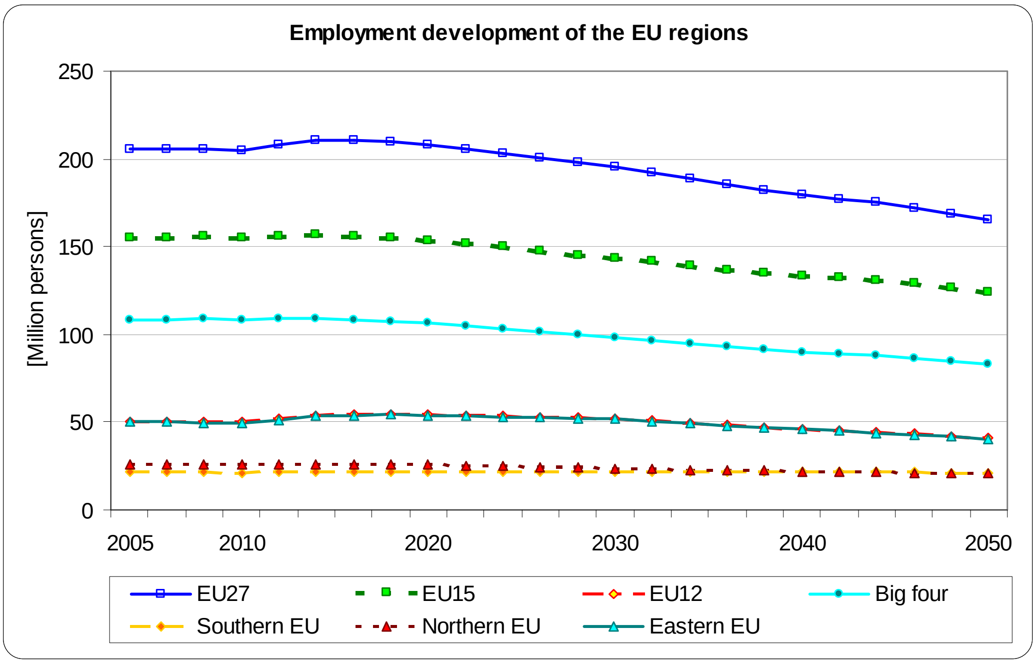


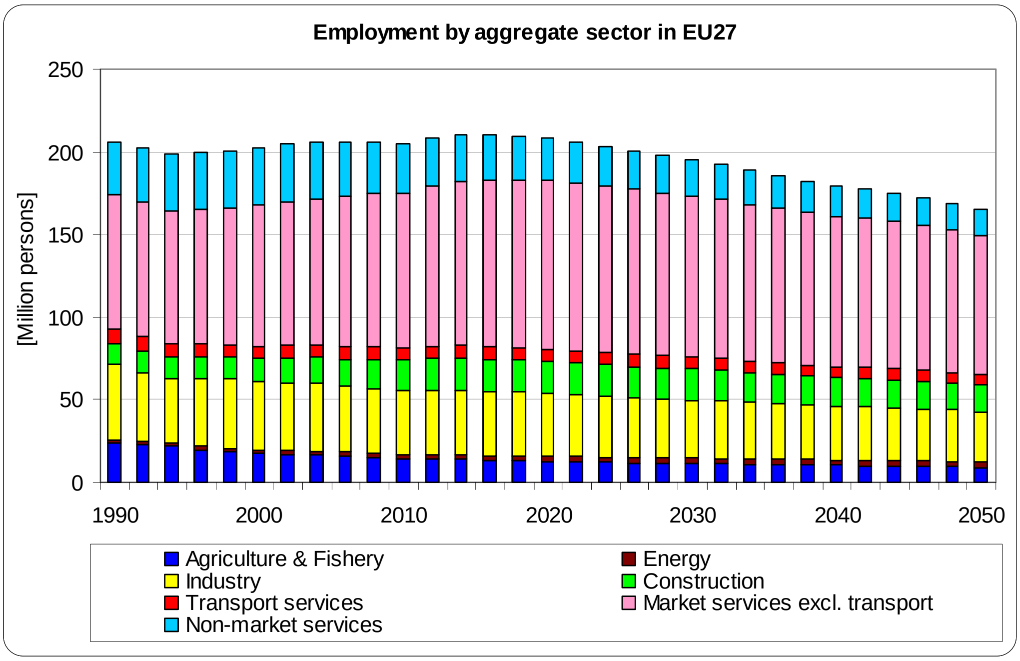
Source: ASTRA calculations in HOP!

The reductions of the labour force are also reflected in the decline of the actually employed persons (see Figure 17). In EU15 and the EU27 employment starts to decline after the mid of the next decade, while this will happen about 10 years later in the EU12 (new member states). Given the population development of the latter this implies that the activity rate of the potential labour force increases in those countries.

Looking at the development of the aggregate sectors it is mainly the market services and to some extent construction and the energy sector that gain employment in the reference scenario. The former reflects the trend to develop the EU towards a service economy and the latter the higher labour intensity of the energy system developing towards the use of more renewable energies. Industry remains stable over the next two decades and then slightly declines, while the largest reduction is expected for the government sector (the largest part of non-market services) and agriculture & fishery sector.

Figure 17 Reference scenario: Employment in the EU

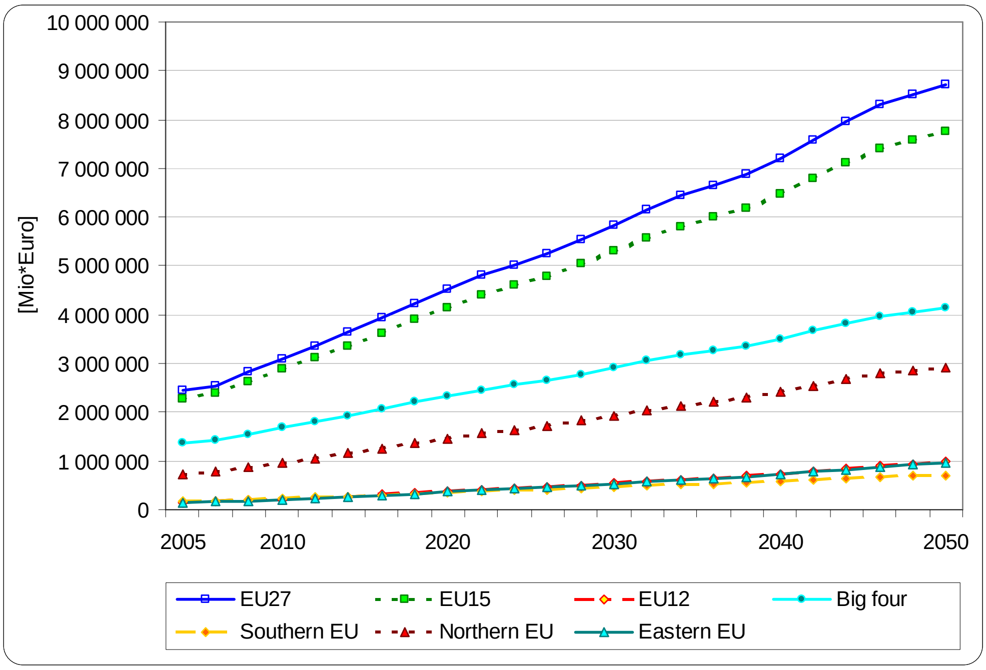




Source: ASTRA calculations in HOP!

The strongest growth can be observed for exports, which grow by about 170% for the EU27 between 2010 and 2050 and by more than 300% for the EU12. This means average annual growth of exports is close to double the growth of GDP. As imports grow at similar speed, the trade balance shows similar or even slower growth rates, as for the EU12 that experience a stronger growth of imports.

Figure 18 Reference scenario: European exports

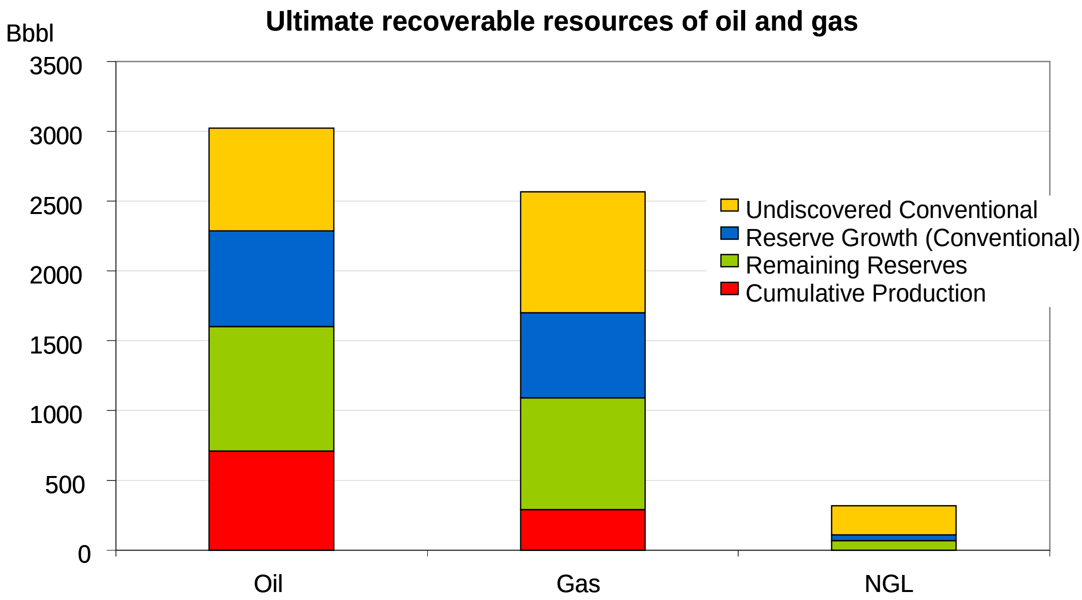


Source: ASTRA calculations in HOP!

4.2.3 Energy system trends

This section provides the definition of the energy side of the reference scenario for the HOP modelling framework. With respect to oil reserves and oil production the reference scenario refers to the optimistic assumptions that stem from the estimation of USGS (USGS, 2000) on the worldwide oil and gas fields. Figure 19 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 Bbbl of the world for the year 2020. Nearly half of such recoverable resources consists of reserve growth and undiscovered resources.

Figure 19 Oil, Gas and NGL resources in 2020



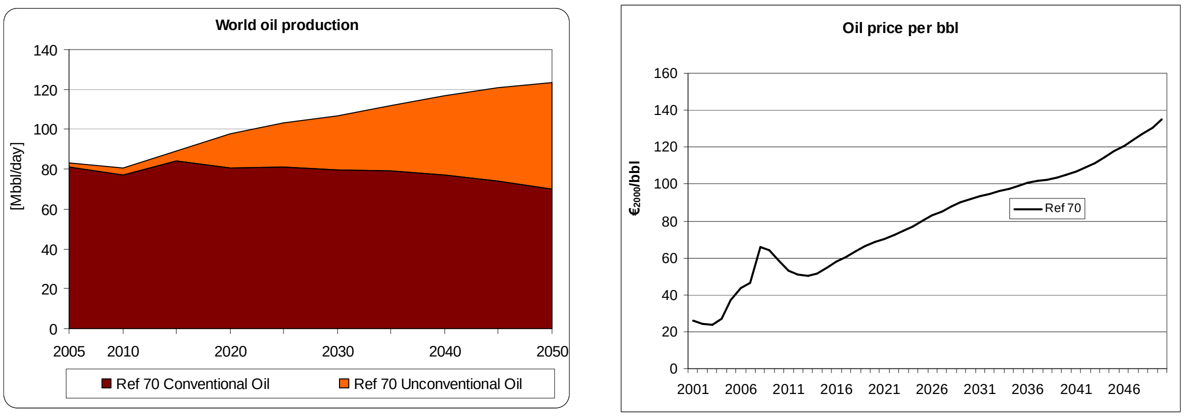
Source: USGS, 2000

This might result in an increase of world oil production as indicated in Figure 20. Unconventional oil is expected to substitute conventional oil to a certain extent. There are three main types of unconventional oil reserves, which are concentrated at specific places: tar sands from Canada, heavy oil from Venezuela and oil shale mainly from the United States (WEC, 2004; IEA, 2005). Most probably tar sand followed by heavy oil will be the largest amount of unconventional oil in the near future.

In the case of synthetic fuels and other fuels, we assume that they substitute transport fuels because of the dependency of transport fuels on oil. Biofuels, GTL or CTL are used to produce gasoline or diesel and, hence, substitute transport fuels and not heating oil or oil as basic material in the chemical industry. Other alternative transport fuels are natural gas and hydrogen, etc.

Under these conditions it is estimated by the POLES model that the oil price remain at a level of 70 €$_{2000}$/bbl until 2020 and might increase slowly towards 130 €$_{2000}$/bbl in 2050 as seen in Figure 20.

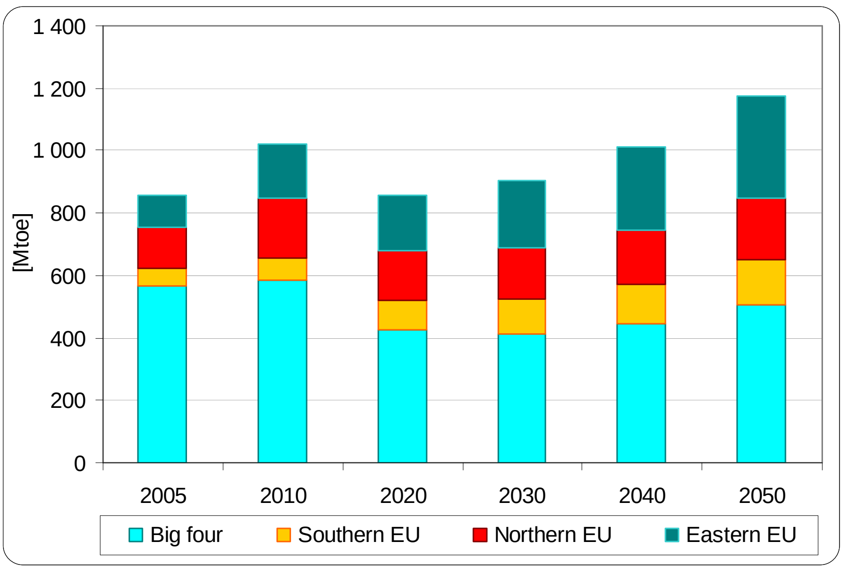
Figure 20 Reference scenario: World oil production per day and oil price



Source: POLES calculations in HOP!

Primary energy production in EU is expected to remain stable until 2030 and increase then after 2030. In the EU15, the substitution process from domestically produced oil and gas towards renewables like wind is expected to continue. Nuclear energy and coal production is expected to be on the same level as today. The situation differs for the new Member States (EU12). The decline of production of oil and coal is offset mainly by an increase of renewables and nuclear energy production and a minor increase of the production of gas.

Figure 21 Reference scenario: Energy production

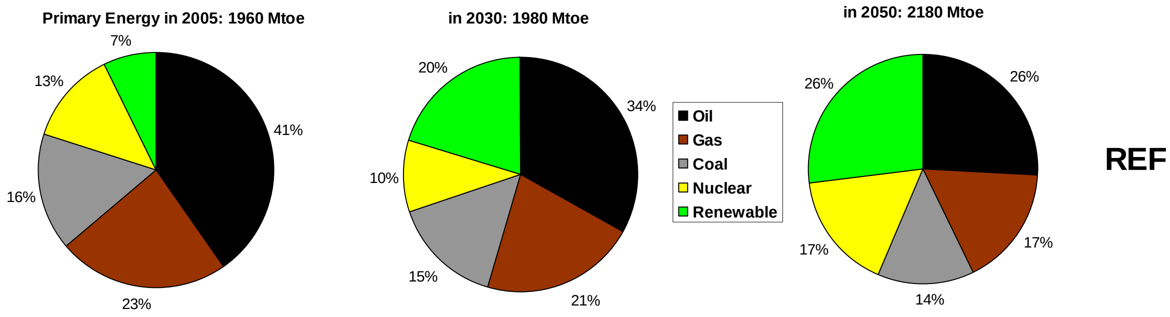


	Growth 2010 to 2050 [%]	
Country group	**total**	**aver. annual**
EU27	15	0.70
EU15	-3	-0.15
EU12	96	3.42
Big four	-14	-0.76
Southern EU	98	3.47
Northern EU	-4	-0.21
Eastern EU	97	3.44

Source: POLES calculations in HOP!

Primary energy consumption (consisting of the domestic energy production plus net imports) in the EU is expected to increase by around 15% between 2000 and 2050. The increase of primary energy demand is moderate and slower than elsewhere in the world due to the trend towards a more service-oriented economy and due to improvements of energy efficiency. We assume 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.

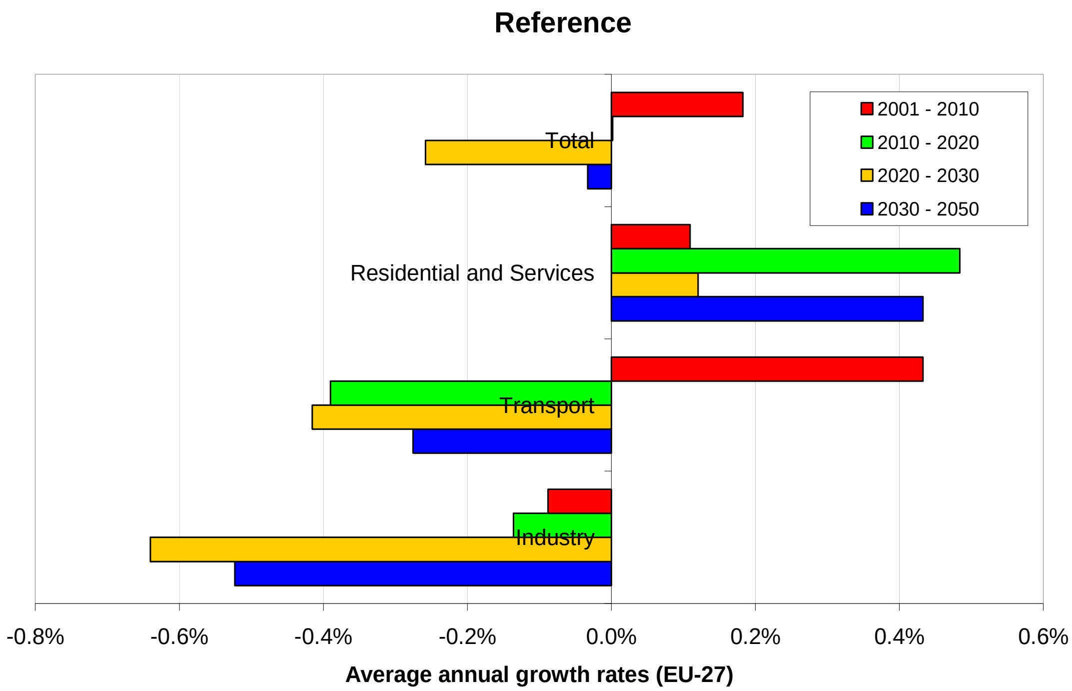
Figure 22 Reference scenario: Primary Energy demand in EU 27



Source: POLES calculations in HOP!

The composition of final energy demand by sector is assumed to change. While for the residential and service (including and agriculture) sectors we assume a growth rates around 0.5% between 2000 and 2050, following the trends observed in the past decades, the increase in the transport and the industrial sector might be slightly negative.

Figure 23 Reference scenario: Annual growth rates of fuel consumption per sector



Source: POLES calculations in HOP!

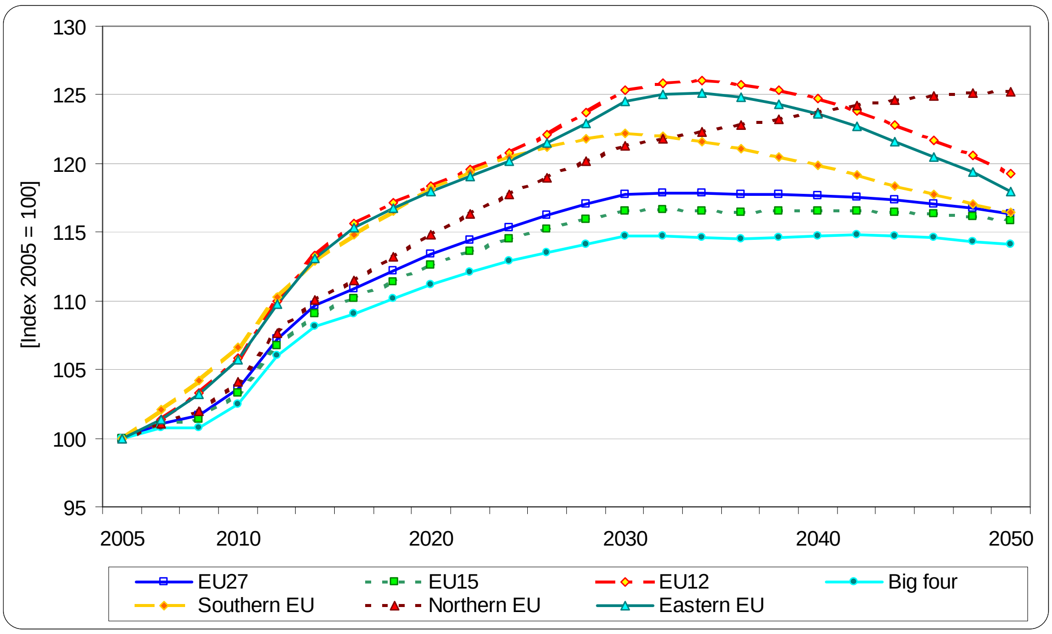
The growth in the services and residential sector is largely driven by the growing need of electricity. This new pattern in energy demand might be interpreted as the energy dimension of the “third industrial revolution” characterised by the swift development of electricity intensive ICTs (Information and Communication Technologies).

4.2.4 Transport system trends

The following graphs summarise the base trend of passenger and freight traffic as well as vehicle fleet composition in the HOP! reference scenario.

The trend of personal mobility shows an increment at different speed when EU15 and more recent EU Member States are considered (Figure 24). The latter are forecasted to grow faster in the near future as impact of higher incomes and motorisation rates. However, the expected decreasing of population in the Eastern Europe countries partially offsets these determinants resulting in a diminished growth rates and finally also in a reducing mobility in absolute terms with respect to the maximum level reached during the decade from 2030 to 2040. Anyway, at the end of the simulation period, the result of the different paths is an increased relative increment forecasted for EU12 area with respect to EU15 countries: the more recent EU Member States show around 32% more passengers-km, which means an average growth rate of 0.6% per year, with respect to the increase of 25% of the EU15 area (with an average growth rate of 0.4% per year). According to the statistics, during the period 2000-2006 passenger traffic has grown by 1.3% per year[8] (as reproduced in the ASTRA model results), therefore the HOP! Reference scenario forecast a slow down of personal mobility for the future, particularly in EU15 countries.

Figure 24 Reference scenario: Trend of total passenger-km



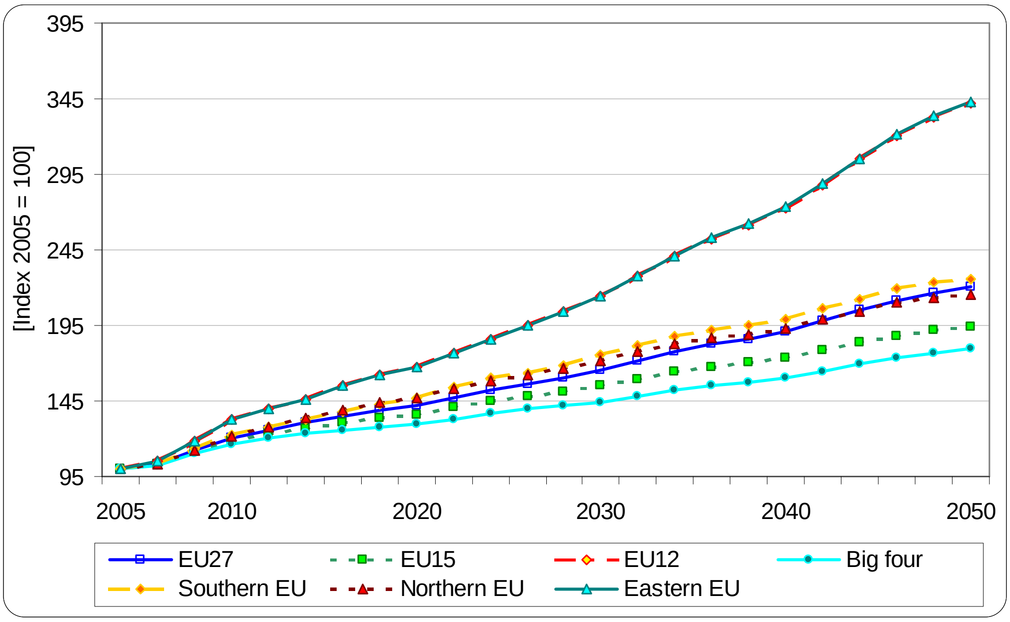
Source: ASTRA calculations in HOP!

The difference between the two groups of countries is even more significant looking at the mobility of goods, which in the Eastern Europe countries is expected to increase more significantly due to the higher economic development rates (Figure 25). For the EU15

[8] Source: EU Energy and Transport in Figures – Statistical Pocketbook 2007/08. All observed data quoted below in this paragraph is drawn from EU Energy and Transport in Figures unless diversely specified.

countries, the HOP! Reference scenario foresees that in the year 2050 the amount of tonnes-km will be doubled with respect to the year 2000. This forecast corresponds to an average growth rate of 1.4% per year, which is lower than the trend observed in the recent past (the growth rate of tons-km in the EU15 countries from 2000 to 2006 has been of 2.2% per year). For the EU12 countries, the average growth rate of freight transport for the whole simulation period is 2.8% per year in reference scenario, which means that in the year 2050 the freight traffic should quadruple than in the year 2000.

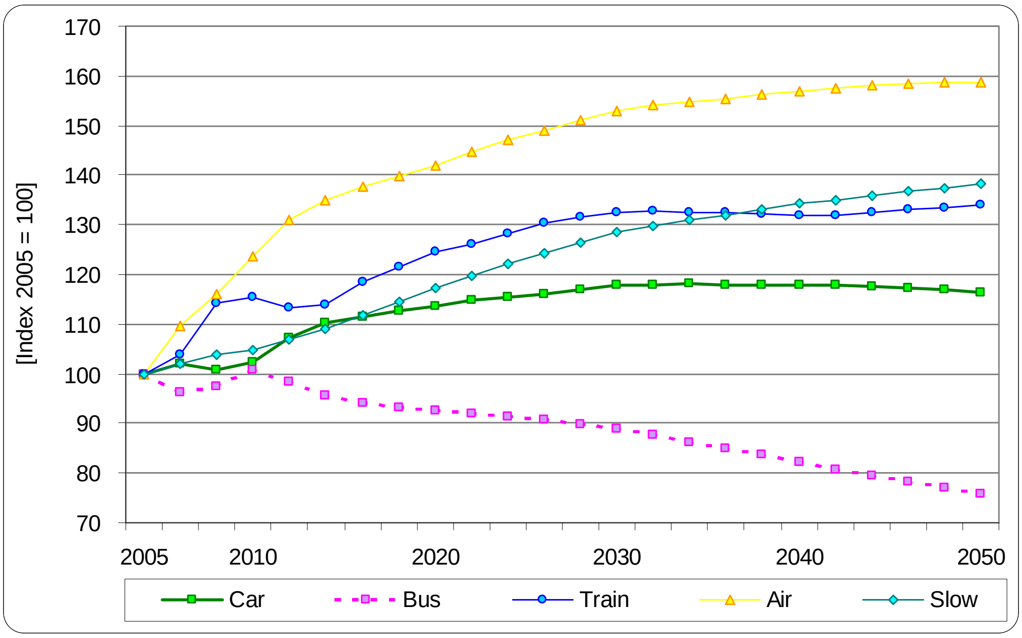
Figure 25 Reference scenario: Trend of total tonnes-km



Source: ASTRA calculations in HOP!

Looking at the trend of the passenger transport modes, Figure 26 shows that for the whole European Union, air is expected to grow more than any other mode, almost doubling the total number of passengers-km at horizon of the year 2050. The growth rate of private cars is expected to be in line with the average (0.4% per year), while for bus and coaches a negative trend is expected, with about 25% passengers-km less in total at the end of simulation period. For train the reference scenario reports a growth higher than the average (0.7% per year), as a consequence of the increased energy price. Nevertheless, if compared to the recent trends the hierarchy between modes is confirmed: air has the fastest growth, while bus and coaches has grown less than any other mode in the period 2000-2006.

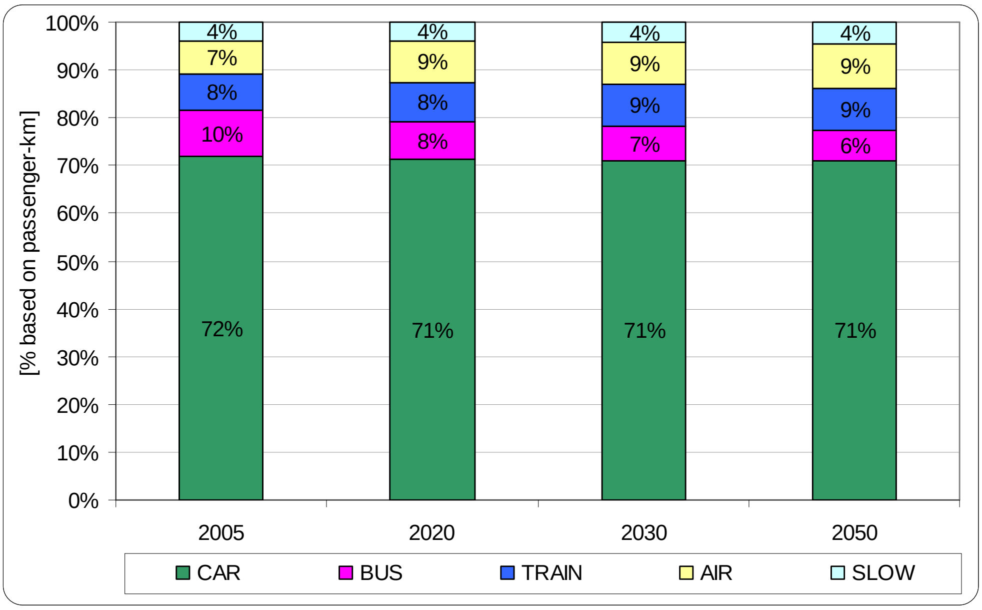
Figure 26 Reference scenario: Trend of EU27 passenger-km by mode of transport



Source: ASTRA calculations in HOP!

The different trend of the modes brings to a modification of the mode split. Figure 27 illustrates how the mode shares evolve in the reference scenario for the EU27 countries.

Figure 27 Reference scenario: Passenger mode split in the EU27 countries



Source: ASTRA calculations in HOP!

The mode share of car is almost unchanged, while air is expected to grow. In particular, air becomes the second transport mode in terms of passengers-km with train, overtaking bus. This is the major loser as its mode share is almost halved. Again these forecasts are reasonably consistent with observed data. For instance, bus share was about 10% in the year 1995 and less than 9% in the year 2006.

As in many other cases, the story is different between EU15 and the most recent EU Member States (Table 5). For the latter, the mode share of car is expected to increase significantly over the whole period and especially until 2020, even if it is not expected to climb to the level of EU15, where the reference forecast is for a slight reduction, especially driven by the growth of the air transport. Indeed, long distance trips are the most dynamic part of passenger demand and air is expected to capture a large share of them under the reference scenario.

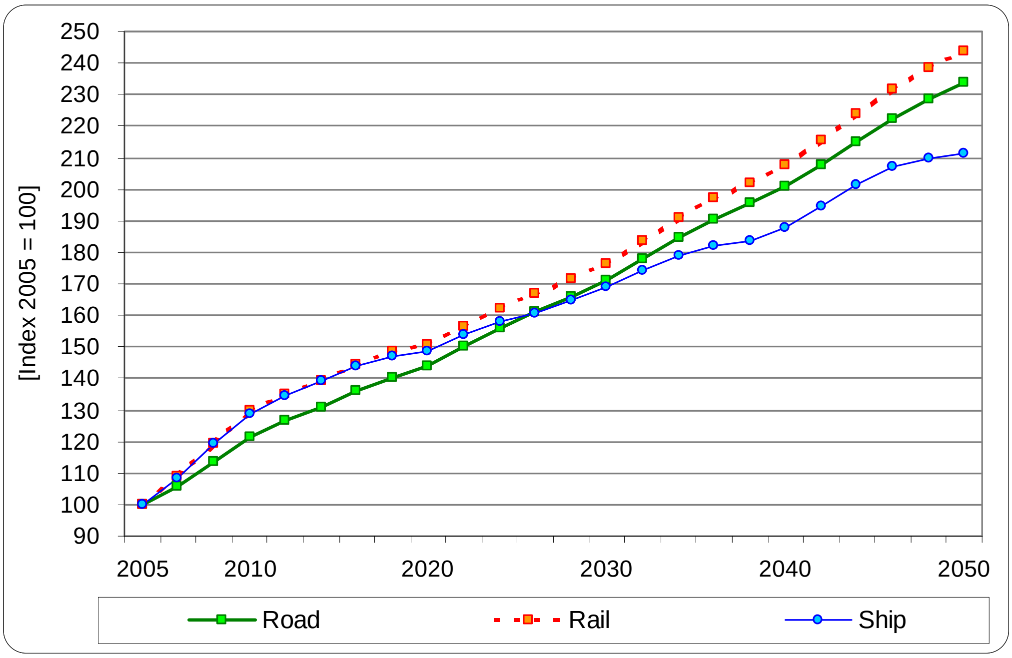
Table 5 Reference scenario: Passenger mode split by region

Passenger mode	Mode split (% of total PKM)			
	2005	2020	2030	2050
EU-27				
CAR	71.9%	71.3%	71.1%	71.1%
BUS	9.7%	7.8%	7.2%	6.2%
TRAIN	7.7%	8.4%	8.6%	8.8%
AIR	7.0%	8.7%	9.0%	9.4%
SLOW	3.8%	3.9%	4.1%	4.5%
EU-15				
CAR	74.6%	73.4%	73.1%	72.8%
BUS	8.3%	6.8%	6.4%	5.5%
TRAIN	6.7%	7.5%	7.8%	8.0%
AIR	6.8%	8.5%	8.8%	9.3%
SLOW	3.6%	3.7%	4.0%	4.4%
EU-12				
CAR	54.9%	58.6%	59.8%	60.5%
BUS	18.0%	13.5%	12.1%	10.6%
TRAIN	14.1%	13.3%	13.3%	13.4%
AIR	7.9%	9.7%	10.0%	10.5%
SLOW	5.2%	4.8%	4.8%	4.9%

Source: ASTRA calculations in HOP! , air transport includes domestic and INTRA-EU flights

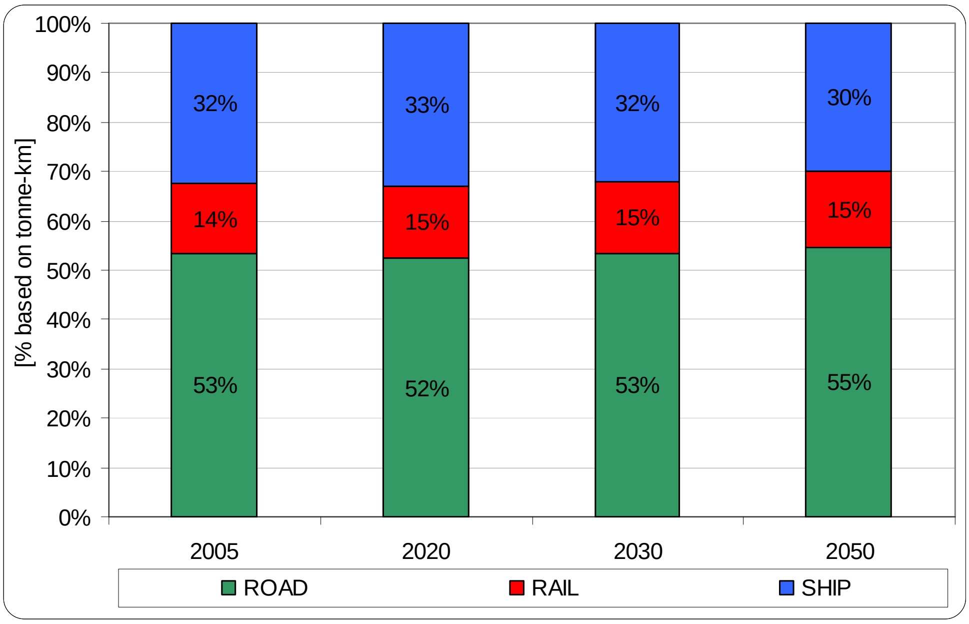
Also for freight transport, the foreseen reference growth of modes is different (see Figure 28) even if differences are small. Road is expected to grow slowly with respect to other modes during the first half of the simulation period, while it overtakes ship in the second half: the average yearly growth rate is about 1.8%. Rail growth is always faster than its competitors – road and maritime – at a pace of about 2.0% per year (while ship is around 1.7%). In the recent past (1995-2006 data) maritime has actually shown larger growth rates than rail. However, it should be taken into account that in the ASTRA model, only intra-Europe freight transport demand is simulated in some detail while part of the maritime demand observed in statistics concerns trades with overseas countries. Furthermore, in the last two years for which comparable data is available freight rail transport has grown faster than maritime (+1.0% for sea transport and +5.2% for rail between 2006 and 2005).

Figure 28 Reference scenario: Trend of EU27 Tonnes-km by mode of transport



Source: ASTRA calculations in HOP!

Figure 29 Reference scenario: Freight mode split in the EU27 countries



Source: ASTRA calculations in HOP!

As a consequence of the slight different trend of the transport modes, mode shares do not change much over time in the HOP! Reference scenario, as shown in Figure 29. Rail maintains his share while road freight share is growing at the end of the simulation period, to the detriment of maritime share. As road and maritime usually are not direct competitors (road is used on shorter distances and for smaller loads), the evolution of mode shares suggests a double shift: from rail to road and from ship to rail. At the basis of this mode shift there is the different development of the economic sectors. Coastal ships are mainly used for bulk goods (oil products, irons, cereals, etc.) whose relevance on the intra-EU trade is decreasing over time. Container ships are especially used to and from overseas, while within EU rail is an alternative mode for this share of traffic, which is the fastest developing one. Therefore, the HOP! reference scenario reflects that the future freight demand will be differently composed: higher value goods will be a higher share of total traffic and therefore modes like rail and especially road will be preferred to ship. The trend of mode shares is not significantly different between EU15 and EU12 (Table 6).

Table 6 Reference scenario: Freight mode split by region

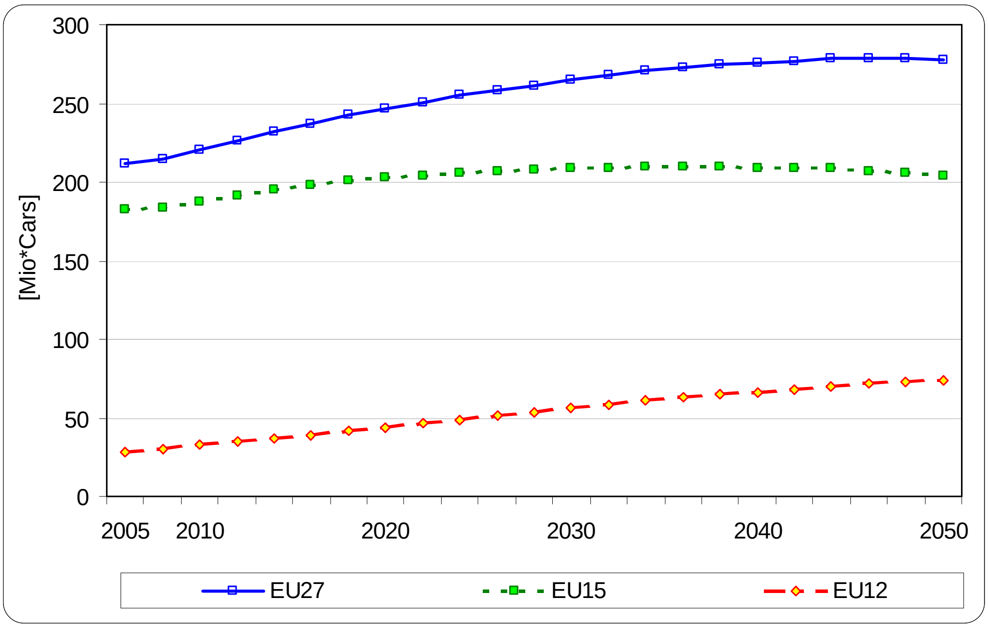
Freight mode	Mode split (% of total TKM)			
	2005	2020	2030	2050
EU-27				
ROAD	53.3%	52.4%	53.3%	54.7%
RAIL	14.3%	14.7%	14.7%	15.3%
SHIP	32.4%	32.9%	32.0%	30.0%
EU-15				
ROAD	53.8%	53.8%	54.6%	55.7%
RAIL	11.4%	11.3%	11.0%	10.8%
SHIP	34.8%	34.9%	34.3%	33.5%
EU-12				
ROAD	50.9%	47.1%	48.7%	52.0%
RAIL	28.4%	27.8%	27.3%	27.3%
SHIP	20.7%	25.1%	24.0%	20.7%

Source: ASTRA calculations in HOP!

4.2.5 Vehicle Fleet Trends

The ASTRA car fleet model estimates a growth of EU27 passenger car fleet of 34% until 2050 compared with the year 2005. In absolute numbers this means that fleet size in EU27 member states should reach 274 Mio registered cars in the year 2050 (Figure 30). Car fleet increases most significantly in EU12 countries while most EU15 are already characterised by only slight car fleet growth rates and in the final part of the simulation period even a reduction is expected. In comparison with Western European countries, several EU12 countries are still lacking behind regarding the motorisation and therefore have a higher demand for new cars and faster growth of motorisation. The average motorisation rate in EU27 in the year 2050 would be of 587 cars per 1000 inhabitants compared to the 466 cars per 1000 inhabitants in the year 2006.

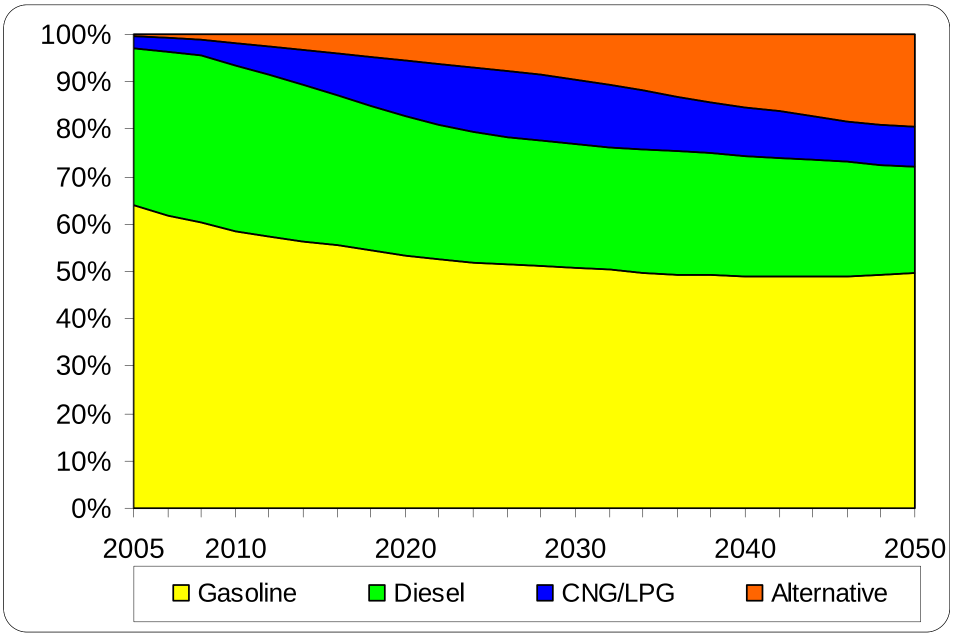
Figure 30 Reference scenario: Car fleet size in the EU27 countries



Source: ASTRA calculations in HOP!

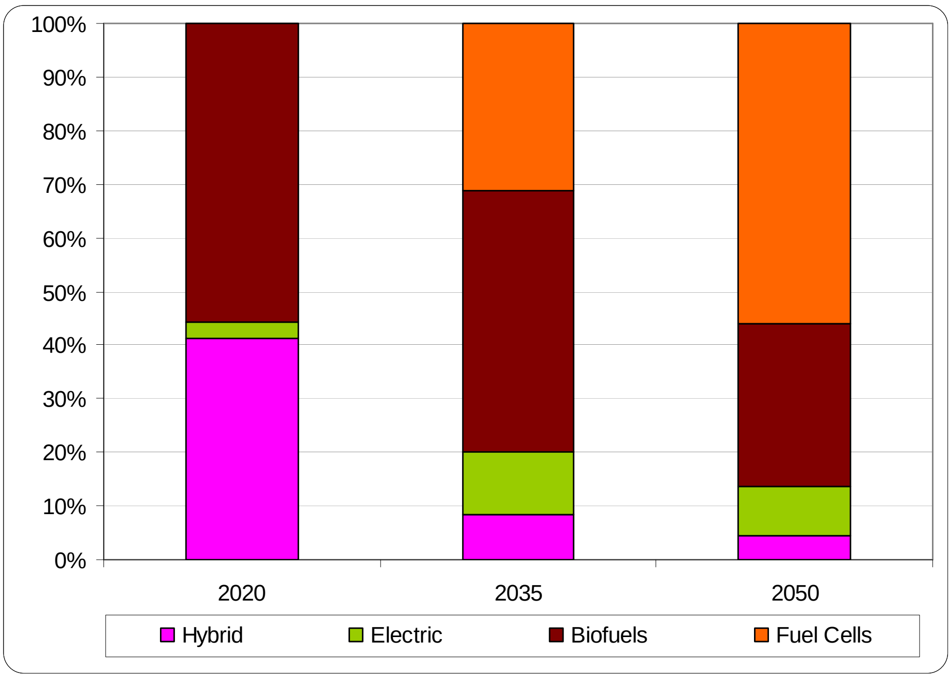
In terms of fleet composition, it can be seen that alternative fuels/technologies (i.e. biofuels, hybrid, electric, fuel cells) are expected to gain significant market shares from about 2020 – 2030, reaching about a 20% market share at the horizon of 2050 (Figure 32). Initially, the largest share of innovative cars would consist of biofuels and hybrid cars. Later, electric and especially fuel cells would enter the market replacing especially hybrid vehicles, while biofuels would still represent a significant part of the car fleet in the EU27. The low penetration rate of battery electric vehicles reflects that the car fleet model in ASTRA is not including the most recent advancements in battery technology and the market entry of new low price competitors for electric vehicles (e.g. companies based in India or China), which is expected to significantly reduce cost of these vehicles and drive market penetration much faster and much earlier (i.e. shortly after the year 2010 significant penetration of electric vehicle seems to be feasible under these conditions).

Figure 31 Reference scenario: Car fleet composition in the EU27 countries



Source: ASTRA calculations in HOP!

Figure 32 Reference scenario: Share of innovative car in the EU27 countries



Source: ASTRA calculations in HOP!

4.3 Overview on Scenario Results

This section presents an overview of the scenario results of the HOP! project showing main indicators for transport, energy and the economy across all ten major scenarios. The basic input to the scenarios, i.e. the differences in crude oil prices between the scenarios have been presented in the previous section.

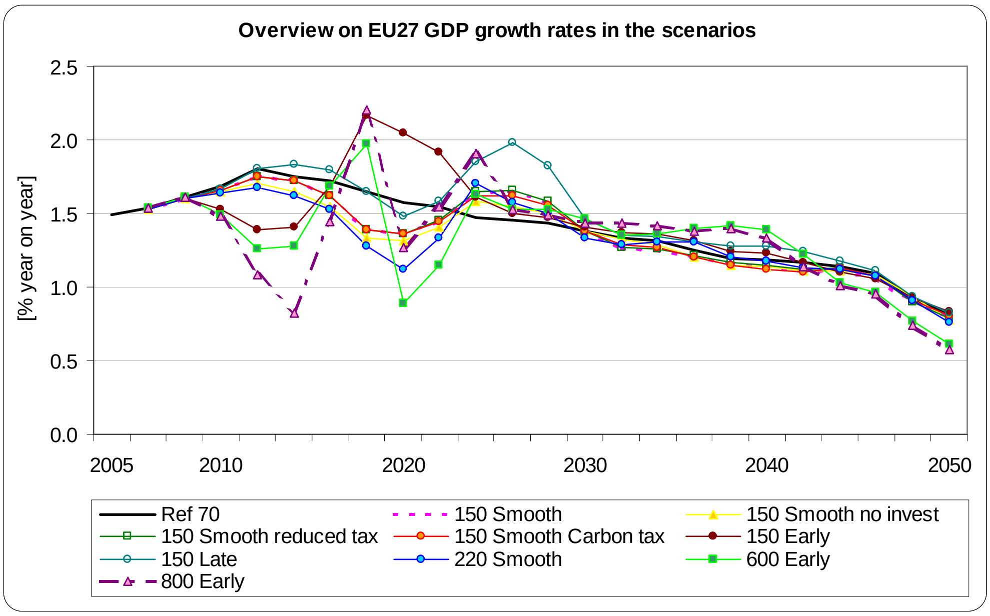
GDP development is significantly affected by the high oil prices, though a number of compensating mechanisms like investments into alternative energies, modal-shift to public transport dampen the negative impacts of the high oil prices on the economy. Figure 33 shows the impact on GDP development with two different representations: first, the absolute growth rates on a year-on-year base are presented and second the changes to the absolute GDP of the reference scenario (*Ref 70*) are shown.

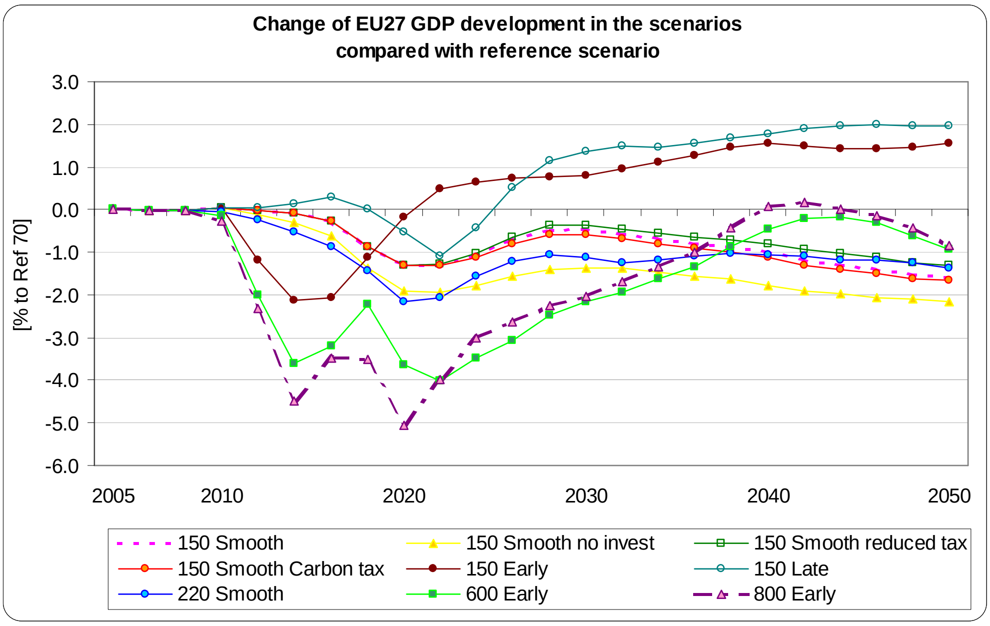
One can observe that for the scenarios increasing the oil price to 150-220 €/bbl growth rates are reduced by up to 0.5% over about a decade leading to about losses of 1-2% of GDP over the whole period. Specifics can be observed for the scenario in which the bottom-up investments from POLES and the investments into the adaptations of the vehicle fleet are limited to the reference scenario (scenario*150 Smooth no invest*), which reveals in the long run the worst development of all scenarios. This provides the first indication of the utmost importance of investments to tackle high oil prices. Further specifics can be seen for the time variations of the price increase, the early increase to 150 €/bbl (scenario *150 Early*), which means that the 150 €/bbl are reached in 2014 instead of 2020, and the late increase (scenario *150 Late*), which means that until 2017 oil price follows the reference scenario and only until 2023 the 150 €/bbl will finally be reached. These two scenarios in 2050 end with a higher GDP than the reference scenario, though because of different reasons. The *150 Early* scenario seems to stimulate investments in a most productive way and is less negatively affected by the increase of oil imports and oil prices than the 220-600-800 scenario group, while the *150 Late* scenario the fact that the lead time to adapt the energy and transport system is longer makes it happen that the negative impacts are more limited, while higher investment and sectoral shift generate positive stimuli.

The two extreme scenarios *600 Early* and *800 Early* generate losses of GDP growth rate of up to 1%, which leads to a loss of about 5% GDP, or in absolute terms about 500 Billion Euro annually. Sensitivity tests revealed that without the compensating mechanisms of increased investment into energy efficiency and alternative energies the annual loss could reach up to 1.4 Trillion Euro of EU27 GDP.

A common feature to all scenarios is that when the decade of fast oil price growth ends around 2020 a kind of rebound effect occurs that over a period of 3 to 5 years leads to higher growth rates of GDP as in the reference scenario. Partially, this should be because of POLES providing reduction of fuel prices in response to the investments in the energy system reducing the demand for oil and because of lagged effects of the economic system in response to the increased investments e.g. growth effects of productivity. Overall, the response of GDP to these scenarios is small. It seems that the boom in investment can mostly compensate for the shock.

Figure 33 Overview of EU27 GDP growth rates





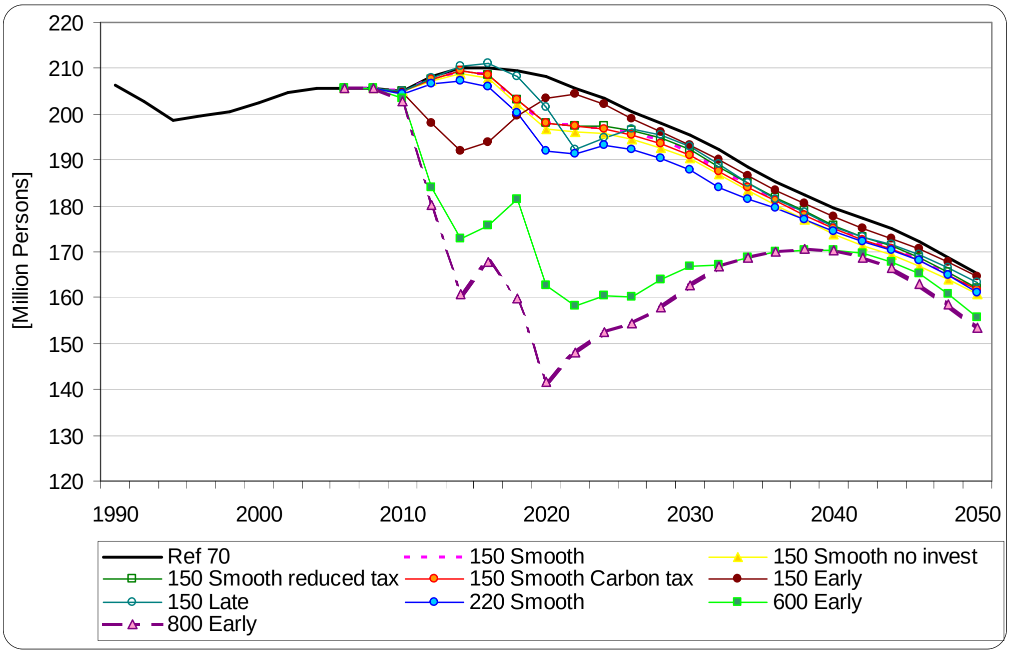
Source: ASTRA calculations in HOP!

One of the strongest impacts of the scenarios is observed for employment. All scenarios expect a reduction of employment, which is caused by several interacting impact chains. Some of them are explained in more detail in later sections. First, there is the reduction of private consumption due to inflation and the reduced GDP in the scenarios. Second, more money is spent for the energy sector, which means less for the other sectors (budget effect). In particular, these impacts negatively affect the service sectors that reveal a comparatively high labour intensity. Third, the structural changes of consumption, investment and exports tend to favour less labor intense sectors, which would even with the same level of GDP imply a reduction of employment (substitution effect). Sectoral shifts and differences in labour intensity of the affected sectors have been identified as major drivers of impacts on employment of climate policy induced changes (Laitner et al. 1998, Jochem et al. 2008). Fourth, the energy price increase affects the input cost of intermediate products to all good and services, thus reducing value-added and employment. This effect could be overestimated in ASTRA, since for these major scenarios it is assumed that the energy sector is able to forward the price increase to about 95% to the other sectors and since response of the wages to the then higher unemployment is limited.

Besides in the drastic scenarios (*600 Early* and *800 Early*) the employment loss remains in the range of -2-3%, with peaks of about -5%. However, in the drastic scenarios the employment losses could reach levels of -20 to -30% in the worst periods.

Even though these numbers seem to be overestimated it is obvious that due to the potential employment impacts the issue of high oil prices has to be taken serious by policy-makers to avoid that such dramatic losses of employment occurs.

Figure 34 Overview of EU27 employment

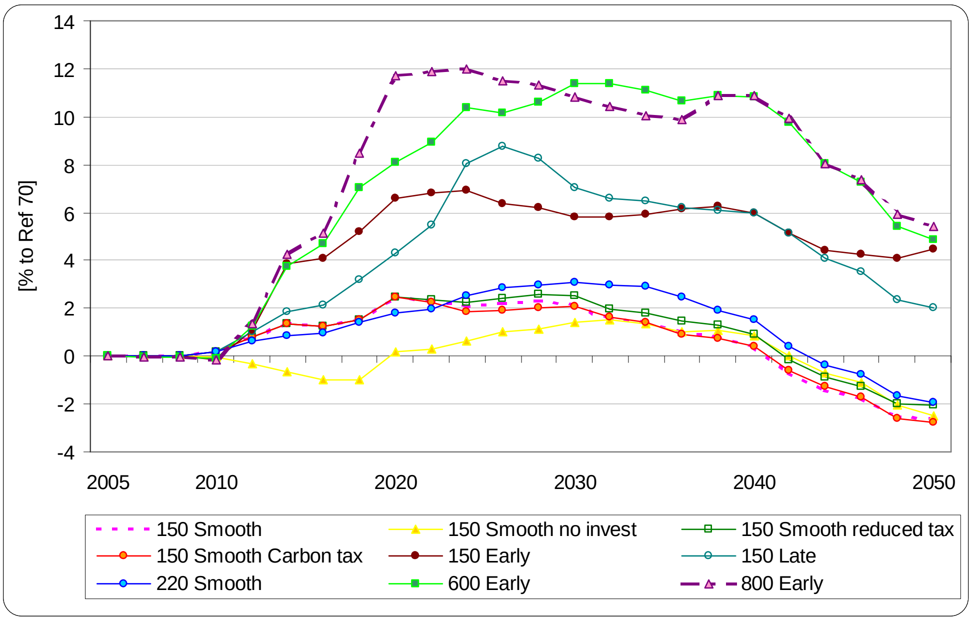


Source: ASTRA calculations in HOP!

Figure 35 presents the change of investments in EU27 due to the high oil prices. Besides in the scenario *150 Smooth no invest*, in which the investment are forced to remain roughly at the level of the reference scenario. All scenarios show a significant increase of investments. These occur from three sources: (1) the POLES model estimates investments to adapt the energy system, i.e. investment into energy efficiency and alternative energies, (2) the ASTRA model estimates investment into the transport system and related systems to adapt transport i.e. investment in R&D and production facilities to build energy efficient vehicles, and (3) the endogenous investment model of ASTRA reacts to the sectoral shifts also by generating additional investment since demand is shifted to more investment intense sectors.

In general, it can be noticed that the higher the oil price grows and the faster the growth occurs, the more rapid the growth in investment.. The limited increase of investments in the moderate scenarios seems to be feasible without any further considerations. However, the larger increases in the early step scenarios can only be expected to occur, when (1) there is no scarcity of investment capital, but in the last decade there was a scarcity of promising investment options, which is now solved by the clear need to restructure the energy system and the confidence that energy constitutes one of the basic goods for which demand will exists continuous, (2) the energy system itself generates a significant amount of investment capital by the fact that those large players who have access to oil and gas extraction sharply increase their profits with a rising oil price but fixed extraction cost of the existing wells, and (3) the situation is different from an economic downturn due to a business cycle, where it could be sufficient to cut back activities and wait for the next boom period, which in the situation of high oil price would not happen if no active investment strategy to tackle those is implemented.

Figure 35 Change of EU27 investment in HOP! scenarios compared with Reference Scenario

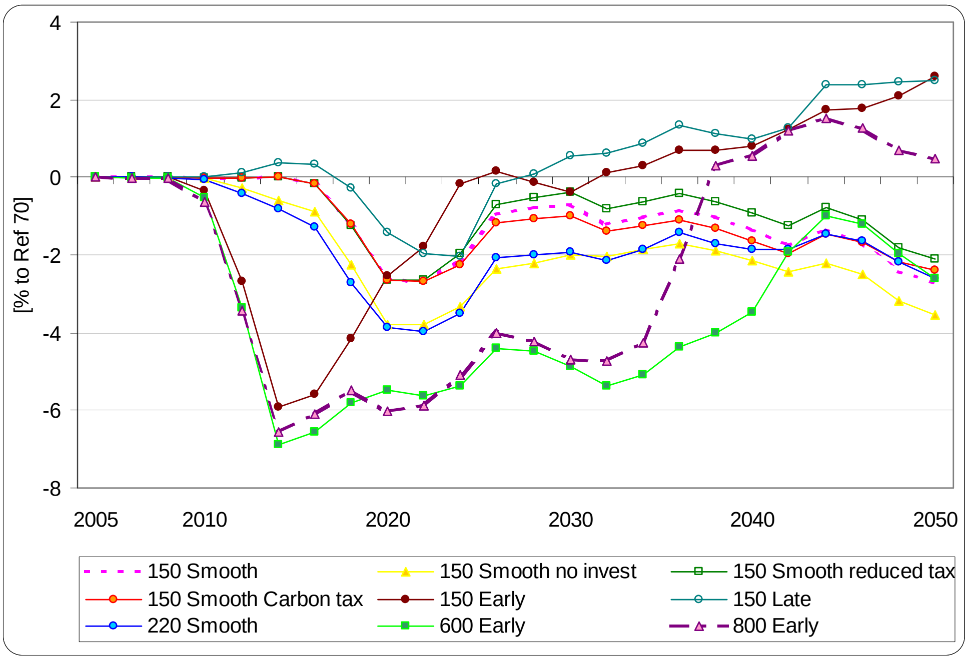


Source: ASTRA calculations in HOP!

Consumption shows some quite dynamic patterns, as can be observed in Figure 36. In all scenarios the first reaction is to decline when the oil price starts to grow, which is caused by inflation and the reduced GDP in the different economies. The reduction of taxes to counteract this effect in scenario *150 Smooth reduced tax* has a positive effect as consumption is higher than in *150 Smooth*, the basic scenario with the price increase to 150 €/bbl. But the positive effect remains limited.

More interesting is that in two scenarios (*150 Early* and *150 Late*) the growth of GDP in the last two decades enables that a higher consumption level is reached compared with the Reference Scenario. Further, it is documented that non-linear relationships also shape these results as the scenario *800 Early* after 2030 leads to a significantly more positive development than the scenario *600 early*, with an oil price that would be 200 €/bbl lower such that the opposite result would intuitively be correct. One of the reasons is that alternative transport technologies are stimulated earlier and faster in *800 Early* leading to more expenditures for vehicles, that are produced domestically in EU27, and less expenditures for fossil fuel imports, that would otherwise lead to a loss of demand in the EU27 economies.

Figure 36 Change of EU27 consumption in HOP! scenarios compared with Reference Scenario

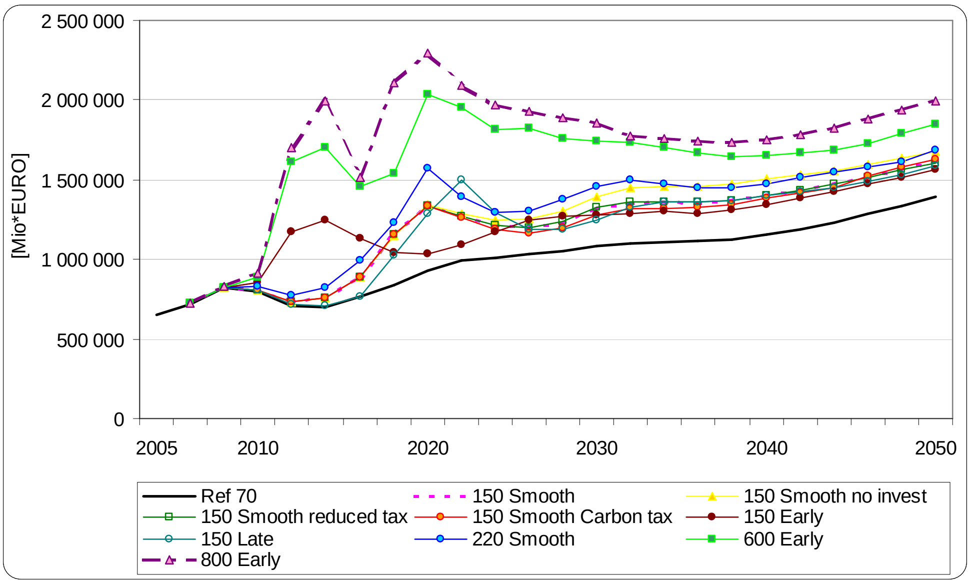


Source: ASTRA calculations in HOP!

Figure 37 presents the expenditures for energy imports of EU27 including imports of oil, gas, coal and electricity. A small share of these imports are satisfied by members of the EU, but the bulk of the energy imports comes from countries outside the EU. It should be noticed that even within the Reference Scenario (*Ref 70*) the imports measured in real terms roughly double between 2005 and 2050. However, in the HOP! scenarios this doubling occurs within less than ten years from about 2013 to 2020. In the less drastic scenarios the energy import bill reaches about 1.3 Trillion € per year in 2020, while this could amount to about 1.5 Trillion € in scenario *220 Smooth*, and 2.0 and 2.3 Trillion € in scenarios *600 Early* and *800 Early*, respectively.

Putting these numbers in relation to GDP it can be observed that in the Reference Scenario the energy import is roughly at the level of 8% of GDP, in the more moderate scenarios at the level of 10% with peaks in 2020 reaching up to 13%, and in the drastic scenarios (*600 Early* and *800 Early*) reaching the level of more than 20% in the peak, falling down to about 13% afterwards.

Figure 37 Overview of EU27 Energy imports in monetary terms

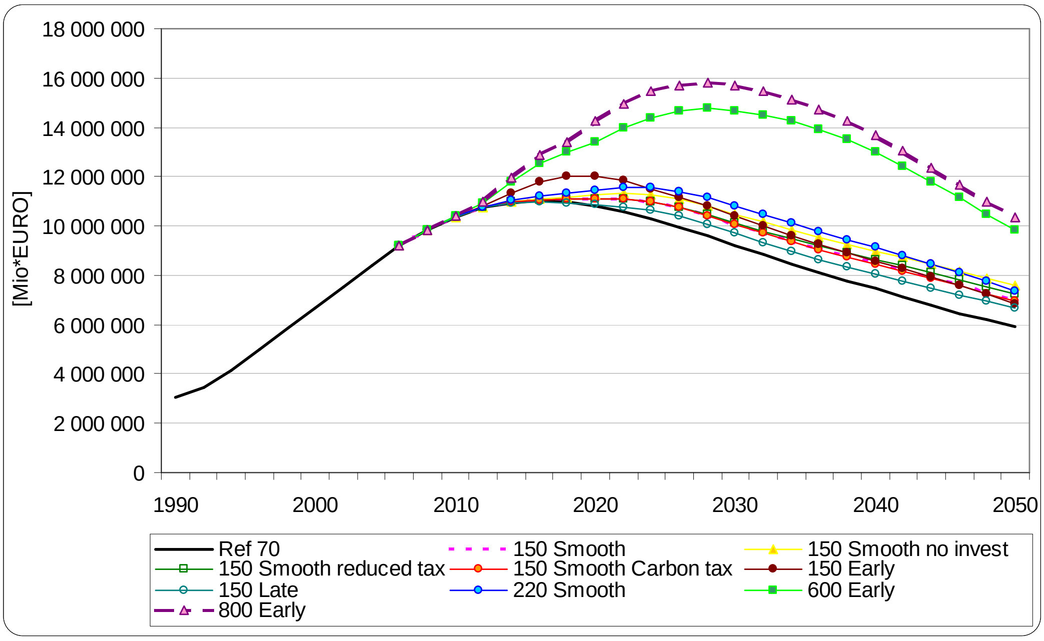


Source: ASTRA calculations in HOP!

An interesting issue is related to the influence of high oil prices on government debt. This is shown in Figure 38. In general, ASTRA expects a consolidation of the European government budgets until around 2015. However, the high oil prices tend to increase the debt and thus delay the consolidation of the government budget by about 10 years, due to increased unemployment requiring higher unemployment payments, less fuel tax revenues due to reduced fuel demand and lower revenues of VAT due to slower economic growth.

The drastic scenarios would strongly increase the government debt by about +50% and delay the consolidation of the budget to after 2030. The increased debt compared to the Reference Scenario makes that crowding out prevails leading to lowered investment in the last two decades in the scenarios (which can be identified in Figure 35).

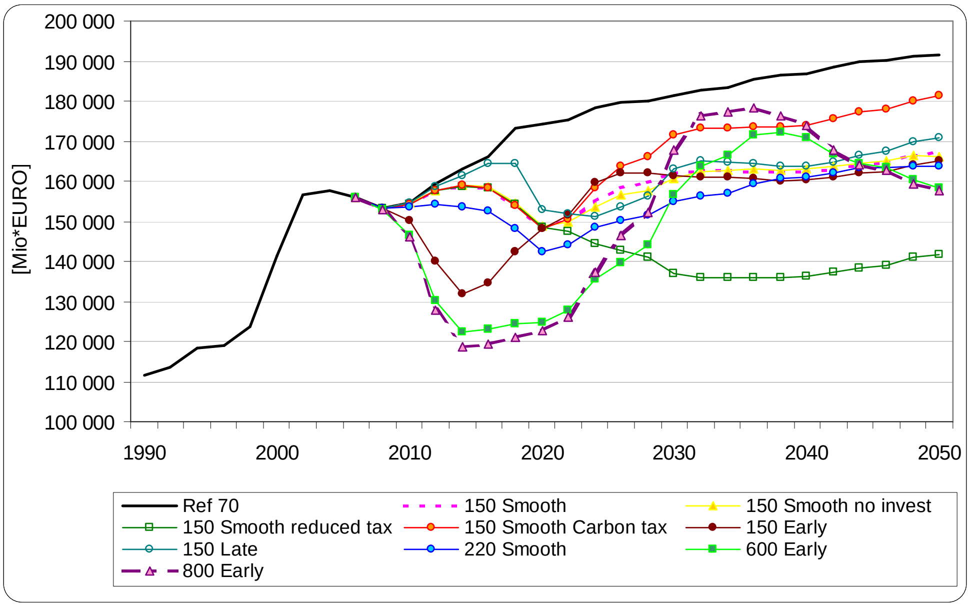
Figure 38 Overview of EU27 Governments debt



Source: ASTRA calculations in HOP!

As the later figures on transport demand (Figure 40 and Figure 41) will show a significant reduction of transport activity occurs caused by the high oil prices. Together with increased efficiency transport fuel consumption is reduced letting drop also the government fuel tax revenues (see Figure 39). The reduction reaches levels between -15 and -30%, or in absolute terms 20 to 50 Billion € less revenues annually. Similarly, the level of vehicle tax revenues is reduced due to impacts on the car fleet (reduction of number of cars and downsizing) as well as the level of transport infrastructure charges collected. It has to be pointed out that governments might respond to their loss of revenues from transport related taxes and tolls by changing the tax and toll level. This was not assumed, such that, besides in scenario *150 Smooth reduced tax*, the tax and toll levels remain as in the reference scenario.

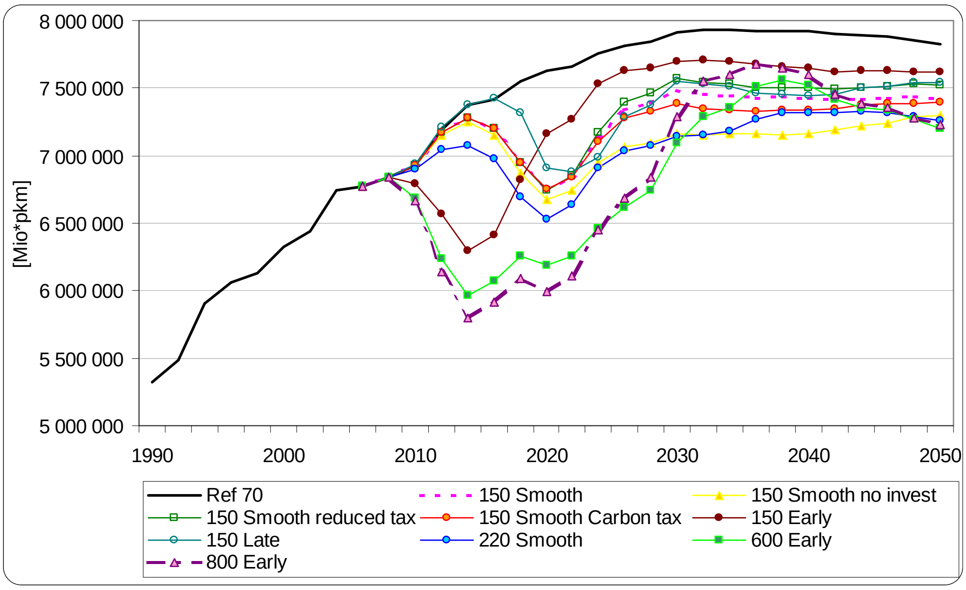
Figure 39 Overview of EU27 fuel tax revenues



Source: ASTRA calculations in HOP!

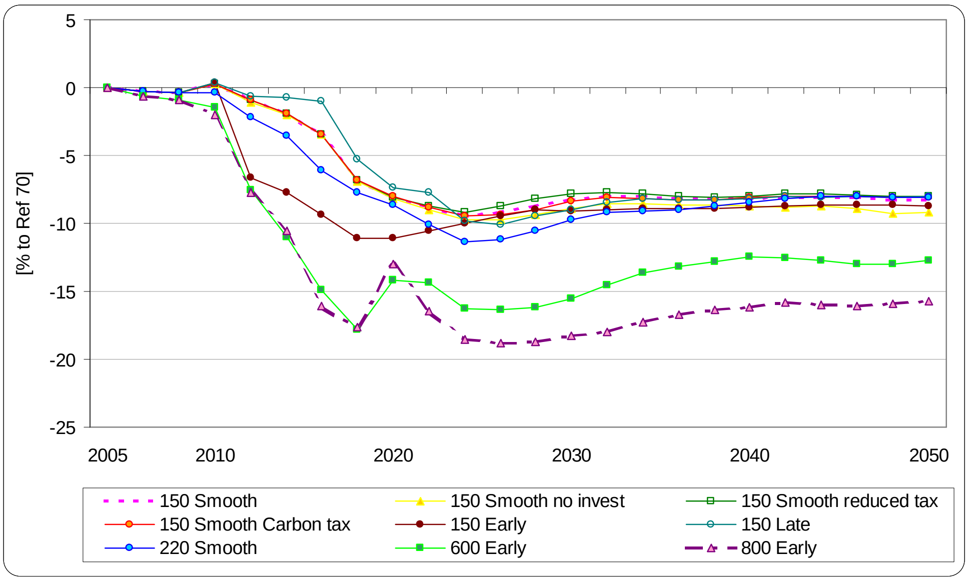
Figure 40 and Figure 41 present the reactions of passenger and freight transport demand. Both are reduced by between -10 and -20%, which is the consequence of manifold reaction patterns like mode-shift, change of destinations and reduced distances as well as lower economic activity as explained in more detail in section 4.4.2. In general, inherent transport system reactions are stronger for passenger transport, while freight transport is reacting stronger to changes in economic activity (e.g. reduced trade flows) than passenger transport. Doubling with 4.4.2. (graph of EU 27 pkm)

Figure 40 Overview of EU27 passenger transport demand



Source: ASTRA calculations in HOP!

Figure 41 Change of EU27 freight transport demand compared with Reference Scenario

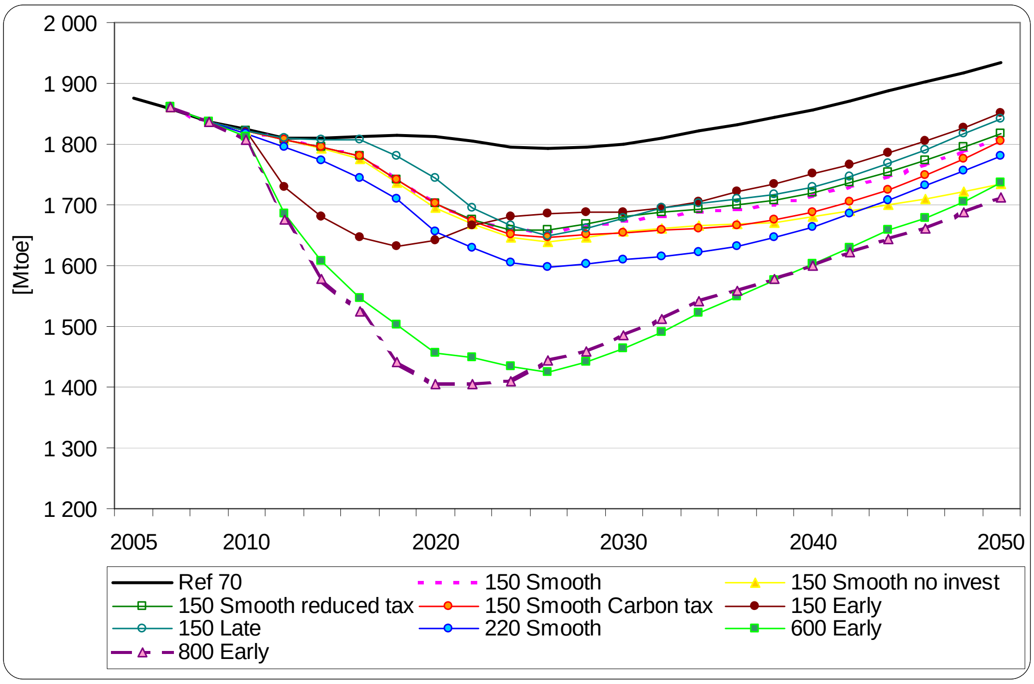


Source: ASTRA calculations in HOP!

Figure 42 describes the development of energy demand (gross inland consumption) of the EU27. Due to the increase in oil prices and the induced efficiency gains energy demand is stable until about 2030. After 2030 with slower growth of energy prices and efficiency gains reduce and growth of economic activity drives growth of energy demand.

In the scenarios the reduction of energy demand reaches levels of -10% in the moderate scenarios and of -20% in the drastic scenarios (*600 Early* and *800 Early*). Obviously, only periods with significant growth of energy prices enable a reduction of energy demand, while moderate growth of energy prices is not sufficient to set incentives to increase efficiency above the levels of economic growth, such that an absolute decoupling of energy demand and GDP would occur, as in the case of significantly growing energy prices.

Figure 42 Overview of EU27 total energy demand



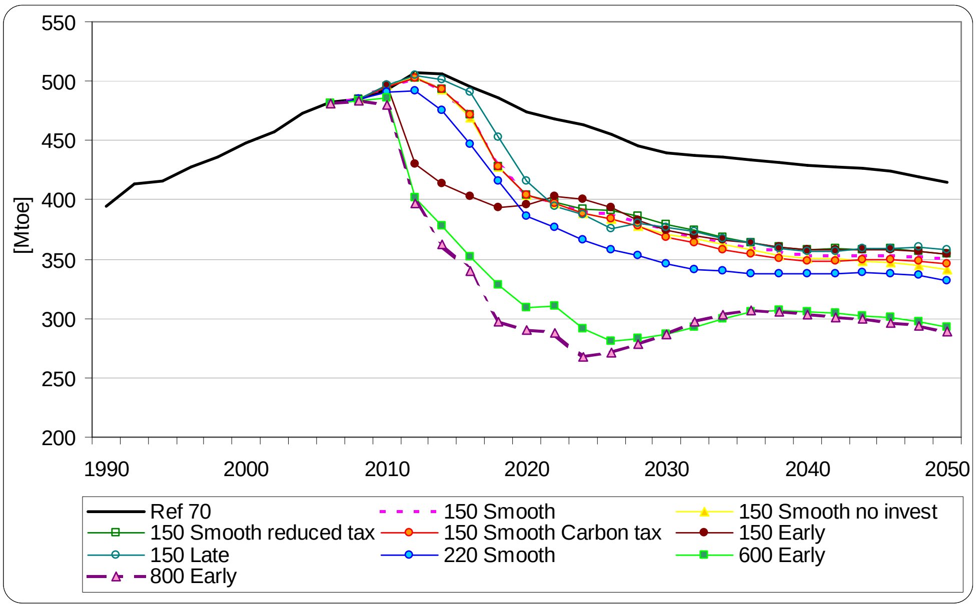
Source: POLES calculations in HOP!

The picture differs for transport energy demand. The growth in oil prices enables to break the growth in energy consumption of transport around 2015 even in the Reference Scenario, though it should be considered that two elements of transport energy demand are excluded from this aggregate numbers: intercontinental air transport and intercontinental shipping as the ASTRA model only considers air transport and shipping within the EU plus Norway and Switzerland. This is important to know as both intercontinental air transport and shipping are expected to experience the highest growth rates amongst all transport segments in the coming years.

The moderate scenarios reveal that with some delay the transport sector starts to respond significantly to the growth in oil prices after around 2015 and after 2020 achieves a reduction of energy demand by -20% compared with the reference scenario. This is caused by both reduction of demand (pkm and tkm as explained above) and improvements of efficiency due to more efficient vehicles, improved logistics, modal-shift towards more efficient modes, etc.

In the scenarios with early increase of oil prices (*150-600-800 Early*) the reaction commences right from the beginning of the oil price increase, which is thus reflecting a strong demand response and a response of modal-shift than a response caused by technology shift. In the drastic scenarios (*600 Early* and *800 Early*) the reduction reaches -40% compared with the reference scenario in the peak years around 2030 and -30% afterwards.

Figure 43 Overview of EU27 transport energy demand



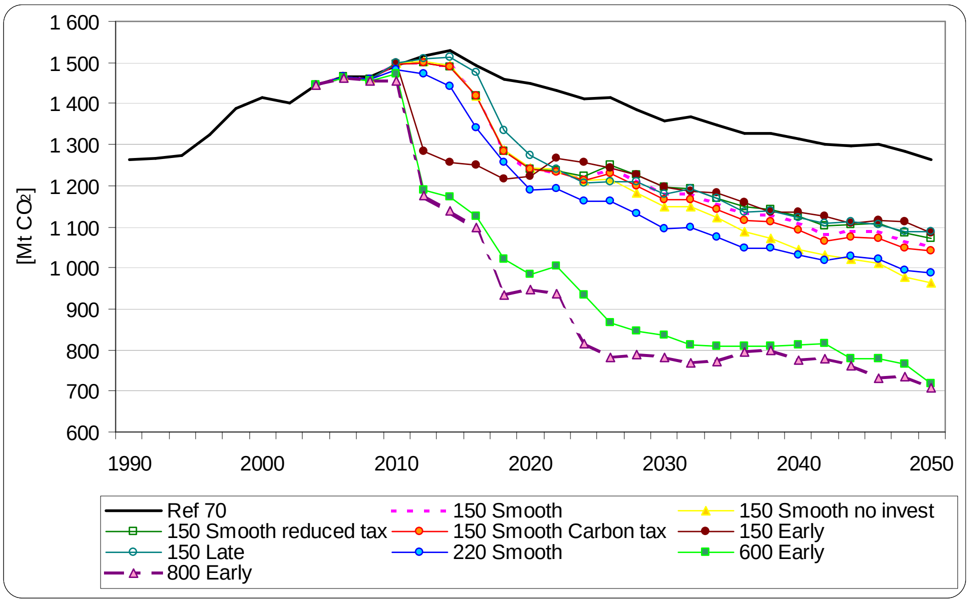
Source: ASTRA calculations in HOP!

Transport CO_2 emissions behave similar as transport energy demand, besides that in the last two decades during which alternative energy technologies strongly enter the vehicle market (e.g. hydrogen fuel cells with hydrogen generated by a growing share of renewables) the CO_2 emissions continue to decline bringing CO_2 emissions in the drastic scenarios down to -45% compared with the reference scenario and by more than -40% compared with the 1990 emission levels. In the moderate scenarios the reduction reaches -14 to -23% compared with the CO_2 emission levels of 1990.

Total energy-related CO_2 emissions would experience an even higher reduction. Already in the *Ref 70*, energy-related CO2 emissions would be reduced from 1990 levels by some 15% and 27.5 % by 2030 and 2050, respectively. This reduction is mostly due to a combination of relatively elevated oil prices[9] in the REF scenario, reaching 135 $€_{2000}$/bbl, with a carbon price rising from 5 to 30 €/t CO_2. With higher oil prices, CO_2 emission would reduce much further to be some 40% below 1990 levels in *150 Smooth.* In the extreme scenarios, CO_2 emissions may even be halved. However, these figures neglect the upstream emissions that arise from the exploration of unconventional oil and certain transport fuel alternatives such as CtL. If these were taken into consideration, even though they do not occur on EU grounds, the 2050/1990 emission reductions would be less by some 25 percentage points in *Ref 70*, 38 percentage points in *150 Smooth* and 49 percentage points in the extreme scenarios.

Despite those substantial reduction, This means the high oil prices alone will not make that transport sufficiently contributes to the reduction of CO_2 proposed by the European Commission (EC COM 2007/2) that are be sufficient for reducing GHG emissions in line with the recommendations of the IPCC (2007) . Both propose to reduce CO_2 emissions in industrialized countries by -60 to -80% until 2050 to avoid dangerous climate change, except for very high oil prices. This shows, that even with high oil prices there will be a gap of 20 to 60% reductions that have to come from climate policy, which can be aligned with a need for policies to tackle high oil prices GHG emissions. This is even more so the case in order to steer investments in oil substitutes and transport fuel alternatives into those options that decrease CO_2 emissions rather than increasing them.

Figure 44 Overview of EU27 transport CO_2 emissions



Source: ASTRA calculations in HOP!

[9] Compared to previous scenario exercises.

4.4 Results by main domain

In the following the impacts of high oil prices are discussed making reference to model results considering separately the energy, transport and economic domain.

4.4.1 The impact of high oil price on the energy sector

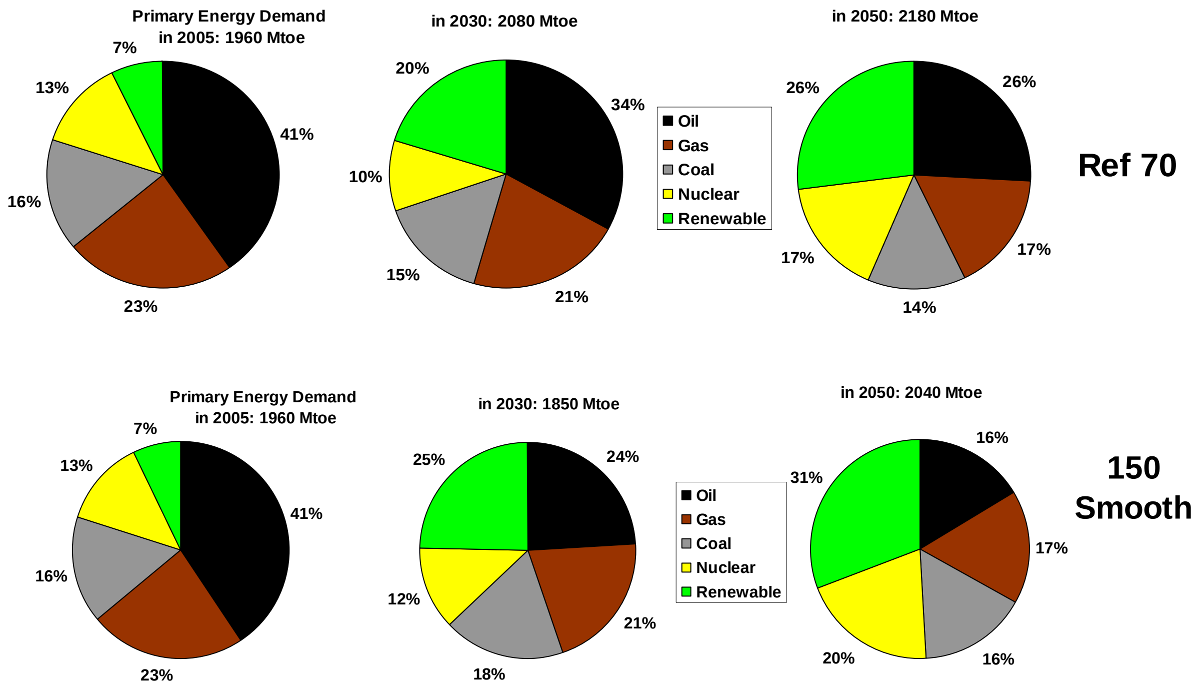
The responses of the energy system to high oil prices have been sketched out qualitatively in section 3.1.1. This section provides a quantitative assessment of the developments in the energy sector with regard to the energy mix, final energy consumption, energy production and transport fuel prices. It ends with a description of the energy-related CO_2 emissions that result from the high oil prices and the subsequent responses of the energy system

Changes in the fuel mix of primary energy consumption are one of the most direct impacts of high oil prices, due to the altered relative competitiveness of the various energy carriers. In *150 Smooth*, oil prices would increase by a factor of 7.5 between 2050 and 2005 (in real terms) and gas prices would follow this rise to some extent (factor 4.5), while the prices for coal would 'only double' over that period.

As a direct consequence, oil would loose its dominant share in the EU's primary energy consumption between 2005 and 2050 (see Figure 45). This trend is much more pronounced than in *Ref 70*, where oil would nevertheless still provide more than a quarter of total primary energy consumption. In the extreme scenarios, oil consumption could be reduced to account for less than 10% of total energy consumption.

Both compared to *Ref 70* and to today's levels, renewable energy carriers, coal and nuclear power would benefit most from the oil-price induced changes in the fuel mix in the order mentioned. Renewables would provide more than one third of the overall energy consumption, partly due to biofuels but also to renewable energy sources in electricity production, given that electricity will further gain in importance.

Figure 45 EU27 fuel mix of primary energy consumption in the *Ref 70* and *150 Smooth* scenario

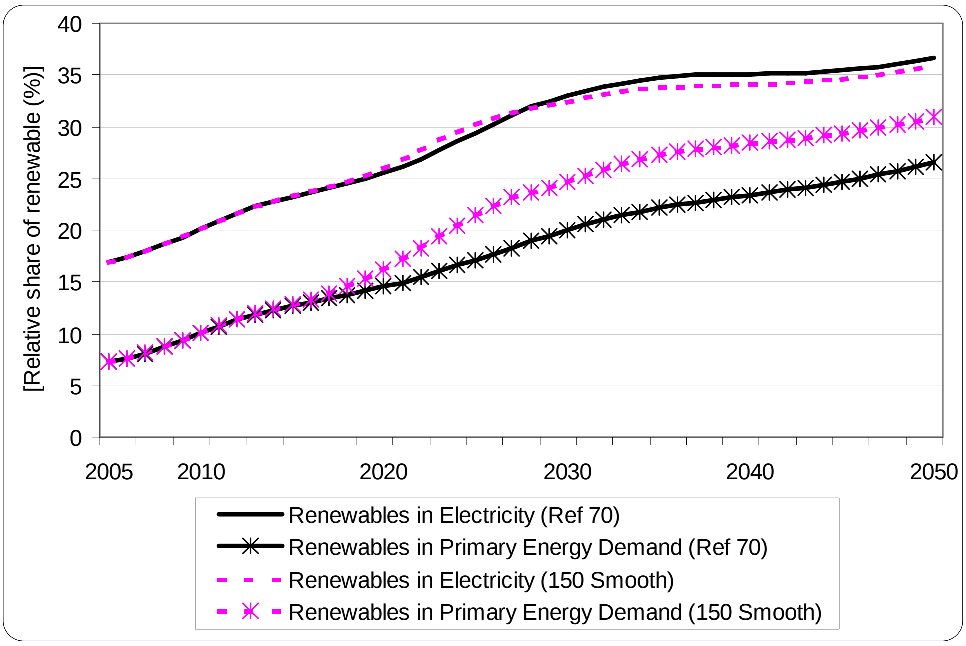


Source: POLES calculations in HOP!

If we look more specifically at the fuel mix for transport, the fast deployment of biofuels become obvious as their relative competitiveness to the fossil substitute improves (see Figure 46). This, however, depends on whether investments in biofuel production facilities will be available: Scenario *150 Smooth no invest* shows that the biofuel share would hardly increase from reference levels despite the much improved competitiveness to the fossil alternative, if investments were insufficient.

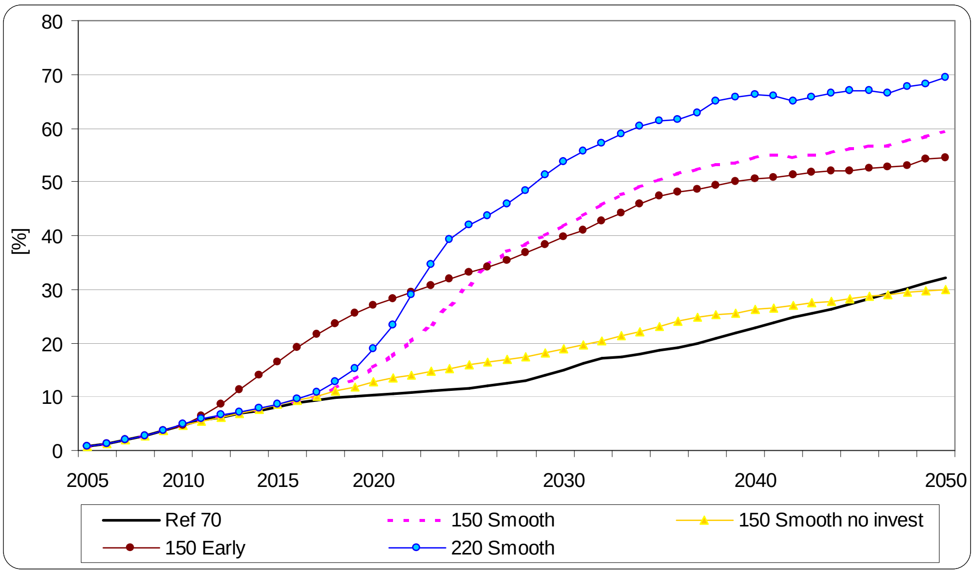
A second pre-condition would be the availability of biofuels for imports, which are assumed to be around 30% in the scenario as an upper boundary. Note also that very high shares of biofuels would probably come at the cost of decreasing the availability of land for nature protection purposes and for food crops, leading to increases in food prices.

Figure 46 Contribution of renewable energy carriers to electricity and overall energy in EU27



Source: POLES calculations in HOP!

Figure 47 Share of biofuels in EU27 transport fuel demand



Source: POLES/BioPOL calculations in HOP!

Discussion Box

How realistic is a biofuel share of 50%?

According to the model outcomes, the share of biofuels in transport gasoline and diesel demand would rise to 15% by 2020 if the oil price reached 150 €/bbl. Assuming a continuous increase of the oil price to 270 €/bbl by 2050, the share of biofuels would increase even further to deliver almost 60% of the transport fuel demand.

Such elevated biofuel shares necessitates a further discussion, in particular when having in mind the current discussion's about the EU's 10% biofuel target for 2020. Some key issues shall thus be explained in the following:

Key issue 1): absolute and relative values

Elevated oil price strongly reduce transport fuel consumption. In the scenario *150 Smooth*, transport fuel demand would be some 20 % below reference levels, and 37 % below its 2005 levels. By 2050, this discrepancy would be slightly increased 22 %.

A 15% biofuel share in scenario *150 Smooth* thus equals 40 Mtoe and a 60 % share by 2050 equals 120 Mtoe. In the reference scenario, similar amounts of biofuel consumption would represent a share of 13% and 47 % by 2020 and 2050, respectively.

Key issue 2): time and technology development

It is important to keep in mind the time profile of the market deployment of biofuels. Even though most biofuels would have become competitive with fossil fuels at oil prices of 150 and 2020 €/bbl, by 2020 their market share would not exceed 15 % and 19%, respectively. This is due to the fact that by then, first generation biofuels would still dominate the biofuel mix. 2^{nd} generation biofuels would account for mere 9-10% of overall biofuel production. In later years, this would drastically change in the high oil price scenarios, leading to 2^{nd} generation technologies providing between half and two thirds of the total biofuel production by 2050, depending on the scenario.

This shift to advanced biofuels[10] is a key factor for achieving the high biofuel shares estimated in the HOP! scenarios. If only first generation biofuels were considered, their production would rise further until around 2030, but stagnate afterwards.

Furthermore, biofuel penetration in the model follows an S-shaped curve, thus preventing an unrealistically rapid uptake when biofuels become competitive. The model applies an upper

[10] Note that the BioPOL model assumes that the capital costs of 2^{nd} generation biofuels will be reduced over time, mainly driven by economies of scale that result from larger plant sizes. Using the cost reduction factors provided in (Boerrigter, 2006; see also: Hamelinck and Faji, 2006) and following the assumption from (Deurwarder et al., 2007) that a doubling of capacity can happen fastest only every three years, the following cost developments could be observed: a reduction of the investment cost by 50% until the year 2030, which results in a reduction of production cost by 30% for the same time horizon.

limit to the annual extension of biofuel production capacity in order to account for the necessary investment raising, planning procedures and construction times of those plants.

Key issue 3): competition with food: value choice vs. market mechanism

Cultivation of crops as a feedstock for first generation biofuels and food and fodder production can come into competition, in particular at elevated biofuel shares. Competition may occur both for a certain commodity (e.g. wheat or maize) or for arable land. Such competition effects are much less pronounced for second generation biofuels, which can make use of a much broader range of feedstock, including residues.

When discussing competition with food production, we will primarily focus on domestically produced first generation biofuels. Note that the HOP! scenarios assume that around one third of the overall biofuel consumption is provided by imports rather than domestic consumption.

With oil prices reaching 150 €/bbl by 2020 and rising further to 270 €/bbl by 2050, total domestic production of first generation biofuels in the EU would rise to 30 Mtoe by 2020 and 53 Mtoe by 2050. This equals a need for primary feedstock in the order of some 60 and 108 Mtoe respectively.

A number of studies indicate that in theory, such potential can be provided. The REFUEL project estimated that the available primary biofuel feedstock potential (1st generation only) in the EU-27 could amount to around 80 Mtoe in a low scenario and 100 Mtoe in a high scenario. Thraen et al. (2006) estimates that the energy potential of oil and starch crops for 1st generation biofuels in the EU28 (i.e. incl. Turkey) could be some 160 Mtoe by 2020, well-above the needs estimated in the HOP! scenarios. If environmental constraints were applied, the same potential would be some three times lower, reaching around 50 Mtoe (Thraen et al., 2006; also EEA, 2006). This demonstrates that fulfilling the oil-price induced push of first generation biofuels could bear a risk for nature protection objectives.

Nevertheless, constraints in the availability of biofuel feedstock or of land are not explicitly dealt with in the BioPOL model. Instead of imposing a value-judging about which parts of the European arable land should be dedicated to biofuel feedstock production and which to food / fodder production, it leaves the choice to the market. For this to be accurate, it takes into account the impact of a rising feedstock demand on feedstock prices. Such approach may not reflect reality, yet any such decision would be a societal choice that is difficult to predict on the grounds of today's discussion.

Key issue 4): availability of investments

The analytical toolbox applied in the HOP! project is based on the assumption that market mechanism work. In the absence of additional constraints, all investments that are necessary for expanding the biofuel production capacity would be made available. In reality, this assumption can be doubted.

For this reason, a scenario with a limited availability of investments has been assessed (*150 Smooth no invest*). This clearly indicates that biofuels would remain more or less at reference levels if investments were not available to the extent needed.

Conclusion

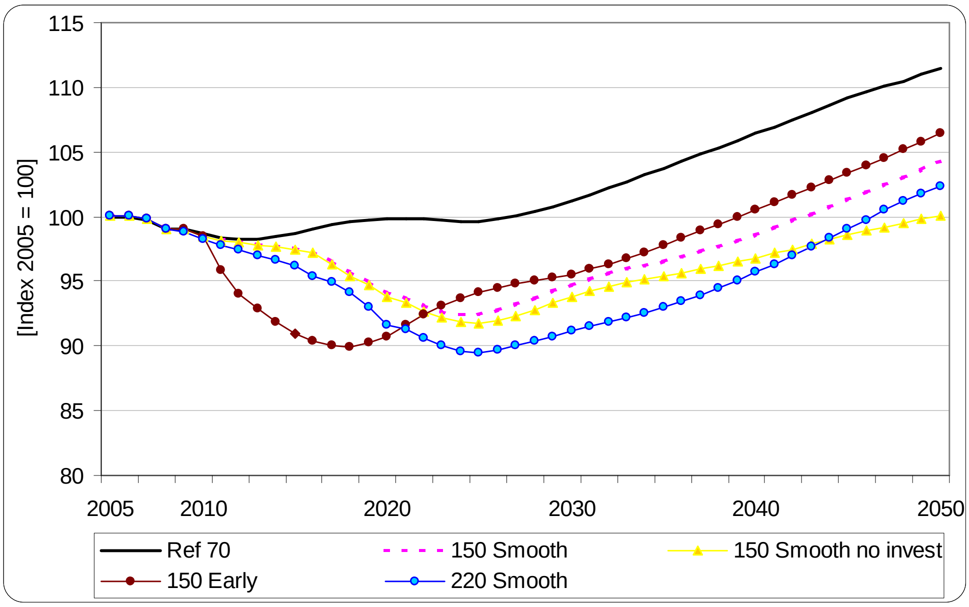
Taken into considerations the points raised above, the biofuel trends as estimated in the HOP! scenarios may be interpreted of an upper boundary of their pure market-based penetration, assuming the availability of investments and of 2nd generation production technologies as well as of imports. The outcomes illustrate the importance of discussing biofuels in the wider context of food and fodder production, of international trade and of technological innovation.

The estimates also indicate that the rapid development of oil prices may require policy making to adapt their perspectives in discussing biofuels. Ultimately, a biofuel policy would not primarily look into how to increase their market shares, but rather on how to restrain biofuel feedstock production to a level that restricts its impact on food/fodder production and environmental pressures to an acceptable limit. Yet, the definition of these 'acceptable levels' of trade-offs is a societal choice and as such not built in into the model applied.

The second direct consequence of the increasing energy prices will be a reduction in energy consumption. Primary (or: gross inland) energy consumption is projected to decrease by in-between 5% and 10% in the period following the oil price shock in all scenarios (see Figure 47). Final energy consumption would decrease even more. It would reach levels of more than 10% (16%) below *Ref 70* by 2030, and 11% (14%) by 2050 in scenario *150 Smooth* (*220 Smooth*). Not surprisingly, the transport sector would experience the most drastic reductions in energy consumption (see Figure 48).

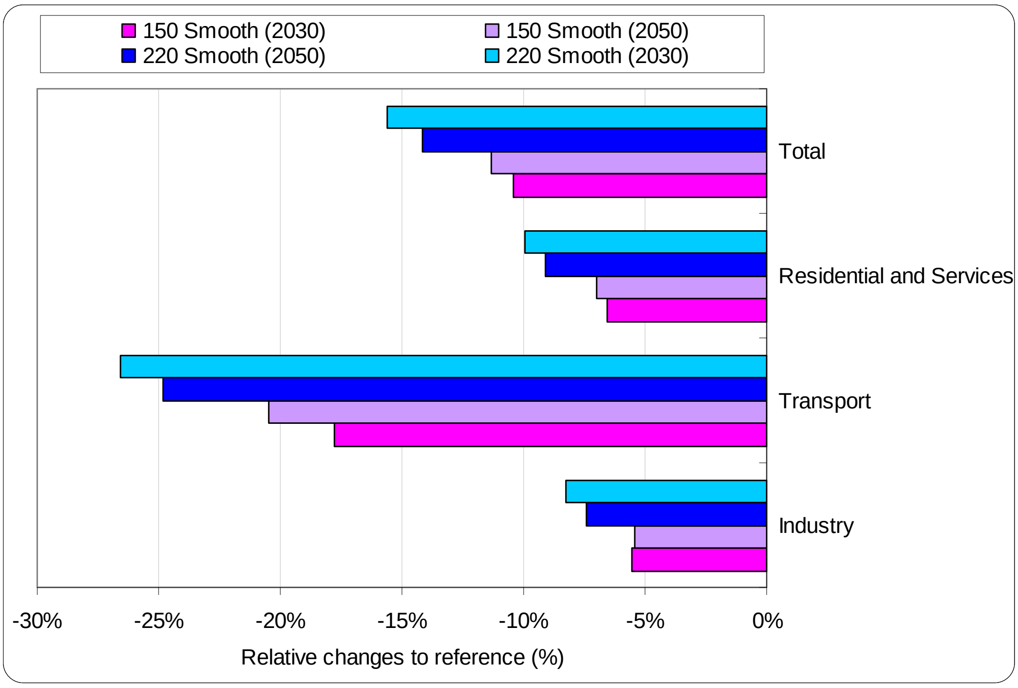
Note that electricity consumption would react in the opposite way: in all scenarios assuming high oil prices, it would increase by some 2-8% above reference levels. This is influenced by the fact that final energy sectors would switch further from e.g. oil to electricity use (a trend that could already be observed in the EU over the past decades). At the same time, the electricity sector is considered to be relatively flexible in switching to non-fossil resources such as nuclear and renewables, but could also experience a renewed increase in coal-based power generation, given that the competitiveness of coal also gains in relative terms.

Figure 48 Trend of EU27 primary energy consumption



Source: POLES calculations in HOP!

Figure 49 Relative changes of EU27 final energy consumption by sector with respect to reference scenario (years 2030 and 2050)

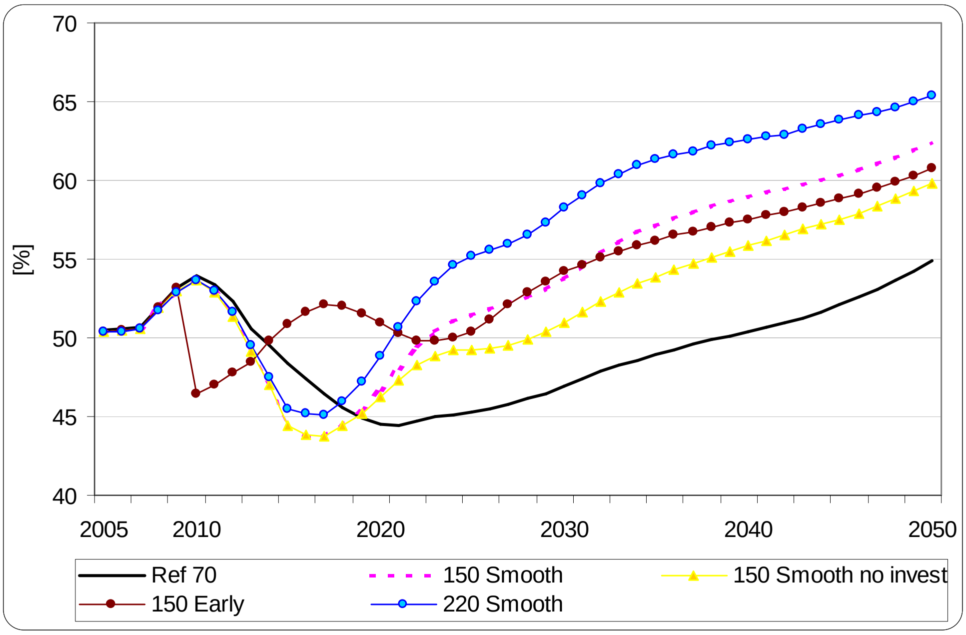


Source: POLES calculations in HOP!

A co-benefit of the oil-price induced changes in the energy supply and demand is that a larger part of the EU's energy consumption can be derived from domestic energy production. This implies a reduced rate of imports and may thus be beneficial for energy security. By 2030 (2050), the share of domestic energy production in the EU's gross inland energy consumption would increase from 47 % in the reference to 54 % in the scenario *150 Smooth*, and may even rise further to exceed 65% in *Smooth 220*.

The increased domestic energy production is primarily driven by the substantial rise in the use of renewable energy carriers, in particular wind energy and biofuels. Also electricity generation from nuclear power would increase in absolute terms. Domestic coal production would be above reference levels, but nevertheless decrease over the period 2005-2050.

Figure 50 Share between EU27 domestic Energy Production and EU27 Energy Consumption

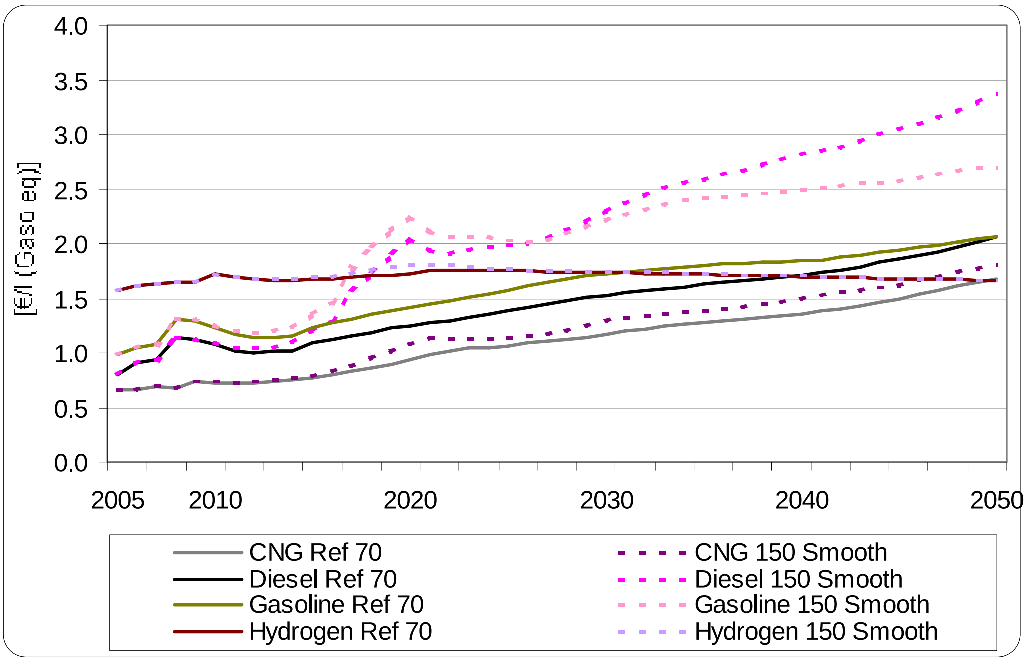


Source: POLES calculations in HOP!

Overall, the above changes have a dampening feed back on the oil price. The resulting transport fuel and electricity prices until 2050 are assessed in the following for the reference scenario and scenarios 1 and 9 (smooth grow to high or very high oil price). In the reference scenario prices are already growing, and of course if oil price increases the fuel prices react accordingly. The growth is more apparent until 2020, then reaction on the demand side (see for instance paragraph 4.2.3) and the availability of alternative sources, slow down the growth.

Given all the response described above, transport fuel prices would change as depicted in Figure 50. The assumed oil prices of 150 €/bbl would lead to gasoline and diesel prices above 2 €/bbl in 2020, taking into consideration current and agreed fuel taxes. Diesel and gasoline price are given as a mix of fossil fuel and biofuel. After a decade of price stabilization above 2 $€_{2000}$/bbl diesel and gasoline price continue to rise but less strong than the oil price. Transport fuel prices rise less firstly due to the dampening effects of fuel taxes and secondly due to the biofuel production cost which are lower than the fossil fuel cost. As we consider a certain link between oil and gas prices the latter are expected to increase slightly as well while hydrogen remains almost stable. The most important cost component for hydrogen are the investment cost. However, is has to be kept in mind that the main factor of the competitiveness of hydrogen as transport fuel are the hydrogen vehicle cost.

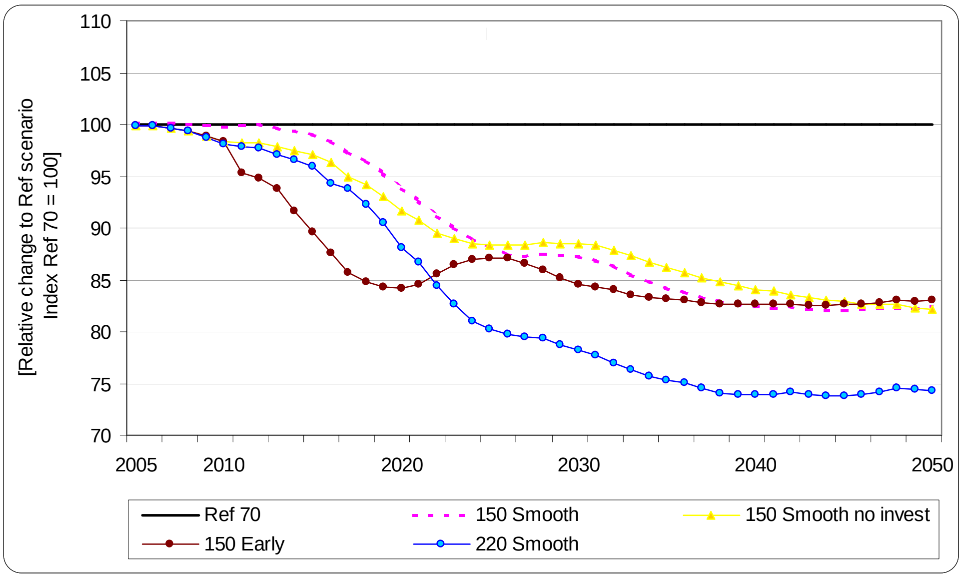
Figure 51 Average EU27 transport fuel prices



Source: POLES calculations in HOP!

Eventually, the changes in energy demand and in the fuel mix of energy supply impact on the energy-related carbon dioxide emissions, which still account for the vast majority of total GHG emissions in the EU. This is shown for the various scenarios in Figure 52. The largest impact on emission was achieved for very high oil prices and for the scenario assuming a combination of a high oil price with a carbon tax (that comes on top of the already assumed carbon dioxide value of some 5 €/t, rising to 30 €/t CO_2). But already in scenario *150 Smooth*, emissions would be reduced by some 7% in 2020 and some 13% in 2030 compared to the reference levels.

Figure 52 EU27 CO_2 emissions compared with Reference Scenario



Source: POLES calculations in HOP!

It has to be mentioned that POLES considers only the downstream emission and does not consider the emissions over the whole life-cycle. The effects on emissions due to the switch from conventional to unconventional oil and to CTL are therefore not taken into account in Figure 52. The differences of the emission factors are quite considerable: CO2 emissions from tar sand are estimated to be 24% higher than for conventional oil. In the case of CTL they are with more than 100% even higher. However, including CTL and unconventional emissions for petroleum products for transport would alter the results only minor as the reference scenario contains unconventional oil as well. The CO2 emissions in *150 Smooth* would be reduced by some 6% in 2020 and some 13% in 2030.

4.4.2 The impact of high oil price on the transport sector

The transport sector is very energy intensive and therefore the impact of higher oil prices – translated into higher fuels prices – can be readily seen. It is generally believed that transport demand is very rigid and therefore only minor adjustments should be expected. However, when fuel prices climb to unusual high values and remain high, people behaviour can change. Even if mostly anecdotic, some evidence of transport demand reactions is already available for USA. For instance, The Wall Street Journal wrote last March 3rd 2008[11] that "in the past six weeks, the nation's gasoline consumption has fallen by an average 1.1% from year-earlier levels […] that's the most sustained drop in demand in at least 16 years, except for the declines that followed Hurricane Katrina in 2005 […] There is evidence that Americans are changing their driving habits and lifestyle.". Also USA Today reported last May 16th 2008[12] a statement from ExxonMobil Corp chief executive Rex Tillerson saying that "We're already seeing some demand slackening in gasoline demand in terms of miles driven"[…] So I think

[11] http://online.wsj.com/article/SB120451858896807177.html

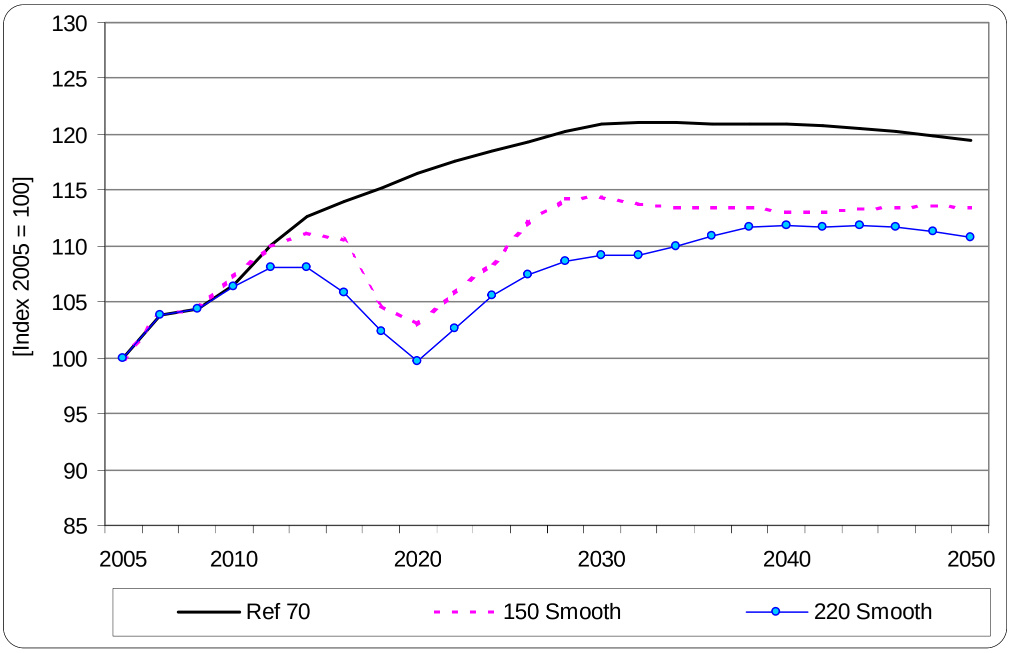
[12] http://www.usatoday.com/travel/news/2008-05-15-memorial-day-travel_N.htm?csp=34

we're very near, if we're not already at, the price where people clearly are altering their daily behaviour".

4.4.2.1 The impact of high oil prices on the passenger transport sector

Actually, the simulations suggest that transport demand is reactive to higher fuel prices. In Figure 53 the trend of total passengers-km in EU27 is shown. In the reference passenger demand is sharply growing until about 2030, then it is stable or declining given the expected reduction of population in Europe. The growth of conventional fuels prices, which is particularly relevant between 2015 and 2020 (see paragraph 4.2.1 above) leads the passenger performance to slow down its growth and than even to a reduction. A the year 2020 passengers-km are forecasted to be only 5% more than in the year 2000 in case of 150 $Euro_{2000}$/bbl or even only 2% more in case of 220 $Euro_{2000}$/bbl.

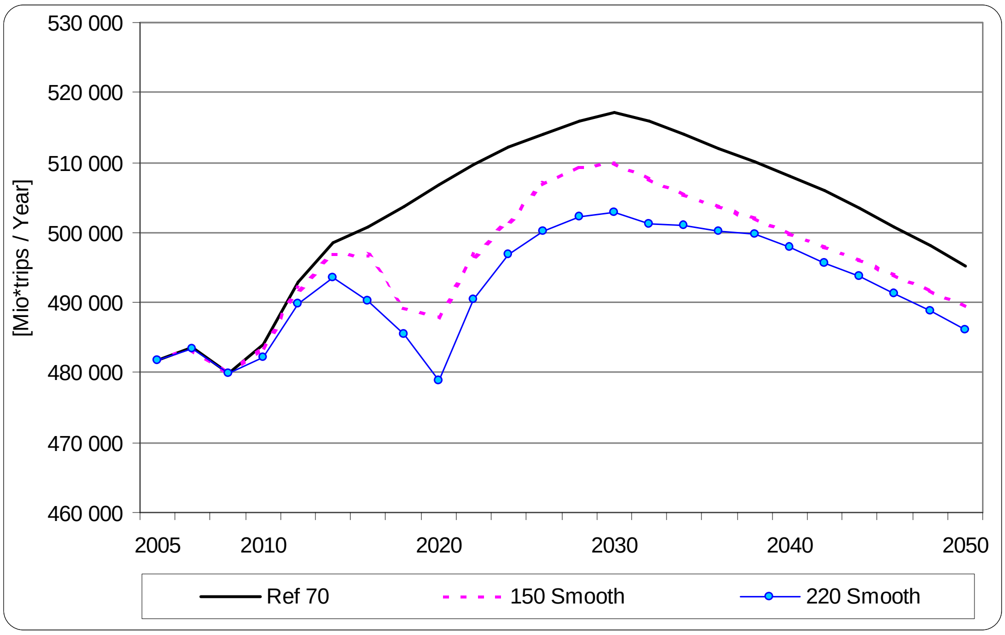
Figure 53 Trend of EU27 passengers-km



Source: ASTRA calculations in HOP!

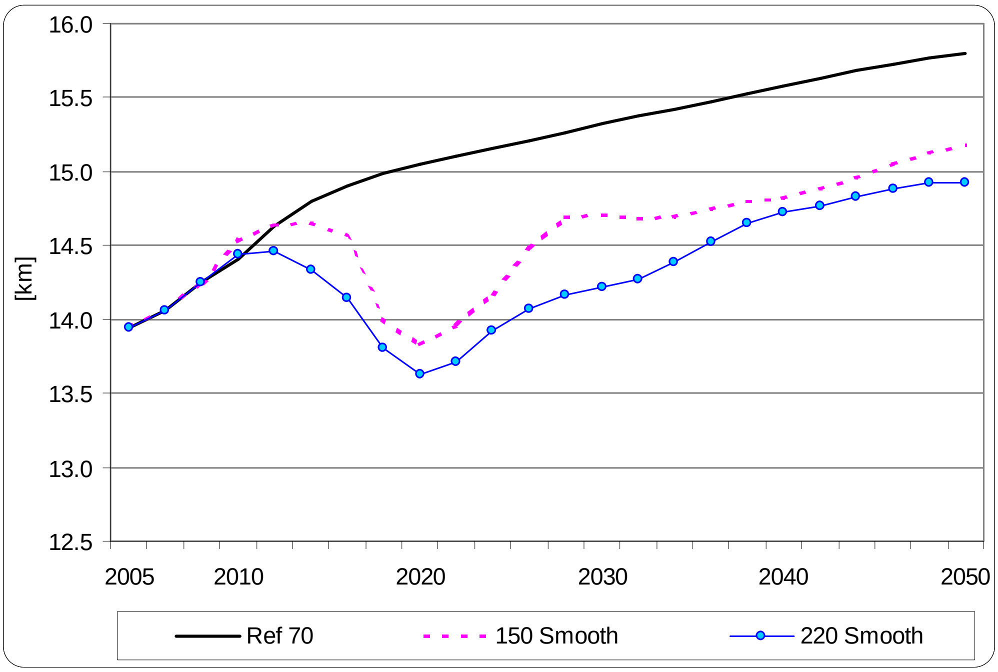
The reduction of transport performance is more the result of shorter trip distances than of less trips. As explained in chapter 2, trip rates are rigid in the model. The small reduction of total number of trips shown in figure 11 with respect to the reference scenario is due partially to a lower motorisation rate (the availability of car induces more mobility) and more significantly to the assumed impact of technology applications for reducing the need of travel (e.g. teleworking). However, the real difference between scenarios is the reduction of trip lengths. figure 12 shows how the average trip distance is lowered when energy price increases. This effect corresponds to a larger share of trips made on shorter distances (figure 13).

Figure 54 EU27 passengers trips until 2050



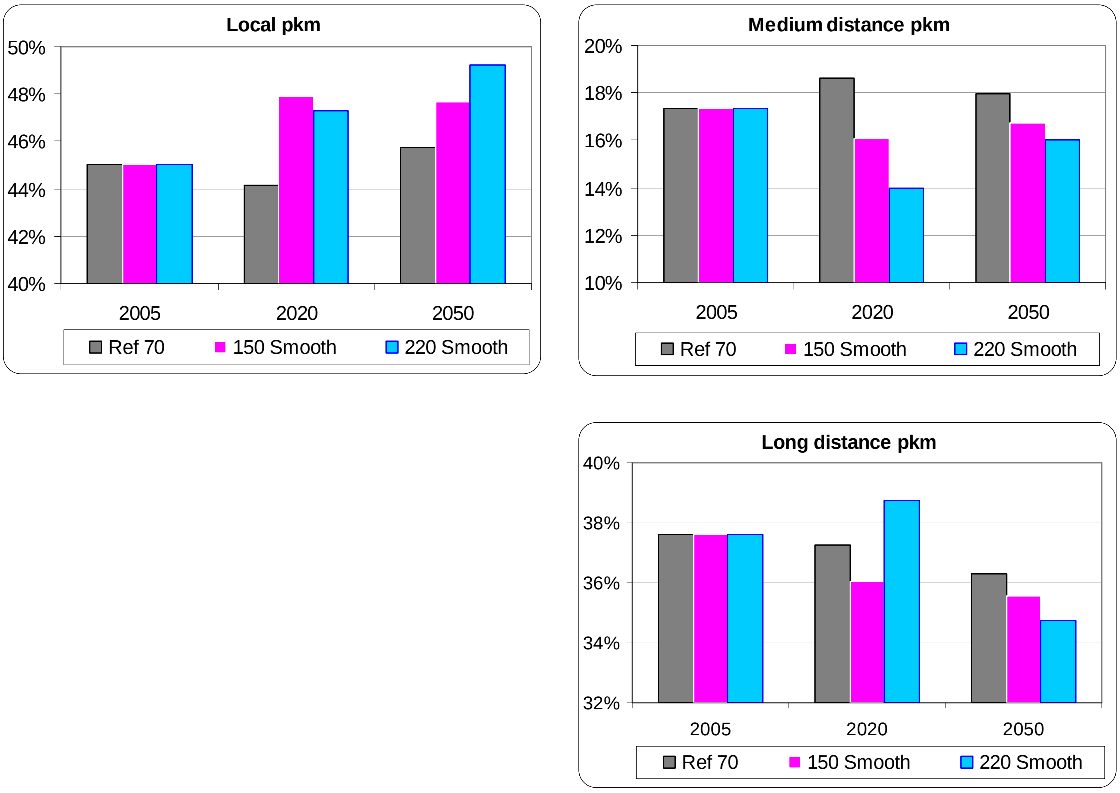
Source: ASTRA calculations in HOP!

Figure 55 EU27 average passenger travel distance



Source: ASTRA calculations in HOP!

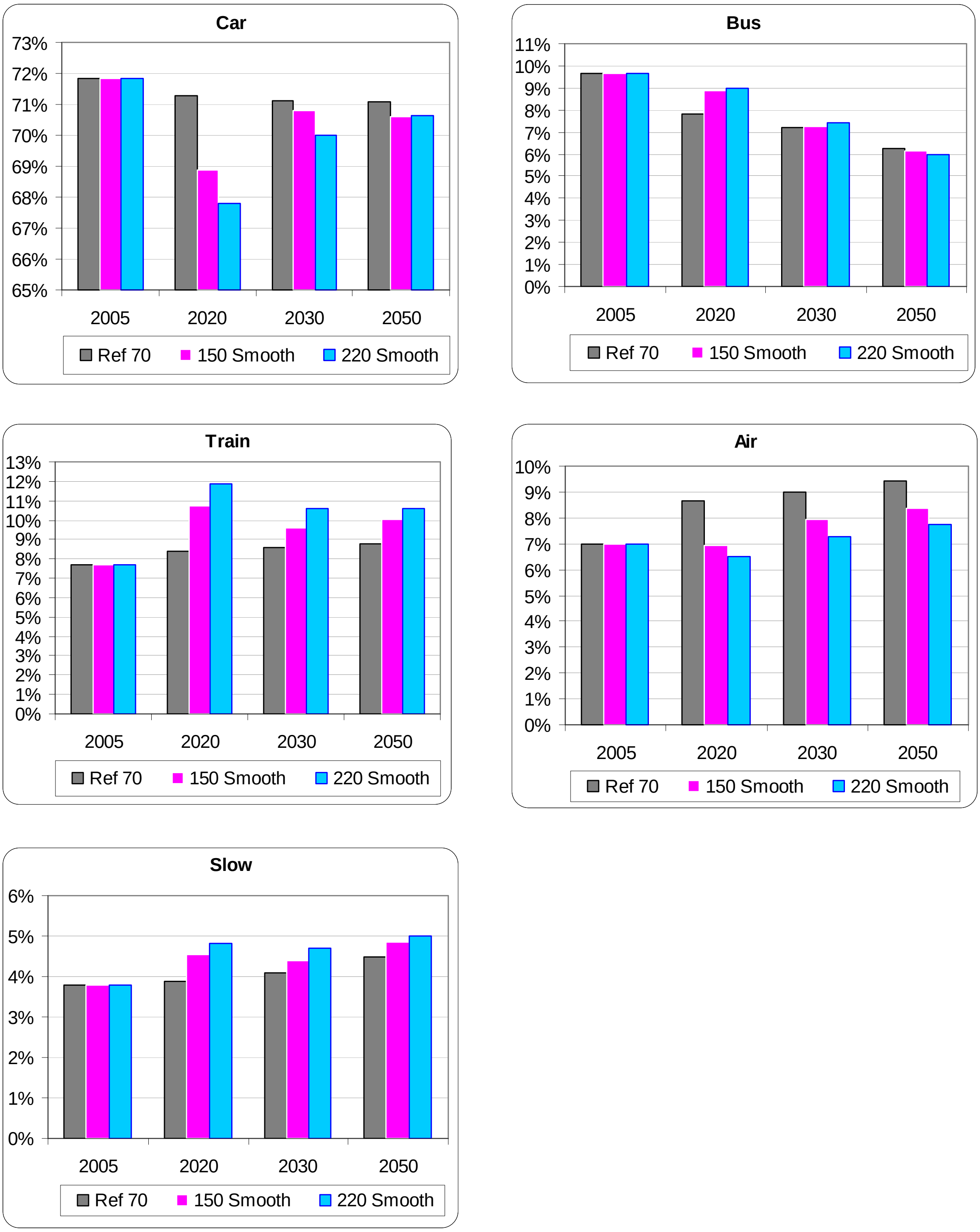
Figure 56 EU27 passengers-km shares per distance band



Source: ASTRA calculations in HOP!

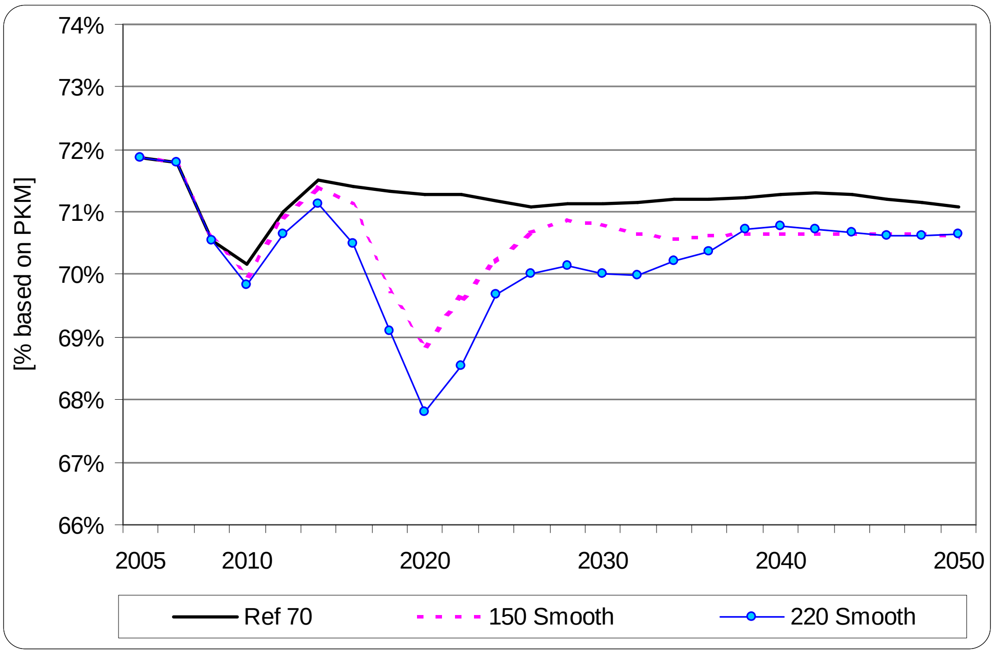
As shown in the following figures, the passenger mobility reduction is associated to a different mode split with car and air losing mode share whereas public transport and slow modes gain demand. Car share could be reduced to 67%-68% (so car would remain the dominant mode anyway) at the year 2020, to recover some share lately but staying below the current level. Air demand growth would be significantly stopped: air market could lose about 20% of its demand between 2014 and 2020. At the same time, train attract demand more than any other alternative (Figure 60) climbing to 11%-12% in the year 2020 and remaining over 10% even when fuel prices are reduced.

Figure 57 Overview of EU27 passenger Mode shares



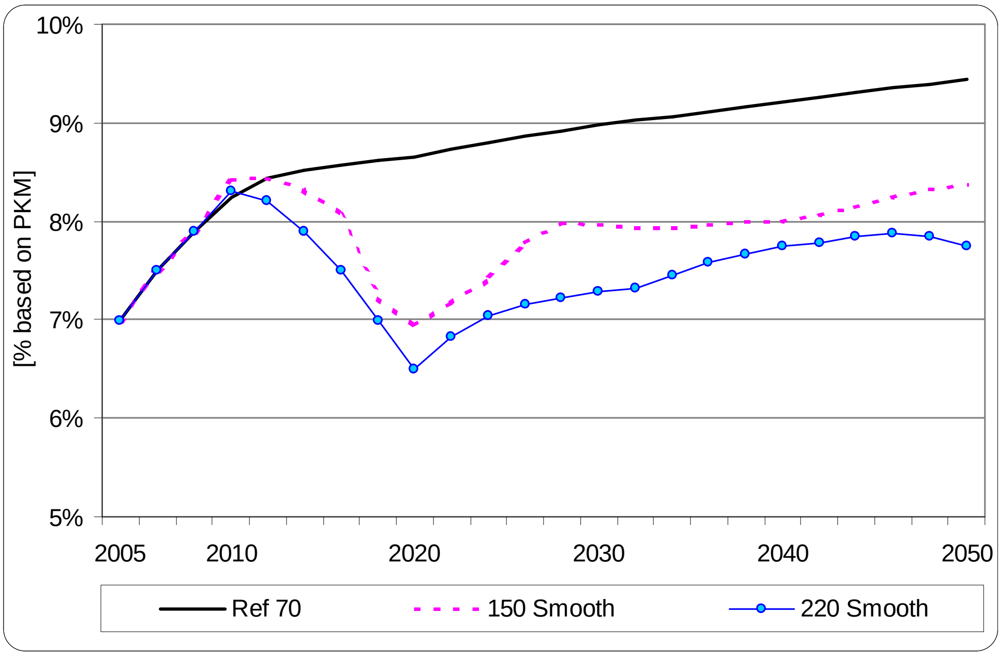
Source: ASTRA calculations in HOP!

Figure 58 EU27 Car mode share



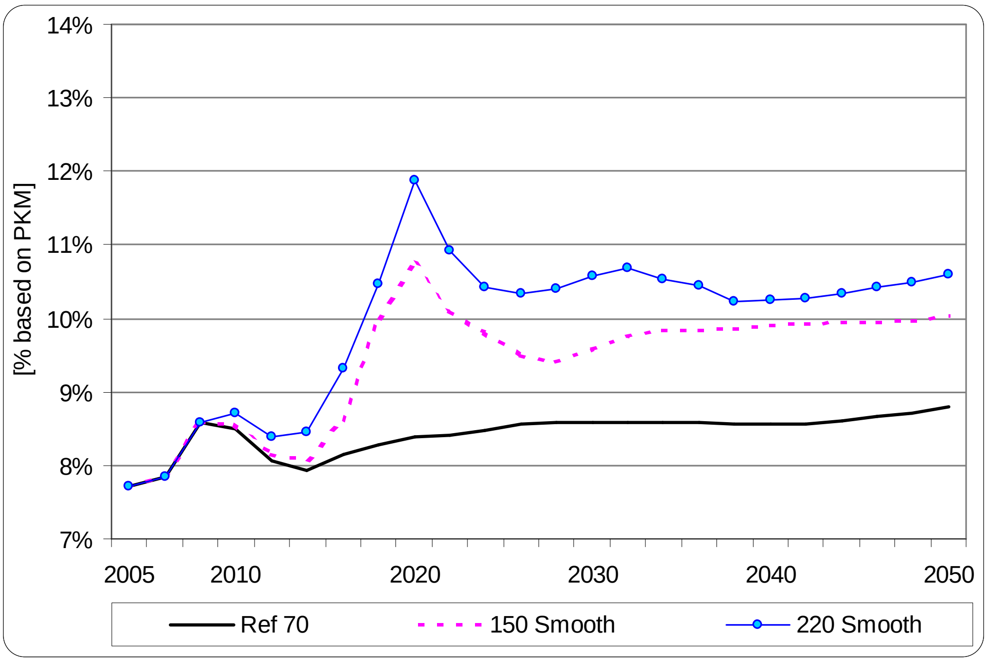
Source: ASTRA calculations in HOP!

Figure 59 EU27 Air mode share



Source: ASTRA calculations in HOP!

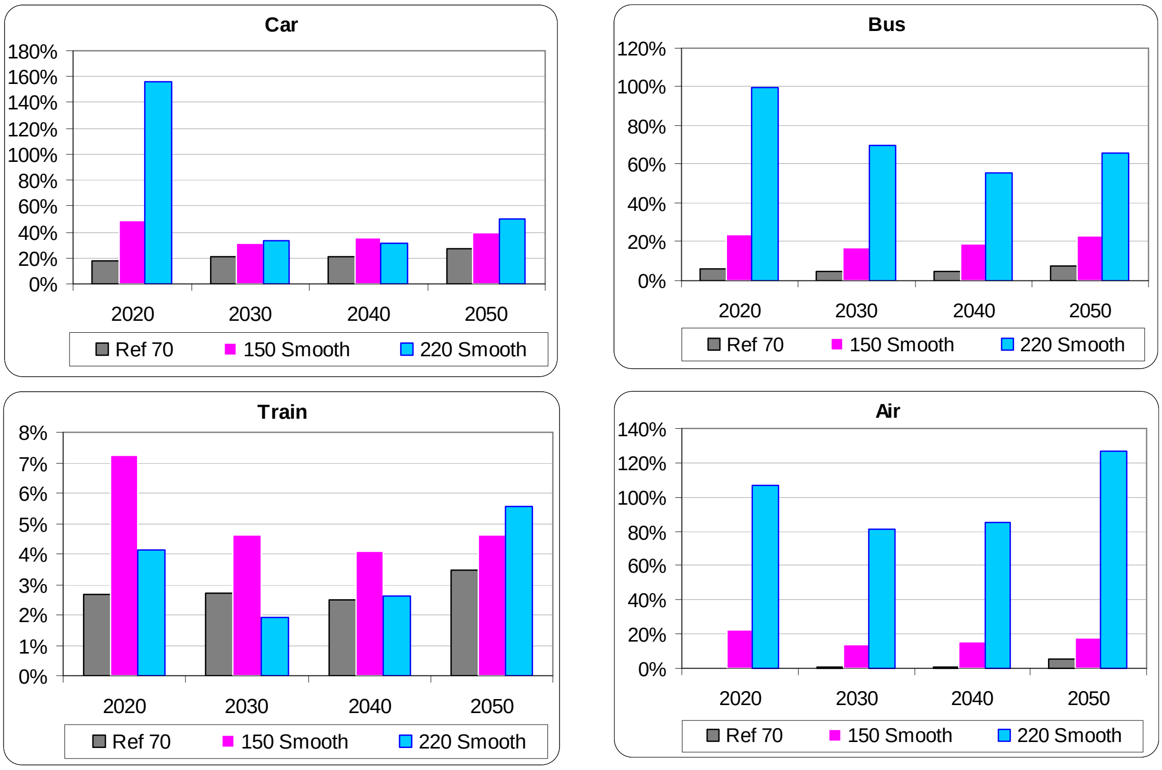
Figure 60 EU27 Train mode share



Source: ASTRA calculations in HOP!

The mode shift can be easily explained by the relative change of user costs across transport modes. As shown in Figure 61, in the year 2020 car perceived cost would grow up to more than 150% of 2005 cost level and also air average fare would doubled or more. The renewal of the car fleet (see below) with the adoption of alternative fuels and improved efficiency explains why the growth of car costs is much lower in the year 2050, while for the air sector cost is steadily higher. The impact of fuels cost is also quite high for bus, while train is not much affected since direct energy costs are only a small percentage of total operating costs.

Figure 61 Overview of relative change of the EU27 average cost per passenger-km with respect to the year 2005



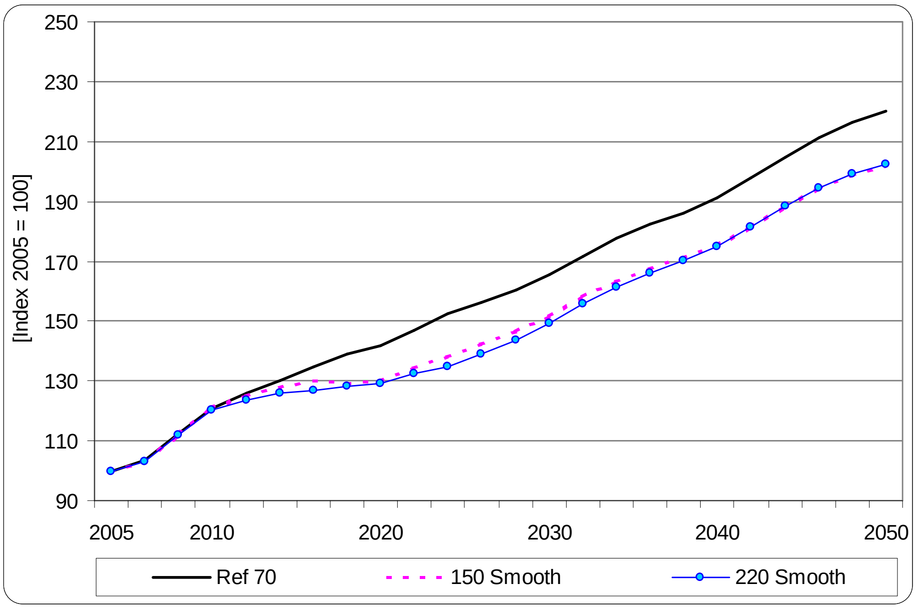
Source: ASTRA calculations in HOP!

4.4.2.2 The impact of high oil price on the freight transport sector

The impact of energy prices on freight performance (Figure 62) is less significant in absolute terms. The increase of fuel prices is only able to slow down the growth of tonnes-km for some year (between 2010 and 2020) but not to reduce freight traffic. The relative constancy of freight traffic is strictly linked to the economic growth, which involves the industrial sector and is the main determinant of goods movements. Since the economic growth is expected to continue even in case of high oil prices (see section 4.4.3), the freight traffic performance is largely maintained.

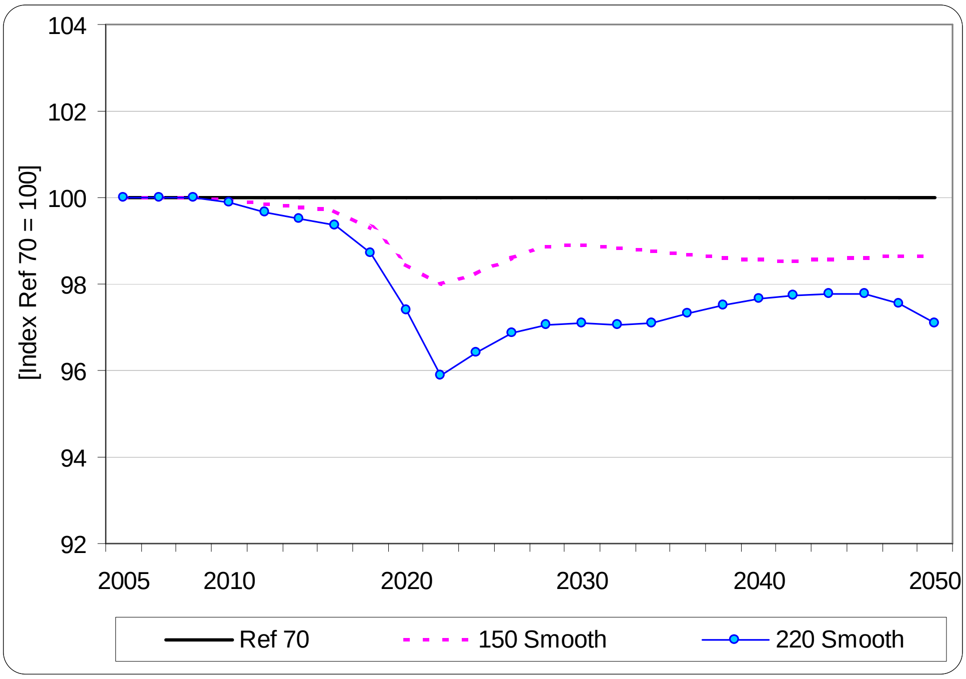
However, this overall result can be analysed in more detail to show that even if the freight traffic performance is not largely decreased, some changes in the traffic structure is induced. One component of freight transport demand is the mobility of goods caused by import/export flows. When energy prices, and then transport costs, are increased, the growth of intra-EU export is slowed down with respect to the reference scenario (Figure 63). At the same time, high oil prices have a different economic impact on different sectors (see section 4.4.3). The production of goods is increased in sectors like energy and construction, which generates significant amounts of bulk goods on short distances (e.g. ores, building materials). The combination of such two effects shorten the average distance of transported goods (Figure 64).

Figure 62 Trend of EU27 freight-km



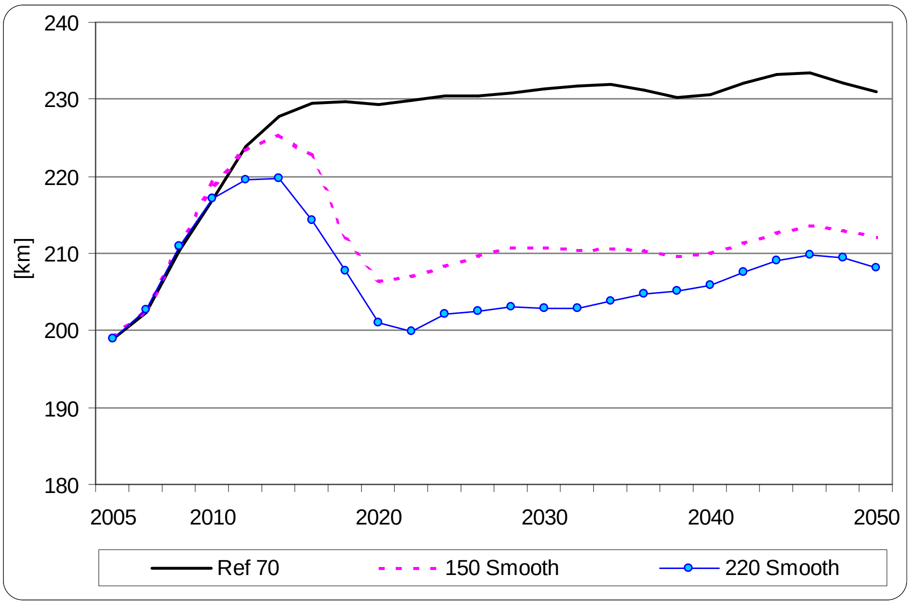
Source: ASTRA calculations in HOP!

Figure 63 EU27 Intra-EU export compared with Reference Scenario



Source: ASTRA calculations in HOP!

Figure 64 EU27 average freight travel distance

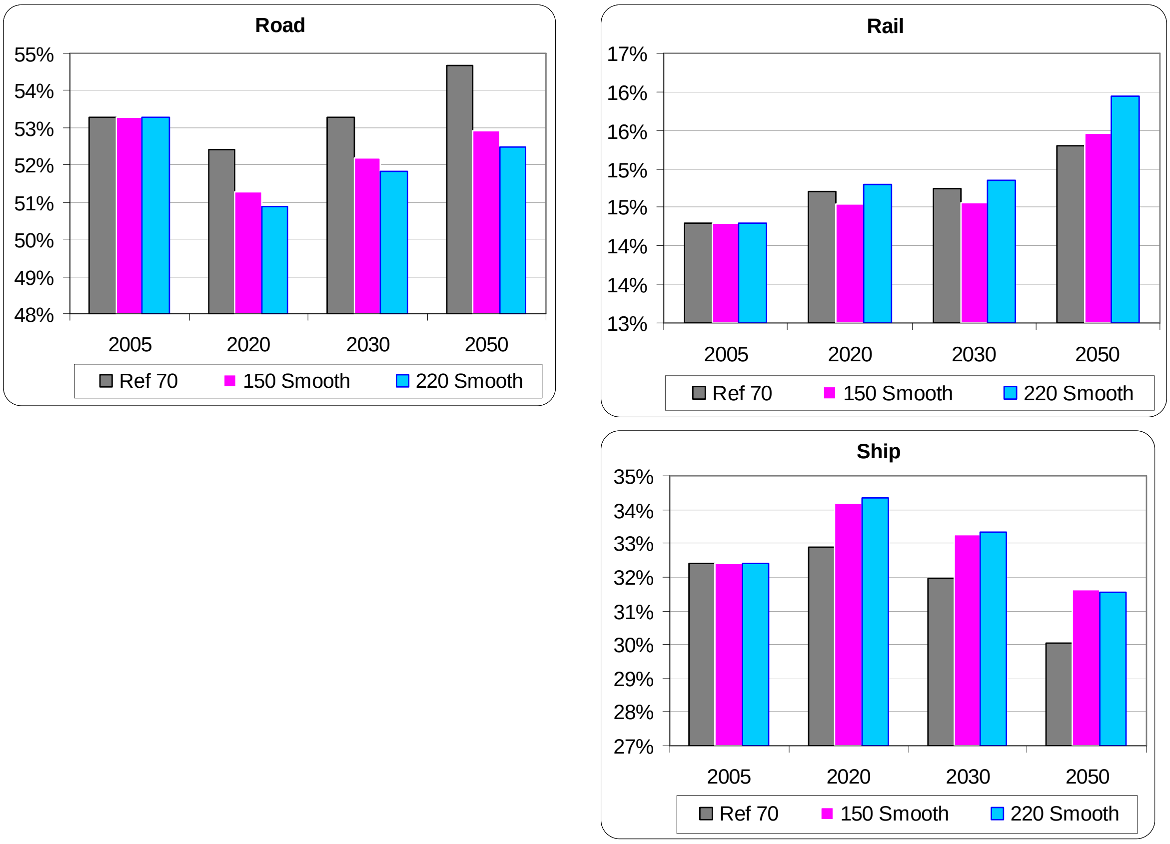


Source: ASTRA calculations in HOP!

Thus, even if the traffic performance is only slightly changed, the total number of tonnes-km is made of more tonnes and less kilometres.

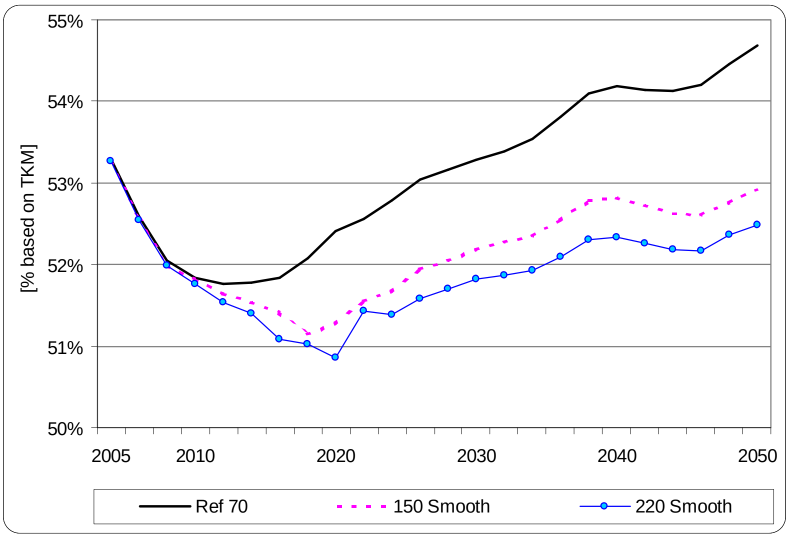
Some changes are also expected on the mode split side. As shown in Figure 66, the share of road freight in terms of tonnes-km is forecasted to be about a couple of percentage point lower when oil price is higher than in the reference case. So alternative modes – maritime and rail - gain share. Taken into account the reduction of average distance, this mode split is in turn the result of separate effects: on longer distances the mode shift is larger and maritime gains more than rail whereas on the shorter distance rail is the only feasible alternative.

Figure 65 Overview of EU27 Freight Mode shares



Source: ASTRA calculations in HOP!

Figure 66 EU27 Road freight mode share

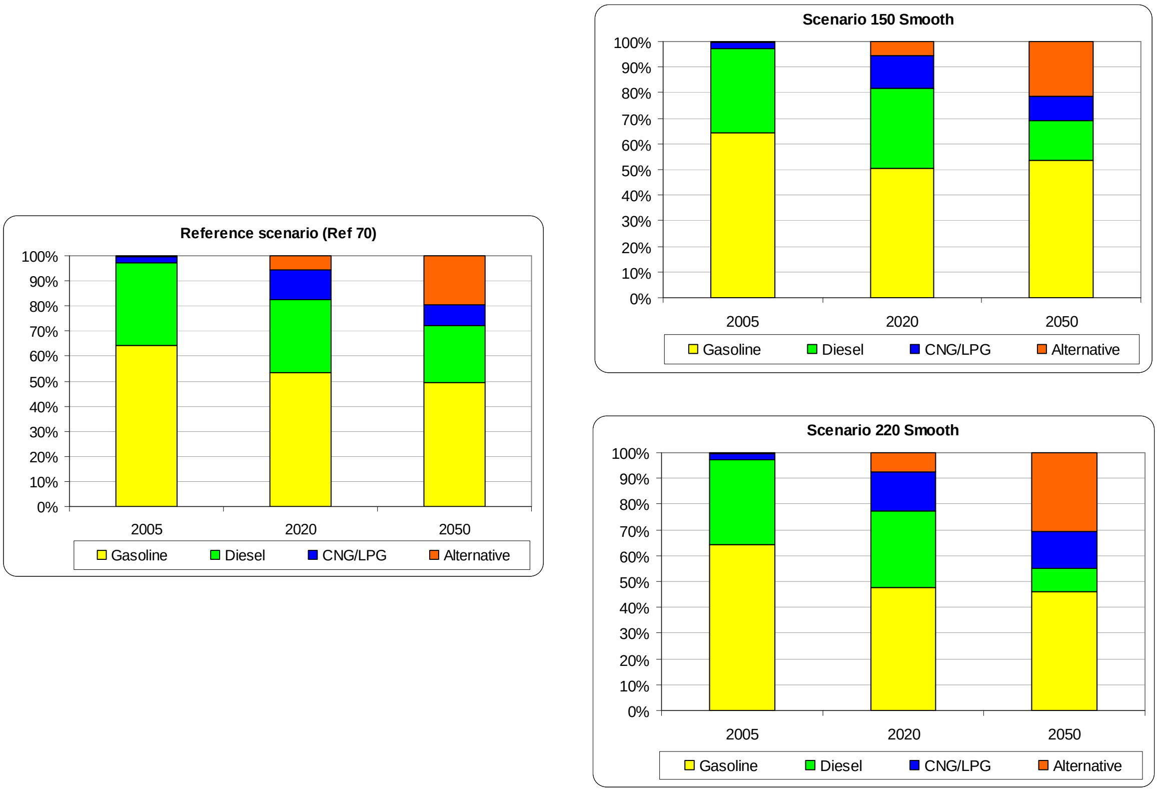


Source: ASTRA calculations in HOP!

4.4.2.3 The impact of high oil price on the vehicle fleet composition

If the private road modes largely maintain the highest share on transport demand even with high or very high oil prices, some differences is foreseen for the type of vehicles used. Figure 67 shows that innovative cars enter the fleet more significantly when oil price is high or very high. Including within the innovative cars: biofuels, hybrid, electric and fuel cells vehicles, their share is expected to be about 15% in the year 2050 in the reference case, while in case of high and very high oil price the share grows up to 21% and, respectively 30%. At the same time, also the size of the vehicle fleet is a bit lower in the high price scenarios.

Figure 67 EU27 car fleet and its composition



Source: ASTRA calculations in HOP!

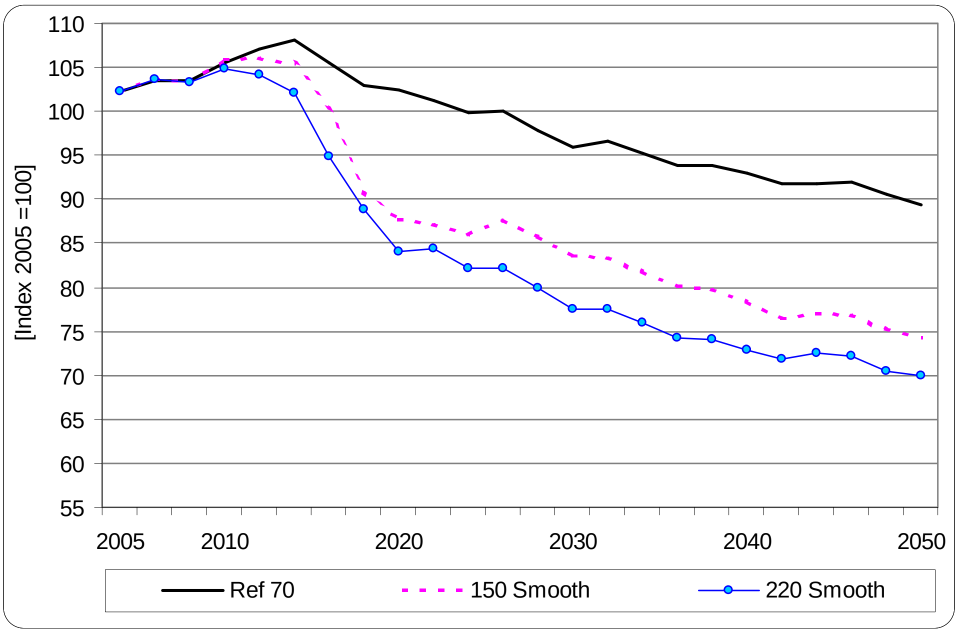
Nevertheless, even in the case of very high oil price, three out of four cars would be still conventional cars in the year 2020 and more than half of the fleet would rely on fossil fuels in the year 2050. Furthermore, a significant share of alternative cars would be biofuels car, i.e. using alternative fuels rather than innovative technologies. These results indicate that high oil prices alone will not induce major changes in transport to low carbon technologies even if they can accelerate the penetration of alternative vehicles.

4.4.2.4 The impact of high oil price on the transport greenhouse gas emissions

The reduction of demand and the renewal of the fleet has a beneficial impact on CO_2 emissions from transport (Figure 68). The technological development is expected to start providing emission reductions since about 2015 in the reference. But in the high and very high oil price scenarios the reduction happens earlier and develops faster up to a –33%

reduction of emissions with respect to the year 2000 (-12% in the reference scenario). These numbers include upstream emission of conventional fossil fuels and vehicle production, but exclude (1) the additional emissions of unconventional fossil fuels (e.g. coal-to-liquid, gas-to-liquid), and (2) the emissions of intercontinental shipping and air transport. There should be some compensation between these two excluded effects since unconventional fossil fuels increase CO_2 emissions, while the impact on intercontinental shipping and air transport by the high oil prices should be dampening the activities thus reducing CO_2 emissions.

Figure 68 Trend of EU27 CO_2 transport emissions



Source: ASTRA calculations in HOP!

4.4.3 The impact of high oil price on the economy

The impact of the high oil price on the economy is assessed by using the ASTRA model. Thus the following analysis focuses on the relevant macroeconomic indicators provided by ASTRA: GDP, employment, consumption, investment and energy imports. In this section results of the scenarios *150 Smooth*, *150 Early* and *220 Smooth* are addressed. This section intends to provide an overview on the economic reactions observed in the model. Important reactions are discussed in more detail in subsequent sections.

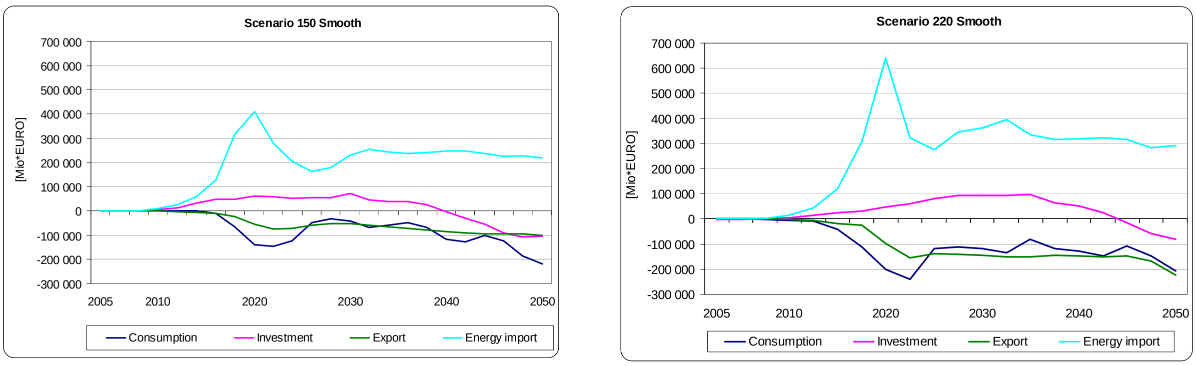
Figure 69 presents the change of components of GDP for the EU27 for two scenarios that have the same timing of the oil price peak but reach different levels of oil prices: 150 Smooth and 220 Smooth. We have seen above (see Figure 33) that in all scenarios the high oil prices lead to a reduction of GDP, in particular during the decade of the strongest oil price growth between 2010 and 2020. Now we can observe, in particular for 150 Smooth, that during the first years (around 2010 to 2014) when the oil price growth is moderate investments are the first major variable responding positively to the price increase, which is triggered by adaptations of the energy system (investments in efficiency and substitution by alternative energies). Then the oil price increase accelerates, which can also be identified by the

additional expenditures for energy imports reaching 400 Billion € in *150 Smooth* and about 650 Billion € in *220 Smooth* in the peak of energy imports around 2020. In parallel, the negative impacts accelerate: consumption is reduced by inflation and second round effects i.e. more consumption is shifted to the energy sector, which implies less expenditures for other sectors (budget constraint and income effect), slower GDP growth means less income and again less consumption. Exports are also reduced as transport cost raise and GDP in all EU countries is reducing feeding back further second round effects that reduce GDP.

It can also be observed that consumption recovers to some extent after 2020, which occurs because in response to reduced demand because of adaptation of energy and transport system the energy prices drop providing a positive stimulus for economic development, leading again to higher prices, more energy imports and again reduced consumption. This can be observed for both scenarios, but in particular the turquoise curve (energy imports) and the blue curve (consumption) in *220 Smooth* reveal this counter-oscillating behaviour.

Finally, it should be pointed out to the behaviour of both scenarios after 2040, where investment start to fall and are becoming smaller than in the Reference Scenario (*REF-70*) i.e. additional investment become negative. One major reason for this is that the higher oil prices reduce government revenues (e.g. less fuel tax revenues, less direct taxes due to lower employment) and increase government expenditures (e.g. more unemployment payments). Thus government debt grows such that in a number of European countries levels are reached when ASTRA expects some crowding out of private investment. Thus first the investments are reduced (around 2035) affecting consumption and exports negatively with some delay after around 2040.

Figure 69 Change of major GDP components for the EU27 compared with reference scenario



Source: ASTRA calculations in HOP!

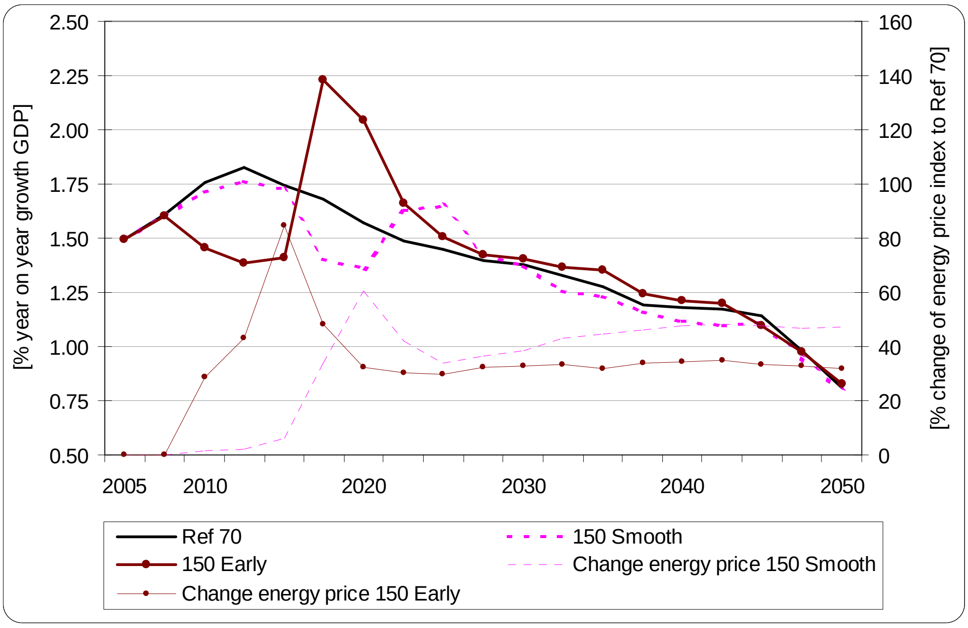
The following discussion focuses on the timing and interaction issues between energy price growth and GDP growth. Figure 70 shows the annual GDP growth rates for the Reference Scenario (black) and the scenarios *150 Smooth* (pink) and *150 Early* (brown). The more thin lines present the change of the transport energy price index, which considers fossil fuels but also alternative fuels, compared with the transport energy prices in the Reference Scenario. The difference between an early price increase (brown) and the more smoothed increase (pink) is obvious. The early increase starts with a steep increase from 2008 until 2014 increasing energy cost by +80% against the Reference Scenario in the peak. Afterwards the increase drops significantly to only +30% higher than in the REF-70, which is due to a reduction of energy prices but also due to adaptation of transport shifting to alternative energy carriers (e.g. CNG, bioethanol, electricity), to less energy intense modes (e.g. rail, shipping) and improving efficiency. In *150 Smooth* the peak is much lower (+60%), but also the reaction of the transport system is more moderate such that the price increase falls back to +40% only, which is above the prices in the *150 Early* scenario, though in both cases the crude oil price reaches about the same peak price. Obviously the speed of price increase matters for the strength of the adaptation reactions.

Looking at the interaction between energy price and GDP growth rate, as expected it can be observed that when the energy price raises sharply that GDP growth rates are declining (e.g. brown thick versus brown thin 2008 to 2014). More interesting is the following overshoot starting with the strong reduction of energy prices from a +80% increase to a +30% increase due to the above described mechanisms. This causes a significant increase of GDP growth rate, which reveals an asymmetric pattern of the two mechanisms, i.e. when energy price declines the elasticity of GDP seems to be higher than when energy price grows.

Literature clearly supports the negative relationship between oil price increase and GDP growth (Awerbuch 2006; Blanchard/Gali 2007; Huntington 2004). Several authors estimated an elasticity of GDP with respect to the oil price. These estimates range from -9,8% decrease in GDP due to a one percent oil price change to only -0,5% (Awerbuch 2006). Overall the more recent calculations predict a weaker reaction of GDP to a rise in oil price. The ECB, the IEA and other recent studies predict a negative elasticity of between -0,2 and -0,5% for a 1% crude oil price increase (Jimenéz-Rodríguez/Sánchez 2004; IEA 2005; Huntington 2004; Allen 2005).

Attempts to calculate a simple elasticity based on the HOP! simulations, however, did not provide an unambiguous result. The dynamic modelling of ASTRA and POLES leads to rebound effects e.g. significant oil price declines following price peaks such that we were not successful to isolate the particular effect of the oil price increase, only. Nevertheless, overall the decrease in GDP growth due to an oil price rise and the subsequent recovery of growth through stimulated investments and the rebound of oil prices, happened in all simulations.

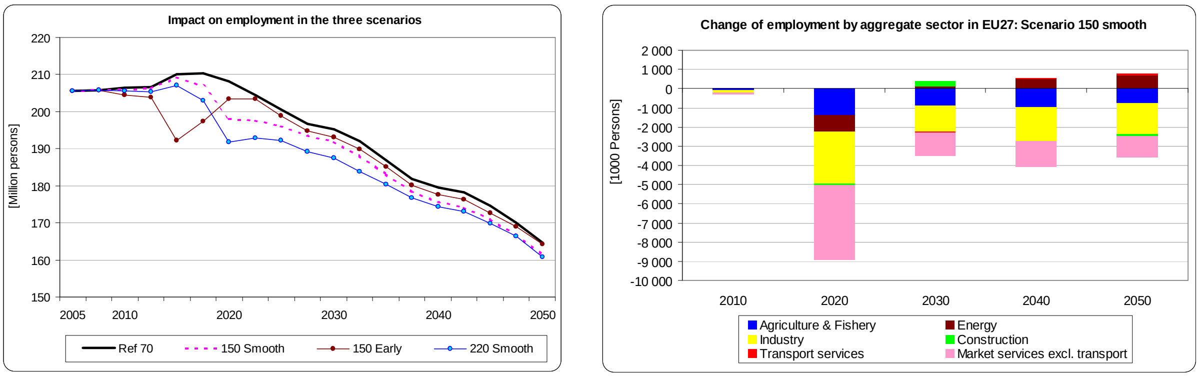
Figure 70 Interaction between change of energy price and EU27 GDP growth rate



Source: ASTRA and POLES calculations in HOP!

The pattern observed for GDP can be also noticed for employment, though with an even stronger reaction to the high oil prices. In fact, employment is the macroeconomic indicator reacting strongest compared in percentage changes to the Reference Scenario. Figure 71 presents the employment in *REF-70* scenario and the three scenarios compared in this section. The sharp and early loss in *150 Early* scenario, but also the recovery of employment, which goes in line with recovered consumption and GDP in this scenario, are reflected in the brown curve. The two other scenarios behave as expected: employment loss in *150 Smooth* is lower than in *220 Smooth* as the price increase in the former is smaller. Reasons for the losses of employment would be the shift of consumption to sectors with low labour intensity, in particular the energy sector, with higher import intensity, again the energy sector. Further some sectors with particular high labour intensity e.g. agriculture are affected more strongly by energy price increases due to their relatively higher energy input. This can be observed in the right side of Figure 71, where agriculture looses significantly employment in absolute terms, which is even more grave looking at the relative losses that would be twice as high as the average loss of employment.

Figure 71 Impact of high oil prices on EU27 employment

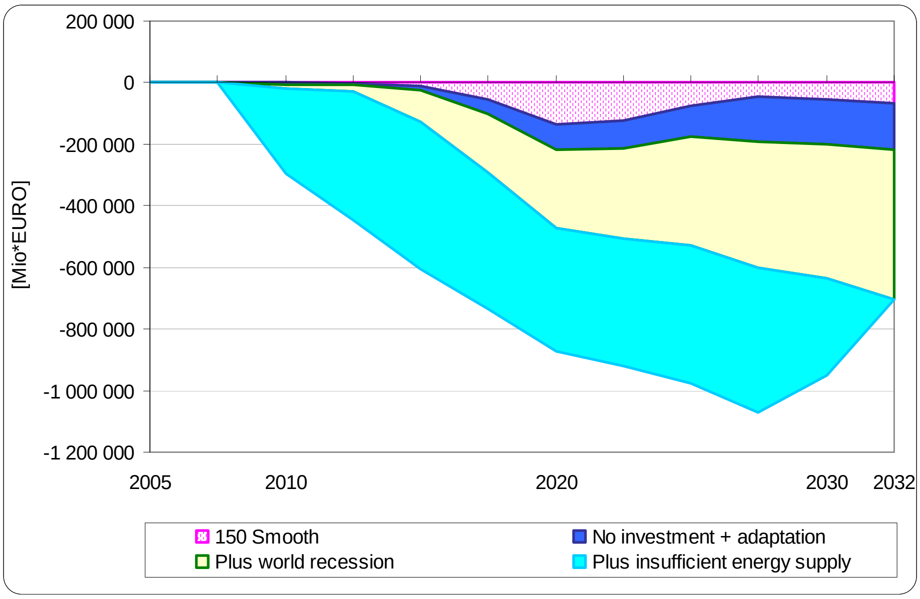


Source: ASTRA calculations in HOP!

The analysis so far focused on the major ten HOP! scenarios, which incorporate mitigation of the impact of high oil prices by policy and/or market driven investment into alternative energies and energy efficiency as well as adaptation of behaviour e.g. of transport users. Further, neither the emergence of a world recession nor insufficient energy supply in physical terms is assumed to happen in this scenario.

Figure 72 provides the picture on which GDP changes could happen if early adaptation of the energy and transport system would not occur, if a world recession emerges as a consequence of high oil prices and if there would be a lack of sufficient energy supply. The analysis is made for the *150 Smooth* scenario. The pink dotted plane roughly shows the loss of GDP in this scenario compared with the Reference Scenario. If no adaptive investments into energy and transport systems would be made, the loss of GDP would roughly be doubled (the blue plane). If additionally a world recession occurs with about -50% reduced world GDP growth this could increase the GDP loss by a factor of 3 to 4 (or -1 to -3% further GDP loss) and the most drastic impact would be observed for the EU27 if a physical shortage of energy would emerge (up to -11% further GDP loss). More details on the specific analyses are provided in subsequent sections.

Figure 72 Potential economic impacts beyond the ten basic HOP! scenarios



Source: ASTRA calculations in HOP!

4.4.4 The impact of economic impact chains on the results

The interaction between the bottom-up modelling of the energy system (in POLES) and the transport system (in ASTRA) and the macroeconomic modelling in ASTRA runs through four major impulses:

- **Investment**: the high oil prices induce structural change in the economy. Investments in alternative energies and energy efficiency become more cost competitive compared with investment in conventional fossil energy based technologies. Thus the high oil price stimulates additional investment into the former technologies and crowd out investment into conventional technologies. The net investment effect of stimulated alternative investment and crowded out conventional investment is estimated by the bottom-up models and is entering the equations of the investment model as a stimulating economic impulse. We would call this the **investment impulse**.

- **Energy price**: the POLES model estimates the prices of crude oil, gas and coal considering besides the resource base the GDP inputs for the EU29 (thus the economic activity) that comes endogenously from ASTRA and an exogenous trend for the rest-of-the-world. These prices enter the BioPOL model, in which the biofuels prices are estimated and the full scale of energy prices of fossil fuels, biofuels, heating oil, electricity and hydrogen are provided to the ASTRA model where they are affecting the household and industry models (see Figure 6). We would call this the **energy price impulse**.

- **Energy imports**: investment and changes of energy prices in the POLES model reflect a technological change of the energy system to which a reduction and substitution of fossil fuel demand goes along with in parallel, such that the imports of fossil energy for heating and electricity to the EU29 is reduced. ASTRA estimates the savings of energy imports for the transport system. Together these energy savings are translated into a monetary value and are used as savings of energy imports in the final demand models and the calculation of the value-added of the energy sector of ASTRA. We would call this the **energy import impulse**.

- **Inflation**: the ASTRA model is only including a few monetary models, since with the focus on long-term policy-making the consideration of short-term financial market oscillations in the model is less relevant. To consider the impact of energy price induced inflation constitutes one of these models. Above a certain threshold of price increase the energy price impulse is translated into additional energy induced inflation considering the country specific split of energy expenditures for heating, electricity and transport as well as the oil intensity of the countries. The impact of inflation is then that disposable income is reduced, affecting consumption and kicking-off second round effects via the impact of consumption on demand and GDP. We would call this the **inflation impulse**.

A fifth potential impulse was not considered: the oil exporting countries generate high additional gains from their oil exports. These gains are at least partially used to increase imports, both of consumer and investment goods, of these countries on the other hand increasing exports of the EU29 and thus constituting a positive economic stimulus for the EU29. Following the literature we would call this the Petrodollar recycling impulse. Since, ASTRA does not include an endogenous model for GDP and imports of oil exporting countries this impulse was excluded. Basically, this means that there is also a conservative assumption contained in the economic results of HOP!.

The following paragraphs separate and explain the impacts of the four bottom-up impulses on the economy. For this analysis the scenarios *150 Smooth*, *150 Early*, *800 Early* were run again four times each time switching off one impulse per run to isolate the impact of this impulse. This means we obtain a new scenario simulation including synergistic impacts of three out of the four impulses and by comparing this simulation with the simulation of the full scenario we are able to derive the impact of the switched-off impulse. We call this the **ASTRA switch-off analysis**. An alternative approach would be to use the Reference Scenario, just switch-on one selected impulse and compare the resulting simulation with the Reference Scenario. For sure the observed impact of the impulse would differ from the result of the ASTRA switch-off analysis. Past experience revealed that the switch-off analysis is the preferential approach as it is better enabling to consider synergies between impulses than the mere comparison with the Reference Scenario (Schade 2005).

Nevertheless, one should take into account that the switch-off scenarios are artificial, e.g. a large fossil energy price shock will always be accompanied by a strong increase in fossil energy imports – and the switch-off analysis simulates that one happens without the other. Thus, the switch-off analysis supports (1) to rank the importance of the different impact chains, and (2) to show the direction of the impact of one impact chain, and (3) in some cases enables to show the differentiation for which indicators (e.g. GDP, employment, transport consumption, value-added) which impact chains are most relevant.

Figure 73 and Figure 74 present the impacts of the four impulses as derived from the switch-off analysis for GDP and employment of EU27 together with the full impact in the scenarios *150 Smooth* and *150 Early*. The ranking of importance of impacts is shown from the most important to the least important in Table 7.

Table 7 Ranking of importance of bottom-up impulses

Ranking	impact on GDP	impact on Employment
Most important	Energy price impulse	Energy price impulse
Important	Investment impulse	Energy import impulse
Important	Energy import impulse	Investment impulse
Less important	Inflation impulse	Inflation impulse

Source: ASTRA results

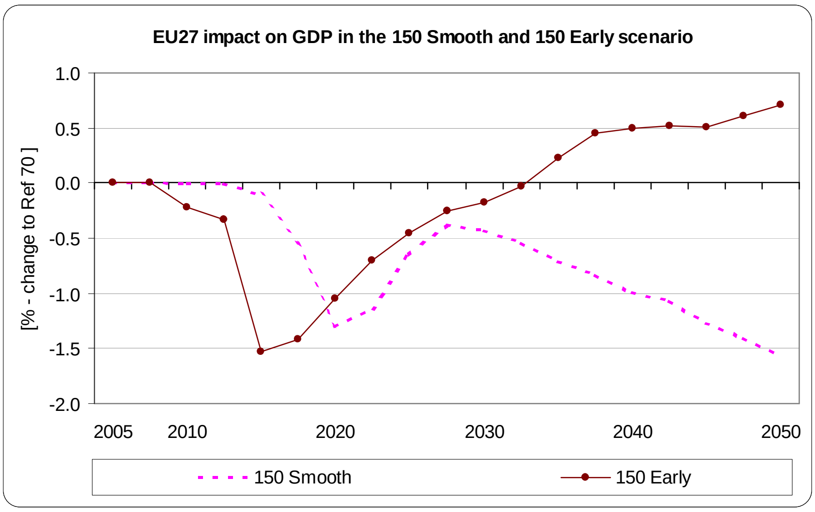
The direction of changes differs between the impulses. Clearly the energy price impulse of high oil prices is always generating a negative impulse on the economy, here expressed by the indicators GDP and employment. The investment impulse is always generating a positive impulse, though the strength differs between the scenarios. The energy import impulse and the inflation impulse are causing a negative impulse in the medium term and become rather neutral in the long run. The reason would be that due to energy savings and increased use of alternative energies the energy import are significantly reduced and shift towards the expenditure level for imports observed in the reference scenario, while inflation in general constitutes a temporary phenomenon that, given suitable economic and monetary policy, disappears after a period of time.

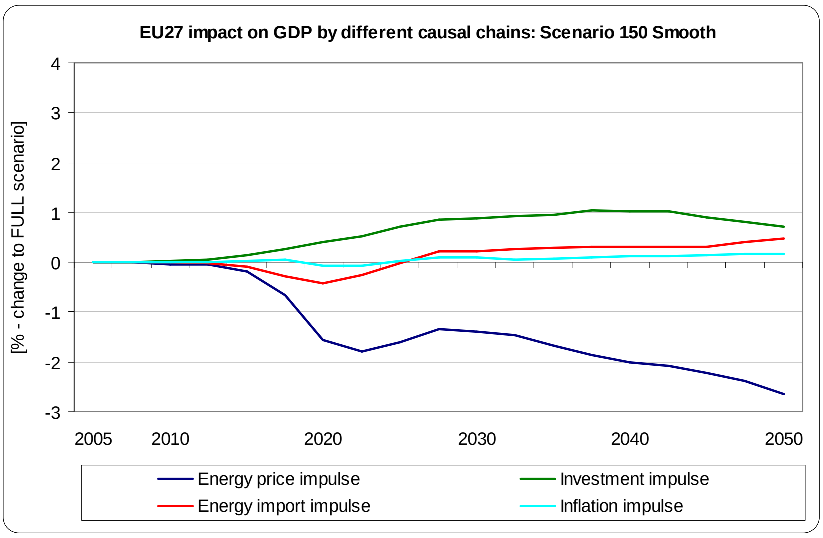
Thus most interesting for further analysis would be the energy price impulse and the investment impulse. The energy price impulse causes a strong negative impact on employment as it stimulates a number of negative impact chains like the reduction of consumption via the income effect (budget constraint), the push of inflation, the increase of input cost of all sectors and thus the reduction of value-added of all sectors besides the energy sector. In particular, the latter chain is reducing employment, since labour productivity (as the proxy for wages in ASTRA) is only reduced when unemployment increases significantly, which occurs with a delay such that over the shorter term productivity (and wages) is fixed and decrease of employment and increase of unemployment is unavoidable with a strong increase of cost of other input factors (of course, ceteris paribus for other impact chains).

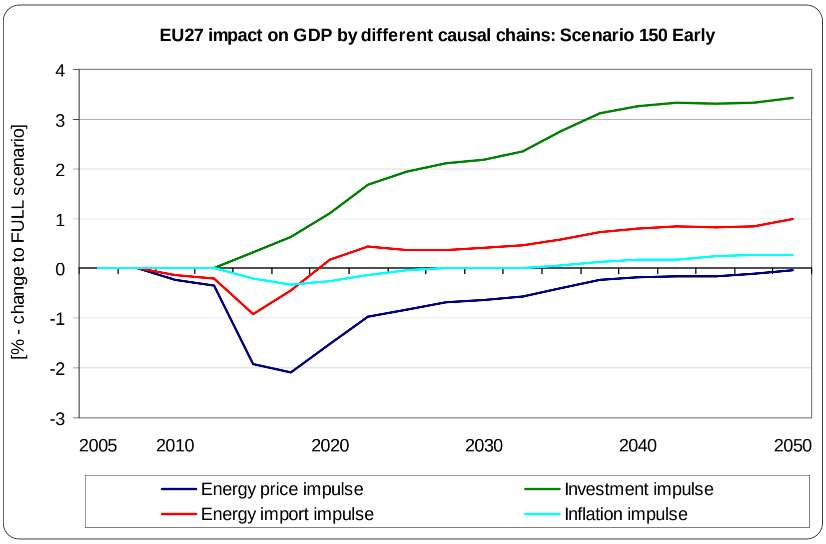
On the other hand the investment impulse may cause a positive impact counterbalancing the energy price impulse. The energy and transport system react to high oil prices by investing in energy efficiency and alternative energies, such that the general reduction of investments is overcompensated by these additional investments that are estimated by a bottom-up approach with POLES/BioPOL model for the energy system and ASTRA for the transport system. The argument for that even with a less favourable economic development (as GDP decreases below the Reference Scenario) we would have more investments is that in the last decades there was a lack of promising (real world) investment opportunities, but not a lack of investment capital. Thus investors invested in real estate (causing bubbles in many countries like the US, UK, Spain) and in financial markets. The major reason for this was a scarcity of other promising real economy investments. The situation changed drastically with the high oil prices, which constitutes a clear break-in-trend, generating promising investment alternatives in the real economy (Lovins et al. 2004, Foxon 2003, IEA 2008). Such investment would either be investment into bringing additional oil and gas onto the market or to invest into energy efficiency and alternative energies. The former investment option is not possible or at least very limited only due to EU (and other Western Companies) having no/limited access to the oil and gas reserves that in the major resource owning countries are owned and restricted by state-owned companies as well as that the availability of promising resources is limited (Aleklett 2008, Zittel/Schindler 2007). Remains the latter investment option to invest in alternatives and efficiency. For investors this would be the more promising option because since the high oil price (1) make alternative energies cost competitive (and in most countries they are additionally government supported), (2) increase the revenue from savings of energy by efficiency measures, and (3) indicates that in the medium- to long-run renewable energy sources will be advantageous compared with limited non-renewable energy sources due to their long-term availability. Thus it can reasonably be expected that the break-in-trend generates higher investment levels as in the Reference Scenario.

However, what can also be identified from the Figure 73 and Figure 74 is the different time scales on which the impact chains enfold their impacts. The energy price impulse provides an immediate negative impact, in particular on employment (see the negative peak between 2011 and 2014 in *150 Early* scenario, which enfolds in parallel to the most steep slope of energy price increase), while the investment impulse enfolds over at least 10 years for employment.

Figure 73 Comparison of impact of different causal chains on EU27 GDP in the *150 Smooth* and *150 Early* scenarios

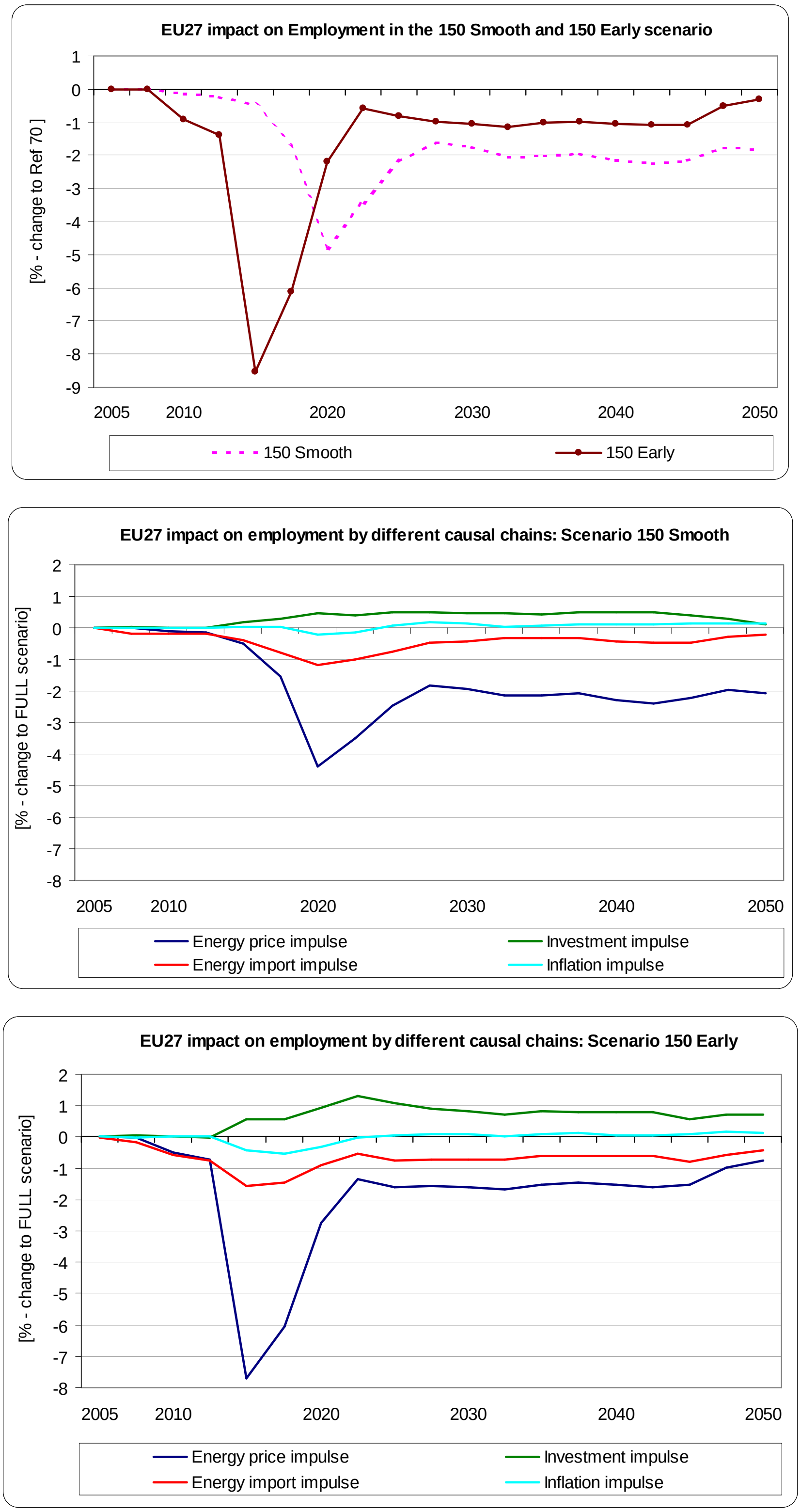






Source: ASTRA calculations in HOP!

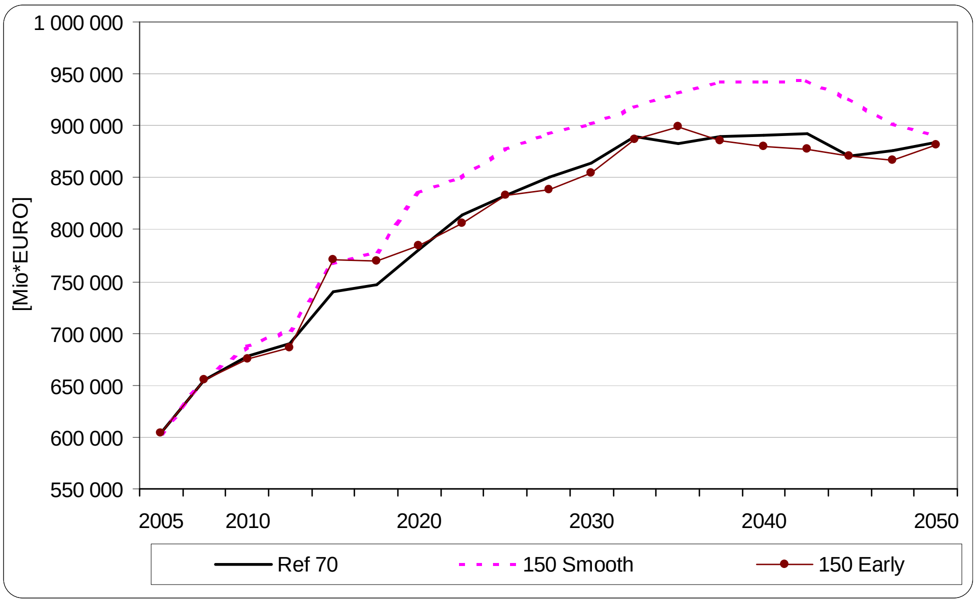
Figure 74 Comparison of impact of different causal chains on EU27 Employment in the *150 Smooth* and *150 Early* scenarios



Source: ASTRA calculations in HOP!

A further answer on why the economic development in *150 Early* is more favourable than in *150 Smooth* comes from the transport system. Looking at Figure 75 it can be observed that in *150 Smooth* the consumption expenditures for transport net of all taxes increase by about 50 Billion €, which means that this amount of money has to be spent less for other sectors. Including taxes the amount is even higher since transport on average has a higher tax level than the other sectors. Transport consumption in *150 Early* remains at the level of the Reference Scenario.

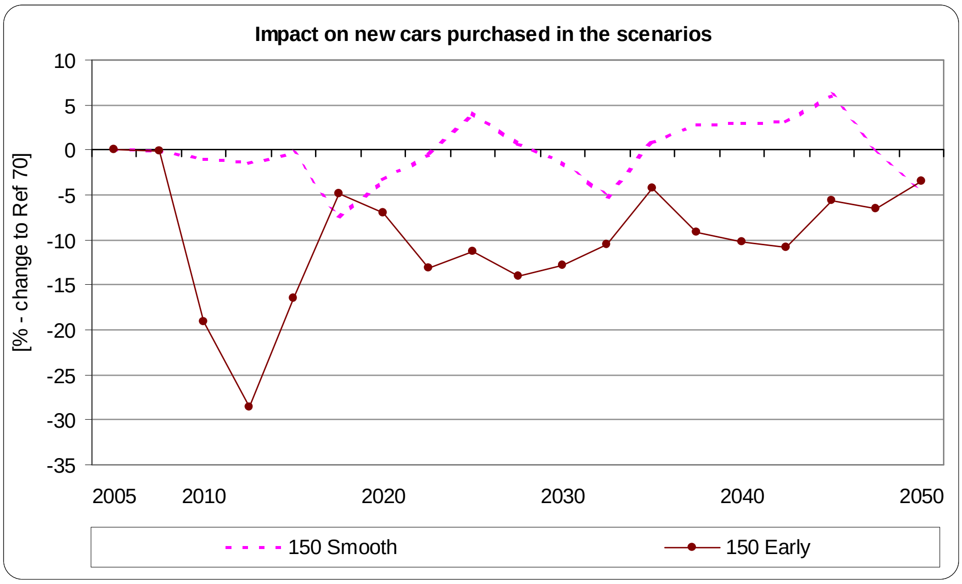
Figure 75 EU27 Transport consumption in the *150 Smooth* and *150 Early* scenarios

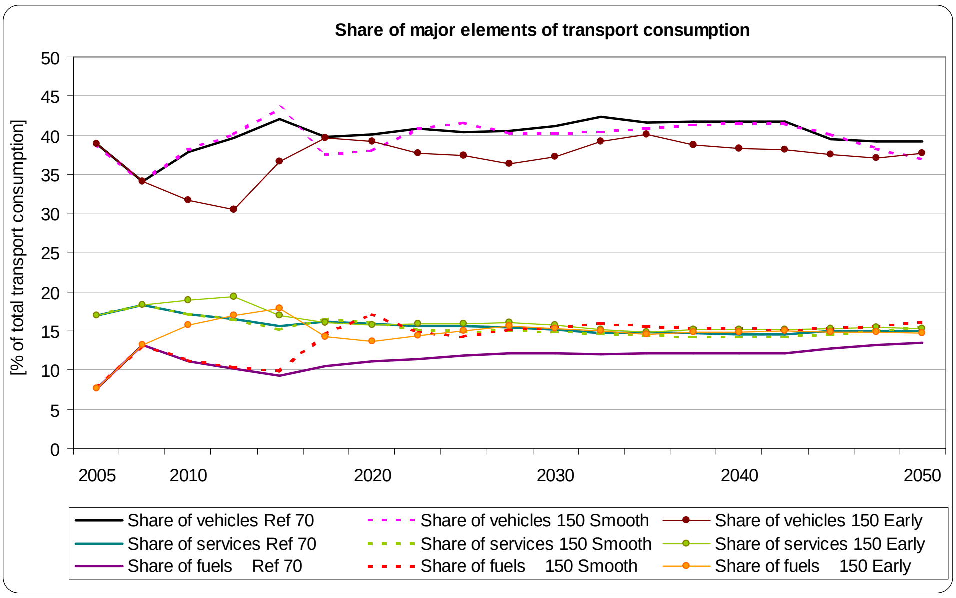


Source: ASTRA calculations in HOP!

The reason for this difference in consumption structure can be observed in Figure 76. The purchase of new cars is showing a much different reaction when oil price increases smoothly compared with a steep oil price increase as in *150 Early* scenario. The smooth oil price increase causes in the peak a reduction of -7% new registration of cars compared with the Reference Scenario, which is caught-up in the long-term. However, though in *150 Early* scenario the same level of oil price is achieved the much steeper slope of the price increase causes a different reaction. The peak of reduced new registration of cars reaches -27% compared with the Reference Scenario and the new registrations never catch-up to the Reference Scenario. Looking at the distribution of transport consumption it can be observed that in both scenarios the share of expenditures for public transport services remains slightly above or around the Reference Scenario, while for fuel it is increasing in both scenarios and for cars it is reduced in only one scenario (*150 Early*) compared with the Reference Scenario, such that in the total balance the result emerges that transport consumption remains at the level of the Reference Scenario, such that the shift from non-transport consumption to transport consumption does not occur.

Figure 76 Change of EU27 car purchase with respect to reference scenario and structure of transport consumption in the *150 Smooth* and *150 Early* scenarios





Source: ASTRA calculations in HOP!

A further analysis of the energy price impulse that differentiates into the impulse that comes from fossil fuels and electricity but excluding heating oil and the impulse including heating oil reveals that the change of cost of heating oil is having a significant impact alone amounting to more than one third of the impact of the energy price change on GDP.

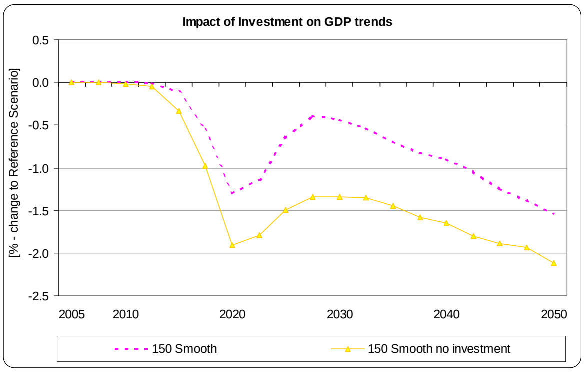
4.5 Results focussing on specific impacts

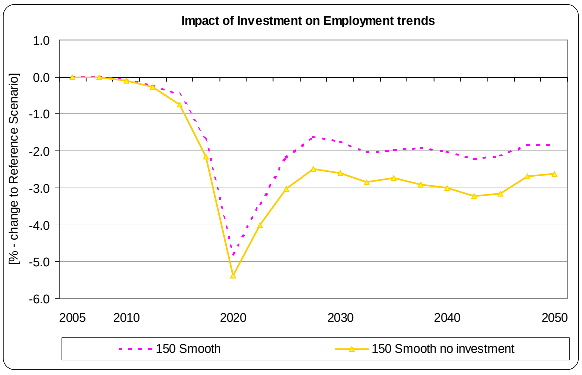
4.5.1 The impact of investments on the results

In previous sections it has already been shown by switch-off analysis that the investment impulse constitutes the most important mitigating impulse of the negative impacts of high oil prices. This section focuses on a comparison of two of the 150 Smooth scenarios: one with the standard reaction of investments in POLES/BioPOL model (*150 Smooth*) and one with investment in POLES/BioPOL kept to the reference level (*150 Smooth no investment*), such that no significant transition of the energy system occurs.

In Figure 77 we can observe that without investment into the energy system the negative impact on GDP and employment would be significantly more pronounced. In fact, in the long run the *150 Smooth no investment* scenario constitutes the most negative scenario out of the ten major HOP! scenarios.

Figure 77 Impact of investment on key indicators



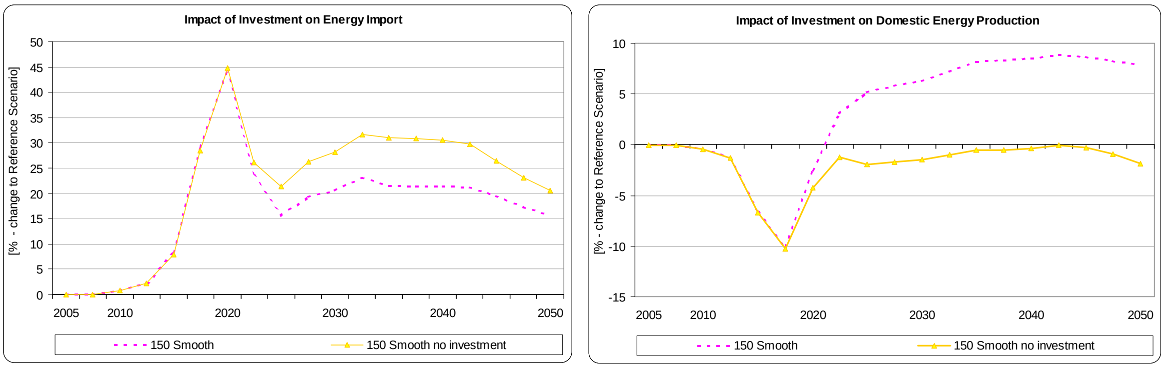


Source: ASTRA calculations in HOP!

As expected the availability of investment into the energy system affects also energy related indicators. Figure 78 shows that investment also constitute a requirement to reduce the expenditures for energy imports (the increase of energy imports in *150 Smooth* scenario is about 10% lower) and contribute to the increase of the capability to produce energy domestically, which is about 10% above the level of the Reference Scenario in *150 Smooth* scenario.

Of course, this has further impacts. When energy is produced domestically (e.g. by renewable energies) expenditures for energy and value-added remain domestically and create employment and wealth in the EU countries. Further, the independence from the increasing volatility of oil and gas prices is raising the stability of the European economic development.

Figure 78 Impact of investment on energy import and domestic energy production

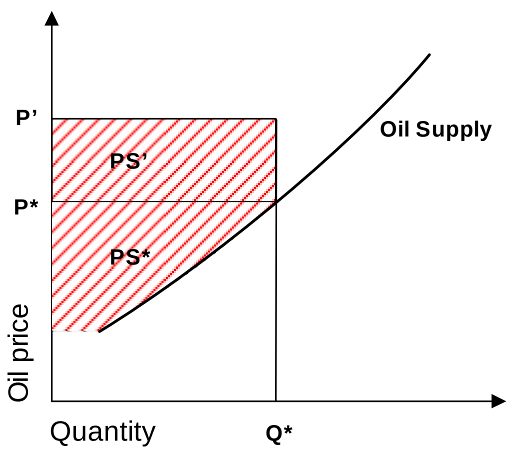


Source: ASTRA calculations in HOP!

4.5.2 The impact of behaviour and treatment of the energy sector

The raise of oil prices as simulated in the HOP! scenarios strongly affects the producers side. Figure 79 represents a simplified summary of the effects of high oil prices on the firms in the energy production sector in form of a supply graph.

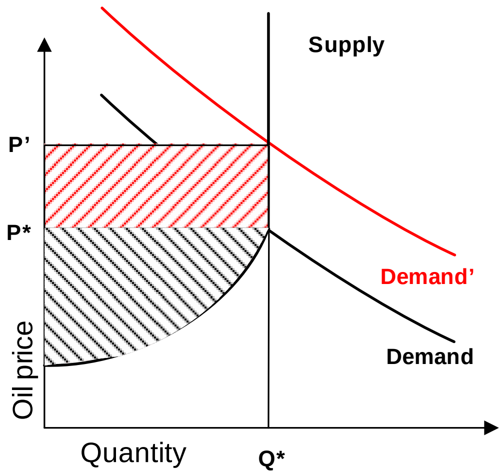
Figure 79 Producer Surplus and rising oil prices



These firms receive the producers surplus (PS*) above the supply curve and below the paid price P*. If prices raises the surplus increases by PS' if demand (Q*) remains stable (which is a proxy supported by the small elasticity of energy demand to price), and given that in the short-run fossil fuel supply can not be increased as exploring new wells takes time and spare capacity is limited.

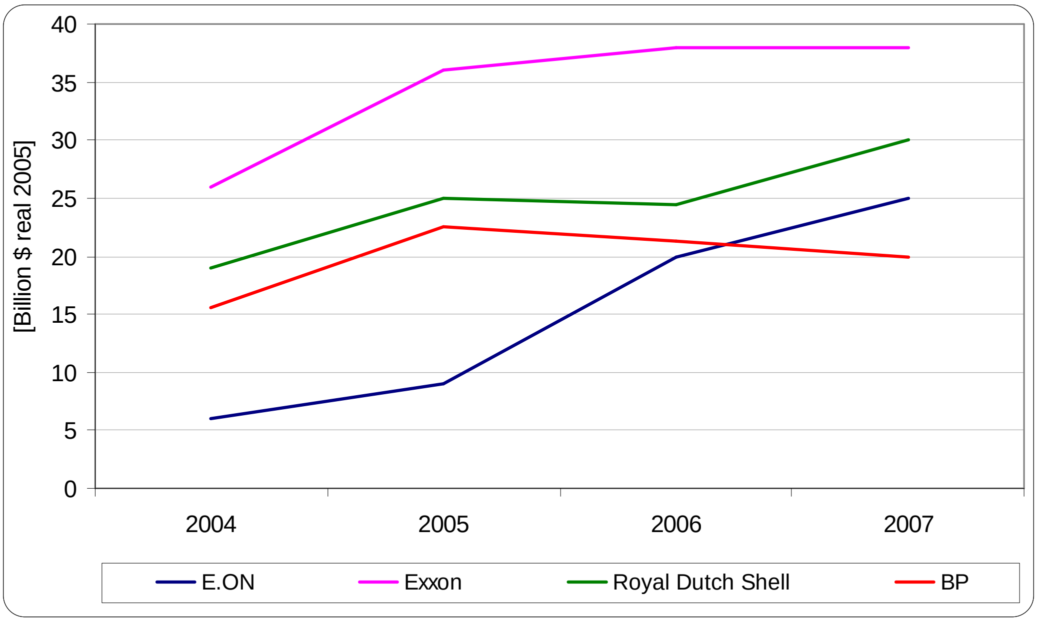
Though this analysis, seems only valid in the very short run, because a higher price would lead to substitution effects, innovation and additional competitors, there are arguments that this could be a situation maintained even over the medium term, stabilizing this increasing producers surplus. The major reason is a growing demand in particular in Asia and the Middle East due to high economic growth rates and consumers subsidies. As a result the growth in demand due to expanding oil consumption in some areas offsets the savings of oil in other areas, as e.g. Europe (EC 2008). This claim is supported by the IEA, that reports global oil demand to have been rising from 84,9 mbl/day in 2006 to 86,0 mbl/day in 2007 and expects it to reach 86,6 mbl/day in 2008 (IEA 2008). This leads to a market price above the initial price P* with an increase of producers surplus (Figure 80). At the same time the supplied amount of oil is inelastic, which is why there is only an increase in the surplus and no increase in Q*. This reaction, contradicting textbook supply curves, shows the assumption that the maximum extraction capacity for oil has been reached and, at least in the medium-term, cannot rise further to keep pace with growing demand. Thus the upward shift of the demand curve is a structural change and prices cannot be expected to sink if demand does not sink as well.

Figure 80 Twofold effect of price rise



This theoretical analysis can be underpinned by empirical data by looking at the effect of high oil prices on the energy producing sector - the increase of profits. Figure 81 shows the profitability of selected large energy producing companies and one can observe a raise in profits in the last years for Exxon, Royal Dutch Shell and E.ON. In the first Quarter of 2008 Royal Dutch Shell and BP could further increase their profits (BP by +72%, BP 2008).

Figure 81 Profits of oil and gas producing energy companies (Fortune Magazine 2008)



Source: Fortune Magazine 2008

Within this situation the question arises what to do with the accumulating profits. Risk management offers a strong argument for investment into alternatives to oil. The energy producing firms face two risks in the future: firstly, the danger of increased substitution of oil through unconventional resources such as sands or shales and secondly the depletion of their resources in the future. Therefore, earning high profits at the moment, one way to handle these risks should be investing into innovative alternatives. This will manage the substitution risk because the firm would profit from the substitution markets as well. Furthermore alternative energy innovation will help to secure the core business of the energy firms the production of energy in the long run. As it is not clear which innovation will be the most successful in the future a diverse portfolio seems to manage the risk best. In this respect the high oil prices and a risk minimizing strategy of the energy sector should even lead to pushing innovation into alternative energy resources. In the long run investment in new energy technologies will be necessary, although so far this did not show in the investments of energy producers. In the US e.g. they amounted only to 11% of the emerging energy investment in 2006 (Bradley et al. 2006). A similar risk hedging strategy would be also beneficial for governments that would like to increase their countries security of energy supply, for which increasing the diversity of used primary energy suppliers is a major strategy. This means, such governments should develop policies that directly (e.g. via subsidies) or indirectly (e.g. via tax incentives, feed-in tariffs) foster the investment in alternatives to mitigate the economic risks associated with high oil prices (Jesse/van der Linde 2008).

Apart from risk hedging of the firm, the increasing profits have been subject to political debate and the question if the oil firms should not compensate the lower incomes for the high oil prices through their accumulating profits. As persons with lower income have to spend a proportionally larger share of their income on energy they are affected more strongly than persons with higher income. Recently the Italian minister of Economy Tremonti proposed a so-called Robin Hood Tax that would transfer profits from the oil firms to the lower incomes.

(FAZ, 19.07.2008). Similar proposal have risen in Portugal and Germany (here the introduction of social tariffs was discussed). Also in the US the discussion about a windfall tax for the profits of the oil firms has been going on. (IHT, 21.07.2008).

However, our analysis shows that such a tax should be used to trigger investments into alternatives to oil and thus reduce oil and gas demand instead of merely subsidizing demand (see sections 4.4.4, 4.5.1 and 4.5.4). The former will stabilize the economy and mitigate the negative impacts of future high oil prices, while the latter will artificially keep the demand levels, transfer additional money to the oil exporting countries and delay the negative economic impacts with the consequence that the country will be hit even harder by the oil price shock.

As a side note the rise in crude oil prices does not affect the firms in the sector evenly, but mainly the crude oil producers. E.g. profits in refining have been sinking in 2007, because the refiners could not pass on the rise in crude oil prices to their customers as quickly. (Pirog 2008). This hints once more to the market imperfections with a couple of large vertically integrated companies.

The question of how the price increase of fossil fuels as inputs to the energy sector is forwarded by the different players in the energy sector (oil producers, refineries, wholesale, filling stations, etc.) to the other sectors is also crucial for the impacts on employment. The basic parameterization in ASTRA used in all the ten major HOP! scenarios is that 95% of energy price increases would be forwarded to the other sectors. Since, this is a decisive parameter for the calculation of gross-value-added and employment of the other sectors it has been analysed what would happen if price increases can be forwarded to a lesser extent. Figure 82 shows the impact if only 50% of the price increase could be forwarded to other sectors for the scenario *150 Smooth*. In the basic scenario *150 Smooth* employment in EU27 would be reduced by -10 million persons in the impact peak in 2020 and would reduce to a loss of about -4 million persons over the long-term due to adaptation effects in the economy (pink dotted plane). With limited price forwarding to 50% (green plane) about +4 million jobs could be saved in the non-energy sectors (which is the net of jobs lost in the energy sector and jobs gained in other sectors) in the impact peak and about +2 million jobs in the long run. In total this would mean for a revised scenario *150 Smooth with limited forwarding* a loss of close to -6 million jobs in the impact peak and -2million in the long run. The effect can be observed for all scenarios and is much more relevant in the extreme scenarios (*600 Early* and *800 Early*). Since, ASTRA is handling the price increase in the IO-Table only in monetary terms a limitation of price forwarding could also come from efficiency gains within the energy sector reducing the physical input of resources to the energy sector and thus reducing the forwarded monetary impulse. Again, such reduction would be the consequence of investments, in this case in particular into efficiency of the conversion process.

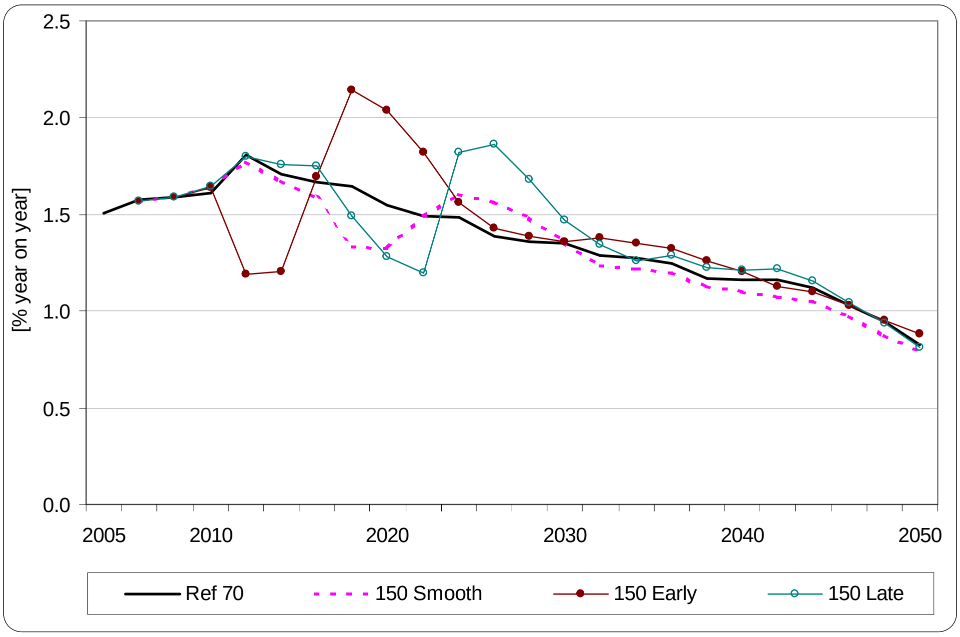
Figure 82 Change of EU27 Employment compared to reference scenario if only 50% energy price increase is forwarded to other sectors

Source: ASTRA calculations in HOP!

4.5.3 The impact of an early or late oil price step

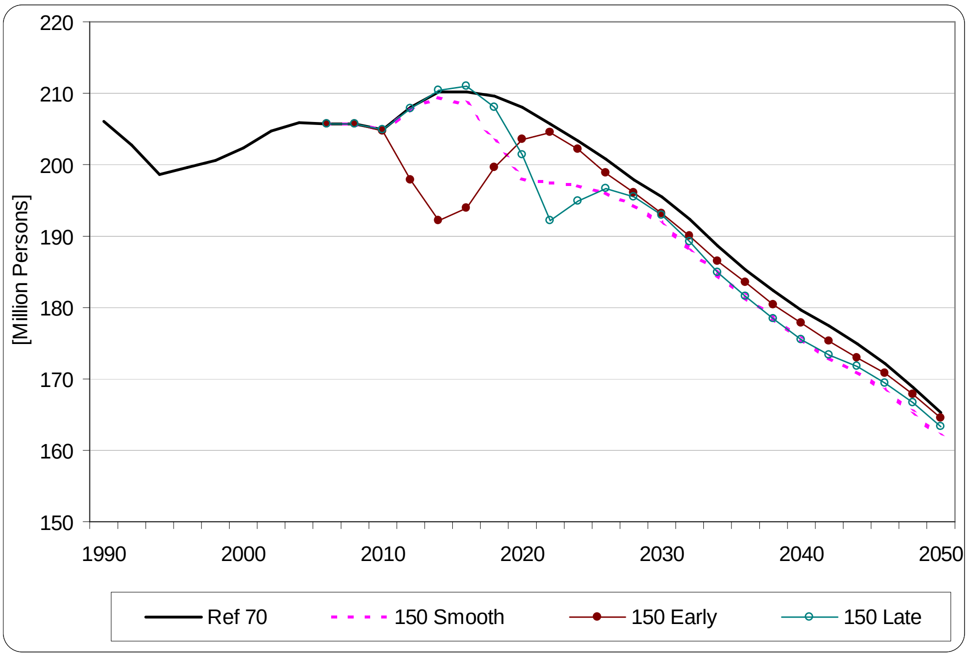
As shown in Figure 83, when the high oil price is the result of a step rather than a smooth process, the economic growth is slowed down in correspondence of the price shocks, but after some years the growth pace returns to the reference values. If the step occurs early (i.e. just after 2010, 150 Early scenario) the reduction of growth is more significant than in the case when the step occurs around the year 2020 (150 Late scenario). This seems reasonable assuming that until 2020 oil intensity and oil dependence will be further reduced and alternatives to oil should be more developed. However, in case of the early step the reaction of the economy, in particular of investment, is faster and stronger so that after some years the growth rates are even higher than in the reference scenario. The impacts on the economic growth have a correspondence in the trend of the employment, as shown in Figure 84.

Figure 83 EU27 GDP growth rates in case of early or late oil price steps



Source: ASTRA calculations in HOP!

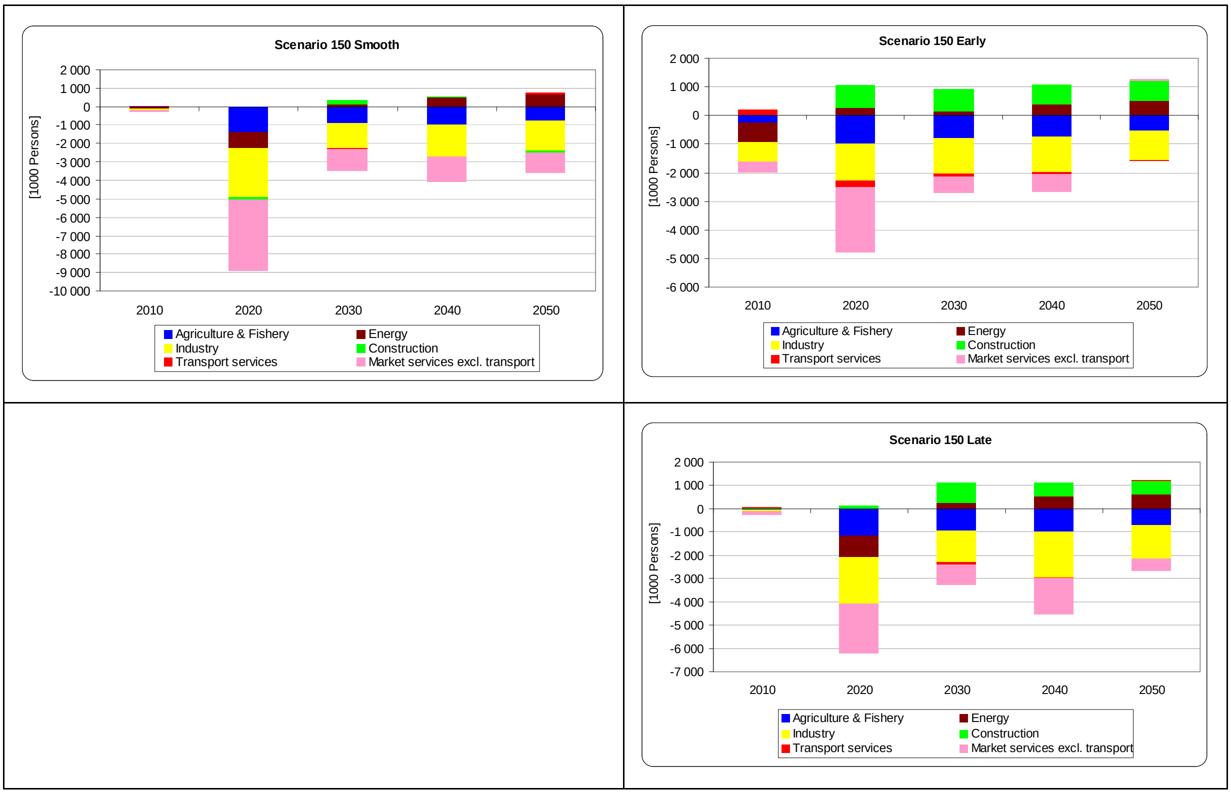
Figure 84 EU27 employment in case of early or late oil price steps



Source: ASTRA calculations in HOP!

Following to the decrease in GDP growth one can observe job losses compared to the reference scenario and then a recovery through job gains, mainly in the construction and energy sector. The different scenarios lead to different sectoral restructuring. Overall job losses occur in all three scenarios in the market services sector, agriculture, industry and transport. On the other hand, jobs are created in the construction and energy sector. These job gains are especially pronounced in the scenarios with sudden changes of the oil price (*150 early/late*). The jump in oil prices induces investments into alternatives to oil that were not feasible while the oil price was rising gradually, only. A firm having the choice to adapt its current oil use to prices or to costly switch will unlikely incur the switching costs as long as the price rises only gradually. If the oil price jumps, switching to a new system becomes more likely. If the oil price reaches a certain threshold, investment alternatives that were not feasible before might be feasible now. This in turn leads to investments into alternatives, creating jobs in the energy and construction sector. Therefore the job gains in Scenarios *150 early/late* can be interpreted as the investments needed for the structural adjustments to high oil prices. (Figure 86

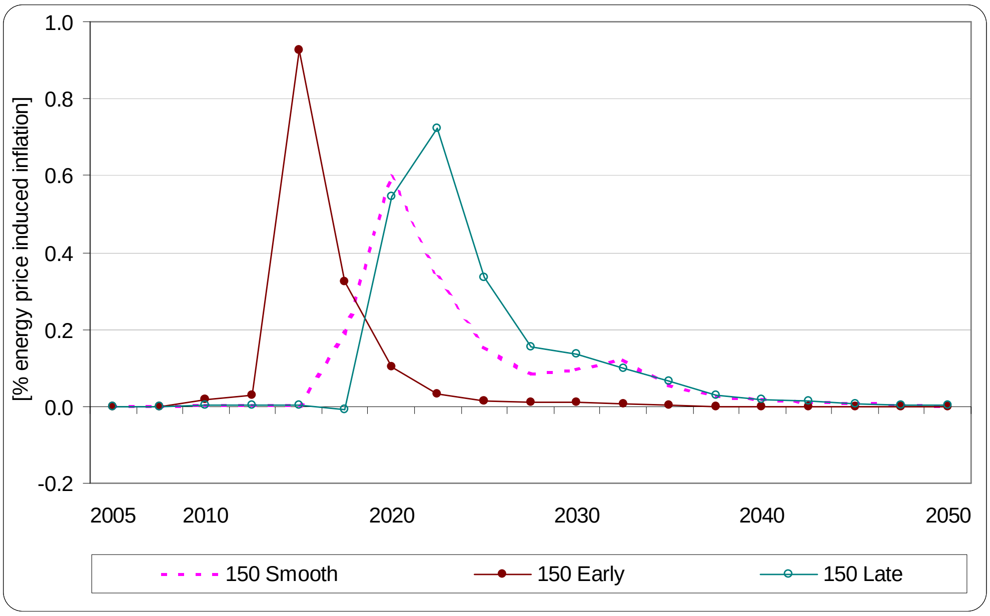
Figure 85 Change of EU27 Employment by aggregate sector compared to reference scenario



Source: ASTRA calculations in HOP!

The high oil prices also have an effect on inflation (Figure 86). The inflationary shock is highest in 150 early scenario and lowest in the 150 Smooth scenario with the gradual price increase.

Figure 86 Additional Energy Price Induced Inflation in EU27 (annual value)

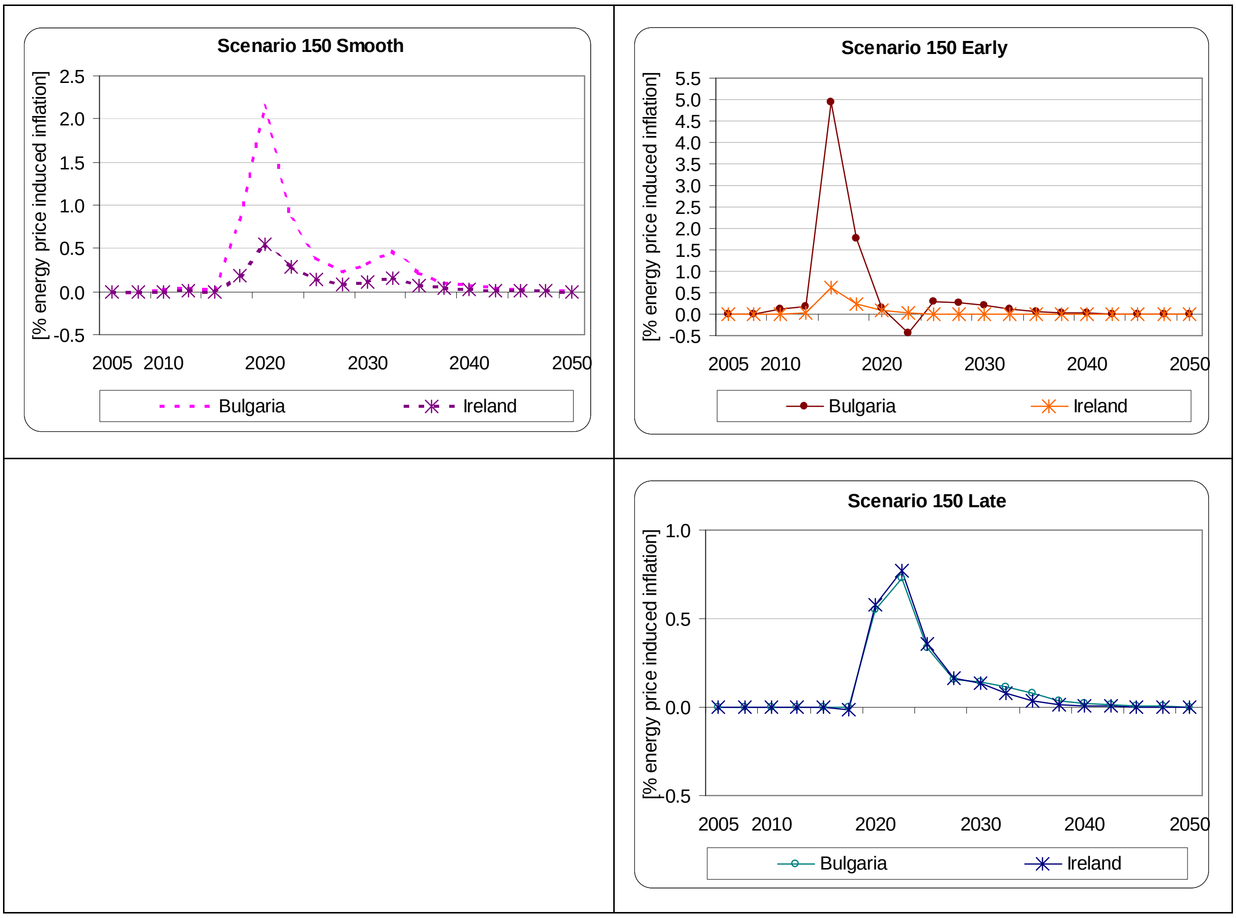


Source: ASTRA calculations in HOP!

To explain the different trajectories, one reason is once more investment. In *150 early* scenario the price increase in oil prices can be passed on into the prices because few substitution possibilities exist and demand for oil is rising due to GDP growth. In *150 smooth* scenario investments into alternatives to oil can be undertaken and kick in, leading to an overall lower impact of the oil price. The same is valid for the late increase in oil prices, although the sudden rise of the oil price leads to a higher inflation than in scenario *150 smooth* , technological progress and investments are mitigating the impact of higher inflation.

Inflation differs among countries, with two examples shown below. Bulgaria reacts with very large inflation and even deflation to sudden changes in the oil price, while Ireland shows only a moderate reaction in all Scenarios. One explanation for the strong reaction of Bulgaria is oil intensity, which is higher there than in the service based economy of Ireland. Overall for EU27 and adjusted for GDP, however, we find the reactions shown in Figure 86.

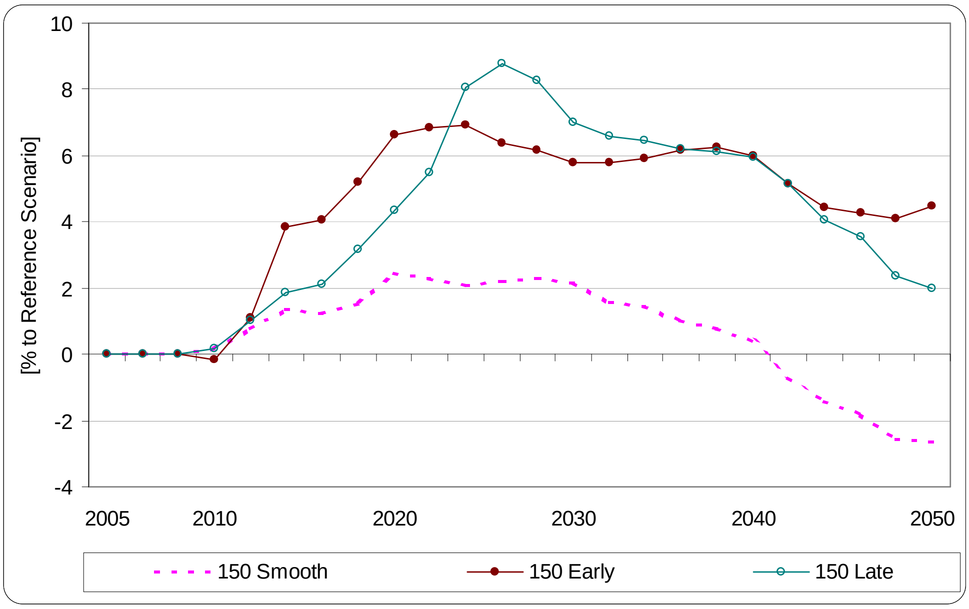
Figure 87 Energy Price Induced Inflation in Bulgaria and Ireland



Source: ASTRA calculations in HOP!

The impact of a late or early step in oil prices also shows in investment. The scenarios with a sudden increase trigger a lot higher investments than the smooth increase. In 150 Early scenario, however, one can observe the investment lag. The market participants first decrease investment into alternatives to oil before heavily investing. This once more underlines the necessity to invest into alternatives to oil before the funds for necessary investments are consumed through the expenses for higher oil prices.

Figure 88 Change of EU 27 investment compared to reference scenario



Source: ASTRA calculations in HOP!

Consumption in the simulation is mainly driven by disposable income. If the expenses for products such as fuel e.g. rise due to a higher oil price then consumption for other products decreases compared to the reference scenario. In *150 Smooth* scenario consumption decreases and remains lower than its initial level until 2050. In *150 Early* and *150 Late* scenarios consumption decreases shortly after the oil price shock (2013/2023) but then recovers and even rises above the initial level. In the scenario with the early price shock the effect on consumption is larger and it takes longer to recover. This can be explained with the higher inflation, the unpreparedness of the market participants to the oil shock, leading to investments that decrease consumption, at the same time having to support the higher price until the investments kick in. The overall loss in consumption compared to the reference in *150 Smooth* scenario can be attributed to lacking adjustments towards alternatives to oil as well. (Figure 89)

Figure 89 Change of EU27 consumption compared to reference scenario

Source: ASTRA calculations in HOP!

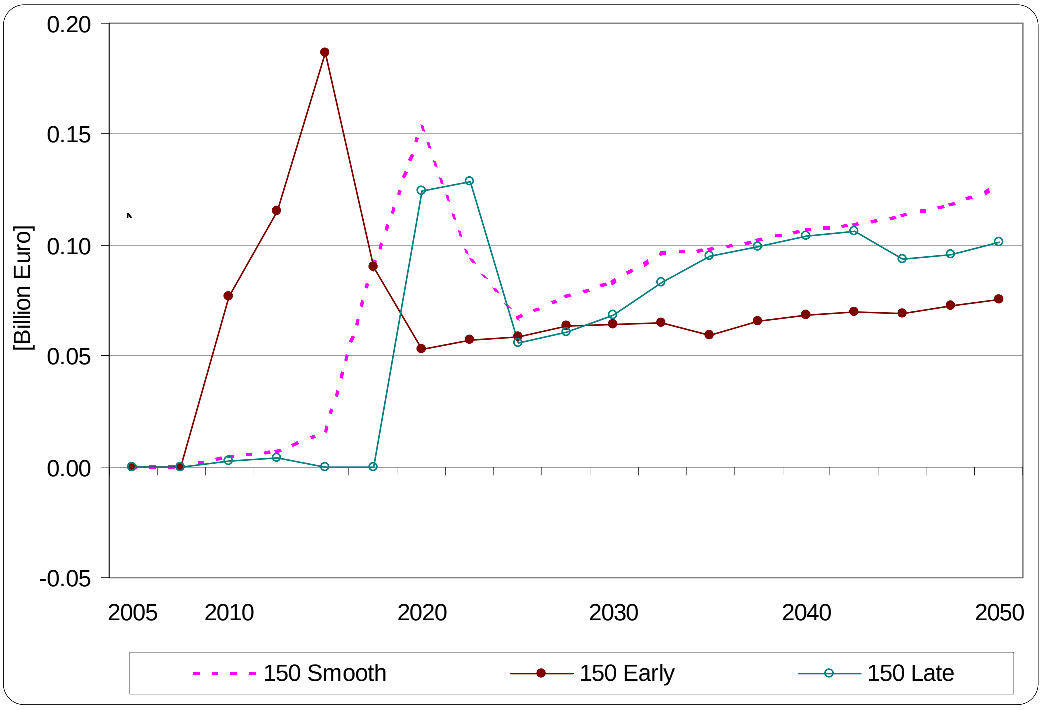
One interesting difference is the decreased overall consumption of transport for *150 Early* scenario. This could be explained with changing habits towards transport and successful substitution of oil through alternatives. (Figure 90)

Figure 90 Change of EU27 consumption of transport and related services compared to reference scenario

Source: ASTRA calculations in HOP!

The consumption of fossil fuels shows the raising energy efficiency of cars. The peak in oil consumption for the scenario with the early step is higher than the one for the smooth increase and the late step.

Figure 91 Change of EU27 Fossil Fuel Consumption compared to reference scenario



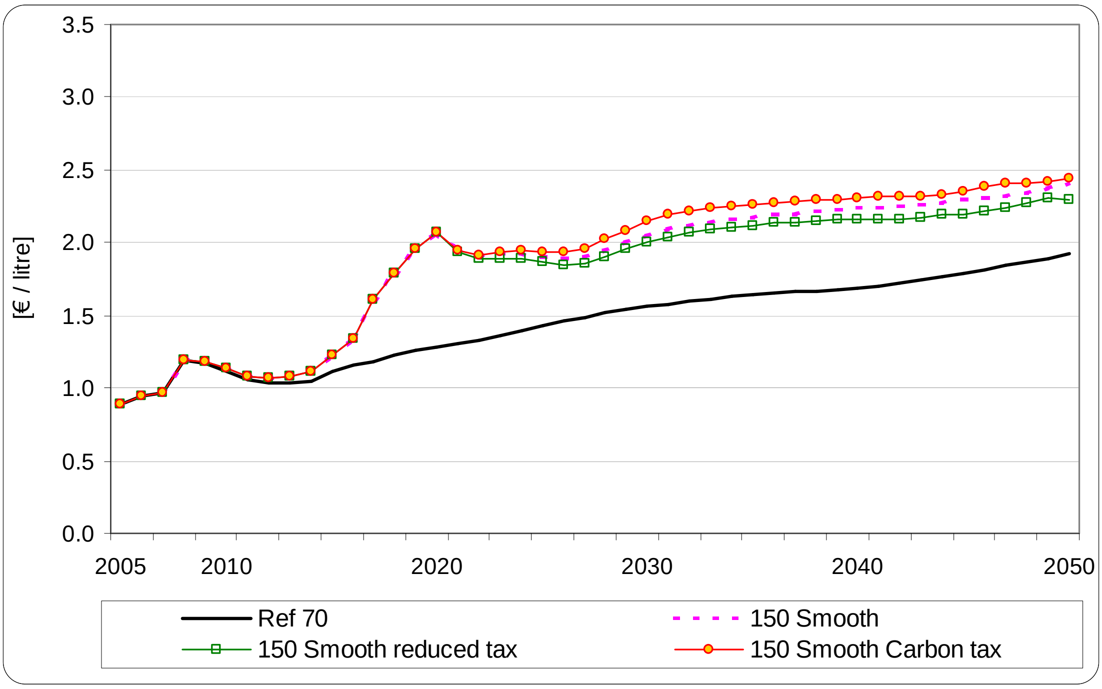
Source: ASTRA calculations in HOP!

Overall the reaction to the jumps in oil prices are stronger but lead in the long run to more investment and consumption. It becomes also clear that the main trigger for the recovery of consumption and GDP growth rates is investment. Encouraging investments into alternatives to oil is therefore likely to pay off in the future assuming permanent high oil prices.

4.5.4 The impact of energy taxes

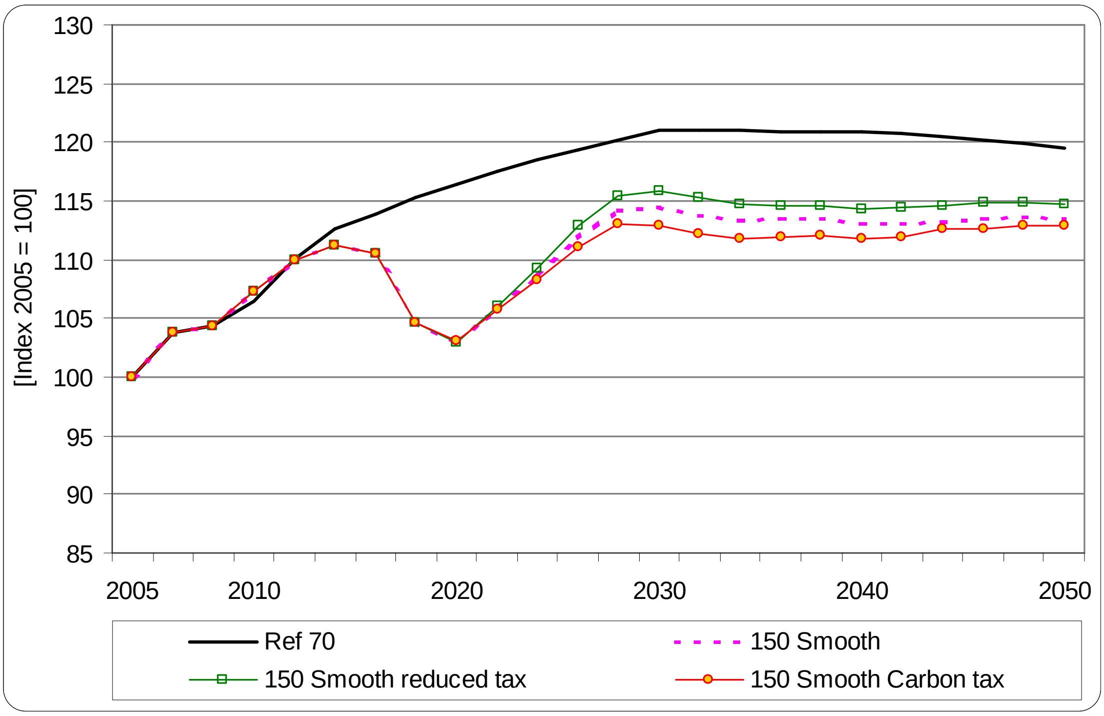
The application of a carbon tax (40 Euros in 2030 per tons of CO_2 emitted - *150 Smooth carbon tax* scenario) or the discount of fuel excises (reduction by 20% after 2020 - *150 Smooth reduced tax* scenario), do not affect significantly the trend of energy price. Figure 92 reports, for instance, the development of gasoline price. It is apparent that differences with respect to *150 Smooth* scenario , are very small. In fact, the average cost of trips is increased only by +1/+2% in the *150 Smooth carbon tax* scenario and decreased by –1/-2% in the *150 Smooth reduced tax* scenario. Not surprisingly, such minor differences, do not cause significant changes on results, see e.g. for the impact on passenger transport demand and on GDP growth rates in Figure 93 and Figure 94.

Figure 92 EU27 average gasoline price with carbon tax or discount on excises



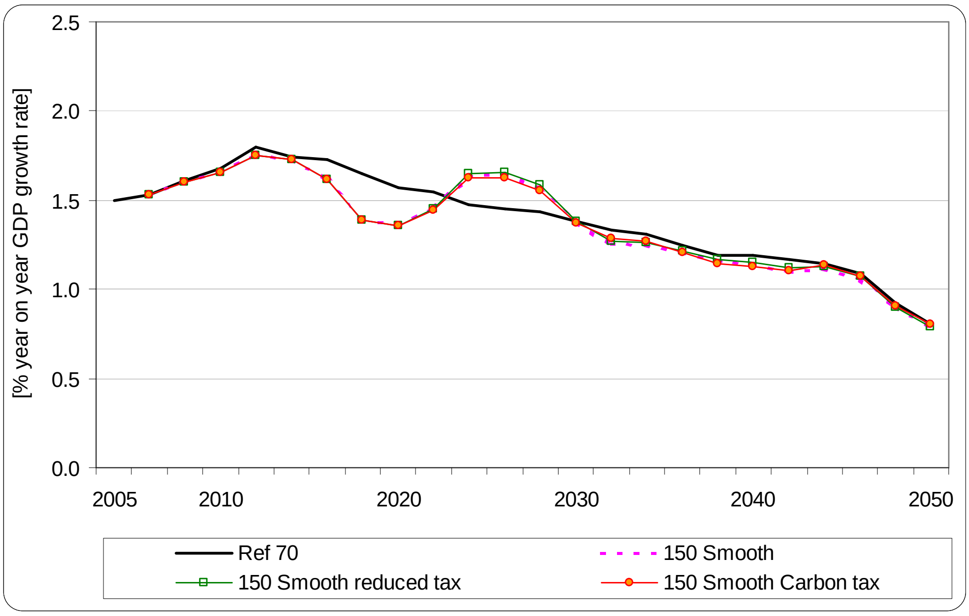
Source: POLES calculations in HOP!

Figure 93 Trend of EU27 passengers-km with carbon tax or discount on excises



Source: ASTRA calculations in HOP!

Figure 94 EU27 GDP yearly growth rates with carbon tax or discount on excises



Source: ASTRA calculations in HOP!

The impact of a discount is however not so low if the revenues from the fuel taxes are considered as in Figure 95: revenues are lowered to even a lower amount than in the year 2000. This result can have some significant implication for transport policy.

Using the leverage of pricing and taxes to lead the transport system towards sustainability is one priority of the European policy as well as of national policies of at least some Member States. The effectiveness of pricing policies is linked to other objectives like fairness (e.g. polluters pay) but also to financial considerations since transport taxes provide a significant contribution to public budgets. For instance, the Dutch Government is studying a reform of the transport taxation where fixed taxes like registration taxes are abolished and the use of the vehicles is charged and, at the same time, guarantees budget neutrality.

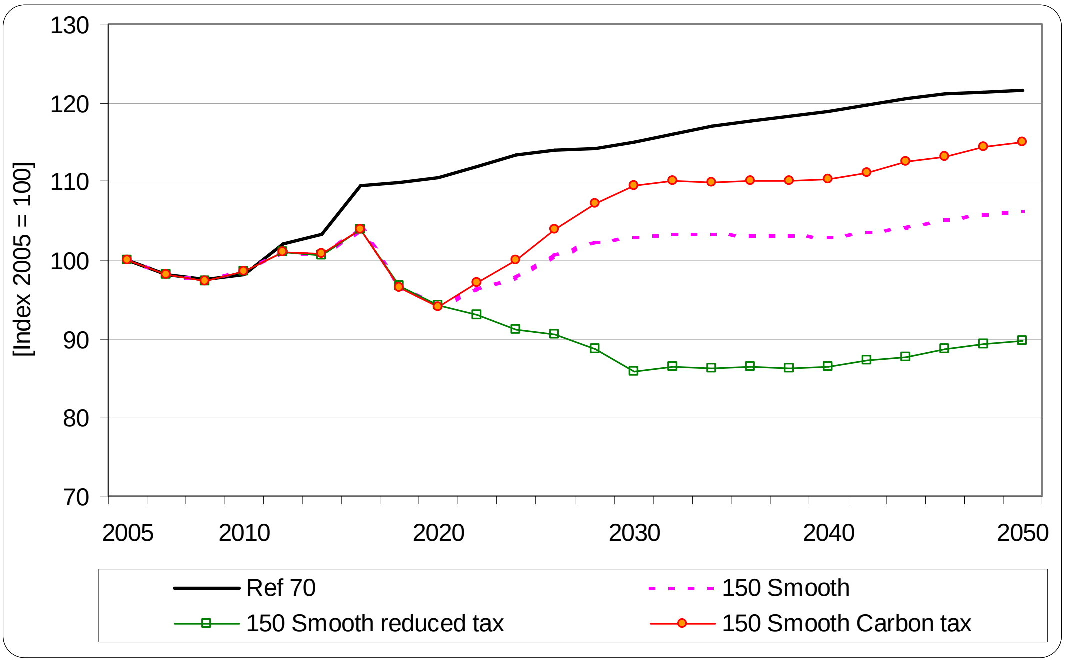
However, from Figure 96 it can be seen that fuel taxes amount to more than 50% of all transport tax revenues[13]. When fuel taxes revenues are reduced as effect of lower transport demand, eliminating car-ownership fixed taxes would cut total revenues of about one third or more and even an additional carbon tax of the size simulated in *150 Smooth carbon tax* scenario would not alleviate significantly the loss, while larger taxes would be politically impracticable. On the other side, reducing fuel taxes as a policy tool to reduce travel costs would be even more problematic in budget terms and still be not very effective.

This suggests that taxes or discounts able to affect prices more significantly are politically impracticable in one sense or another (either because to impose high carbon taxes on the top of high resource fuel costs would be very unpopular or because the reduction of revenues for the public sector would be too large). This effect can be seen in the current developments of

[13] Data in Figure 96 does not include registration/property taxes for freight vehicles

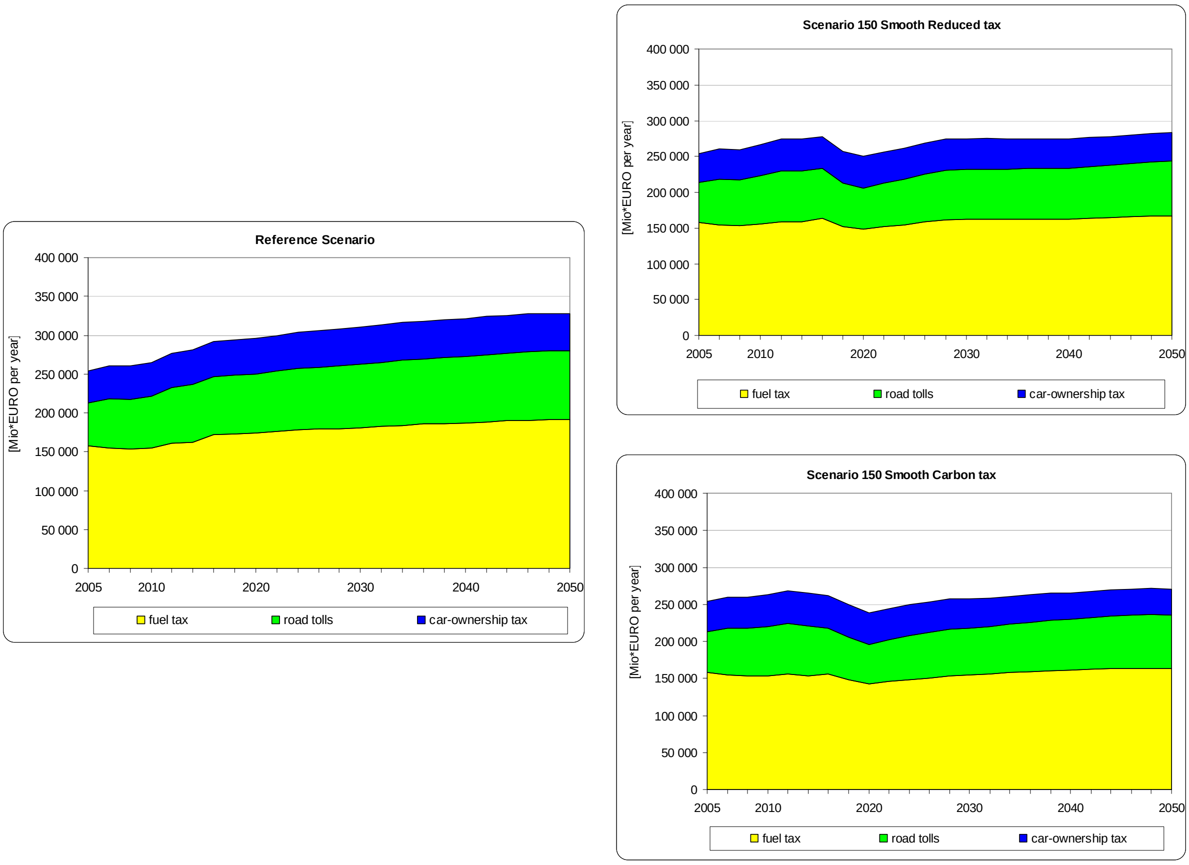
UK transport policy, where perceptions of high fuel prices are leading to the government cancelling some of its proposed tax increases on fuels for environmental purposes.

Figure 95 Trend of EU27 fuel taxes revenues with carbon tax or discount on excises



Source: ASTRA calculations in HOP!

Figure 96 EU27 Transport tax revenues and its composition



Source: ASTRA calculations in HOP!

4.5.5 The impact of insufficient energy supply

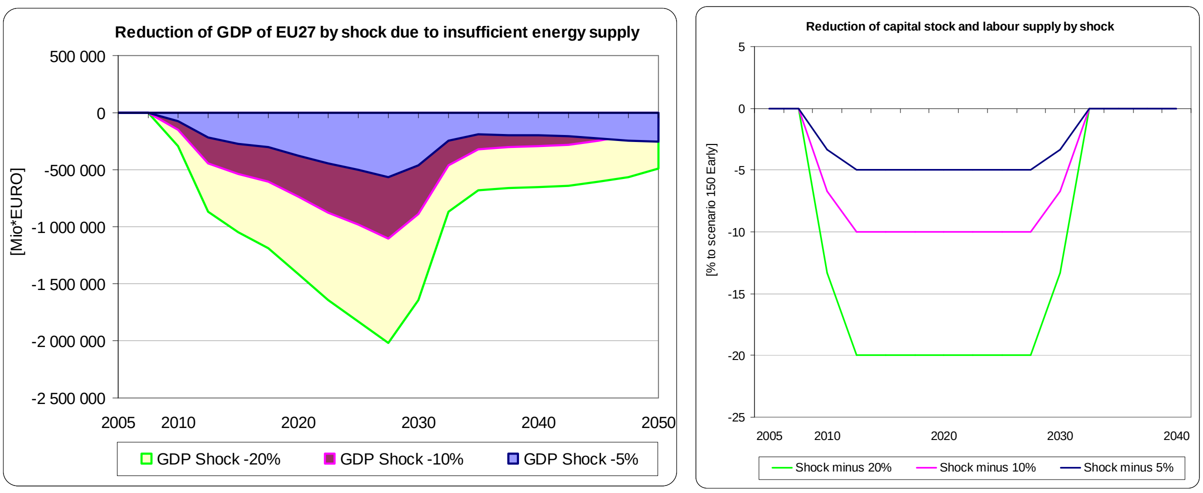
In the ten HOP! scenarios, oil price can be very high but physical energy shortage is not contemplated because - driven by investments - a gradual replacement of oil with unconventional oil and oil substitutes and reduced energy demand due to efficiency investment is estimated, led by relative prices and made possible by the investment of revenues of the energy companies and redirected investment that because of a lack of investment opportunities went into less productivity enhancing investment like housing and office buildings in the last decade, while given the acknowledged transition of the energy system and the related profitable investment into alternative energy and efficiency technologies today it goes into such investments in the energy system. This relies on two key implicit assumptions. First, there is the expectation that the need for more energy produced by non-fossil energy sources can always be financed from revenues from higher energy prices or by attracting investors who dispose of money to invest, which globally is the case that sufficient investment capital is available. The latter becomes more important if investments would be delayed such that due to a recession "free" investment capital is already disappeared as a consequence of the economic turbulences. Second, investments in the energy sector are assumed to be rapidly effective, i.e. the delay between investing in the construction of a new large scale power plant or the rehabilitation of a significant share of the stock of buildings could be underestimated in the models.

Thus a number of tests were made with the ASTRA model to analyse what would happen if oil remains scarce (which very probable will be the case), alternatives are not developed by investments as well as efficiency is not improved such that energy demand is not reduced. In such a scenario energy supply to Europe would become insufficient and shortage of energy would occur such that certain activities could not be undertaken anymore. E.g. firms would reduce the number of production hours, materials, half-manufactured goods or even workers would not reach their destination location for further production activities. This could be translated in ASTRA into a reduction of the productive capital stock and the available labour supply, which would last over a certain period until the productive system has been adapted.

The order of magnitude of the potential supply shock was derived from the POLES results on reduction of energy demand in the extreme scenario (*600 Early* and *800 Early*), which was in the range of -20% shortly after the oil price increase. Figure 97 on the right hand side shows the corresponding reduction of the capital stock and labour supply in the three tested scenarios. The maximum shock means that 20% less energy is available then demanded such that the capital and labour stocks are reduced by -20% between 2010 and 2030. The further two scenarios present a -10% and -5% reduction of the two stocks.

The impact on GDP of EU27 is shown in the left hand side of Figure 97. The figure shows the additional losses of GDP compared with the *150 Early* scenario. The losses would be substantial. In the short term (until 2014) the loss in *150 Early* scenario would be -2% compared to the reference. The supply insufficiency of -5% would mean an additional -3% loss, the -10% a further -3% and the -20% further -6%, such that in the latter scenario in the shorter term additional -11% of GDP, or -1 Trillion Euro, are getting lost. The negative reactions trickle down the impact chains and amplify over time such that in 2030, when the supply insufficiency is ending, the largest negative impact on GDP is measured.

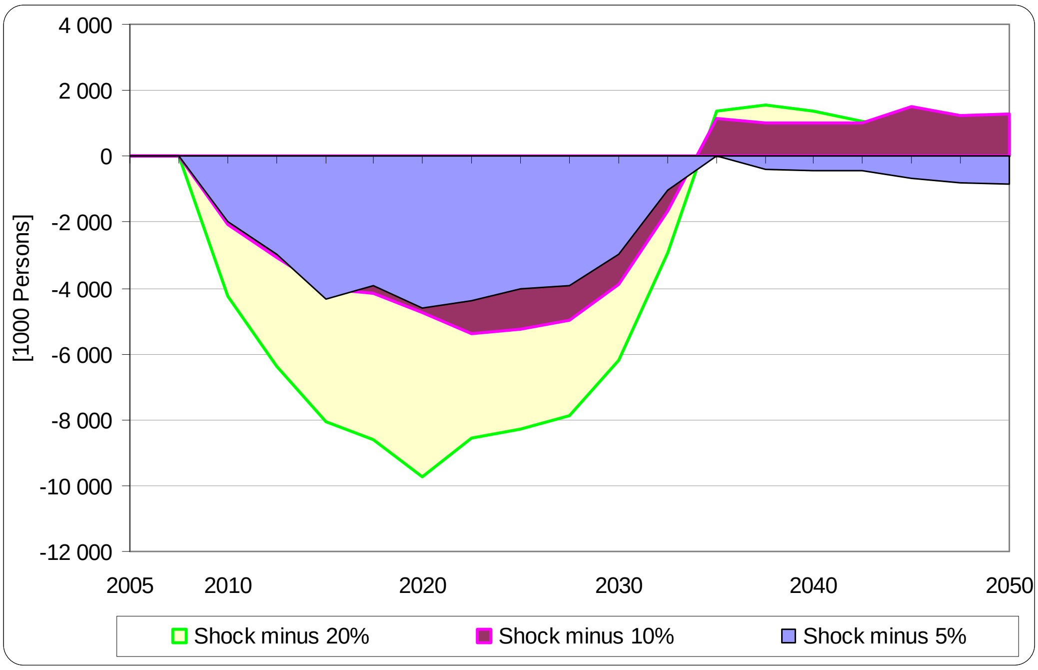
Figure 97 Impact of energy supply shock on GDP: additional change of EU27 GDP in *150 Early* scenario



Source: ASTRA calculations in HOP!

Though for GDP the losses due to insufficient energy supply seem to be quite linear (double the energy insufficiency leads to double the GDP loss) the impact on employment looks different and non-linear as shown in Figure 98. Sectoral restructuring towards more labour intense sectors and a general slower growth of labour productivity achieves that the most negative impacts are observed around 2020 after which the situation is slightly improving, and after 2035 employment is even higher than in the *150 Early* scenario. Also the difference between a -5 and -10% energy supply insufficiency is very limited, while the -20% insufficiency doubles the loss of employment compared with both other scenarios.

Figure 98 Impact of energy supply shock on employment: additional change of EU27 employment in 150 Early scenario



Source: ASTRA calculations in HOP!

Though one should take into account that the chosen implementation in ASTRA affecting the capital stock and labour supply constitutes a top-down implementation of the scenario test, while usually the scenario inputs enter bottom-up into ASTRA (e.g. on sectoral level in the transport or energy system), which means that not all impact chains are addressed in the full scale manner, we would summarize the picture as follows:

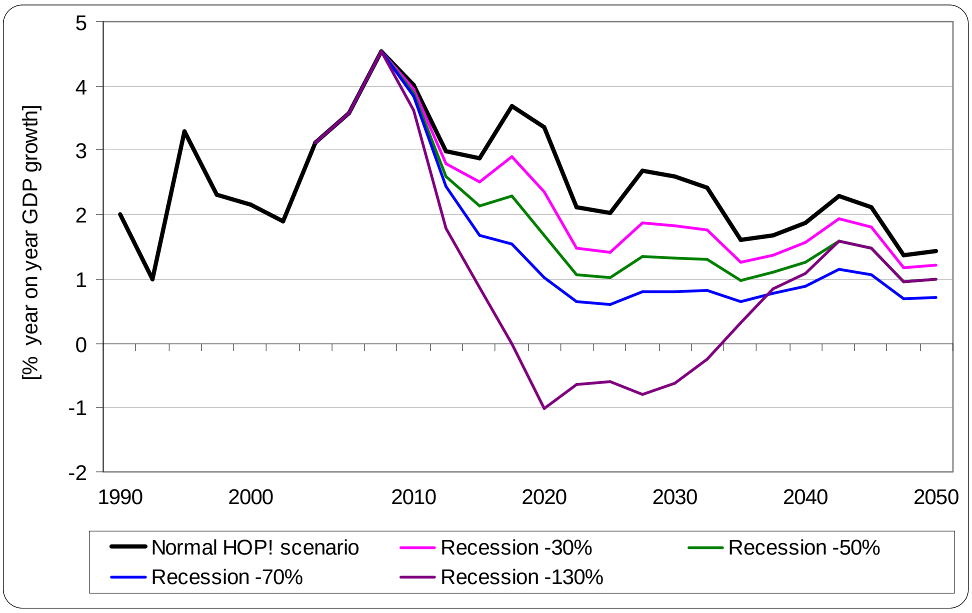
A failure to adapt the energy system by investments into alternative energies and energy efficiency gains with the consequence of insufficient energy supply for the EU27 would have by far more drastic consequences than even observed for the highest oil price scenarios tested in HOP! This emphasizes once more the importance of early action and adaptation of the energy system by investments that reduce fossil fuel demand by efficiency gains and provision of alternative energy technologies.

4.5.6 The impact of a world recession

World GDP growth constitutes an exogenous input to ASTRA, which drives the trade model as world GDP growth is one of the three drivers of the bilateral trade flows between the EU countries and the nine rest of the world regions. Since in the ten HOP! scenarios this growth was not altered, additional analyses were made checking the potential additional impact of an oil price shock induced world recession on the EU economy, which would be transferred to the EU via reduced exports to the rest-of-the-world regions.

Figure 99 presents the world GDP growth rates for the normal HOP! scenarios (bold black) and four recession scenarios. World recession would smoothly start at 2008 and reach the target level relevant for the scenario naming between 2020 and 2030. E.g. the scenario Recession -50% represents a reduction of World GDP growth by -50% compared with the normal ten HOP! scenarios over the period between 2020 and 2030. After 2030 it returns back to higher levels, but remains still below the normal HOP! scenarios. This means for analyses in particular the period 2010 to 2030 is relevant.

Figure 99 World GDP growth rates in the world recession scenarios

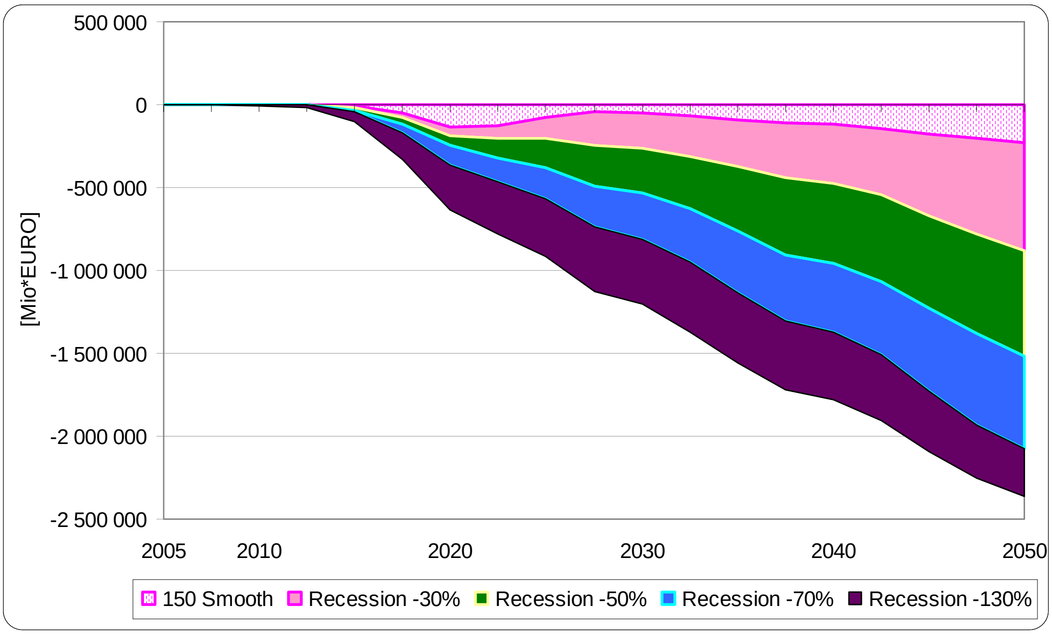


Source: exogenous input to ASTRA to simulate world recessions in HOP!

Figure 100 presents the additional losses of GDP that could be expected from a long period of recession as assumed in the recession scenario analysis. Until 2030 in the worst case this would mean an additional loss of 1.3 Trillion € of EU27 GDP compared with a loss of 50 Billion € in the 150 Smooth scenario applied for this comparison. The four scenarios with lower world GDP growth rates by -30%, -50%, -70% and -130% would lead to additional losses of GDP until 2030 of about -1.6%, -3.6%, -6% and -9% respectively. This means, such recessions would have stronger impacts than the impacts caused by the high oil price, when they were mitigated by investments and reduced oil demand due to increased efficiency and increased usage of alternative non-fossil energies. Looking at the world GDP growth rates since 1970 there were only two short periods during which the growth went down to +1%

only (or slightly below), which were the oil crises in the 70ies and early 80ies, such that it seems reasonable to consider in particular the -30% and -50% scenarios as realistic. This means, taking potential world recessions into account the EU27 GDP could be about -1% to -3% lower than estimated for the normal HOP! scenarios, or in other words if in a HOP! scenario a loss of -1% GDP is expected, this could reach -2% to -4% if the world economy would grow significantly slower than expected in the reference (bold black curve in Figure 99).

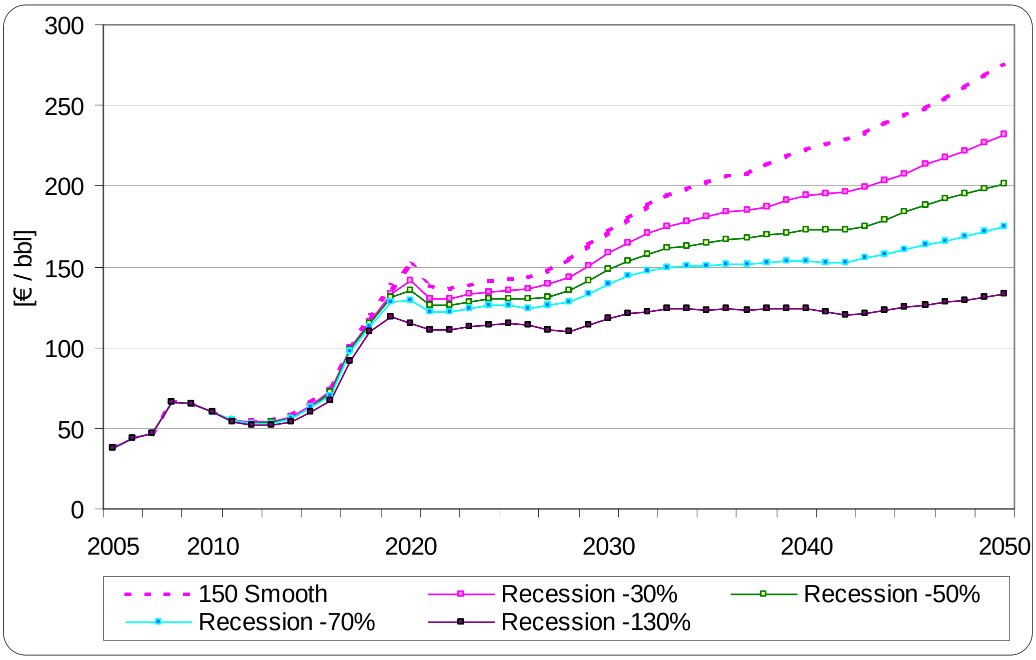
Figure 100 Impact of world recession: additional EU27 GDP change compared with the *150 smooth* scenario



Source: ASTRA calculations in HOP!

The development of the oil price differs significantly between the *150 smooth* and the world recession scenarios. In 2030, with lower world GDP growth rates by -30%, -50%, -70% and -130% the oil price would be -8%, -14%, -19% and -32% respectively lower compared to *150 smooth*. The results underpin the strong impact of growth on oil demand and thus on the oil price.

Figure 101 Development of the oil price in the world recession scenarios compared with 1*50 smooth*



Source: POLES calculations in HOP!

5 Policy discussion

This section summarizes the findings of the quantitative analyses in HOP!, complements it by a few qualitative aspects that could not be handled by the ASTRA and POLES models and discusses the implications for policy-making.

The perspective chosen for this summary is to look at the period of the oil price peak and to present the impacts observed for this period. Due to the way scenarios are defined in HOP! (see section 4.1) the point of time of this price peak differs, because it was anticipated with the scenario definition that timing and time paths play a crucial role in the analysis of the impacts of high oil prices. Thus, scenarios differed in a way that they considered a doubling, tripling or extreme increase (about tenfold) of the crude oil price in real terms during the price peak. The timing of this peak could either be early (2014), medium (2020) or late, where the early and late points of time involve a period of steep increase of the oil prices. Further, specific policy elements were tested: missing incentives for investment leading to limited investments into adaptation of energy and transport technology, reduced fuel tax and increased carbon tax. The impacts on the economy during the peak periods are presented in Table 8. Roughly a 1-percentage point loss of GDP would amount to a GDP of EU27 that is 100 billion € lower than in the reference. In most scenarios the GDP losses can be observed over at least one or two decades, in some even until 2050. Linking the results with the conclusions of the sensitivity tests it could be that the annual loss of GDP would reach even over 1 Trillion € for the EU27 (see also section 4.5).

In terms of employment the numbers are more dramatic: a 1-percentage point loss of employment amounts to 2 million less employed persons in Europe, which means that even in the less drastic scenarios about 10 million jobs get lost in the EU27. Here, also the timing plays a crucial role such that with the early price peak the loss of jobs is nearly double than with the later peaks. This shows the important role of adaptation of the energy system, which for the later price peaks has developed further than in the early peaks.

Table 8: Overview on GDP and employment loss in EU27 during the peak oil price period

Price peak	**Characteristic**	**Loss in peak**	
		GDP	**Employment**
Doubling	smooth increase	-1.5%	-4.8%
Doubling	smooth + limited investment	-2.1%	-5.4%
Doubling	smooth + reduced fuel taxes	-1.3%	-4.8%
Doubling	smooth + increased carbon taxes	-1.6%	-4.8%
Doubling	early + steep increase	-2.1%	-8.5%
Doubling	late + steep increase	-1.1%	-5.4%
Tripling	smooth increase	-2.2%	-7.8%
Extreme	early + steep increase	-3.8% to -5.1%	-22% to –32%
Sensitivity to specific shocks induced by oil crises			
World recession		additional loss: -1% to -5%	
Insufficient energy supply		additional loss: -5% to -11%	

Source: ASTRA calculations in HOP!

The expected oil-GDP response to an oil price shock relationship would be, however, less pronounced than those observed for the oil price shocks in the 1970s and 1980s. This is due to the large variety of dampening effects on both the oil price and its economic impact. Compared to past oil price shocks, the oil intensity of the European economy has halved and the service sectors have increased their importance at the expense of the more energy-intensive industrial sectors. A broad variety of alternative energy technologies have become available, many of which would become competitive at the higher oil prices analysed. A crucial issue in this respect is the timing of measures to tackle high oil prices i.e. both investment into energy efficiency technology and investment into alternative non-fossil energy production technology. It is even a realistic possibility that due to these investments that would replace imported goods (fossil fuels) by domestic goods (e.g. renewable technology and maintenance of this technology), the overall impact on the economy would be positive. On the other hand, delays in investment into such measures would make the impact of high oil price significantly worse.

The results of the HOP! scenarios have several implications for the definition of future policies in the domains addressed by the analysis: transport, economy, energy. The main factors for the oil-price induced lowering of GDP growth are the shift in domestic consumption towards the energy sector, the reduction of value-added of the non-energy sectors due to higher cost of energy inputs into their products, which is not fully compensated by the increased revenues of the energy sector as this has a high import share, and the reduction in transport activity. The latter is particularly pronounced for passenger transport activity (some -14% points by a doubling of oil price and some -17% points by a tripling), but can also be observed for the transport of goods (some -11%). The high oil price would also reduce the dominance of road transport in the modal split, even if it still remains the most important mode. As a result of the decreasing activity but also due to the introduction of energy efficiency measures, final energy consumption in the energy sector would reduce by around -16% by 2030 (compared to the reference trend) for a doubling of the oil price, and around -26% at a tripling.

The HOP! results suggest that investments in alternative energy sources and energy efficiency are the key factor for dampening negative impacts of high oil prices. If investments were either not available or too late, the macroeconomic impacts of high oil prices in the EU-27 would be significantly greater. A first policy issue is therefore how to promote investments in the required size either directly through public budgets or by creating incentives that encourage investments of the private sector.

There are several channels through which policy affects investments. A government may decide to dedicate public budget to finance both research in the energy sector and implementation of new infrastructures and technologies or it may set the incentives to affect investment decisions.

Nevertheless, it is obvious that the private sector will need to carry large parts of the additional investment needs. There are a number of arguments that this would also be in the interest of the private sector. First, with the framework of the high fossil fuel prices investments into alternative energy technologies become more profitable as the prices of competing technologies increase. Second, the last decade saw a lack of promising investment opportunities e.g. documented by the fact that significant investment capital went into low productive real estate investment and into mergers and acquisitions. This means, lack of investment capital should not be the problem, presupposing that governments do not disturb the price signals and the expectations of a sustained high oil price. Third, uncertainty prevails in the energy markets with respect to two aspects: the actual price path of fossil fuels and the set of energy technologies that become successful in the medium to long run. Risk management of these uncertainties would also suggest the private sector to increase the portfolio of non-fossil energy technologies and thus invest into a diversity of alternative energy technologies. Fourth, due to the already existing legislative framework for renewable energies and the stimulated technology and market development the EU is in a lead market position for these technologies offering promising export opportunities and thus providing a further incentive to invest into the new technologies.

Policy can support investments of the private sector through various means: Fiscal and monetary policies can be used to influence investments from the private sector. For instance a differential taxation could be imagined for capital invested in energy efficiency and for capital gains obtained e.g. on the real estate market, in order to affect the expected net rate of return of the investments. Feed-in tariffs proved to be successful to develop new markets for renewable energy. Specific loans for house owners could provide the incentives for insulation of buildings, either together with the cyclical renovation of buildings or with the purpose to speed-up the renovation cycles. Such a measure would also be a promising element of a package to tackle the loss of employment as it would positively affect sectors with high labour intensity.

Moreover, the adoption of standards may prompt technical progress as standards create additional incentives for private businesses and enterprises to invest. Even though such a framework may be less needed in the times where very high oil prices already provide sufficient incentives for investments, they create a more stable, predictable framework than the fluctuating global oil prices. Standards for insulation of buildings and heating appliances would be one example. Energy consumption limits for vehicles would be another one.

HOP! results indicate that the behaviour and the treatment of the energy sector is crucial for the impact of high oil prices. Two particular reasons have been identified: first, especially the vertically integrated large energy companies are able to increase their profits drastically and thus would be one of the first players in the private sector who should undertake the strategic investment into a less fossil dependent and resilient energy system. Second, the way the energy sector forwards the oil price increase to the other sectors has been identified as a key for the negative impacts on employment. Only a halved forwarding of the price increase to the other sectors would reduce the employment loss by about 40%. The question here is: does society's interest to mitigate the impact of high oil prices and the private interest of the energy sector converge? Or in other words what to do, when the energy sector, and in particular the large vertical integrated companies, would not invest a large share of its additional profits derived from the high oil prices into alternative energies and energy efficiency?

In countries like Italy or Germany answers to this question are currently developed.[14] The HOP! results actually would support government intervention, in particular as several market failures in the energy sector have been identified, which usually are a prerequisite for government intervention. Such intervention should only happen under certain conditions, of which the first would be that the energy sector would not significantly increase its investment into alternative energies and efficiency. In this case, an additional taxation of the profits seem to be justified, eventually together with a moderate limitation of price forwarding by the energy sector to dampen the impact on employment. The tax revenues clearly would have to be dedicated only to support measures to increase the investment into energy efficiency and alternative energies. Of course, the better solution would be that governments manage to set the incentives right such that the energy sector invests driven by its own private interest.

The third policy-sensitive aspect concerns lower income households. In the HOP! analysis the impact of high oil prices on different groups could not be analysed. In Germany, it has been shown that inflation rates differ at least by a factor of two between low and high income groups, as e.g. the former have to spend about 14% of their income for energy while high income groups spend about 6%, only. It is likely that even if on average the European economy can live with higher energy prices, less well-off households will not be able to cope with significantly higher expenditure for heating, electricity, car fuel, etc. Furthermore, the modelling simulations suggest that even if GDP growth can be maintained with high oil prices, employment is more at risk due to structural change that favours sectors with higher productivity and thus lower labour intensity e.g. energy sector. In case of jobless economic growth, the inequality of income distribution would rise as well as the number of less well-off households. This prospect suggests that if the promotion of investments in energy efficiency and alternatives should be on the top of the political agenda in a high energy price world, the

[14] The Italian Ministry for the Economy has proposed a so-called “Robin Hood” tax to collect part of the profits of the energy sector and use revenues for social matters. In Germany the introduction of social tariffs for less well-off households are suggested that, at least partially, should be funded by the energy companies.

definition of specific policy to address social impacts should also be ranked high. With this respect it is important that lowering the energy cost by tax reductions did not cause a positive stimulus in macroeconomic terms. Similar should hold for direct subsidies. Instead, following the HOP! line of arguments that investments are the key to solve the problems, the less well-off households should better be supported by adapting their technology and behaviour. One suggestion would be a kind-of micro-credits funded by the government and (partially) paid back by the energy savings. The micro-credits would be used e.g. to finance energy efficient appliances (e.g. A++ fridges). A further example from Germany would be energy consulting where an energy consultant directly advices the households how to save energy (e.g. offering a package of energy saving lamps, electricity metering and regulating appliances). In the German case it is estimated that such a package would cost about 60 € but saves 120 € energy cost annually.

If high oil price is one of the critical issues at the global level, climate change is another one. It is important to note that even though investments in oil substitutes can contribute to high global warming, this is not necessarily the case. If, on the one hand, high oil prices would lead to a massive exploitation of unconventional oil resources and the use of coal-based transport fuels (CtL), emissions would rise compared to a reference scenario that is based on conventional oil. On the other hand, a number of technological options can simultaneously decrease oil consumption and lower greenhouse gas emissions. Such options include renewable energies and fuels, and above all, energy savings.

In order to guide investments into low-carbon alternatives, it is important to maintain or even strengthen an active climate policy in times of high oil prices. This can be challenging as there is pressure to reduce “green” taxation in order to dampen the effect of high oil prices on the end user.

The historically singular boost of oil prices together with an increasing spectrum of technological options leads to a restructuring of the energy sector and can push technologies that currently play a minor role. Policy action will have to respect that those innovative technologies might exert important side-effects when entering the market in large quantities, much larger than those expected to be realistic in times of moderate oil prices. Those side-effects of e.g. biofuels or unconventional oil and CtL may put at risk the achievement of overarching EU policy goals, such as stopping the loss of biodiversity or further reducing GHG emissions. Detecting such negative impacts rapidly and ultimately introducing policies to limit them to acceptable levels is a challenge to policy-making that indirectly results from the high oil prices.

Given the importance of energy savings, policies addressing consumer behaviour also play an important role in limiting the effects of high oil prices. Transport is a key sector where policy can play a role to drive positive changes. On the passenger side different mobility choices (e.g. reduced distances travelled, different modal split) require availability of alternatives (public transport, bike lanes, land use). On the freight side, logistics optimisation requires cooperative approach among players and agreed energy footprint metrics.

Thus the plea for investments into new technologies should not conceal the findings of many earlier studies that the conglomerate of major problems (e.g. high oil price, climate change, poverty and hunger) could not only be solved by technology, but also requires behavioural changes. Thus governments should also take care to stimulate behavioural change by increasing awareness of the problems and the solutions, educating the youth accordingly and provide the people the instruments to consider the problems in their daily decisions e.g. by simple tools as labelling energy efficient and CO_2 lean products or by setting the prices right to reflect negative external effects.

6 Conclusions

The overall conclusion is that high oil prices have a significant economic impact in the short-term and may have a limited impact in the medium- and long-term. In general the impact on employment is more severe than on GDP. The effects on investments are critical to shape the final macroeconomic outcome. In the first instance a high oil price will have a negative effect due to increases in costs in many areas of the economy, but this can be offset by the boost of investment induced by the search for alternatives to fossil fuels and for efficiency technologies. The key messages derived from the HOP! scenario analyses can be summarized as:

- GDP and employment are negatively affected during the peak period of the oil price increase with employment being reduced significantly stronger.
- The impact after the peak period of oil price increase strongly depends on the mechanisms kicked-off by the price increase. Mitigating the impacts by investing into energy efficiency and alternatives could even lead to a positive economic impact in the medium to long-term, while a world recession or a situation with insufficient energy supply could multiply the negative impacts by factors of 5 to 10.
- A rapid price increase over a few years would have different effects in the short and the medium-term. In the short term, the lack of response time due to high inertia of the industry hampers the mobilisation of alternative sources, leading to a more profound impact on GDP growth. In the medium term, a rapid price increase, if not reaching the extreme levels of 600-800 €$_{2000}$/barrel, would be advantageous compared with a smooth price increase since the shock most effectively triggers the compensating mechanisms in particular the investments into energy efficiency and alternatives. This presupposes that investors expect a sustained oil price increase and not a temporary one, and that governments do not take actions to lower the fossil fuel prices artificially distorting the price signal.
- The most relevant impact to counterbalance the negative impact of high oil prices are investments into energy efficiency and alternatives, as first they directly provide a positive stimulus for the economy as part of final demand and as second they indirectly help to reduce the vulnerability of the economy to oil price increases by reducing energy demand, energy cost and imports of fossil energy.
- In terms of impacts on employment the most important issue is how the energy sector can forward the price increase to other sectors. Full forwarding of the price increase causes the strong losses observed for employment and boosts the profits of the vertically integrated large energy companies. Limiting price forwarding, either indirectly by the energy companies reinvesting their profits into efficiency technologies and alternatives that are produced domestically in the EU or directly by the government taxing the profits and creating investment incentives into efficiency technologies and alternatives by subsidies, would strongly reduce the negative impacts on employment.

Overall, the conclusion is that oil scarcity and oil price shocks can have significant negative impacts on the EU – but they need not, if the EU prepares itself adequately. Looking at the fast decreasing mid-term oil production forecast, the EU should have enough reasons to prepare.

7 Glossary

Conventional oil is defined as crude oil and natural gas liquids produced from underground reservoirs by means of conventional wells. This category includes oil produced from deep-water fields and natural bitumen. Conventional oil includes liquid hydrocarbons of light and medium gravity and viscosity, occurring in porous and permeable reservoirs. If such hydrocarbons require enhanced recovery techniques, they are considered to be unconventional oil.

Crude oil: a mixture of hydrocarbons that exists in a liquid phase in natural underground reservoirs and remains liquid at atmospheric pressure after passing through surface separating facilities. Production volumes reported as crude oil include:

- liquids technically defined as crude oil;
- small amounts of hydrocarbons that exist in the gaseous phase in natural underground reservoirs, but which are liquid at atmospheric pressure after being recovered from oil well (casing head) gas in lease separators;
- small amounts of non-hydrocarbons produced with the oil.

Derived energy sources are produced from the primary energy sources by converting them into other forms of energy for end use consumption. Examples are electricity, petroleum products and heat.

Energy conservation is usually taken to refer just to the energy saving on the demand side.

Energy efficiency is a measure of the overall efficiency of providing energy services, ie, the efficiency with which energy is produced from primary resources, transformed into useful forms, delivered to end users and consumers.

Energy intensity is a statistical measure which relates energy consumption (eg, gross inland consumption) to the level of economic activity (e.g. GDP). Thus trends in energy intensity reflect changes in the amount of energy needed to produce a unit of economic output. This indicator is dependent on the efficiency of using energy for the various energy services required (eg, light, heat, power) and the structure of economic and social activities (eg, a high proportion of heavy industries consuming large amounts of fuel being used at comparably low efficiency, versus a service-oriented society).

Estimated Ultimately Recoverable (EUR) oil. This is oil that is infeasible to recover for reasons that are either economic or technical. This category also includes yet-to-be-found oil.

Final energy consumption is the consumption of primary and derived energy by the end-use sectors: mainly industry, transport, and households and services/commerce. Final energy consumption is always lower than gross inland consumption since it does not include the energy losses in conversion and distribution..

Gross energy consumption corresponds to the total primary energy consumed, including quantities delivered to marine bunkers.

Gross inland consumption (or Total Primary Energy Supply (TPES)) is indigenous primary production, plus imports, minus exports and international marine bunkers, and plus/minus stock changes of primary energy.

Gross production: the total flow of natural gas from oil and gas reservoirs of associated-dissolved and non-associated gas.

Marketed production: corresponds to gross production, minus the volumes of gas flared or re-injected into fields, minus the shrinkage.

Natural gas: a mixture of hydrocarbon compounds and small quantities of various non-hydrocarbons existing in the gaseous phase or in solution with oil in natural underground reservoirs at reservoir conditions.

Natural gas liquids (NGLs): those reservoir gases liquefied at the surface in lease separators, field facilities or gas processing plants. NGLs consist of field condensates and natural gas plant products such as ethane, pentane, propane, butane and natural gasoline.

Non-Conventional oil (BP): Oil from coal, oil shale, oil sands, tar sands, bitumen, heavy and extra heavy oil, deep water oil, polar oil and natural gas condensates.

Non-conventional oil: includes oil shales, oil sands-based extra-heavy oil and derivatives such as synthetic crude products.

Primary energy sources include non-renewable fossil fuels (mainly solid fuels, crude oil, natural gas), nuclear power and renewables such as hydropower, geothermal, biomass and solar energy. Combined together, they provide a measure of primary energy production. Primary sources may be divided into two further categories in respect of their impact on global warming: carbon-intensive (solid fuels, oil, gas) and low- or zero-carbon (wind, solar, biomass, hydropower, geothermal and nuclear).

Proven Reserves (BP) defines “the estimated quantities of oil which geological and engineering data demonstrate with reasonable certainty to be recoverable in future years from known reservoirs under current economic and operating conditions”.

8 References

Aleklett K (2008): *Peak oil and the evolving strategies of oil importing and exporting countries: Facing the Hard Truth about an Import Decline for the OECD Countries*. In OECD/ITF: *Oil Dependence: Is transport running out of affordable fuel*?, Paris.

Allen, M. (2005): *Oil Market Developments and Issues*. International Monetary Fund.

Arnold, S.; Hunt, A.; Markandya, A. (2007): *National and EU level estimates of energy supply externalities.* Deliverable D5.1 of CASES project (Cost Assessment of Sustainable Energy Systems) funded by the European Commission.

Awerbuch, S.; Sauter, R. (2006): *Exploiting the oil-GDP effect to support renewables deployment*. Energy Policy 34. Elsevier

Barrel, R. and Pomerantz, O. (2008): *Oil Prices and World Inflation, National Institute Economic Review: National Institute of Economic and Social Research*.

Blanchard, O. and Gali, J. (2007): *The Macroeconomic Effects of Oil Price Shocks: Why are the 2000s so different from the 1970s?*, Working Paper Series: Massachusetts Institute of Technology.

Boerrigter, H. (2006): *Economy of Biomass-to-liquids (BTL) plants: an engineering assessment*. ECN-C-06-019.

BP (2008): BP p.l.c. *Group results: First quarter 2008*. London.

Bradley, R. et al. (2006): *Oil and Gas Industry Investments in alternative Energy, Frontier Hydrocarbons and Alternative End-Use technologies*, http://www.api.org/aboutoilgas/upload/API_EMERGING_ENERGY_FINAL5_2.pdf

Brown, M. (2001): *Market failures and barriers as a basis for clean energy policies*, Energy Policy: Elsevier, 1197-1207.

Dées, S. et al. (2008): *Assessing the Factors behind oil price changes*, Working Paper Series, Frankfurt: European Central Bank.

DESTATIS (2008a): *Volkswirtschaftliche Gesamtrechnungen*. Fachserie 18 Reihe 2. https://www-ec.destatis.de/csp/shop/sfg/bpm.html.cms.cBroker.cls?cmspath=struktur,vollanzeige.csp&ID=1020954.

DESTATIS (2008b): Press Release 218 in 2008: 1. Quartal 2008: *Anstieg des Außenhandels mit Russland.* http://www.destatis.de/jetspeed/portal/cms/Sites/destatis/Internet/DE /Presse/pm /2008/06/PD08__218__51,templateId=renderPrint.psml.

Deurwaarder, E.P., Lensink, S.M., Londo, H.M. (2007): *BioTrans biofuels data.* Appendix to 'Use of BioTrans in Refuel'; functional and technical description Refuel deliverable D10b. REFUEL project.

E.On (2007): *E.On Annual Report 2007*, http://www.eon.com/en/downloads /EON_GB07_US_komplett_v2.pdf.

EC COM (2007)2: *Limiting Global Climate Change to 2 degrees Celsius: The way ahead for 2020 and beyond*. Communication of the European Commission to the Council, the EU parliament and the Committee of the Regions, Brussels.

EEA (2006): *How much bioenergy can Europe produce without harming the environment?* EEA Report No 7/2006

Exxon (1-5-2008): *Exxon Mobile Announces First Quarter Results,* http://www.exxonmobil.com/Corporate/Files/news_release_earnings1q08.pdf.

Fenton, D., (2004): *The Economic Impact of High Oil Prices*. RBS Royal Bank of Scotland, Edinburgh.

Fischer, G., Hizsnyik, E., Prieler, S., van Velthuizen, H. (2007): *Assessment of biomass potentials for biofuel feedstock production in Europe: Methodology and results.* REFUEL project. Deliverable D6: Methodology and assessment of biomass potentials in EU27+ under alternative future scenarios

Fortune Magazine (2008): *Fortune 500 - Our annual ranking of the world's largest corporations*. http://money.cnn.com/magazines/fortune/global500/2008/index.html.

Foxon, T.J. (2003): *Inducing innovation for a low-carbon future: drivers, barriers and policies*. The Carbon Trust, London.

Hamelinck, C.N., Faaij, A.P.C. (2006): *Outlook for advanced biofuels,* Energy Policy, Vol.34, 17, pp.3268-3283, 2006.

Huntington, G., (2004): *Shares, gaps and the economies response to oil disruptions*. Energy Economics 26. Elsevier.

IEA (10-7-2008): *Oil Market Report.* International Energy Agency, http://omrpublic.iea.org/currentissues/full.pdf.

IEA (2004): *Analysis of the Impact of High Oil Prices on the Global Economy*. International Energy Agency, Paris.

IEA (2008): *Energy Technology Perspectives: OECD*. International Energy Agency, Paris.

IMF (2005): *World Economic Outlook 2005*. Chapter 4: Will the oil market continue to be tight?

IPCC (2007): *Climate Change 2007: Synthesis Report*. Intergovernmental Panel on Climate Change, Vienna, Valencia.

Jesse JH, van der Linde C (2008): *Oil turbulence in the next decade – An Essay on High Oil Prices in a Supply-constrained World*. Netherlands Institute of International Relations, The Hague.

Jiménez-Rodríguez, R., Sánchez, M. (2004): *Oil price shocks and real GDP growth, Empirical evicence for some OECD Countries*. European Central Bank. Working Paper Series. No. 362

Jochem E et al. (2008): *Investitionen für ein klimafreundliches Deutschland*. Report on Behalf of the German Ministry of Environment and Nuclear Safety, Karlsruhe, Berlin. http://www.kliminvest.net/download/endbericht.pdf.

Kilian, L. et al. (2007): *Oil shocks and external balances*, IMW Working Paper: International Monetary Fund.

Krail M, Schade W, Fiorello D, Fermi F, Martino A, Christidis P, Schade B, Purwanto J, Helfrich N, Scholz A, Kraft M (2007): *Outlook for Global Transport and Energy Demand*. Deliverable 3 of TRIAS (Sustainability Impact Assessment of Strategies Integrating Transport, Technology and Energy Scenarios). Funded by European Commission 6th RTD Programme. Karlsruhe, Germany.

Laitner S, Bernow S, De Cicco J (1998): *Employment and other macroeconomic benefits of an innovation-led climate strategy for the United States*. In: Energy Policy 26. Elsevier.

Lovins A, Datta EK, Bustnes OE, Koomey JG, Glasgow NJ (2004): *Winning the Oil Endgame – Innovation for Profits, Jobs, and Security*. Earthscan, London.

OECD, ITF (2008): *Oil dependence: Is transport running out of affordable fuel?* Organisation for Economic Co-operation and Development, International Transport Forum, Paris.

Pellény, G., et al. (2008): *Economic and Trade Policy Impacts of Sustained High Oil Prices,* WIIW Research Report, Vienna: The Vienna Institute for International Economic Studies.

Pirog, R. (4-4-2008): *CRS Report for Congress: Oil Industry Profit Review 2007*: Congressional Research Service.

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 W (2005): *Strategic Sustainability Analysis: Concept and application for the assessment of European Transport Policy*. Nomos Verlag, Baden-Baden.

Schade W, Helfrich N, Wietschel M, Krail M, Scholz A, Kraft M, Fiorello D, Fermi F, Martino A, Schade B, Purwanto J, Wiesenthal T, Christidis P (2008): *Alternative Pathways for Transport, Technology and Energy to promote sustainability in the EU*. Deliverable 4 of TRIAS (Sustainability Impact Assessment of Strategies Integrating Transport, Technology and Energy Scenarios). Funded by European Commission 6th RTD Programme. Karlsruhe, Germany.

Segal, P. (2007): *Why do oil price shocks no longer shock?*, Oxford: Oxford Institute for Energy Studies.

Stewart, M. (1990): *The economic impact of higher oil prices*. NERA National Economic Research Associates.

Thraen, D. et al. (2006): *Sustainable Strategies for Biomass Use in the European Context – Analysis in the charged debate on national guidelines and the competition between solid, liquid and gaseous biofuels*, IE-Report.

USGS (2000): U.S. *Geological Survey World Petroleum Assessment 2000 – Description and Results*. USGS World Energy Assessment Team, Denver.

VIEWLS (2005) *Environmental and economic performance of biofuels*, Report for the project VIEWLS (Clear Views on Clean Fuels), April 2005.

Zittel, W, Schindler, J. (2007): *Crude Oil Supply Outlook.* Report to the Energy Watch Group, October 2007.