Links between energy and food markets

A preliminary assessment

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This report addresses the links between energy and food markets, and the long-term trends and large short-term fluctuations they have undergone. The ways in which these markets are related and which feedback mechanisms must be taken into account in scenario analyses were investigated. On the basis of international studies and prognoses, three links connecting energy and food markets were identified. The first link is formed by the common drivers on the demand side, namely demographic and economic developments, the second link is related to the energy costs of agricultural and food production and distribution, and the third link comprises the role of agriculture as a producer of energy.

Dit rapport is gericht op de verbanden tussen de energie- en de voedselmarkt. Beide markten hebben te maken gehad met trends op de lange termijn en hevige schommelingen op de korte termijn. In hoeverre zijn deze markten aan elkaar gerelateerd en welke feedbackmechanismen moeten worden betrokken bij scenarioanalyses? Op basis van internationale studies en prognoses zijn er drie verbanden aan te wijzen tussen de energie- en de voedselmarkt. Het eerste verband betreft gemeenschappelijke waardestuwers aan de vraagzijde, namelijk demografische en economische ontwikkelingen. Het tweede verband heeft betrekking op de energiekosten van de landbouw- en voedselproductie en -distributie. Het derde verband betreft de rol van landbouw als energieproducent.

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Preface

The recent world price crisis has drawn attention to the energy and agrifood markets and their interrelationships. Prices of agricultural products and energy commodities (e.g. crude oil) increased rapidly in 2007-2008, reaching average maximums in mid 2008. They dropped dramatically during the second half of 2008, and returned to a smoother but upward trend in the first quarter of 2009. The global economic recession contributed to the drop in energy and food prices, but it remains to be seen whether the combination of factors that drove energy and food prices to the high levels of 2007/2008 will continue affecting them in the medium/long term and, moreover, how prices in these two markets are linked.

This report was compiled upon the request of the Netherlands Ministry of Agriculture, Nature and Food Quality. It addresses the interrelations between the energy and food markets based on a review of existing studies and prognoses for these two markets. The research focused on identifying the main forces driving the demand for and the supply of energy and food, and the interactions between the food and energy markets. The study is enhanced with a quantitative simulation of future agricultural price developments in two alternative oil price scenarios.

For the elaboration of this report, we are grateful for the support we received from our colleagues (in particular Ignacio Pérez Domínguez and David Verhoog) and for the comments made by the energy expert Coby van der Linde (Clingendael International Energy Program). We also want to thank the members of the committee that guided the project on behalf of the ministry, in particular Sicco Stortelder, Bernard Cino, Krijn Poppe and Hannah Koutstaal.

Prof. R.B.M. Huirne
Director General LEI Wageningen UR

Summary

This report addresses the links between the energy and food sectors, and more specifically the ways in which these markets are related and which feedback mechanisms must be taken into account in scenario analyses. It is based on a review of existing studies and prognoses and includes a quantitative impact assessment. The research focused on identifying the main forces driving the demand for and supply of energy and food, and the links between the energy and food markets. Three such links are described in this report.

The first link is formed by the common factors that drive energy and food demand: both population and economic development are leading to large demand increases in both energy and food markets. Population and gross domestic product (GDP) are expected to grow in the coming decades, especially in emerging and developing economies. This growth will exert pressure on the demand for energy and food. On the supply side, in both energy and food markets, supply takes some time to adjust, and capacity adjustments highly depend on investments. This is an indirect link, but it at least partly explains the similar price developments in recent years. The central question for the future is whether the growing population and growing GDP will continue to drive up energy and food prices in the very long term. It is possible that food prices will continue to decline in the long term in real terms.

The second link is related to energy being an input cost of agricultural and food production. As farmers lack the ability in the short term to translate higher input prices into selling prices, increased input costs (e.g. of energy) would affect farmer incomes and production decisions by constraining future production. Higher input costs would probably lead to production decreases and consequently to higher commodity prices. But higher commodity prices would provide farmers with the incentive to increase production, which means that the initial price increase would be partly mitigated. Due to the high volatility of input and market prices, monitoring the input/output price relation in agricultural production seems to be a crucial issue. Beyond the farm gate, the food processing sector has a larger capacity to translate higher input prices into higher consumer prices. Therefore, higher energy costs can be more easily translated into higher consumer prices in the food chain (i.e. food processing, transport, storage in acclimatised facilities). The question is whether this factor would increase food prices permanently if higher energy prices expectations

turn out to be correct. Energy efficiency and productivity increases in agricultural production can soften the impact of higher energy prices. If the rise in crude oil prices continues, this will shift agricultural commodity prices to higher levels. It is not clear whether this would slow down the long-term decline in real prices or change the downward trend permanently.

The third link is related to energy production by agriculture, for example, biofuels production and policies that provides incentives to increase biofuels production. First-generation biofuels are produced from agricultural commodities, which creates distortions in the agricultural and food markets and more negative environmental impacts than expected. Expectations are now directed to second-generation biofuels, which are produced through the conversion of cellulosic material, agricultural and forest residues or other non-food crops into liquid fuels. With the current biofuel policies in place, biofuel production is expected to increase in the coming decades. The increasing biofuel production will exert further pressure on the demand for agricultural commodities and, therefore, on their prices. Moreover, both first- and second-generation biofuels are expected to cause land-use changes and competition for land between food or fuel crops is expected to continue.

The long-term price projections for agricultural commodities presented in this study are the results of simulation experiments carried out with the LEITAP2 model, which is based on the GTAP general equilibrium model. The results show that the long-term downward trend in real prices will continue in the agricultural sector for most commodities in the two crude oil price cases considered (i.e. USD50 and USD90 in real prices). Until 2030 there is a difference in agricultural prices from less than 10% between a high and low oil price scenario, and real prices are projected to continue in both cases the long-term downward trend, with the exception of vegetable oils. The real prices of vegetable oils in the high oil price scenario are projected to increase from 2014, probably because the higher oil prices provide incentives to increase biofuel production. In nominal prices, by considering a 1.5% annual inflation rate, these results would be in line with the OECD FAO projections. It is important to mention that the results presented in this study are long-term results and that such projections would not have predicted the recent price crisis. The results are also very dependent on assumptions about economic and population developments, biofuels share, technology developments in the agricultural sector and productivity growth. A greater demand for biofuel crops or lower productivity growth could drive the prices upwards.

This study provides a preliminary assessment of the links between energy markets and food markets. It shows that the effects of the links in the short term are quite different from those in the long term. More research is needed in order to gain a better understanding of the complexities and interrelations between the sectors. An issue for further research is the impacts of supply constraints, such as climate change, land availability, water and phosphates availability, and government policies. To enhance energy efficiency a better insight is needed into the energy consumption at the various stages of the food production and distribution chain. In order to assess price effects of short-term changes in demand and supply, the simulation model should be extended. Finally, the issue of commodity speculation requires more attention. Commodity speculation affects both energy and agricultural markets and has probably contributed to the price boom of recent years. Further economic analysis of the effects of speculation and a discussion on the options for preventing 'excessive' speculation would add to this study.

Samenvatting

Dit rapport is gericht op de verbanden tussen de energie- en de voedselsector: in hoeverre zijn deze markten aan elkaar gerelateerd en welke feedbackmechanismen moeten worden betrokken bij prognosestudies? Het rapport gaat uit van een beoordeling van bestaande studies en prognoses, waaraan vervolgens een kwantitatieve effectbeoordeling is toegevoegd. De beoordeling is gericht op het vaststellen van de belangrijkste factoren achter vraag en aanbod van energie en voedsel en op het in kaart brengen van de verbanden tussen deze twee markten. Er zijn drie verbanden vastgesteld tussen de landbouw- en de energiemarkt.

Het eerste verband betreft de gemeenschappelijke factoren die de vraag naar energie en voedsel bepalen. Daarbij gaat het onder meer om de ontwikkeling van de bevolking en de economie, factoren die kunnen leiden tot grote verschuivingen in de vraag op zowel de energie- als de voedselmarkt. De bevolking en het bruto binnenlands product (BBP) zullen de komende decennia naar verwachting groeien, met name in opkomende en ontwikkelende economieën. Door deze groei wordt de druk op de vraag naar energie en voedsel steeds groter. Aan de aanbodzijde zal zowel op de energie- als op de voedselmarkt het aanbod enige tijd nodig hebben om zich aan te passen. De aanpassingen in capaciteit zullen in grote mate afhangen van investeringen. Hierbij gaat het om een indirect verband, maar het verklaart in ieder geval ten dele de gelijk opgaande prijsontwikkelingen van de afgelopen jaren. De centrale vraag voor de toekomst is of de groeiende bevolking en het BBP op de zeer lange termijn de energie- en voedselprijzen omhoog zullen blijven stuwen. Een andere mogelijkheid is dat de voedselprijzen op de lange termijn in reële zin blijven dalen.

Het tweede verband is gelegen in het feit dat energie een input en dus een kostenbron vormt voor de landbouw en de voedselproductie. Omdat landbouwbedrijven op de korte termijn niet de capaciteit hebben om de hogere inputprijzen om te zetten naar verkoopprijzen, zijn de wijzigingen in de prijzen van input (dat wil zeggen: energie) van invloed op de inkomsten en productiebeslissingen van landbouwbedrijven, namelijk in de zin dat ze de toekomstige productie beperken. Hogere inputkosten leiden waarschijnlijk tot een afname van de productie en dus tot hogere grondstofprijzen. De hogere opbrengstprijzen zullen echter voor landbouwbedrijven weer een stimulans vormen om de productie te verhogen, wat betekent dat de aanvankelijke prijsstijging ten dele wordt ingeperkt. In verband met de grote schommelingen van de input- en marktprijzen lijkt het van cruciaal belang om de relatie tussen input- en outputprijzen van de landbouwproductie bij te houden. Buiten de grenzen van het boerenbedrijf heeft de voedselverwerkende sector veel meer mogelijkheden om de hogere inputprijzen om te zetten naar hogere consumentenprijzen. Daardoor kunnen de hogere energiekosten makkelijker worden vertaald naar hogere consumentenprijzen in de voedselketen: voedselverwerking, transport en opslag in geacclimatiseerde faciliteiten. Als de verwachtingen omtrent hogere energieprijzen uitkomen, doet deze factor de voedselprijs dan blijvend stijgen? Een grotere energie-efficiëntie en -productiviteit in de landbouwproductie kan het effect van de hogere energieprijzen verzachten. Als de stijging van de aardolieprijzen in de toekomst doorzet, zullen de grondstofprijzen voor de landbouw naar een hoger niveau worden getild. Het is niet duidelijk of dit de afname op de lange termijn van de reële prijzen zal vertragen dan wel de dalende trend blijvend zal veranderen.

Het derde verband betreft de energieproductie door de landbouw, onder meer de productie van biobrandstoffen en beleidsmaatregelen die een toenemende productie van biobrandstoffen aanmoedigen. De eerste generatie biobrandstoffen wordt geproduceerd uit landbouwgrondstoffen, wat gepaard gaat met verstoringen van de landbouw- en voedselmarkt en een negatiever effect op het milieu dan verwacht. De ogen zijn nu gericht op een tweede generatie biobrandstoffen op basis van de conversie van cellulosehoudend materiaal naar vloeibare brandstoffen. Uitgaande van het huidige beleid inzake biobrandstoffen zal de productie van biobrandstoffen naar verwachting de komende decennia groeien. De groeiende biobrandstoffenproductie oefent verdere druk uit op de vraag naar landbouwgrondstoffen en dus op de prijzen. Daar komt bij dat naar verwachting zowel de eerste als de tweede generatie biobrandstoffen tot wijzigingen in het landgebruik zal leiden en de concurrentie tussen grondgebruik voor voedsel en brandstofgewassen zal blijven bestaan.

De in deze studie gepresenteerde prijsprognoses op de lange termijn voor landbouwgrondstoffen zijn het resultaat van de simulatie-experimenten die zijn verricht met behulp van het LEITAP2-model, dat uitgaat van het algemene evenwichtmodel GTAP. Uit de resultaten blijkt dat in de twee geteste gevallen van hoge en lage aardolieprijzen (respectievelijk USD50 en USD90 in reële prijzen) de dalende trend op de lange termijn van de reële prijzen in de landbouwsector zal aanhouden voor de meeste grondstoffen. Tot 2030 is er een verschil in de landbouwprijzen van minder dan 10% tussen de scenario's van hoge en lage aardolieprijzen en zullen de reële prijzen naar verwachting in beide gevallen de dalende trend op de lange termijn voortzetten, met uitzondering van plantaardige oliën. De reële prijzen van plantaardige oliën zullen in het scenario van hoge olieprijzen naar verwachting vanaf 2014 gaan stijgen, waarschijnlijk omdat de hogere olieprijzen een stimulans zullen vormen voor de biobrandstoffenproductie. Als wij uitgaan van een jaarlijks inflatietempo van 1,5%, komen deze resultaten bij nominale prijzen overeen met de vooruitzichten van de OESO-FAO. Vermeld moet worden dat de resultaten van deze studie de lange termijn betreffen en dat bij dergelijke prognoses geen rekening wordt gehouden met de huidige prijzencrisis. Deze resultaten zijn daarnaast ook zeer afhankelijk van de consumptie: ontwikkelingen ten aanzien van economie en populatie, het aandeel aan biobrandstoffen, technologische ontwikkelingen in de landbouw en de groei van de productiviteit. Een grotere vraag naar gewassen voor biobrandstoffen of een lagere productiviteitsgroei kan de prijzen omhoog stuwen.

Deze studie heeft geleid tot een voorlopige evaluatie van de verbanden tussen de energie- en de voedselmarkt. Aangetoond is dat de uitwerking van deze verbanden heel anders is op de korte termijn dan op de lange termijn. Er is nader onderzoek vereist om tot een beter inzicht te komen in de specifieke complicaties van en onderlinge relaties tussen deze sectoren. Wat bijvoorbeeld nog nader onderzoek vereist, is de uitwerking van aanbodbeperkingen zoals klimaatverandering, beschikbaarheid van land, water en fosfaten, en overheidsbeleid. Om de energie-efficiëntie te vergroten is meer inzicht nodig in de energieconsumptie gedurende de verschillende fasen van de voedselproductie- en distributieketen. En om de prijseffecten van korte termijn veranderingen in vraag en aanbod te beoordelen, zal het simulatiemodel moeten worden uitgebreid. Tot slot zal speciale aandacht moeten worden besteed aan grondstoffenspeculatie..Nader economisch onderzoek naar de effecten van speculatie, alsmede een bespreking van de mogelijkheden voor het voorkomen van 'buitensporige speculatie', zouden aan deze studie kunnen bijdragen.

1 Introduction

Concerns about energy and food security have become important items on political agendas. Both food and energy (i.e. crude oil) prices increased rapidly from 2003, reaching their peak in mid 2008. They then declined sharply until the first quarter of 2009, During the last months of 2009, they started on a smooth but significant upward trend.

The Netherlands Ministry of Agriculture, Nature and Food Quality asked LEI to investigate the interrelations between energy and food markets, and more specifically the ways in which these markets are related and which feedback mechanisms must be taken into account in scenario studies. The research was guided by the following research questions:

a. What are the feedback mechanisms between energy markets and food markets, and what effects do the two markets have on each other? How do the variables - such as: price of oil; prices of oilseeds, feed, cereals (maize) and sugar; biomass quantity and price; direct energy use in primary production and processing; indirect energy use (use of fertilisers and other inputs); prices of food for the consumer at retail level; the dollar/euro exchange rate - interact?

b. What are the qualitative and quantitive effects on the variables mentioned under question a. of an oil price in a low price scenario of USD50/barrel and in a high price scenario of USD90/barrel?

To answer these questions, we reviewed a number of studies and prognoses that analyse the driving forces of energy and food markets and recent and future price developments. In this study, we explain the issues and mechanisms that emerge from the complex interaction between energy and food, as well as some environmental considerations.

The global energy and food systems are very complex: there are millions of producers and products on the one hand, and billions of consumers on the other, making it impossible to analyse all of the interrelations between the two systems. A detailed analysis of the value chains of energy and food (including processing, storage and transportation) is not within the scope of this study.

Liquid fuels currently form the most visible linkage between energy markets and food markets.

In Sections 2 and 3, the energy and food markets are described separately. In Section 4, the interplay of the driving forces between energy and food markets is examined, thus providing a clearer picture of the mechanisms affecting energy and food prices. In Section 5, the analysis is enhanced by presenting the results of a simulation of future food price developments under alternative high and low oil price scenarios. The main conclusions of the study are presented in Section 6.

2 Energy markets

2.1 Introduction

The focus in this section is on the crude oil market, as in terms of quantity crude oil is one of the most important sources of energy used for meeting the energy demand, especially in the transport sector (61% in 2007). According to the most recent world energy outlooks, crude oil will remain the principal source at least until 2030. However, we also take into consideration other energy sources. We start by giving a brief description of the various energy sources and types of energy; this is followed by a brief history of energy prices. We then provide insight into the main drivers of future energy prices by presenting an analysis of demand and supply.

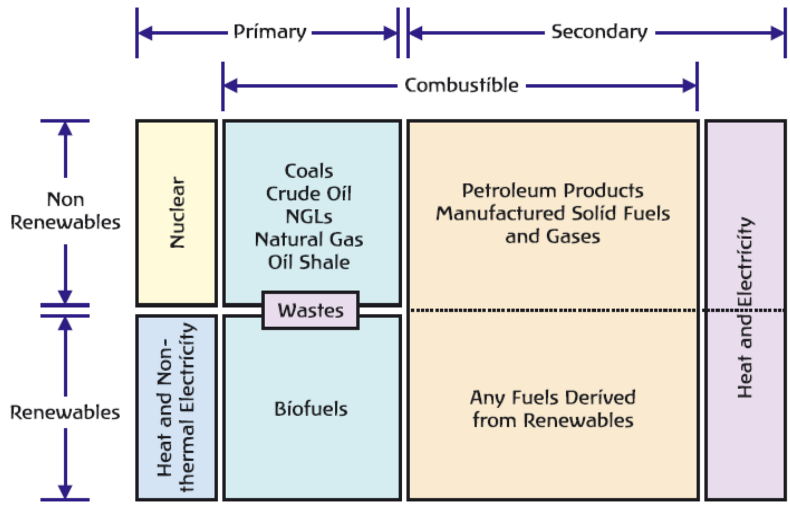
Energy commodities

The Energy Statistics Manual (OECD-IEA, 2005) defines primary and secondary energy commodities. Primary energy commodities are those extracted or captured directly from natural resources, such as crude oil, hard coal, natural gas. Secondary energy commodities are produced from primary commodities (electricity generated by burning fuel oil is an example of secondary energy). Both electricity and heat may be produced in a primary or secondary form.

Primary energy commodities can be divided into non-renewable energy commodities (fossil fuels, uranium) and renewable energy commodities. According to the definition used by the Energy Information Administration (EIA), energy sources are considered non-renewable if they cannot be regenerated in a short period of time (for example fossil fuels, which were formed from the buried remains of plants and animals that lived millions of years ago). On the other hand, renewable energy sources such as solar and wind can be regenerated naturally in a short period of time and can be sustained indefinitely. The four non-renewable energy sources used most often are (EIA): oil and petroleum products (including petrol, diesel fuel, heating oil, propane), natural gas, coal and uranium (nuclear energy). The five renewable sources used most often are (EIA): biomass (including wood and wood waste, municipal solid waste, landfill gas, biogas, ethanol and biodiesel), water (hydropower), geothermal, wind, and solar. Wind and water energy are mainly used for producing electricity; geothermal and solar energy can be used for producing both heat and electricity.

Figure 2.1 presents the various energy sources and their classification as primary/secondary sources, as combustibles and as renewable/non-renewable sources.

Figure 2.1 Terminology for Energy Commodities



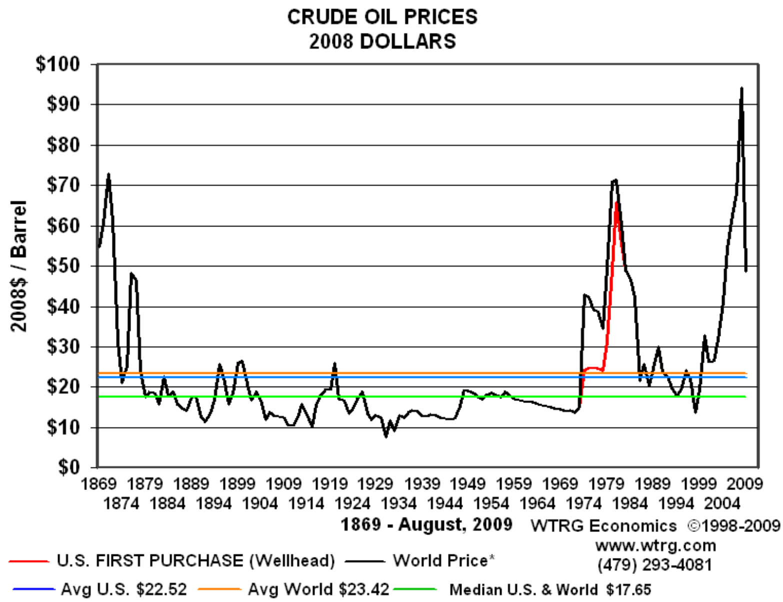
Source: Energy Statistics Manual, OECD-IEA (2005).

2.2 History of energy prices

2.2.1 Crude oil prices

The oil market underwent a long period of declining real oil prices until the 1960s (see figure 2.2). After 1970 the main oil producing countries, which had organised themselves in OPEC in the 1960s, became more powerful because the cheapest oil fields were in their hands. The OPEC market share increased from less than 30% in 1960 to more than 50% in 1973.

Figure 2.2 **Crude oil real prices (2008 dollars)**



Source: WTRG Economics.

The oil boycott in the context of the Israel-Arab conflict (the Yom Kippur War of 1973/74) reduced crude oil production by only 7%, but showed that oil prices are extremely sensitive to supply interruptions by OPEC countries. This is caused by the large dependence of the world economy on oil, a sector in which both the price elasticity of demand and the price elasticity of supply are very low in the short term.

The feeling that oil producers had been abused by the oil producing companies, coupled with political turmoil and the awareness of market power, created an opportunity for enormous increases in the price of crude oil. Given the relatively high production costs of crude oil outside OPEC countries, an oil price of around USD20 per barrel could continue for a long period of time. But the price of oil increased to more than USD40 per barrel, generating both enormous investments in oil fields outside OPEC and a lot of investment in energy saving measures (e.g. insulating houses and buying energy saving cars). It is interesting that in this period (1980s), a lot of people predicted that the price of crude oil in 2000 would be more than USD100 per barrel.

Crude oil prices are very sensitive to geopolitical factors, such as wars, political instability or climatic disasters, which have an enormous impact on the oil supply (see figure 2.3).

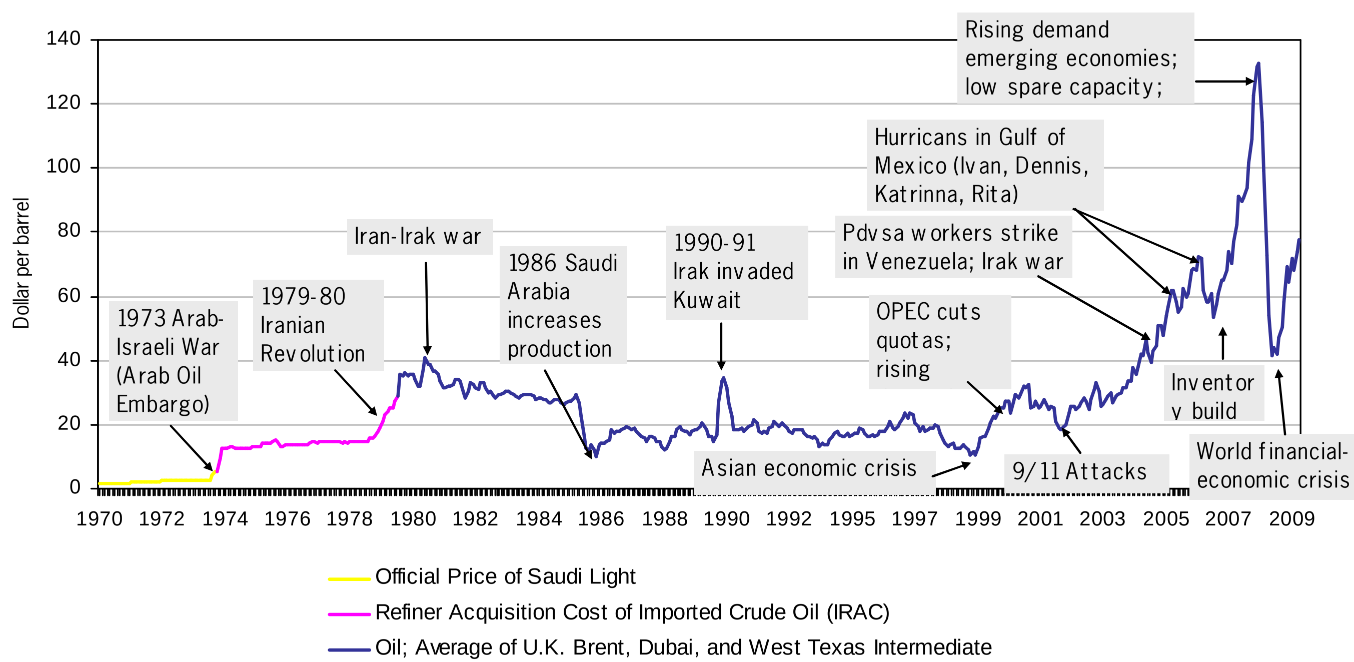
During the first half of the 1980s, OPEC tried to stabilise the market price of oil, but this was at the cost of their market share, which halved during this period. This power game on the part of OPEC ended in 1986, when oil prices halved in terms of dollars. But also the exchange rate of the dollar halved in that year compared with the European currencies, so that the price of crude oil was reduced by 75% for European countries.

The period after 1986 was a period of relatively stable prices (around USD20/barrel), with the exception of a significant price increase in 1990-1991 as a result of the Iraq war (Iraq invaded Kuwait). The predictions made around 1980 for 2000 prices had turned to be incorrect, and there was much more flexibility in the long term in the oil market. OPEC production capacity was higher than production, while their market share was increasing. A country like Saudi Arabia was able to stabilise the crude oil price by adjusting its production to world crude oil demand. But at the end of the 1990s, the Asian crises generated an unexpected decrease in crude oil demand growth that was not corrected by reduced production in OPEC countries. The low oil prices (roughly USD10/barrel) reduced investment in crude oil exploration and extraction technologies, and thus generated a smaller production capacity than would have been the case with higher crude oil prices.

Since 2004, increasing and underestimated crude oil demand, especially from emerging economies like China and India, geopolitical issues across the world (especially in Middle Eastern region) and weather-related supply shocks have contributed strongly to the continued increase in crude oil prices (Asif et al., 2005), which reached a peak in July 2008 (USD132.50/barrel).[1] In summary, the crude oil market shows in the short term a very inelastic supply and demand. Only active policies - for example that pursued by Saudi Arabia between 1986 and 1995 - can stabilise a market in such a situation. But reserves to stabilise the market were not available at the start of the 21st century. As a consequence, an unexpected increase in the demand for energy (especially China and India were growing much faster than expected), combined with too low investment in the past, climatic disasters and wars, led to an insufficient supply and an enormous increase in crude oil prices. The inflexibility

[1] Oil price: Average of UK Brent, Dubai, and West Texas Intermediate; data from IMF.

Figure 2.3 **Historical price trend 1970-2009 for crude oil (nominal dollars per barrel)**

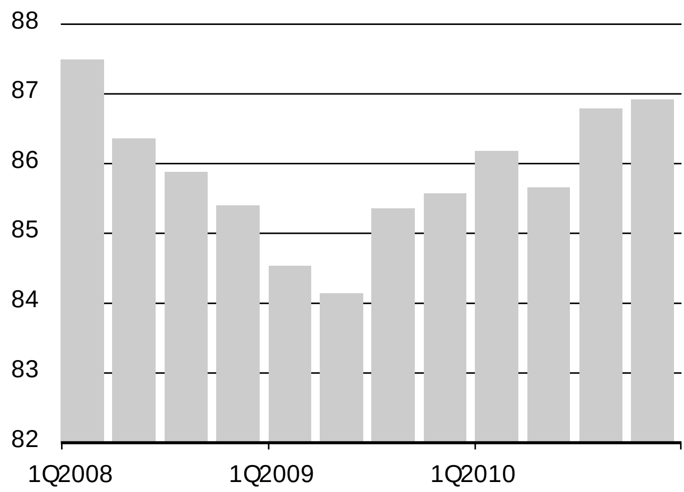


Source: Based on IMF data (www.imf.org) and EIA data.

of supply is therefore a combination of technical, economic and geopolitical factors (Van der Linde, 2009). Speculation added to this tendency: the very high price levels again generated stories that oil prices would rise to very high levels. But these stories generated new investment opportunities, making a self-denying prophecy of these predictions. Higher oil prices should generate incentives to make further investments in exploration and research in extraction technologies, as well as incentives to carry out research into energy substitutes that have higher production costs.

After July 2008, crude oil prices dropped until they reached USD41.5[1] per barrel in December 2008. After that, a new upward price trend started (the oil price in November 2009 was USD77.5/barrel[1]). The decrease in price can be explained by the impact of the world financial and economic crisis that started in 2008. The world demand for oil entered a period of decline in the second quarter of 2008 (see figure 2.4).

Figure 2.4 **World oil demand (mb/d)**



Source: Oil market report - International energy agency (Dec 2009) (www.oilmarketreport.org).

The suddenly decline in demand combined with no supply adjustments in the short term provoked a significant drop in prices. In June 2009, the demand for oil and its price started increasing again, but both demand and price remained at levels below those at the beginning of 2008. This new rise in demand and prices may be in response to the recovery from the world economic crisis and the economies turning to the path of economic growth, and thus increasing output and consequently demanding more energy. Despite the lower prices in the second half of 2008 and the first half of 2009, the price of crude oil remains relatively high and its volatility has increased.

2.2.2 Natural gas prices

Natural gas accounts for about 22% of world energy demand. Because the demand is growing particularly in the electricity sector, it is becoming a key part of national energy policies in many countries. Natural gas offers advantages over other fossil fuels: a relatively low greenhouse effect, energy efficiency and ease of use (OECD/IEA, 2010, www.iea.org).

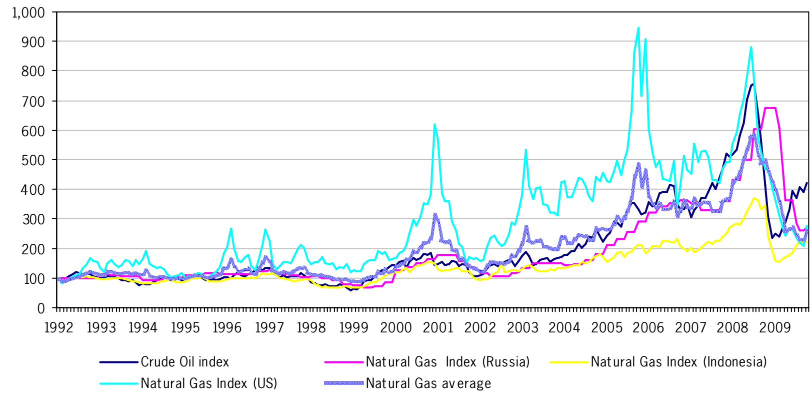
Natural gas prices are a function of market supply and demand. Due to limited alternatives to natural gas consumption or production in the short term, sudden changes in supply or demand often result in large price movements (EIA, 2009).

One of the major factors influencing natural gas markets is economic activity. When the economy grows, the increased demand for goods and services form the commercial and industrial sectors generates an increase in natural gas demand, leading to an increase in gas natural prices. But the global economic recession has also impacted on the gas sector: over 2008 we moved from a tight supply and demand balance with extremely high gas prices, to a significant decrease in gas demand, leading to lower prices. Figure 2.5 shows that average prices of natural gas and crude oil follow a similar pattern.

Some large-volume gas consumers (primarily industrial consumers and electricity generators) can switch between natural gas and oil, depending on their prices. Therefore oil prices can influence natural gas prices (EIA, 2009, http://tonto.eia.doe.gov/energyexplained). Due to the interrelation between oil and gas markets, when oil prices rise in relation to natural gas prices, there may be a switch from oil to natural gas, which pushes up gas prices; and when oil prices fall, the shift in demand from natural gas to oil pulls down prices.

Natural gas markets are regionalised, because it is costly to transport gas over long distances; therefore prices often diverge substantially across and within regions. Nevertheless, regional prices often move in parallel with each other because of their link to the international price of oil, which reflects the competition between gas and oil products.

Figure 2.5	Natural gas and crude oil price trends 1992-2009 (1992=100)



Source: IMF data (2010).

2.2.3 Coal prices

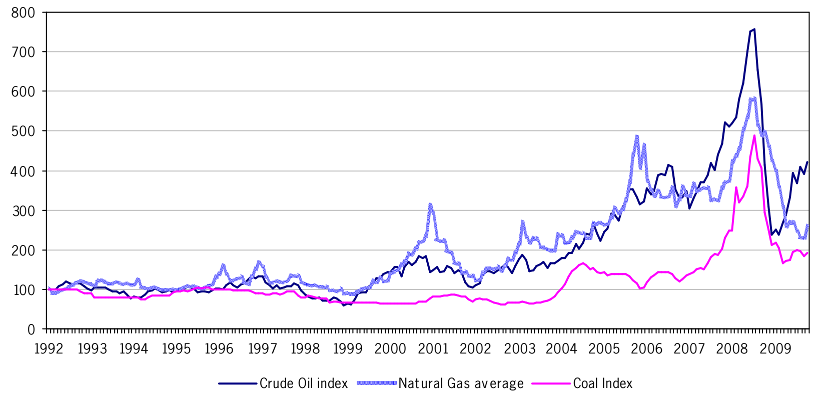
Coal provides 26.5% of global primary energy needs and generates 41.5% of the world's electricity (Key World Energy Statistics - IEA, 2009). Coal has many important uses worldwide. The most significant are in electricity generation, steel production, cement manufacturing and as a liquid fuel.

Coal prices have historically been lower and more stable than oil and gas prices. In terms of quantity, coal is likely to remain for decades the most affordable (excluding environmental costs) fuel for power generation in many developing and industrialised countries.

As transportation costs account for a large share of the total delivered price of coal, international trade in coal is divided into regional markets. Australia is the world's largest coal exporter: in 2007, it exported over 244 m tonnes of its total production of 323 m tonnes of hard coal. The USA and Canada are also significant exporters, while China is emerging as an important supplier.

Figure 2.6 shows the price development of coal from 1992 to 2009. It can be seen that coal prices also move in parallel with oil and natural gas prices but with less oscillation.

Figure 2.6	Coal, natural gas and crude oil price trends, 1992-2009 (1992=100)



Source: IMF data.

Although a growing number of power plants are using gas, coal remains the energy source of some of the world's most important emerging economies, notably China and India. However, coal is still vital for a number of the major industrialised economies, such as the USA, Germany, the UK, Australia and South Africa. It is noteworthy that coal and gas are at opposite ends in the spectrum of environmental impacts. While the increasing trend to promote gas is in line with environmental objectives, some people who are concerned with the security of energy supply defend the retention of coal facilities that have emissions cleaning technology.

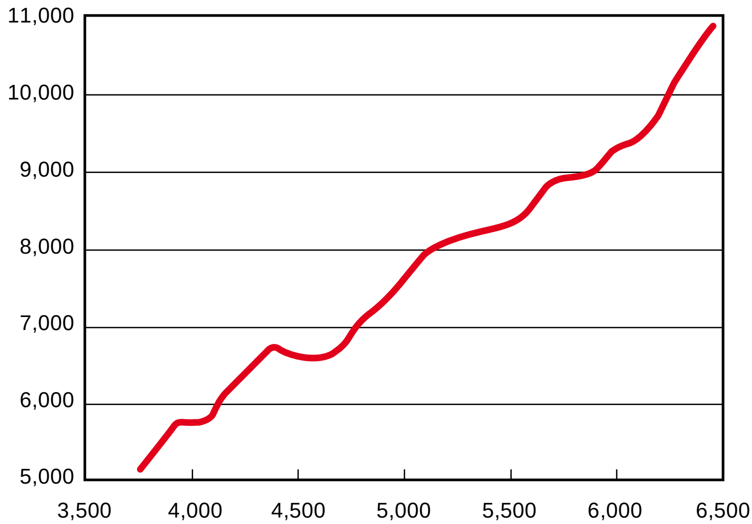
2.3 Energy demand

2.3.1 Driving forces of energy demand

Population development

Energy has been and remains an essential element for human life, human evolution and progress. Population growth has historically led to higher energy demand (see figure 2.7). World population is projected to increase by some 2.5 billion people by the middle of the 21st century, namely from its 2008 level of about 6.6 billion to 9.1 billion people. Most of this increase will occur in developing countries, and as these countries are thirsty for energy, energy demand will grow even faster. The populations of China and India will probably grow between 1980 and 2050 by 400 and 800 million people, respectively. Further data on population growth are presented in Appendix 1.

Figure 2.7 **Relationship between world energy consumption and world population, 1971-2006**



Source: CERI (2007).

Economic development
There is a direct link between levels of economic activity and energy consumption. The factors associated with higher levels of economic activity (economic growth) and energy use are:

- *Urbanisation*
  Economic growth in many countries is associated with the urbanisation of their populations. Urban population growth implies higher energy demand.
- *Industrialisation*
  Energy demand and economic growth are linked to industrialisation. In developed countries manufacturing sectors are stable or declining, with increases in the level of activity in the service sector. The consequent implication for the energy demand is a higher demand for electricity (lighting, air conditioning, computers, other electrical equipment) and a lower

demand for primary fuels. However, developing countries' demands for primary fuels are very high and growing.

- *Higher incomes*
  Increasing economic activity is also accompanied by higher average incomes, which usually imply a higher consumption of goods that consume more energy.

The world financial and economic crisis that started in 2008 (see Appendix 1, table A1.1) has had a significant impact on the world economic growth and the linked energy demand. According to data from the International Monetary Fund (IMF), the world GDP in 2009 was 6% lower than in 2008. The World Energy Outlook (WEO) 2009 from the International Energy Agency (IEA) points out that for the first time since 1981, the global energy use fell in 2009 (see figure 2.4 in section 2.2.1).

Economic development and energy demand are related by the concept of energy intensity - a measure that shows the link between economic growth and energy use. It can be defined as the amount of energy required to produce one monetary unit of economic activity. If energy supply becomes more constrained, the sectors characterised by low energy intensity may experience higher rates of growth (CERI, 2007). Reducing energy intensity will generally decrease the environmental impact associated with rising output. The WEO 2009 affirms that energy efficiency offers the biggest scope for cutting emissions.

Due to technological development, the improvement of efficiency and a shift to less energy-intensive sectors, the energy intensity of the developed nations has been declining since 1970. In the International Energy Outlook (IEO) 2000 forecast, energy intensity in the industrialised countries is expected to improve (decrease) by 1.1% per year between 1997 and 2020. Energy intensity is also expected to improve in developing countries. Changing growth patterns of energy intensity could have significant positive impacts on reducing energy consumption and on the associated environmental impacts.

Commodity speculation
There is a speculative demand for oil. The high level of demand by hedge funds and other investors has probably contributed to higher oil prices. Speculation also contributes to the volatility of prices.

2.3.2 Historical and future developments of energy demand

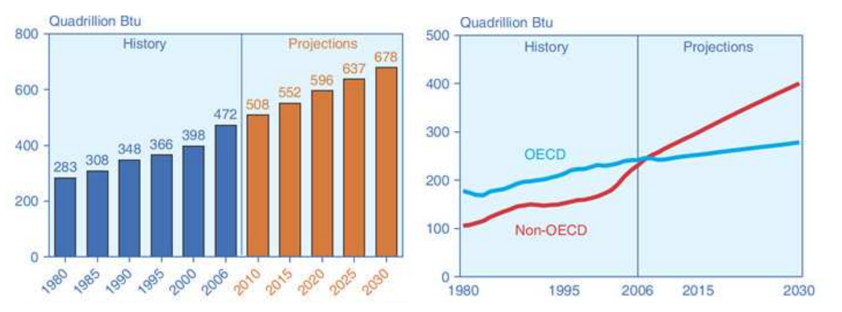
Global demand for energy

Global demand for energy increased sharply in recent decades, and in the mid to long term is expected to continue to rise mainly due to increasing human population and increasing economic growth, which implies world output increases in all sectors, modernisation and urbanisation. According to data from the Energy Information Administration (EIA, 2009), the demand for energy grew between 1980 and 2006 at an average annual rate of 1.5%, and at the remarkable average rate of 3.1% in the period from 2000 to 2006.

Economic development is one of the most important factors to be considered in projecting changes in world energy demand. In the International Energy Outlook 2009 (IEO-EIA, 2009) projections, assumptions about regional economic growth underlie the projections of regional energy demand. In the IEO-09, total world consumption of marketed energy is projected to increase by 44% between 2006 and 2030 (= 1.82% per year), while the World Energy Outlook 2009 from the International Energy Agency (WEO-IEA, 2009) projects in the reference scenario an increase in the world primary energy demand of 40% between 2007 and 2030 (= 1.5% per year). In the IEO-09, non-OECD countries contribute more than three quarters to the increase in world energy consumption. In fact, from 2008 onwards the energy demand of non-OECD countries surpasses that of OECD countries. This trend is expected to continue until 2030. Developing Asian countries, which include China and India, are the main drivers of this growth, followed by Middle East countries (IEA, 2009). By 2020 it is expected that the population in developing countries will have grown by more than 20% and that the per capita income will have doubled (Bunte, 2009).

In both IEO-09 and WEO-09 reference scenarios, the energy demand growth is slower than in the previous 2008 projections due to the impact of the world financial economic crisis in the first years of the projection period. It is a fact that global energy use fell in 2009 for the first time since 1981. However, these projections assume that from 2010 onwards most countries will return to a growth path. However, between 2010 and 2015 the demand for energy is expected to grow at an average rate of 2.5 % per year, and after 2015 to slow down with the maturation of the emerging economies and the further deceleration (see Appendix 1) of population growth (IEA, 2009).

Figure 2.8 **World marketed energy consumption 1980-2030 (left) and world marketed energy consumption: OECD and Non-OECD countries 19080-2030 (right)**



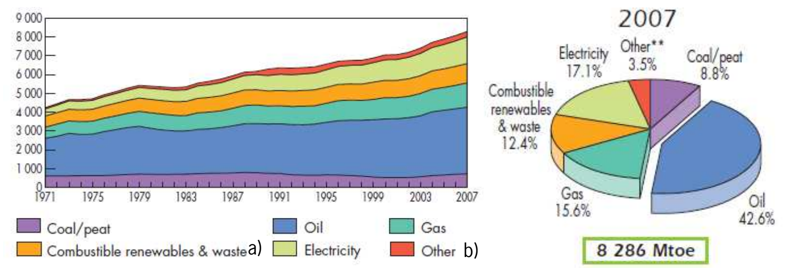
Source: International Energy Outlook by the Energy Information Administration (US).

Demand for energy by source

More than 80% of the world demand for energy is currently met by fossil fuels, with crude oil being the leading source of energy. The demand for crude oil should be affected by the prices of oil substitutes. If in the longer term alternative, reliable and cheaper substitutes for oil can be developed, this could imply a demand shift towards the emerging energy sources. It seems that due to the high oil prices from 2004 to 2008, there has been an increase in research and development in non-oil substitutes. However, the shift to other energy sources can take several years before impacting energy markets.

Figure 2.9 shows the share in energy demand of every type of fuel.

Figure 2.9	Evolution of total final consumption by fuel in million tonnes of oil equivalent (Mtoe) (left), % share (right)



a) Prior to 1993 combustible renewables and waste final consumption has been estimated; b) 'Other' includes geothermal, solar, wind, heat, etc.
Source: Key World Energy Statistics, IEA (2009).

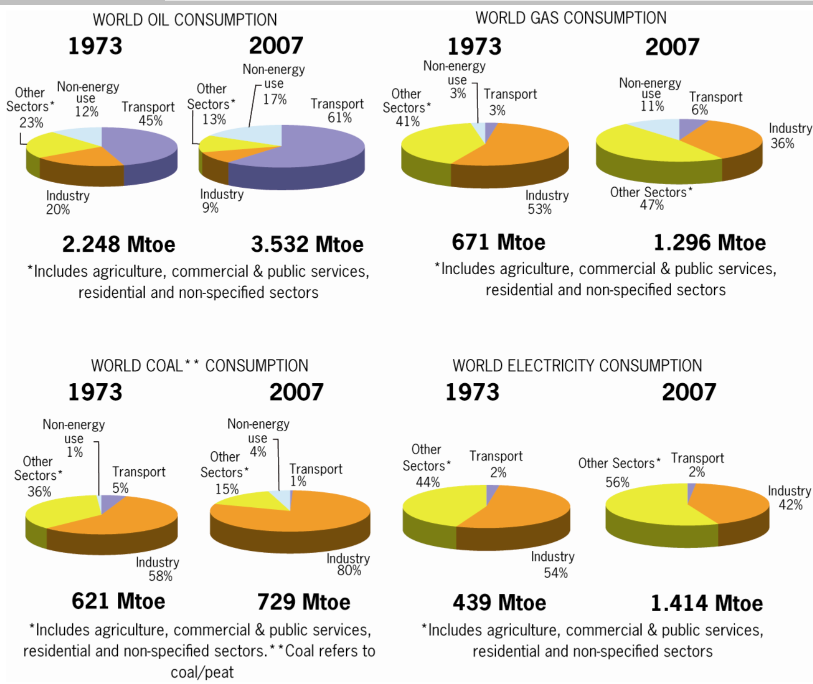
Demand for energy by energy type and economic sector

The consumption of energy type varies among the economic sectors. The figures below show that in 2007 the transport sector accounted for more than 60% of total oil consumption. Industry and 'other' sectors accounted for 35% and 47%, respectively, of total gas consumption. Coal is mainly used in the industry sector, which accounted for 80% of total coal consumption. Electricity is almost only used in industry and 'other' sectors (including agricultural, commercial and public services, residential and other sectors); these two sectors accounted for 42% and 56%, respectively. Transport accounted for only a small share of total electricity consumption.

Looking at the projections of the EIA (2009), over the coming 25 years, world demand for liquid fuels is projected to increase more rapidly in the transport sector than in any other end-use sector. Over the 2006-2030 period, transportation accounts for nearly 80% of the total increase in world liquid fuels consumption. Much of the growth of energy use in the transport sector is expected to occur in non-OECD countries. The projections of the IEA are even more dramatic: oil demand (excluding biofuels) is projected to grow annually at an average rate of 1% (IEA, WEO-09). In the WEO-2009 (Executive summary, page 4) the contribution of the transport sector to the increase in oil consumption is even greater than in the EIA projections: the transport sector accounts for 97% of the increase in oil use. In the climate policy scenario (450-PS)[1] a big reduction of crude oil demand is caused by:

(a) the implementation of measures in the transport sector to improve fuel economy;
(b) the expansion of biofuel demand;
(c) the promotion of new vehicle technologies.

Figure 2.10 **Shares of world energy consumption by source and sector, 1973 and 2007**



Source: LEI, based on Key World Energy Statistics, IEA (2009).

[1] Based on a plausible post; 2012 climate policy framework to stabilise the concentration of global greenhouses gases at 450 ppm CO_2 equivalent.

2.4 Energy supply

2.4.1 Driving forces of energy supply

When looking at energy supply we need to distinguish between short-term and long-term supply (Riley, 2009). From the short-term perspective, the following factors affect the supply:

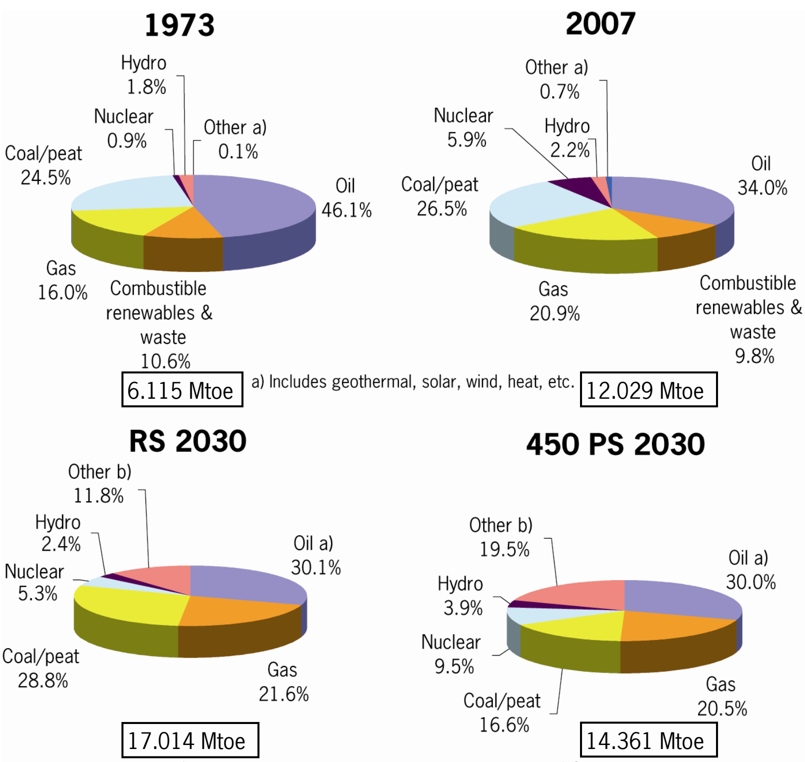
- *Profitability*
  The production decisions taken by OPEC and non-OPEC countries
- *Spare capacity*
  The level of spare production capacity
- *Stocks*
  The current level of stocks (inventories) available for immediate supply
- *External shocks*
  Geopolitical factors (adverse weather, wars, politic instability, etc.).

In the long-term view, the energy supply is linked to such factors as dependence on fossil fuels and their stage of depletion, dependency on OPEC countries, investments and policies.

Dependence on fossil fuels energy
In the WEO-09, the global dependence on fossil fuels is expected to persist until 2030. Although alternative fuels are growing in importance, and despite the more efficient use of oil in production, in 2007 fossil fuels (crude oil, gas, coal) provided 81.4% of world energy supply, while crude oil provided 34% of world primary energy supply. The WEO-09 reference scenario estimates that in 2030, fossil fuels energy supply will still represent 80.4% of total world supply, with crude oil representing 30% of total primary energy supply.

The WEO-09 reference scenario provides the baseline picture of how global energy markets will develop if governments do not change their existing policies and measures. The '450 scenario' (450-PS) shows the results in a world in which world policy action is intended to limit the long-term concentration of greenhouse gases in the atmosphere to 450 parts per million of CO_2, an objective that is gaining support around the world (IEA, 2009). In the 450-PS, energy demand grows at an annual rate of 0.8% (compared to 1.5% in the reference scenario). Increased energy efficiency in buildings, industry and transport reduces the demand for electricity and fossil fuels. In the 450-PS, the increasing utilisation of alternative energy sources implies the reduction of fossil fuels dependency in the world energy supply. The share of non-fossil fuels increases in this scenario from 19% in 2007 to 32% in 2030. However, fossil fuels are expected to remain the dominant sources of primary energy, with crude oil having a 30% share of total energy supply in 2030, gas a 21% share and coal a 17% share.

Figure 2.11 **Total primary energy supply 1973-2030**



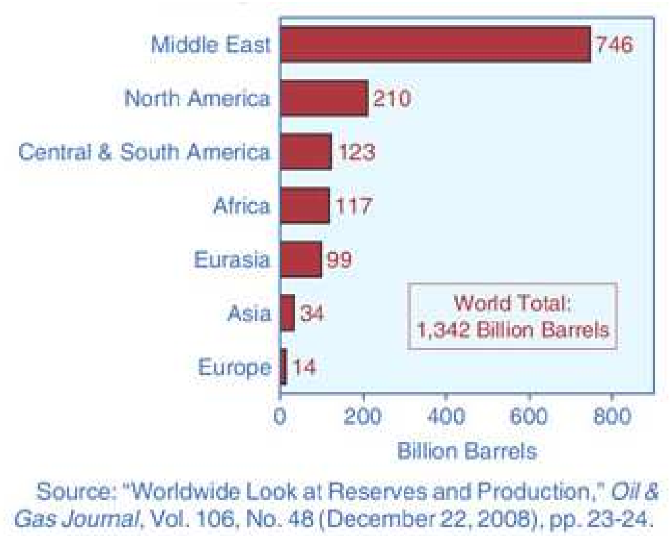
a) Includes international aviation and marine bunkers; b) Other includes combustible renewables and waste, geothermal, solar, wind, etc.; c) Based on plausible post-2012 climate-policy framework to stabilise the concentration of global greehouse gases at 450 ppm CO_2 equivalent

Source: LEI, based on Key World Energy Statistics, IEA (2009).

Depletion of fossil fuel reserves

Crude oil
The Oil & Gas Journal reported that on 1 January 2009 proven world oil reserves were estimated at 1,342 billion barrels (IEO-EIA, 2009). This amount is 10 billion barrels higher (about 1%) than the estimate for 2008. Figure 2.12 from the IEO-EIA (2009) presents the proven world oil reserves by region.

Figure 2.12 **Proven world oil reserves by geographic region on 1 January 2009**



Source: International Energy Outlook, EIA (2009).

According to the definition used by the EIA: '*Proven reserves* of crude oil are the estimated quantities that geological and engineering data indicate can be recovered in future years from known reservoirs, assuming existing technology and current economic and operating conditions. However, the 'resource base estimates' include estimated quantities of both discovered and undiscovered liquid fuels that have the potential to be classified as reserves at some time in the future. In fact, in the IEO-EIA (2009) projections, the volumes for cumulative production through 2030 exceed the estimates of proven reserves, thus EIA assumes potential technology improvements and further exploration in its oil production projections.

The reserves-to-production ratio is the remaining amount of proven reserves, expressed in years. Various studies give the reserves-to-production ratio for crude oil as being between 25 and 40 years.

The stage of depletion of crude oil reserves varies between countries and areas. The International Energy Agency published in the World Energy Outlook 2008 a section that provides information about the stage of depletion of the world's oil producing fields (see table 2.1).

Table 2.1	**Average depletion factors of producing fields a) by size, 2007**		
	Super-giants and giants (%)	**Other (%)**	**All fields (%)**
OECD North America	78	83	81
OECD Europe	77	71	73
Middle East	37	14	32
Africa	61	44	50
Total	*48*	*47*	*48*

a) Based on the full IEA dataset of 798 fields. Note: the depletion factor is cumulative production divided by initial 2P reserves.
Sources: HIS, Deloitte & Touche and USGS databases; other industry sources; IEA estimates and analysis; WEO-IEA (2008) Oil and Gas production prospects.

Source: WEO-IEA (2008) Oil and Gas production prospects.

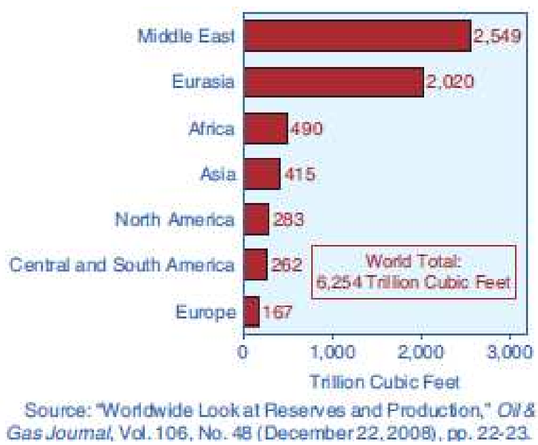
The oil reserves of North America and OECD Europe are in an advanced stage of depletion. Africa has reached the midpoint of depletion, while the major Gulf producers (Saudi Arabia, Iraq, Iran, Kuwait and United Arab Emirates) are at an early stage of depletion and could play a swing role, closing the balance between world demand and supply (Asif et al., 2005).

The depletion of super-giant and giant fields is larger (see world crude oil production by field size in Appendix 2). This has economic implications. On the one hand, the cost of oil extraction from smaller fields is higher; therefore depletion of super-giant or giant fields implies higher oil production costs in the future. On the other hand, investments needed in smaller fields are much higher than in giants (OECD, 2008).

The fact that a region has a reserves-to-production ratio of, for example, 40 years does not mean that it will continue to produce the resource for 40 years, at which point it will suddenly run out, but that production will probably grow until it reaches a peak, and then enter a downward phase. After the peak, declining oil production combined with increasing demand will cause a global energy gap, and therefore rising oil prices are to be expected. This gap should be filled with a more efficient use of energy and alternative energy sources. The dependency on oil can lead to alarming consequences for energy security and prices.

Natural gas
According to the data presented by the EIA in the IEO-09, almost three quarters of the world's natural gas reserves are located in the Middle East and Eurasia (figure 2.13). Russia, Iran and Qatar together accounted for about 57% of the world's natural gas reserves on 1 January 2009.

Figure 2.13 **World natural gas reserves by geographic region on 1 January 2009**

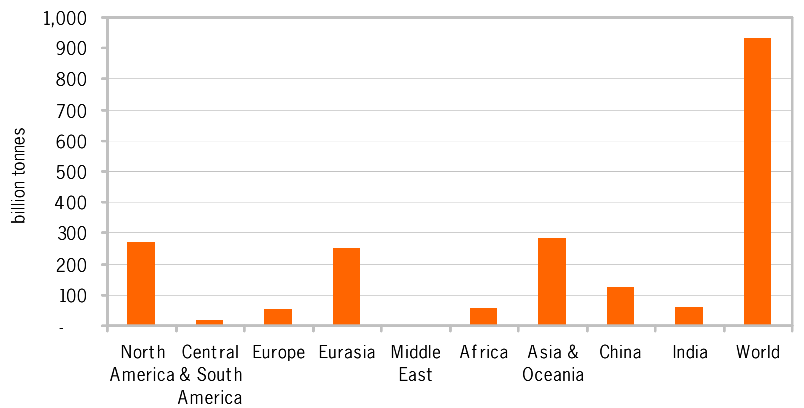


Source: IEA, EIA (2009).

The reserves-to-production ratios for most regions are still substantial. The IEA estimates worldwide reserves-to-production ratios at 63 years. The estimates by region are about 48 years for Central and South America, 78 years for Russia, 79 years for Africa and more than 100 years for the Middle East.

Coal
The World Coal Institute (2009) gives an estimate of over 847 billion tonne of proven coal reserves worldwide, implying enough coal to last over 130 years at current rates of production. In contrast, proven oil and gas reserves are equivalent to around 42 and 63 years at current production levels (IEO-EIA, 2009). About 63% of oil and almost 75% of gas reserves are concentrated in the Middle East and Russia (IEO-EIA, 2009), while coal reserves are more distributed across the world. Figure 2.14 shows where coal reserves are available.

Figure 2.14 **Coal proven reserves by region in 2005**



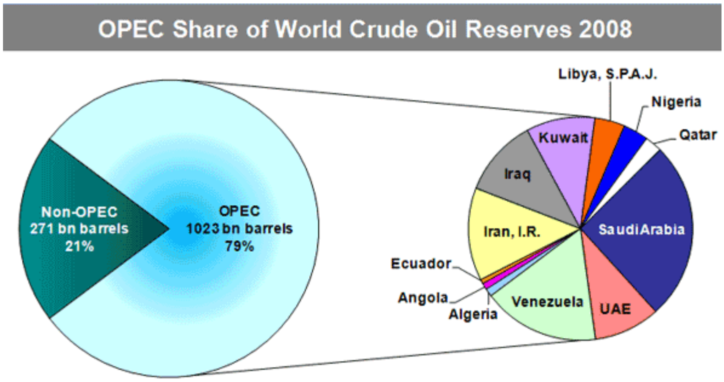
Source: LEI, based on Energy Information Administration, 2010.

To summarise, all fossil fuels will eventually run out. It is essential that we use them as efficiently as possible and that we develop and switch to alternative energy sources in time. If we take into consideration the impact on climate change of fossils fuels, the need to switch to alternative, cleaner energy sources is even greater.

World dependency on OPEC countries
There is a fundamental scarcity of crude oil that is determined by the availability of crude oil reserves. Some people argue that further rises in crude oil production are no longer possible, while for example the IEA predicts that oil production will increase during the coming two decades (see above). The world

oil supply depends on the political situation in OPEC countries, because most reserves are available there. But oil production and investment are dominated by national oil companies and local politics in these countries, implying that investment is very low.

Figure 2.15 **OPEC share of crude oil reserves 2008**



OPEC proven crude oil reserves , end 2008
(billion barrels)

Saudi Arabia	264	25.8%	Iraq	115	11.2%	Libya, S.P.A.J.	44	4.3%	Algeria	12	1.2%
Venezuela	172	16.8%	Kuwait	102	9.9%	Nigeria	37	3.6%	Angola	10	0.9%
Iran, I.R.	138	13.4%	UAE	98	9.6%	Qatar	25	2.5%	Ecuador	7	0.6%

Source: OPEC Annual Statistical Bulletin 2008

Source: OPEC annual statistical bulletin (2006).

The large crude oil reserves in OPEC countries implies that the more oil is produced outside OPEC, the greater the dependency on OPEC will become.

Investments

Today's investments will determine the supply availability in the future. Low oil prices in the mid 1980s and the 1990s did not provide incentives to carry out further exploration or R&D in extraction technologies, and this implies future supply constraints. On the other hand, high oil prices stimulate R&D in crude oil as well as in alternative sources.

The current world financial and economic crisis has also impacted investments in all energy types. Investments have been declining mainly due to a tougher financing environment, weakening energy demand and lower cash flow. Investment in renewable energies fell proportionately more than in other types of energy, and without additional policy stimulus would have declined even more (IEA WEO-09).

2.4.2 Sustainable energy supply and economy

Energy security is one of the world's major concerns: will the energy supply be able to meet the increasing energy demands? The other major concern is climate change mitigation, considering that energy use is causing CO_2 emissions. The idea of energy resource-use sustainability therefore has two aspects:

- the abundance of various sources of energy (see 'Depletion of fossil fuel reserves' above)
- the effect of their use on the environment (is the biosphere capable of absorbing the related solid, liquid and gaseous waste products?).

Impact of energy use on climate change
The high dependency on fossil fuels to meet the growing energy demand will have important consequences for climate change. Global warming consists in that

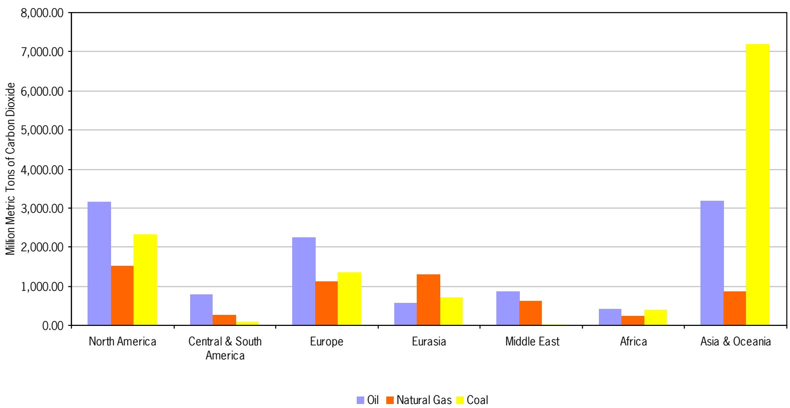
> Certain gases in the Earth's atmosphere result in a thermal blanketing effect that keeps the temperature higher than it would be in their absence. (CERI, 2007)

Energy use generates waste products that can affect humans directly, through health, and indirectly, by affecting the environment at local, regional and global levels. The emissions that must be managed are toxic substances (sulphur compounds, nitrogen and mercury), greenhouse gases, and particulates. Energy use is the principal source of greenhouse gases emissions worldwide. Greenhouse gases (GHGs), include, in order of importance, water vapour, carbon dioxide (CO_2), methane (CH_4), ozone (O_3) and nitrous oxide (N_2O), followed by some other gases that contribute to the greenhouse effect. Figure 2.16 shows the level of CO_2 emissions by fuel and world region. It can be seen that the use of oil is the principal source of CO_2 emissions in most regions, with the exception of Eurasia (natural gas) and Asia (coal).

Coal and oil each contribute about 40% to total CO_2 emissions worldwide, while natural gas accounts for 20%.

Looking at the projections, in the IEO2009 reference case, world energy-related carbon dioxide emissions increase by an average of 1.4% per year from 2006 to 2030. In line with the EIA projections in the WEO-09, CO_2 emissions are expected to grow in the reference scenario at an average of 1.5% per year.

Figure 2.16	CO_2 emissions by fuel and region in 2006 (million tonnes)



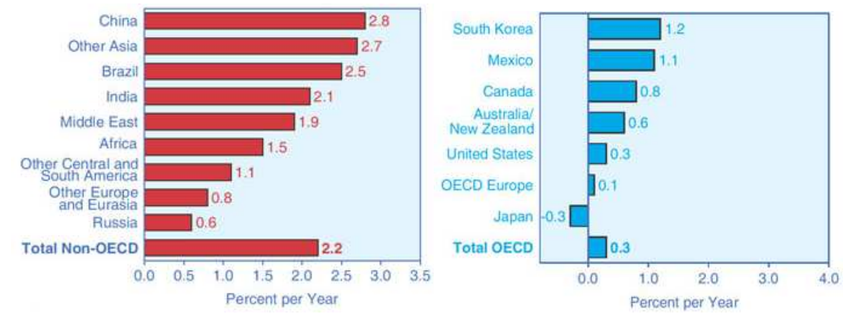
Source: Data from International Energy Annual (2006), EIA.

The projections in figure 2.17 show that the developing world (e.g. China, other' Asia, Brazil and India) is expected to increase total emissions much more rapidly than developed countries. This is partly due to the large coal dependency of many developing countries.

The projections of both EIA and IEA in the reference scenarios assume no policy changes. Policy measures in the context of international policy agreements are expected to have an important effect in reducing both energy consumption and dependency on fossil fuels.

The increasing global awareness of the implications of greenhouse gas (GHG) emissions raises the possibility of a limit on the use of fossil fuels not only because of their physical availability but also because of their impact on the environment. However, the effect that alternative fuels have on the environment must also be considered in assessing their suitability to play a role in replacing fossil fuels.

Figure 2.17	Average annual growth in energy related CO_2 emissions: non-OECD (left) and OECD (right) 2006-60



Source: International Energy Annual (2006), EIA.

Substitutes for fossil fuels

Crude oil is the principal energy source for the transport sector: it accounts for more than 60% of total oil consumption. Further development of energy efficiency would contribute to reducing the demand for oil. There are also techniques to use other fossil energy sources (e.g. gas and coal) to produce substitutes for crude oil, but they do not contribute to the global aim to reduce CO_2 emissions.

In the very long term, alternative energy sources may become available, and their availability may limit the increase in crude oil prices. Solar energy, wind energy, electric cars and a lot of other technologies may develop such that they become price competitive at prices of USD100 per barrel or more.

Nature provides a variety energy sources, but the main question is how to convert sunlight, wind, biomass or water into electricity, heat or power as efficiently, sustainably and cost-effectively as possible.

Biomass can be converted into a liquid fuel (i.e. ethanol or biodiesel) and used as a transport fuel. Ethanol is currently used as a fuel additive in order to reduce emissions, and there are subsidies and other fiscal incentives to increase the ethanol component in petrol. Biodiesel is used as transport fuel as a substitute for petrol or diesel. Several countries have already implemented policies to stimulate the production of biofuels. Although biomass can also be used in power generation, recent studies point out that there are some problems related to the large-scale use of biomass, including land requirements, effects on soil fertility and food security, unfavourable energy balance, etc.

However, improvements in the conversion technology and the raw materials used could convert biomass into a modern, clean source of energy.

As the transport sector has the greatest demand for oil, improving vehicle efficiency and vehicle technology are very effective measures to reduce petroleum dependence.

Other renewable energy sources like wind, solar or geothermal have insignificant emissions intensity. These energy sources are currently used in power generation.

Figure 2.18 **Global renewable resources energy base, current and potential use**

	Current use	Technical Potential
Hydro Power	10.0	50
Biomass Energy	50.0	> 250
Solar Energy	0.2	> 1600
Wind Energy	0.2	600
Geothermal Energy	2.0	5000
Ocean Energy	-	-
Total	**62.4**	**> 7500**

Source: CERI (2007) (left) and German Advisory Council on Global Change (WBGU) (right).

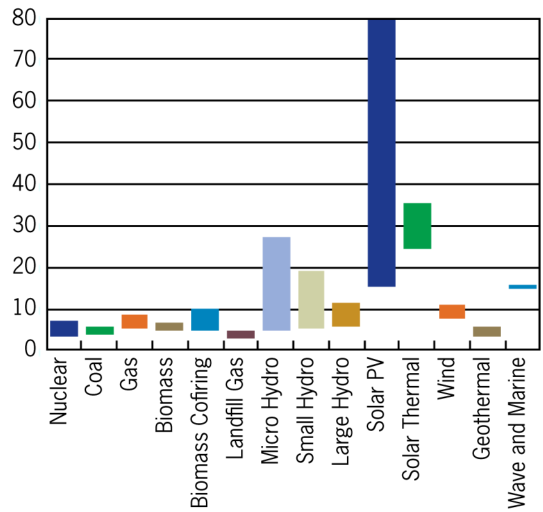
One of the most widely recognised sources of renewable energy is the wind, a previously expensive means of producing electricity that has declined substantially in cost over the past few decades. Solar energy may be captured directly using photovoltaic systems, or indirectly from the concentration of energy and thermal conversion through such media as air or water to generate electricity.

However, the relative importance of renewable energy remains at about 13% of total primary energy supply, and current projections on a business-as-usual basis suggest a similar percentage in the future. Renewable energy sources are not expected to be economically competitive with fossil fuels in the medium term without significant support from government policies. But as renewables' costs come down and technologies advance, they will become more important. The climate change implication of energy use will also play an important role. The future use of renewable energy sources will depend partly on achieving a balance between economic viability and environmental impacts. The availability of cheaper fossil fuels would be a barrier to the expansion of renewable energies.

Due to the fact that nuclear energy is one of the emissions-free sources, some experts think that it remains a legitimate option to consider in meeting future needs.

Figure 2.19 presents a comparative analysis of the costs of generating electricity from various sources.

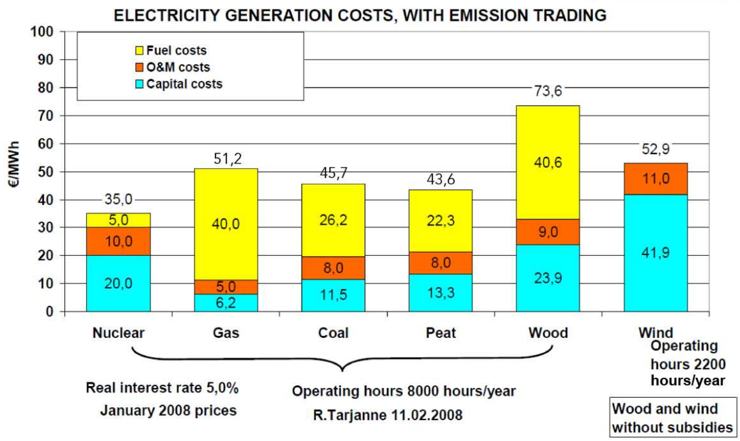
Figure 2.19 Relative costs of electricity generation technologies

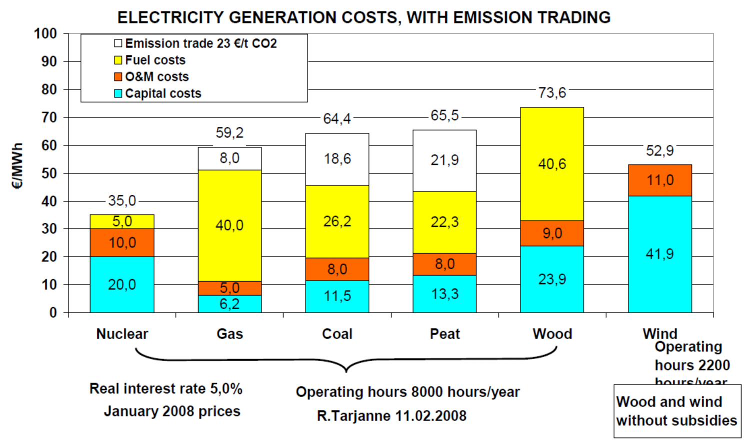


Source: Prepared by CERI (2007) with IEA data.

The framework of the study behind the above graphic excluded costs to society of emitting CO_2 when using fossil fuels. Such costs will improve the relative competitiveness of renewable and nuclear-generated electricity compared with gas and particularly with coal-generated electricity. Box 2.1 presents an example of a comparative analysis of the cost of generating electricity with and without consideration of CO_2 emissions.

Box 2.1	Cost of electricity generation with and without emissions trading





In this study nuclear energy turns out to have the lower costs for power generation in both cases. Coal and gas are cheaper than wind without emissions trading, but become more expensive than wind with emissions trading.

Source: Tarjanne Risto, Kivistö Aija, Lappeenranta University of Technology (2008).

The cost of a secure access to energy, along with the infrastructure and the security of supply, tends to support nuclear and coal rather than gas. The value of security of fuel supply is difficult to quantify but it is a key factor in the national energy policies of many OECD countries (Costs of generating electricity, IEA).

2.5 Role of policy

There are two major concerns driving international and national policy actions:
- energy security
- climate change mitigation.

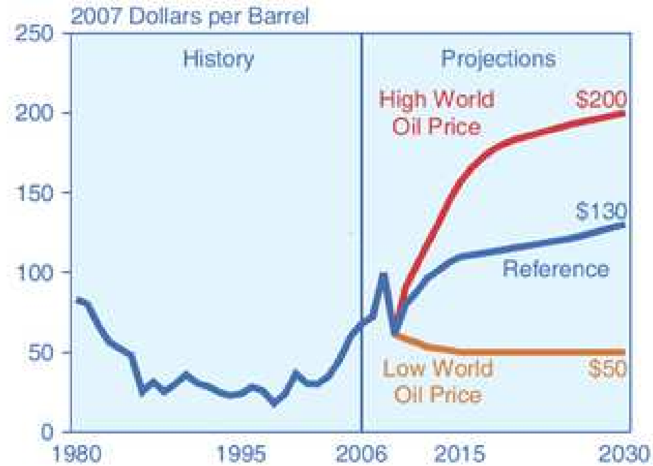
The objective of international climate policy agreements is to limit the long-term concentration of greenhouse gases in the atmosphere. Energy policies should promote the reduction of the oil intensity in the economy, the development of energy substitutes and energy-saving technologies. Households and businesses are responsible for making the required energy investments, but governments play a key role in setting up the appropriate incentives to promote energy savings and switch to new sources. Moreover, despite concerns over climate change and energy security, subsidies granted to fossil fuel industries remain in place worldwide. Although many of these subsidies are the result of decades of policy evolution, in the past couple of years there has been a sharp increase in the scale of subsidies related to fossil fuels in many countries. Some of these subsidies were implemented for social reasons, such as regional development, but many exist mainly due to successful lobbying by the beneficiary industries. Better focusing subsidies and eliminating them where possible would be advisable. Such reforms are also a logical first step in supporting the transformation to cleaner fuels.

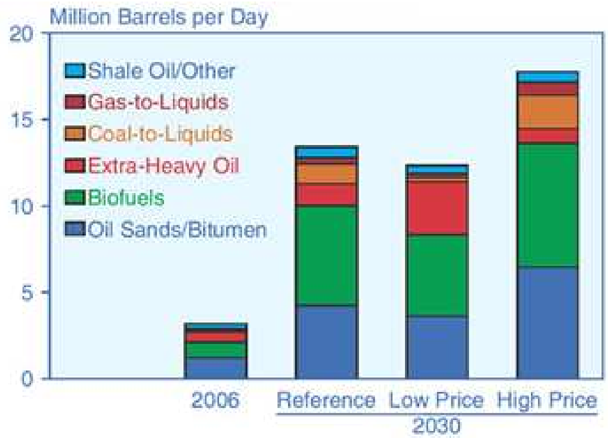
2.6 Future energy prices

Projections of oil prices up to 2030 are provided by the Annual Energy Outlook 2009 (AEO-09; EIA, 2009). In this report it is noted that projections of oil prices are subject to a high degree of uncertainty:

> 'Many of the events that shape energy markets cannot be anticipated, including severe weather, political disruptions, strikes and technological breakthroughs. In addition, future developments in technologies, demographics, and resources can not be foreseen with certainty.'

Figure 2.20	World oil prices 1980-2030 in three scenarios (above) and world production of unconventional liquid fuels 2006-2030





Source: IEO by EIA (2009).

For the projections, the AEO-09 considers three scenarios: reference, high and low price. The oil price in 2030 in the reference scenario is projected to be USD133 (2008 dollars).

The high-price scenario shows a world oil market with the following characteristics:

- Restriction of conventional production due to political decisions and resource availability
- Producing countries using quotas, fiscal regimes and various degrees of nationalisation to increase national revenues from oil production
- Consuming countries turn to high-cost production of unconventional liquid fuels to satisfy demand.

In the low-price scenario:

- Non-OPEC producing countries develop stable fiscal policies and investment regulations to encourage private sector participation in the development of their resources
- OPEC nations are not expected to change current investment restrictions significantly, but they are expected to increase production such that in 2030 they will be responsible for approximately 50% of total world liquid fuels production.

3 Food markets

3.1 Introduction

This section presents a general overview of the development of agricultural markets. First, the historical development of prices and their impacts are described. Next, attention is given to the driving forces of demand and of supply in an attempt to determine their permanent or transitory character. Then the recent and expected market developments are presented. The role of policies is also dealt with. Finally, some projections for future prices are presented.

3.2 History of agricultural commodity prices

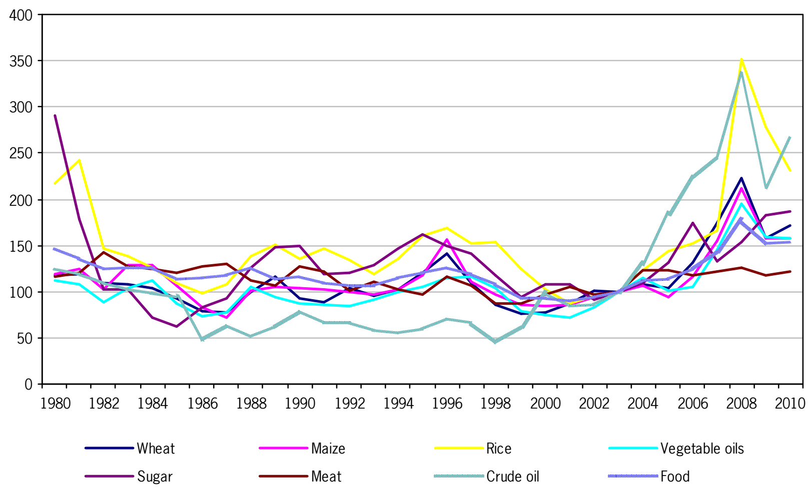
3.2.1 Development of prices up to 2009

From the long-term perspective, real crude oil and food prices have been declining consistently. The recent price developments of some commodities are unusual from the perspective of the last two decades, but less unusual from a longer historical view. Agricultural commodity markets are volatile, and the recent sharp increases in the prices of wheat, coarse grains, rice and oilseeds are not the only ones in the last 40 years. It is noteworthy that in recent years, prices of meat and sugar products have experienced more modest or even no increases.

Agricultural commodity prices are a result of demand and supply movements. Since global commodity stocks are lower than ever, sudden shocks in supply and demand are very quickly translated into large price movements. In recent years there has been an imbalance in food markets that has led to some commodities undergoing large price movements; there were price spikes in 2007/2008 and price decreases after mid 2008. In section 3.3 we present an analysis of the factors that have contributed to the large price movement. In this, we distinguish its permanent or transitory character, which is a crucial issue for projecting market developments and designing adequate policies to deal with adverse consequences.

Basically, prices rise when supply does not keep up with demand. Looking at the price developments, the supply and demand imbalance in food markets was initially less dramatic than in the crude oil market. Figure 3.1 shows that oil prices have increased since 2003 more rapidly than food prices.

Figure 3.1 Trends in the nominal prices of agricultural commodities, food and oil (2003=100)



Source: LEI, based on IMF Data (2010).

Note:

Crude oil

Price index simple average of three spot prices (APSP); Dated Brent, West Texas Intermediate and the Dubai Fateh.

Vegetable oils

Price index includes soybean, soybean meal, soybean oil, rapeseed oil, palm oil, sunflower oil, olive oil, fishmeal and groundnut price indices.

Meat

Price index includes beef, lamb, swine (pork), and poultry price indices

Food

Price index includes cereals, vegetable oils, meat, seafood, sugar, bananas and oranges price indices and beverage indices.

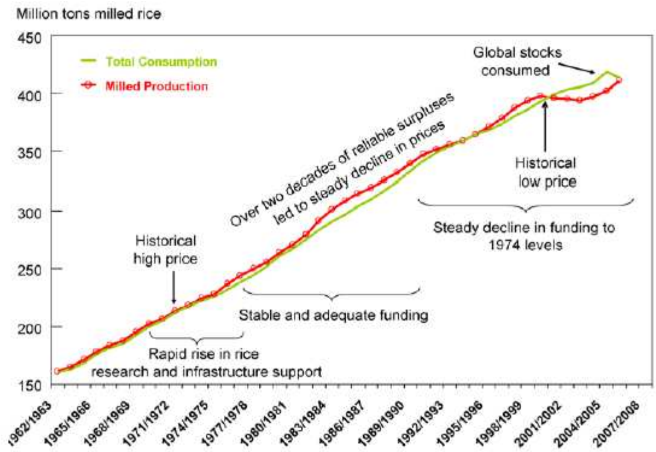
The sharp upward trend in the price of crude oil began first (2003) and the growth was higher (figure 3.1). The sharp upward trend in agricultural commodity prices started later (2005). Most of the agricultural commodities followed a similar pattern of growth. However, rice experienced significant sharper increases in 2007/2008, while the sugar price underwent some more modest increases in 2006 but dropped again in 2007, and meat prices remained quite stable.

Box 3.1 provides some insight into the recent developments of rice prices.

Box 3.1	**Rice market**

Of the world's 1.1 billion poor people, almost 700 million people with an income of less than a dollar a day reside in the rice-growing countries of Asia. Rice is a staple food in Asia. It accounts for more than 40% of the calorie consumption of most Asians. Poor people spend as much as 30-40% of their income on buying rice. The world price of Thai rice was under USD200 per tonne in 2000, but it rose to more than USD360 per tonne by December 2007, and then more than doubled (mid 2008). The second half of 2008 saw the start of a downward trend. Many long- and short-term factors have contributed to the rice crisis:

The sustained rise in the price over the past 7 to 8 years indicates that we have been consuming more than we have been producing. Rice stocks are being depleted.



A major reason for the imbalance between the long-term demand and the long-term supply is the slowing growth in yield, which has decreased substantially. Globally, yields have risen by less than 1% per year in recent years, slower than population growth.

An important factor accounting for the slowdown in yield growth is insufficient public investment in agricultural research and development, the very engine that drove productivity.

Box 3.1	Rice market (continued)

The steady decline in rice prices through the 1990s led many governments to believe that there was a perpetual supply of plentiful food. Lower prices were taken for granted, leading to complacency in agricultural research and development. The possibility of enlarging the rice area is almost exhausted in most Asian countries.

Three key factors have contributed to steady growth in the demand for rice. First, population growth - which continues across the rice-consuming world - is outstripping production growth, and this is projected to get worse. Second, rapid economic growth in large countries such as India and China has increased the demand for cereals for both consumption and livestock production. This income-driven growth in demand has pushed up the price of cereals in general. Third, rice is an increasingly popular food in Africa: imports into Africa now account for almost one-third of total world trade. It is expected that demand from Africa will continue to grow, and there is little chance of a major turnaround in African rice production within 5 years.

The price of oil has increased rapidly during the past year. In addition to contributing to general inflationary pressure, this has pushed up freight costs for countries that import rice. The world price of fertilisers, which are essential for rice production, has increased sharply.

Rising oil prices and concerns about climate change have also spurred rapid investments, particularly in developed countries, in biofuels such as ethanol produced from maize grain or biodiesel produced from oilseeds. This has increased pressure on the international trade of grains and livestock feed, as well as on fertilisers and agricultural land in some countries. Until now, the direct impact of biofuels on rice production and rice trade has likely been small. However, if the industry continues to grow, rice production and prices may be affected more seriously.

Natural disasters - such as flooding, drought and typhoons - have contributed to recent production shortfalls. The steady rise in global temperatures as a result of increasing greenhouse gas concentrations in the atmosphere is expected to hurt rice production

Many pests that caused major problems for rice intensification programmes in the 1970s and 1980s have returned as major threats to production.

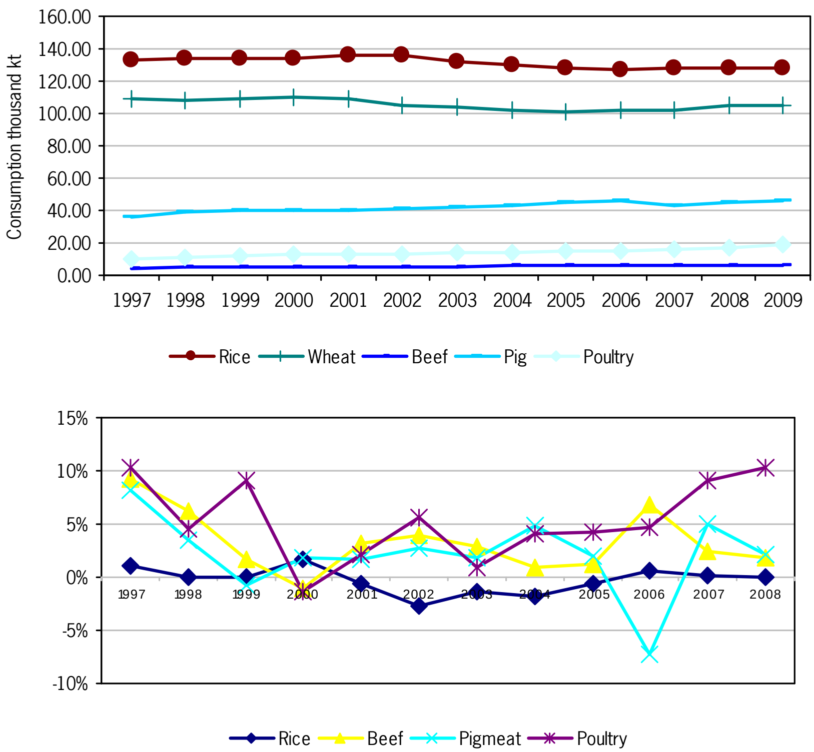
Major exporting countries such as Vietnam and India announced export restrictions to protect their domestic consumers. These restrictions have further contributed to the recent increase in the price of rice, as the rice supply in the world market has dwindled.

Rice prices are not expected to fall to anywhere near their historical lows. The reasons for this include the expected long-term high price of oil (and therefore fertiliser), the time required to construct additional irrigation infrastructure, the possibility of more frequent extreme weather events, the rise of biofuels and continued demand growth. Further, without the buffer of more stocks, there is an increased risk of continued instability in the international rice market.

Source: International Rice Research Institute (2009).

Meat, in contrast to other food commodities, did not reach a significant price peak in 2007/2008. The reason for this could be that even if emerging countries, which are characterised by economic growth and higher per capita incomes, are clearly experiencing a shift in diets to more protein-rich and meat products and the rates of meat consumption are growing considerably, the emerging economies are not yet putting much pressure in absolute terms on the meat demand, so that meat still represents a small share of total food consumption. Figure 3.2 shows the example of China.

Figure 3.2	**Consumption trends in China: absolute values (above) and growth rates (below)**



Source: OECD data.

The figure above shows that cereals are still the main component of food consumption in China. However, there is a clear upward trend in the consumption of poultry.

World sugar prices underwent more modest price increases in 2005/2006, but fell again in 2007. The following table presents some data on the production and consumption of sugar since 2003/2004.

Table 3.1	**World sugar balances (in million tonnes)**						
	2009/10	**2008/09**	**2007/08**	**2006/07**	**2005/06**	**2004/05**	**2003/04**
	(million tonnes, raw value)						
Production	159,887	152,976	169,563	165,508	150,200	140,802	142,253
Consumption	167,134	164,316	158,784	155,220	150,845	146,975	144,596
Surplus/deficit	(7,247)	(1,134)	10,800	10,288	(645)	(6,173)	(2,343)
End stocks	53,471	60,725	73,530	67,209	56,928	57,555	63,368
Source: International Sugar Organisation.							

Between 2003/2004 and 2005/2006, the consumption of sugar exceeded production and stocks were consumed. About 60% of Brazilian sugar cane is used to produce ethanol. The ethanol industry has therefore been exerting strong pressure on the demand for sugar, probably further enhanced by the high crude oil prices, ethanol being a petrol substitute. The sugar prices began to rise in 2005/2006 but the supply response in 2007/2008 was very significant, causing prices to drop to lower levels. Sugar cane for ethanol production has already played an important role for many years, while cereals and vegetable oils have increasingly been used as feedstock in biofuel production in recent years.

However, in 2008/2009 and 2009/2010 there is again a deficit, which may lead to a new sugar price spiral. Poor weather conditions around the world are blamed for the severe shortage. But there are problems: regulation; the high prices of other crops in 2007/2008 might have given incentives to farmers to abandon sugar for more profitable crops such as rice; and the growing appetite of developing countries for sweet food. With a rising oil price, ethanol production looks set to increase further, putting more pressure on the demand for sugar and contributing to supply-demand imbalances. An expected limited growth in sugar output in Brazil, a modest production recovery in India after last season's unprecedented shortfall, and a higher sugar crop in the EU have become the three major supply features of 2009/2010. World consumption is expected to grow at a rate significantly lower than the long-term 10 year average (1.71% and 2.66%, respectively). The lower growth is attributed to impacts of the 2008/2009 global recession on sugar consumption, growth rates in developing countries as well as increasing world market prices. Even sugar consumption is expected to grow at lower rates: the global use of sugar is projected to reach 167.134 m tonnes. Therefore, the growth in global production is too small to cover sugar consumption and the world statistical deficit is expected to reach 7.247 m tonnes (International Sugar Organisation, 2009).

Rice is the main dietary component in the developing and emerging economies (e.g. China, India) and this is probably why the pressure on the demand for rice related to rapid population and economic growth has been stronger than the pressure on the demand for other food commodities.

The story behind wheat, maize and soybean price developments has many common points with rice (Box 3.1), but they have been much more influenced by biofuels production. Consumption has been steadily growing while output has been growing more slowly than consumption since the beginning of the 2000s. In this situation, stocks have fallen dramatically and the market has been very quickly brought to supply-demand imbalances, which have been translated into large price movements, enhanced by the low elasticity of food demand and supply.

Most of the studies conclude that the agricultural price spikes of 2007/2008 were caused by several factors acting at the same time and contributing in various degrees to the demand-supply imbalances of major agricultural commodities.

- Underestimation of increasing world population and increasing economic growth (particularly in emerging economies).
- Declining production and productivity growth rates in recent decades.
- Low investment level in the 1980s and 1990s, investment being a key factor for productivity growth.
- Low commodity stocks (stocks play an important role in adjusting supply to demand).
- External shocks (e.g. weather).
- Higher oil prices (same demand drivers), leading to increases in agricultural production costs (e.g. fertilisers) and these constraining agricultural supply.
- Higher oil prices and national policies stimulating the expansion of biofuels production, leading to an even higher demand for agricultural commodities,

and purchases from speculators buying stocks when prices were still low with the expectation of making profits by selling them when prices are high.
- Policies implemented by several importing and exporting countries to protect the own market and consumers also contributed to worsen the price spiral.

As Banse and colleagues (2008) pointed out, the high prices reflected a 'perfect storm' in which various factors have come together almost simultaneously, resulting in a peak in prices (Banse, 2008; Meijring, 2010).

The decline in oil prices since the second half of 2008 led to lower agricultural input costs. The agricultural supply response to higher agricultural market prices and lower input costs, together with a slight decline in food demand probably related to the world recession 2008/2009, should have brought the prices in 2009 back to the mid levels of 2007, but some commodities seem to have returned to a smooth upward trend.

It is difficult to quantify the relative importance of each factor in the price movements, and this importance varies from commodity to commodity. However, it is a key issue determining the transitory or permanent character, which must be known in order to project future market developments and to design adequate policies.

3.2.2 Impacts of high food prices

Impacts on developing countries

The impact of high food prices in developing countries depends on several factors. Commercial producers usually benefit from higher prices. Livestock producers are put under more pressure by both higher feed and energy costs and relatively flat product prices. Farm households that produce for their own consumption or for local markets are not much affected by international price fluctuations. But the urban poor and people in the major food-importing developing countries experience strong negative impacts and a higher share of their income will be expended on food. Moreover, importing countries are further impacted not only by higher commodity prices but also by higher transport costs.

Impacts on developed countries

The impact of high agricultural commodity prices is relatively small in developed countries. On the one hand, the share of the agricultural commodity in the final food product is small (35% or less; OECD), because food consumed in developed countries is further processed after leaving the farm gate. On the other hand, the proportion of income expended on food is small (10% to 15%). However, it has to be considered that these averages hide much more significant impacts on lower-income consumers, who spend a larger share of their total expenditures on food. Moreover, if higher agricultural commodity prices persist, they can contribute to higher inflation, which would be an important indirect effect of higher commodity prices. According to OECD-FAO Agricultural Outlook 2009, the high commodity prices of 2007/2008 were not translated into higher inflation rates. Inflation is expected to remain at a low level during the coming decade in most OECD economies, and there are some risks of deflation in some countries (e.g. Japan, Spain, Ireland, the UK).

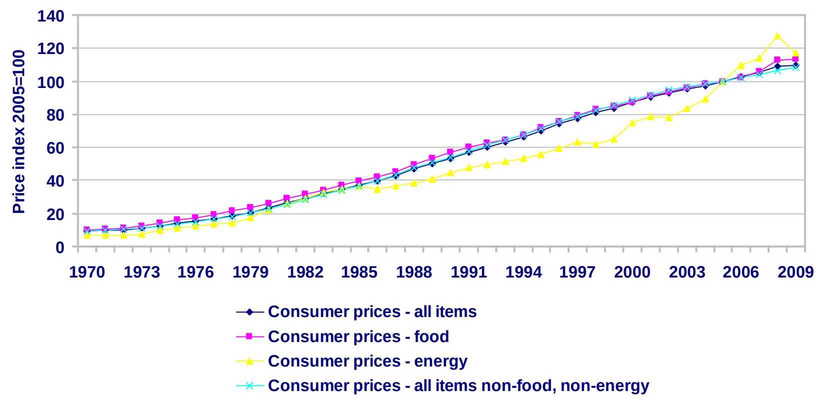
Food price Inflation

Food price increases have contributed very little to overall inflation in high-income countries. This is because the consumer food price increases were relatively moderate and because the share of food in the total consumer basket is small. The impact of food inflation on overall inflation is much larger in low-income countries.

Looking at the prices indices from the consumer perspective, figure 3.3 shows that the consumer energy prices in OECD countries grew slower than the prices of food and other items from 1986 until the beginning of the 2000s, and then there were sharp increases in consumer energy prices especially from 2007 to mid 2008. Energy prices then fall very rapidly, probably as a result of the worldwide recession. Consumer food prices increased slightly more than other consumer items in 2007/2008 and then stabilised. Consumer food prices undergo less oscillation than commodity prices in OECD countries.

To summarise, some important factors from the demand and also from the supply side contributed to the large price changes we have experienced in recent years. Fluctuations in the supply of and demand for food can have their origin in demographic, economic, climatic, technical or political factors and can lead to large price movements, enhanced by global commodity stocks being lower than ever. It is crucial to determine the permanent or transitory character of these factors in order to foresee which factors will shape future market developments.

Figure 3.3	Consumer prices trends 1970-2009 in OECD countries (2005=100)



Source: OECD data.

3.3 Demand for agricultural commodities

3.3.1 Driving forces

Population and economic development

The world demand for food commodities is mainly driven by demographic factors and economic development. In Appendix 1 we present some data about world population and economic developments. Economic per capita growth has to do with higher per capita income. More people and higher per capita incomes can be very easily translated into higher demand for food and therefore for agricultural commodities. But higher per capita income is related not only to more demand for food but also to shifts in diets:

- towards more processed food
- toward higher food quality
- from cereals towards meat, dairies and seafood, especially in emerging economies (China, India).

As coarse grains are a component of meat and dairy production, a growing demand for meat and dairies contributes to an increase in the cereals demand. However, the growth in meat demand has not been large enough to have induced the price crisis (see also figure 3.2) and the prices of meat have not risen as much as cereal prices (Derek Headey, 2009). But due to the significant growth rates, the consumption of animal products could play a more significant role on the demand side in the future.

Due to the low income elasticity of food, the decline since mid 2008 in agricultural commodity prices is related not only to the global recession but also to the large agriculture supply response to high commodity prices.

The macroeconomic conditions that favour economic growth, increased purchasing power and increased demand for agricultural commodities, as well as shifts in diets, are expected to continue, especially in non-OECD countries. Therefore it is expected to remain a permanent factor in the price determination of agricultural commodities, but it is not a new factor. This factor could slow down the long-term decline in real prices, but will probably not lift the prices permanently to higher levels.

Expansion of biofuels

Since 2004, rising crude oil prices and the implementation of biofuel policies have provided incentives to expand biofuel production in some countries. The expansion of biofuels production has led not only to an increased demand for agricultural commodities but also to large changes in land use (i.e. indirect land use change or ILUC), which has a significant impact on the supply side. A recent study by the FAO (OECD-FAO 2009) estimates that the increase in the demand for wheat and coarse grains for biofuel production contributed almost 60% to the total increase in demand for these grains between 2005 and 2007 (see table 3.2). However, the main use remains food and feed.

The lower growth in the demand for feedstock for biofuels production in 2007-2009 was probably influenced by the high commodity prices.

Biofuel production is expected to increase further but at a slower rate. Under current policy conditions, it seems that it will remain a permanent factor in the demand for and price determination of several agricultural commodities.

Section 4 offers further analysis of biofuel production.

Table 3.2	Changes in demand for wheat and coarse grains a): 2005-2007 and 2007-2009 (million tonnes)						
				Change 2005-2007		Change 2007-2009	
Uses	**2005**	**2007**	**2009**	**Amount**	**%**	**Amount**	**%**
Food	636	658	683	22	33	25	28
Feed	741	743	765	2	3	22	24
Other	156	158	167	2	3	9	10
Biofuels	78	119	153	41	61	35	38
Total	*1,610*	*1,677*	*1,768*	*67*	*100*	*91*	*100*

a) Coarse grains include maize, barley, oats, sorghum and other coarse grains.
Source: Based on table from Derek Headey (2009) from OECD Data.

Dollar devaluation
The declining value of the dollar is linked to a higher demand for US agricultural commodity exports, leading to higher prices in both US markets and world markets because of the increased demand (Farm Foundation, 2008).

Aggressive purchase by importers
As the demand for agricultural commodities increased more than the production until the middle of 2008, importing countries experienced declining market supplies and increases in domestic food prices. This led some countries to contract future imports even at world record prices (Trostle, 2008), thus leading to further increases in world demand for agricultural commodities and contributing to the upward prices spiral.

Commodity speculation
The study by Bindraban and colleagues (2008) analyses the impact of stockholders or speculators on stock demand and level. Stockholders may consider that low prices now mean higher prices in the future, and vice versa. Therefore, if low prices prevail, they will probably increase their stocks expecting a benefit when selling the stocks in future periods of high prices. The result would normally be that when prices are low, the behaviour of stockholders leads to demand increases, so that prices rise. When prices are high and stockholders are able to sell, prices are then pulled downward.

A substantial increase in speculative interest in agricultural future markets has contributed to boosting agricultural prices, but whether this factor is transitory or permanent is very uncertain.

3.3.2 Recent and future trends in demand

Although population growth rates have been decreasing in recent decades, the total world population is still growing, especially in emerging economies, and it will grow from the current 6.6 billion people to 9.1 billion people in 2050 (Appendix 1 provides some data about population and economic growth).

Despite the global recession and the readjustment of GDP forecasts, GDP will continue to grow, especially in non-OECD countries. Population and economic growth will remain a permanent factor in the future price determination, but it is not a new factor. This factor should slow the decline in real terms of agricultural commodity prices, but should not drive the prices permanently higher, because increasing agricultural production and productivity would mitigate the impact.

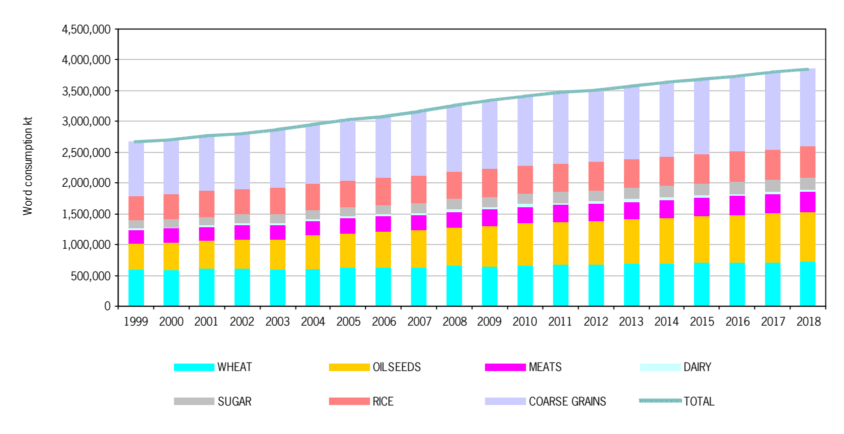
The world average demand for food has been growing in a relatively stable manner (see figure 3.4), but the demand for oilseeds and grains as inputs into biofuel production has undergone larger increases (figure 3.5). Between 2003 and 2007, two thirds of the global increase in maize production went to biofuels. The effect spread from maize markets to wheat markets, as farmers switched to maize production (see figure 3.5). Consumption growth of oilseeds (an input for biodiesel production) shows sharp increases from 2003 to 2004 (figure 3.5).

Demand for agricultural commodities for biofuel production is expected to increase in the future, but at a slower rate under the current policy mandates. While the demand for energy crops is expected to remain smaller than the demand for food and feed uses, biofuel demand is expected to be the largest source of new demand and seems to remain a permanent factor in demand and price determination.

Stocks levels of wheat, coarse grains and vegetable oils have fallen dramatically and are not expected to fully recover during the 2010s. This implies tight markets for a decade, but should not be a factor leading to permanent higher prices. The permanent or transitory character of the commodity speculation in futures commodity markets is very uncertain.

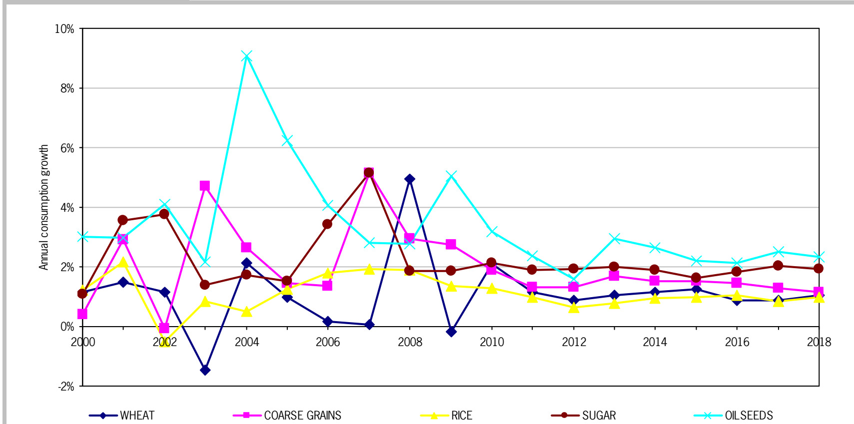
Changing demand patterns as a result of world income increases (e.g. shifting to more meat and dairies richer diets) may also increase the variability in world prices of agricultural commodities.

Figure 3.4	Demand development for agricultural commodities



Source: OECD data.

Figure 3.5	Consumption growth of agricultural commodities



Source: OECD data.

3.4 Supply of agricultural commodities

3.4.1 Driving forces

The supply of agricultural commodities is driven by the following factors:
- profitability perceived by farmers
- agricultural production capacity, being determined by crop yield, the amount of arable land suitable to support crop production and water supply
- investments
- stock levels
- external shocks (e.g. weather)
- policies.

Agricultural profitability: market prices and input costs
Farmer profitability is a key factor determining the farm production level and therefore agricultural supply. A farmer's income is dependent on input costs and output revenues, and price relationships between inputs and outputs determine the variability of net farmer income. Inputs costs are therefore a key factor in the determination of farmer income or profitability and farm production.

How do input costs influence farm production? Farmers must cover their production costs, but since they behave as 'price takers' they are not able to translate higher input costs into higher selling prices; therefore, farm income could very easily fall in the short term. The production decisions of the farmers in response to the increased input costs could be to purchase and use less fertilisers and pesticides, to change the mix of production (to less energy-intensive crops) or the producing technology (less energy intensive), or even to stop production until production again becomes profitable. Lower agricultural output leads to higher agricultural prices.

Lower inputs costs (e.g. lower energy costs) and high market prices give signals to the farmer to allocate more resources to agriculture. For example, lower energy costs allow farmers to increase their use of fertilisers and pesticides. Higher market prices also allow farmers to buy more fertilisers and pesticides, thus leading to increases in production. In turn, production increases would pull agricultural prices again down.

Both market prices and input costs in one period normally serve as a signal to producers when considering the coming period. For this reason, high market prices in one year would normally trigger more agricultural supply in the following year (Bindraban, 2008). When high market prices are combined with low input costs, the effect in production should be further enhanced. However, it is not clear that the price in one period is a good predictor for the subsequent period (Bindraban, 2008).

Higher input costs caused by higher energy prices are expected to continue, but it remains uncertain whether this factor will increase prices permanently or just slow the long-term downward trend.

Monitoring the input costs-output revenues should act as an instrument for foreseen supply shortfalls.

Productivity and investments

Productivity is one of the main factors determining agricultural production capacity and therefore agricultural supply. Thus, the interest in agricultural productivity increases is clearly related to food security issues. The concept of productivity is related to the comparison of changes in outputs given the inputs; for example, we speak in agriculture of output per hectare. In the literature, productivity mostly deals with technology and its changes over the time. The research and development of new methods of production, plant and seed varieties, pesticides, fertilisers and methods of irrigation makes it possible to increase food production from a given area and therefore to increase food supply. This is the main way to increase agricultural production capacity. It is noteworthy that agricultural production capacity is not the same as total production; several factors can drive total production under the production capacity level (low commodity prices, high inputs costs, etc.).

Investment and agricultural R&D are the motor for productivity increases. Lower investments in the agricultural sector in the 1980s and 1990s have led to current lower growth rates in productivity in the sector.

The OECD-FAO Agricultural Outlook 2009 assumes that crop and livestock productivity will continue to rise and that therefore the lower yields of recent years should remain a temporary factor. However, the achievement of the needed yields will require technology development and technology transfer.

Land

Available land suitable for crop production is another factor that determines agricultural production capacity. Some studies suggest that the current increase in yields of the major food crops will not be sufficient to meet demand in light of population and income growth without the expansion of the cropped area (Cassman, 2009). The total amount of land that is potentially suitable for growing crops has been estimated by several models (see Appendix 3).

The OECD agricultural outlook 2009 presents data from the study by Fischer and colleagues (2002). This study points out that total available land suitable for crop production in the world amounts to 4.3 billion hectares, and currently cultivated land is estimated to be 1.4 billion hectares. More than half of the additionally suitable land for agricultural production is in Africa and Latin America. Here we must take into consideration that land has already been allocated to other competing land uses, like forests, urban areas and protected areas, so that only 1.6 billion hectares remain available for crop land expansion.

Table 3.3 World land availability for agriculture a)

	World
Total land suitable for crop production and pastures	4.3
Currently cultivated	1.4
Subtotal available land	*2.9*
Forest, protected areas, urban areas	1.3
Total available land	*1.6*

a) In billion hectares.
Source: Fischer et al. (2002).

Some studies point out that to avoid the need to convert forest or protected areas into agricultural land requires a rapid acceleration in crop yield growth on existing farmland. According to environmental regulations, these higher yields must be achieved while reducing GHG emissions from crop production and preserving soil and water quality.

It is noteworthy to mention that there have been new developments within agricultural investment (i.e. private investment), such as 'land grabs'. Governments and corporations from China, Europe, the USA, South Korea and the Middle East attempt to buy land in other countries, especially in Africa.

Weather

Weather is an important factor that affects agricultural production and yields around the world. Adverse weather conditions have decreased the global cereal production in recent years and contributed to price increases. The severity of the impact of bad weather on plant and animal production depends much on the location and the type of events. The impact on the availability of food for final consumers depends on the food system. People who depend on their own food production are more rapidly affected, while those who have adequate purchasing power inside a complex food chain with global linkages in production, trade, processing and retail seem to be less vulnerable (Bindraban 2008).

Stocks

Stocks can play an important role in accommodating the demand for and the supply of food commodities when production is under demand. Normally the higher the level of stocks, the lower the impact of a potential shortfall in supply and the lower the price movements. Stocks are expected to remain at low levels in the coming decade and thus contribute to the tightness of markets.

Scarcity of phosphorus

A new factor that may be a limiting factor for agricultural production is the availability of phosphorus. Phosphorus is one of the major nutrients needed to sustain life (Smit et al., 2009). The low concentration of phosphorus in the soil makes it a limiting factor for plant growth. The natural delivery of phosphorus by the soil to plants determines the production capacity of unfertilised agricultural systems. Africa and Australia and such countries as Brazil and India are very dependent on external phosphorus inputs, as in these countries the soil's phosphorus content or its release rate is insufficient to allow high yields. External phosphorus inputs became available in the 19th century by mining phosphate deposits. The use of artificial phosphorus and nitrogen fertilisers allowed the intensification of agriculture and output growth. It also allowed the extension of arable land into regions that have insufficient phosphorus. Phosphorus is a finite resource that, according to Smit and colleagues (2009), cannot be replaced by another nutrient. Until now little is know about what would happen to global food production and consumption were phosphorus supply shortfalls to happen, and the concern is not yet on political agendas. The following text box presents some of the conclusions drawn by Smit and colleagues (2009) concerning the use phosphorus in agriculture production.

Box 3.2	Conclusions concerning phosphorus in agriculture
• Phosphorus, applied as fertiliser, is important for world food production, but it is a finite resource. At the current consumption rate, it is expected that reserves will be depleted within 125 years; however, with the growing consumption by the agricultural sector in response to the demand in a context of growing population and per capita incomes, changing diets and growing demand for biofuel crops, the reserves will last only 75 years. • Phosphorus deposits are located in only a few countries; Morocco and China control 50% of world reserves. • Soil erosion causes large losses of phosphorus that cannot be recovered with current technology. • Consequences of biofuel production: if production takes place on marginal lands the phosphorus fertility needs to be improved, leading to a higher demand for it; increased losses of phosphorus may occur when converting rangeland into arable land, because arable land tends to suffer more erosion; it is necessary to recycle the residues produced during the conversion of biomass into energy. • Inefficiency of phosphorus intake: [only about 20% of the phosphorus use in fertilisers is received by the population in the form of products.	
Source: Smit et al. (2009).	

Climate change

Little is known about the potential impacts of climate change on agricultural production. There is however ongoing research on this topic. The PESETA research project (JRC-IPTS, 2009) estimates climate change impacts on sectors in Europe. The results of this study regarding the agricultural sector estimate that climate change impacts on yield improvements would imply for 2020s an EU overall yield gain of 17%. All European regions would experience yield improvements, with the exception of some areas in central and southern Europe. The yield improvement in northern Europe will be caused by the longer growing season, while the crop productivity decreases in southern Europe will be caused by a shortening of the growing period.

3.4.2 Recent and future trends in supply

The 1980s and 1990s were characterised by agricultural surpluses, which did not stimulate investments in agricultural research. Lower investments in agricultural research have led to lower growth rates in productivity in the agricultural sector. The following table shows that the world consumption of a selected group of commodities has been growing steadily, with higher rates between 2003 and 2008, while production grew less than consumption in the period 2000-2003.

Table 3.4	**Growth in consumption, production and stock rates 1995-2009 a)**				
	1995-2000	**2000-2003**	**2003-2006**	**2006-2008**	**2008-2009**
Production, kt	10,000.00	10,015.00	10,030.00	10,040.00	10,045.00
Production growth	1.9%	1.0%	2.8%	4.7%	0.2%
Consumption, kt	2,205,235.19	2,315,280.72	2,461,251.21	2,606,027.13	2,660,057.33
Consumption growth	1.8%	1.7%	2.1%	2.9%	2.1%
Stocks, kt	701,954.83	490,162.98	524,777.59	573,945.62	579,532.31
Stocks growth	5.7%	-10.1%	2.4%	4.7%	1.0%

a) Wheat, coarse grains, oilseeds, rice, meat.
Source: OECD Data.

The annual growth rate in the production of agricultural commodities has slowed down. Between 1970 and 1990, grains and oilseed production increased at an average of 2.2% per year. From 1990 to 2008, the rate declined to 1.3%. Biofuels production not only increased the demand for agricultural commodities, but also led to land use changes, which implied a reduction in the supply of wheat and other crops that compete with food commodities used as feedstock for biofuel production. Higher energy prices and therefore higher agricultural input costs have added to the shortfalls in agricultural supply.

Thus, several factors contributed to the agricultural supply shortfalls, such as lower productivity growth, bad weather, high energy costs and low stocks, and therefore to the strong price rises. However, the agricultural supply response to the higher market prices and lower inputs costs has been very strong (see table 3.5).

Table 3.5 **Supply responses to rising food prices: production in 2008/2009 compared to 2007/2008**

	Maize	Q(%)	Rice	Q(%)	Wheat	Q(%)
Major Consumers	Central America	12.2	East Asia	9.2	North Africa	-13.2
	EU-27	7.2	Central America	0.6	East Asia	17.4
	Sub-Saharan Africa	18.6	Sub-Saharan Africa	20.2	South Asia	9.7
	Southeast Asia	18.5	Middle East	-13.9	Sub-Saharan Africa	25.8
	North Africa	4.9	South Asia	10.4	Middle East	-22.1
	East Asia	22.9	Indonesia	3.5	Bangladesh	-7.1
	Mexico	16.7	China	10.0	Ethiopia	41.6
	Peru	16.0	Brazil	2.2	Egypt	4.8
	Tanzania	17.8	India	10.9	China	17.6
	Congo (DRC)	-1.1	Bangladesh	8.5	Pakistan	5.4
	Malawi	47.9	Congo (DRC)	0.0	India	14.2
	South Asia	12.7	Ghana	-3.7	Uzbekistan	7.6
	Nigeria	17.9	Madagascar	12.7		
	Ethiopia	52.7	Malawi	69.8		
	Ghana	1.9	Nigeria	30.7		
	China	23.3	Philippines	10.9		
	Kenya	-20.2	Tanzania	29.2		
	Average (Kenya)	16.8	Average	12.4	Average	8.5
Major Exporters	Thailand	4.3	South America	4.1	Brazil	27.6
	Brazil	19.0	Southeast Asia	5.4	EU-27	16.8
	South Africa	34.6	Vietnam	5.1	South Africa	10.9
	Former Soviet Union	60.4	Egypt	6.1	Former Soviet Union	43.8
	United States	11.2	Australia	-81.3	Ukraine	92.6
	Ukraine	56.2	Thailand	8.0	Kazakhstan	10.0
	Argentina	-26.8	United States	-4.4	North America	18.7
			Pakistan	20.7	Argentina	-44.9
					Australia	2.3
	Average (excluding Argentina)	25.3	Average (excluding Australia)	5.1	Average (excl. Argentina & Australia)	31.5

Source: Derek Headey 2009 from USDA (2009) data.

Productivity growth has contributed more to the increase in agricultural output occurred since mid 2008 than the expansion of the planted area. Existing arable land is being used more intensively in most regions, mainly due to double or multiple cropping practices and reduced fallow area.

High international agricultural commodity prices together with declining energy prices have given signals to farmers to allocate more resources and to increase agricultural production. Therefore, supply responses have been very strong and have contributed to the decline in prices since the second half of 2008. However, the level of response varies between countries. According to the OCED-FAO Agricultural Outlook 2009-2018, the cereal sector responded with a 7% expansion in output. However, the decomposition of this expansion shows a 13% output expansion in developed countries, while developing countries expanded their output by only 2%. The lower response from part of the world points to the need for policy reform and additional investment in productive agriculture, especially in many developing countries.

Several studies emphasise that global agricultural productivity growth has outpaced food demand for decades now. Even if a much larger share of production goes to biofuels, increased investment and utilisation of unused cropland should ensure an adequate food supply. While this would make future food supply more expensive, it is unlikely to generate long-term food shortages. However, countries with rapid population growths may become increasingly reliant on imported food unless productivity is improved. Further analysis of land availability, potential productivity growth, economic and environmental impacts on developed and developing countries should give more clarity to one of the major concerns: food security.

The OECD-FAO agricultural outlook assumes that crop and livestock productivity will continue to increase in the long term and considers that there will be significant potential further increases over the next 10 to 20 years. The realisation of this potential requires the development and adoption of new technologies. Therefore, the lower crop yields in key producing regions in recent years are likely to be temporary. Without considering climate change impact, adverse weather, water and other constraints that could lead to permanent reductions in yields, higher agricultural output and yields are expected. Not achieving the yields required to meet the increasing demand could have dramatic consequences.

Oil and energy prices are important factors in the production costs of agricultural commodities and food, and ultimately in the market prices of these goods. The expected higher energy prices in the future should raise future agricultural commodity prices to higher average levels, but it is more uncertain whether the long-term downward trend would reverse.

In 2007, adverse weather events affected agricultural production and yields around the world: northern Europe had a dry spring, south-eastern Europe experienced a drought, Ukraine and Russia experienced a second year of drought, a large area of the USA had a hard winter, and Canada's summer growing season was hot and dry, resulting in lower yields of wheat, barley and rapeseed. North-western Africa experienced a drought in some of its major wheat and barley growing areas, Turkey suffered a drought that reduced yields in its non-irrigated production areas, Australia was in the third year of the worst multi-year drought in a century, and Argentina had a late freeze followed by a drought that reduced its maize and barley yields. As a consequence, the global average yields of grains and oilseeds dropped for the second year in a row, leading to lower production and lower stocks at the world level. According to the historical data, two sequential years of lower global yield occurred only three other times in 37 years (Trostle, 2008).

3.5 Role of policies

In the context of sharply rising world commodity prices, some countries took protective policy measures to reduce the impact of rising prices. Some of these measures indirectly contributed to the higher world food prices in recent years. The policy responses of various governments to high food prices have been diverse in both nature and effectiveness. According to FAO, three broad categories of responses can be distinguish: 1) those that target consumption, 2) those that target trade and 3) those that target production (Beekman and Meijerink, 2010). Most of the measures are related more to short-term than to long-term effects.

1) Targeting consumption
The distribution of basic food commodities, the provision of cash to buy food, the provision of consumer price subsidies (Morocco and Venezuela), all of which have led to market distortion because they affect producers' initiatives.

2) Targeting trade

Exporter policies*:* elimination of export subsidies (China), introduction of export taxes (China, Argentina, Russia, Kazakhstan, Malaysia), export quantity restrictions (Argentina, Ukraine, India, Vietnam) and export bans (Ukraine, Serbia, India, Egypt, Cambodia, Vietnam, Indonesia, Kazakhstan). These measures were intended to reduce the increase in prices at the national level. However, they have led to lower supply availability of food in the world and consequently to higher food prices.

Importer policies*:* such policies as the reduction of import tariffs (India, Indonesia, Serbia, Thailand, EU, Korea and Mongolia) have contributed to an increase in global food demand. This has led to food supply shortages and consequently to higher prices.

3) Targeting production

Reduction of producer taxes, production subsidies, input subsidies (fertiliser and seeds), procure grain at low prices from domestic producers for stockholdings.

Although such policies can provide incentives to produce biofuels in the short term, they tend to be costly in the long term because they provoke a suboptimal use of resources.

Biofuels policies

Biofuel policies have provided incentives to increase biofuel production in recent years. In some countries, biofuel polices are an attempt to respond to climate change mitigation needs, while other countries are more driven by energy security concerns and are aiming at less dependency on energy imports.

The EU Biofuels Directive requires that Member States should meet 5.75% of the energy demand for transport through the use of biofuels by 2010 and 10% by 2020 (assuming the availability of second-generation biofuels). The spectacular growth in the German market (54% of EU-27 biodiesel production in 2006) is the consequence of national legislation that grants full tax exemption for biofuels. This exemption has been recently rescinded (Birur, D., 2009).

In the USA, subsidisation of ethanol began with the Energy Policy Act of 1978. In 1990 the Clean Air Act required petrol sellers to have a minimum percentage of oxygen in their product. The demand for ethanol offered good prospects because of its larger percentage of oxygen compared to its main competitor, MTBE (methyl tertiary butyl ether). However, MTBE continued to be the favoured way of meeting the oxygen requirements during the 1990s, as it is produced from petroleum products by oil companies and was cheaper than ethanol. Nevertheless, since MTBE is highly toxic and the US Environmental Protection Agency issued rules eliminating the oxygen requirement in May 2006, oil companies increased their production of ethanol.

In 2004, the Chinese government introduced in some provinces the compulsory use of 10% ethanol blended into petrol (E10), and in 2006 expanded the programme to other provinces. Bioethanol production amounted to approximately 1 m tonnes in 2005 and 80% of bioethanol is made from maize. The Chinese government wants to regulate maize-based ethanol production and to diversify the sources of bioethanol production, especially to cassava. Technological innovation is required to develop cassava-based bioethanol production (Koizumi 2008).

Common Agricultural Policy

The 2003 Common Agricultural Policy (CAP) reform eliminated income-support payments based on production volume and introduced the Single Farm Payment, aiming at the decoupling of direct payments from production. This decoupling might have led to a decline in agricultural output, which probably contributed to the rise in world agricultural prices. The CAP reform income support together with trade liberalisation measures should give opportunities to exporting and importing countries to increase production.

The global supply of agricultural commodities has responded swiftly and strongly to higher prices, supported by a relaxation of production constraints in the CAP, notably the suspension of the mandatory set-aside of arable land and the increased milk quotas from 2008 onwards (IPTS report, European Commission).

Trade liberalisation (WTO)

Worldwide trade liberalisation of agricultural products offers chances to exporters in developing countries that are direct competitors with the EU on grains, sugar or beef (Brazil, Argentina, Thailand, Malaysia). For net food importers (e.g. sub-Saharan countries), trade liberalisation in developed economies such as the EU or the USA implies a higher food bill, since agricultural prices increase. Some of these countries will have incentives to increase agricultural production or even to become exporters, but this will probably be confined to only a few countries.

Sustainable development

Food security was for many years confined to developing countries but it has recently reappeared on the political agenda of developed countries. Food security is therefore an issue of growing concern. With increasing population (even though population growth is declining, world population is still growing considerably), changing diets and growing demand for energy crops (biofuels production), a general concern is whether food supply will keep up with demand. Most studies agree that agricultural productivity will have to increase at rates that exceed those known until now. The use of genetically modified organisms (GMOs) may offer potential and its advantages/disadvantages should be further research and regulations should be improved.

Stimulated by higher energy prices and policies, biofuel production has undergone considerable development in recent years. It seemed to be an attractive alternative to fossil fuels by contributing to reducing greenhouse gas emissions, climate change impacts and fossil fuel dependency, and to improving energy security, farm income and rural development. But concerns about the induced land-use changes, the smaller greenhouse gas savings than expected, and the impact on global food prices, food security concerns and the economic viability of biofuels production have reduce the initial expectations (Stehfest et al., 2010)

3.6 Projections of future food prices

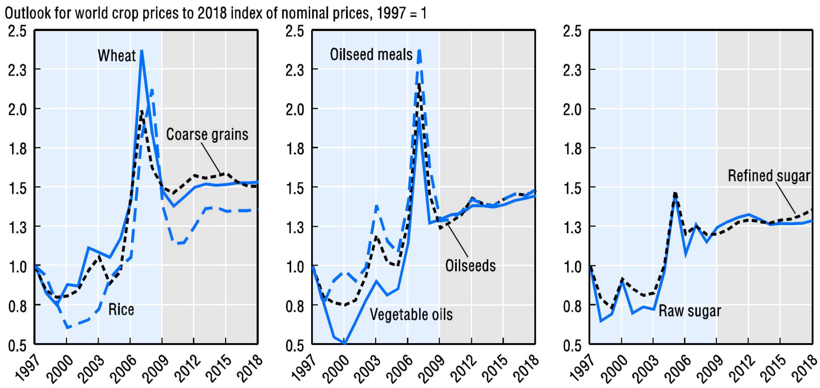
OECD-FAO price projections for the period 2009-2018 are shown in figures 3.6 and 3.7. The general expectation is that these prices will in nominal terms be substantially higher than in the past 10 years, but lower than in 2007-2008. On the demand side: an increasing world population, increasing world welfare, changing food habits (mainly from vegetal to animal products) and increased feedstock demand for biofuels. On the supply side: underinvestments in agriculture (especially in developing countries in Africa), increasing competition for land and water, higher energy and fertiliser prices, increasing shortages of phosphate and other mineral nutrients, and the impacts of climate change.

Much depends on the speed of economic recovery from the current crisis, the impact of the crisis on investments in world agriculture and world food sectors, and longer-term productivity growth and efficiency improvements in international food chains. Underinvestment in world agriculture and food combined with a rapid international economic recovery might even lead in a few years' time to similar price spikes as in 2007-2008. However, the other way around is also possible: a slow economic recovery combined with an acceleration of supply growth might result in lower international prices (see OECD-FAO (2009) for sensitivity analyses).

An additional uncertainty for the EU is the exchange rate between the euro and the US dollar. The price projections in figures are calculated in US dollars. A weaker dollar means a smaller increase in euro prices. However, a change in the dollar value usually also leads to an opposite change in dollar prices.

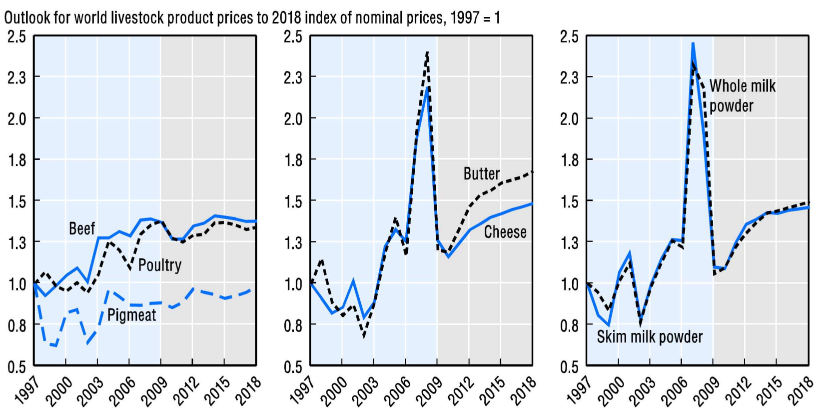
The OCDE-FAO and USDA price projections (see figure 3.8) differ especially for rice, while both projections put maize prices at similar price levels in 2018.

Figure 3.6	OECD-FAO price projections for crops 2009-2018



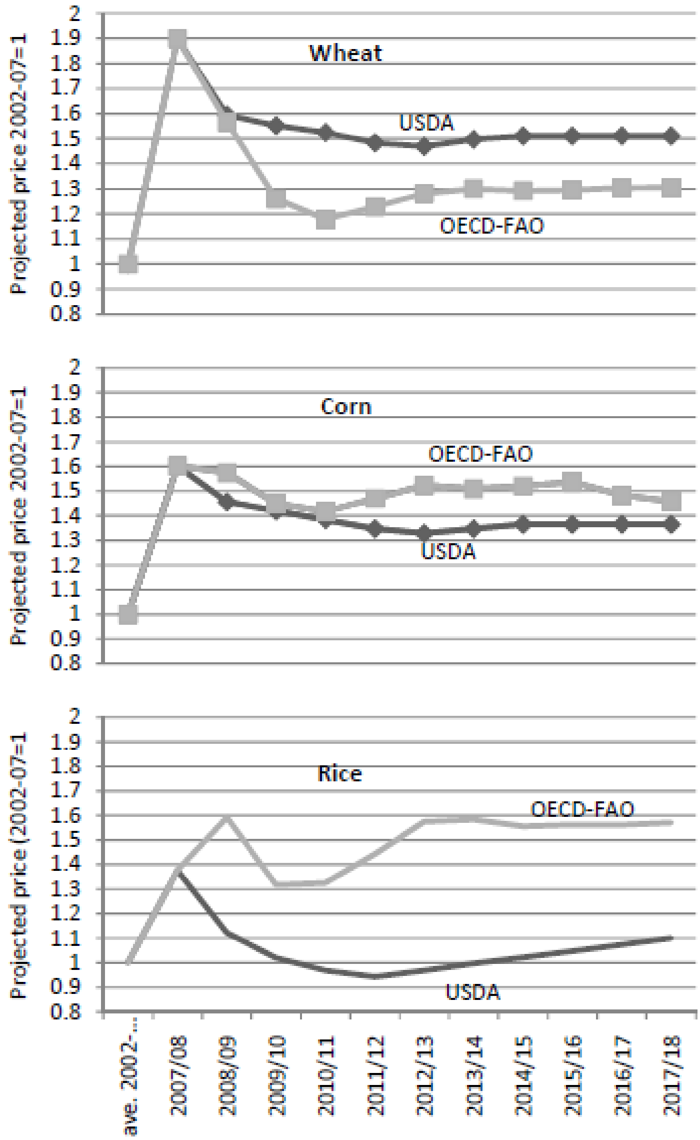
Source: OECD-FAO (2009).

Figure 3.7	OECD-FAO price projections for livestock products 2009-2018



Source: OECD-FAO (2009).

Figure 3.8 **FAO and USDA projection of prices 2009-2018**



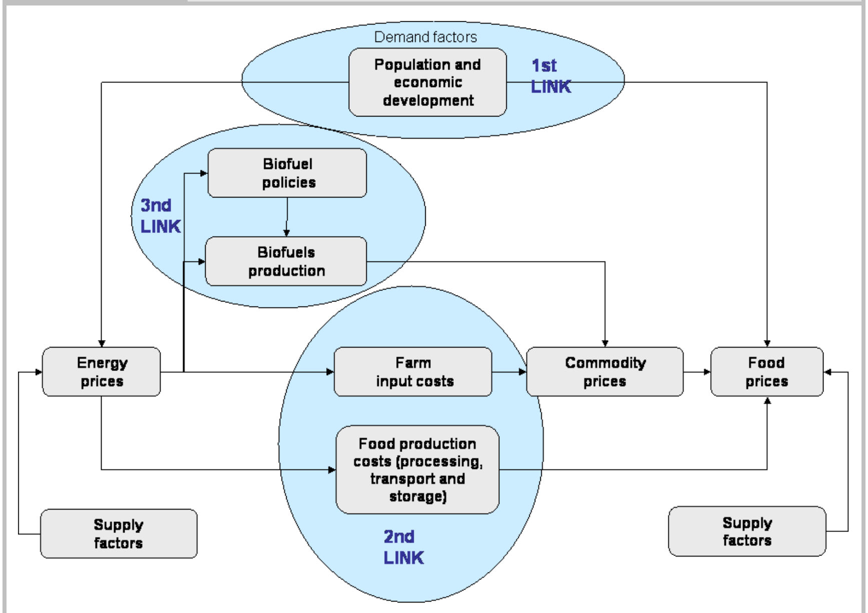
Source: Headey et al. (2009).

4 Links between energy and food markets

4.1 Introduction

In the preceding sections we described the energy and food markets and discussed the main driving forces of supply and demand. This analysis helped to determine which factors contributed to the large increases in energy and food prices from 2003 to 2008, which factors brought energy and food prices in 2009 to lower levels, as well as which factors might shape the markets in the future. In this section, we analyse the relationships between energy and food, focusing first on the common demand-driving factors, then on energy as input for agricultural production and on the agricultural sector as an energy producer. Finally, the transmissions of higher energy prices into higher agricultural commodity prices and, in turn, into higher food prices are explained.

Figure 4.1 Links between energy and food markets



Source: LEI.

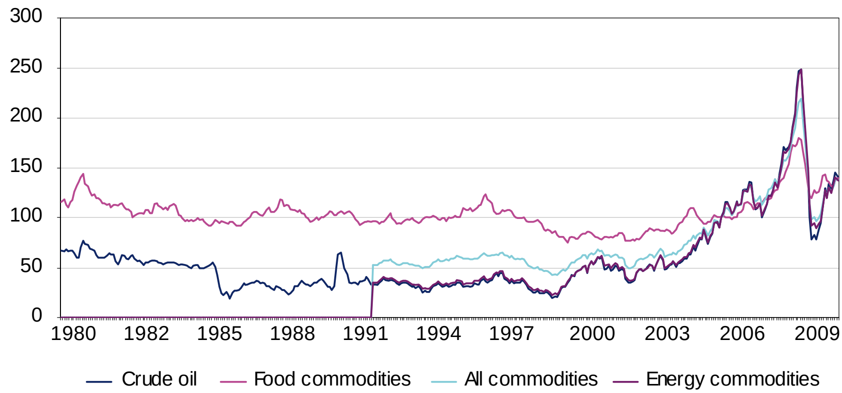
Figure 4.1 shows how the energy and food markets are connected, and the three main links between them: common demand drivers, energy as input and agriculture as an energy producer.

The first two links are not new while the third has developed very strongly in recent years. The first two links have a relatively larger impact on the developing world: on the one hand, population and economic growth is mainly happening in the developing world; on the other hand, as the further mechanisation and modernisation of agricultural production systems that would be needed in developing countries in order to achieve the necessary yields would imply a greater energy demand, countries that depend on food imports will be more impacted by higher transport prices. The third link - especially biomass production for biofuels production - has an impact in both developed and developing countries, because various factors have driven many developed and developing countries to initiate policy mandates that support and stimulate biofuels production. Biofuels are one of the few current alternatives to conventional fuels in the transport sector. Whereas high energy prices create incentives to develop biofuels production, the current higher demand for biofuels has probably more to do with government mandates. The impact of this link on energy markets is small while the consequences for agricultural markets are rather large.

4.2 Common demand drivers

Figure 4.2 shows that energy, food and commodity prices have followed a similar evolution pattern that is partly linked to their main demand drivers: population and economic development.

Figure 4.2	Trends in nominal prices of primary commodities 1980-2009 (2005=100)



Note: crude oil index: average petroleum spot index of UK Brent, Dubai, and West Texas; agricultural commodities index: cereals, vegetable oils, protein meals, meats, seafood, sugar, bananas and oranges; energy index: crude oil (petroleum), natural gas and coal.
Source: IMF data.

There is a common link between energy and food that is related to fulfilling basic requirements, such supplying food and energy to increasing populations that have increasing incomes, and to changes in demand that accompany economic growth. On the demand side, demographic and economic developments are therefore key factors. In food markets the impact of population and economic growth implies not only increases in demand but also changes in dietary preferences, such as a shift from cereals to higher protein foods. These dietary changes still have little impact on the total demand for food (see section 3.2.1), but may do so in future. On the supply side, there are rigidities in both food and energy markets, so that unexpected or underestimated demand increases are fairly rapidly translated into higher prices. In both markets, supply takes some time to adjust.

The intensity of the impact varies among the commodity types shown in figure 4.2. Between 2005 and 2008 food prices rose by about 175%, energy prices by about 250% and all commodities by almost 225%. In 2009 food prices declined but remained at a level that was almost 40% higher than in 2005. Energy prices first fell in 2009 to 2004 levels, and at the end of the year were about 40% above the 2005 level. All commodity prices first dropped to 2005 levels, and at the end of the year were about 40% higher than in 2005.

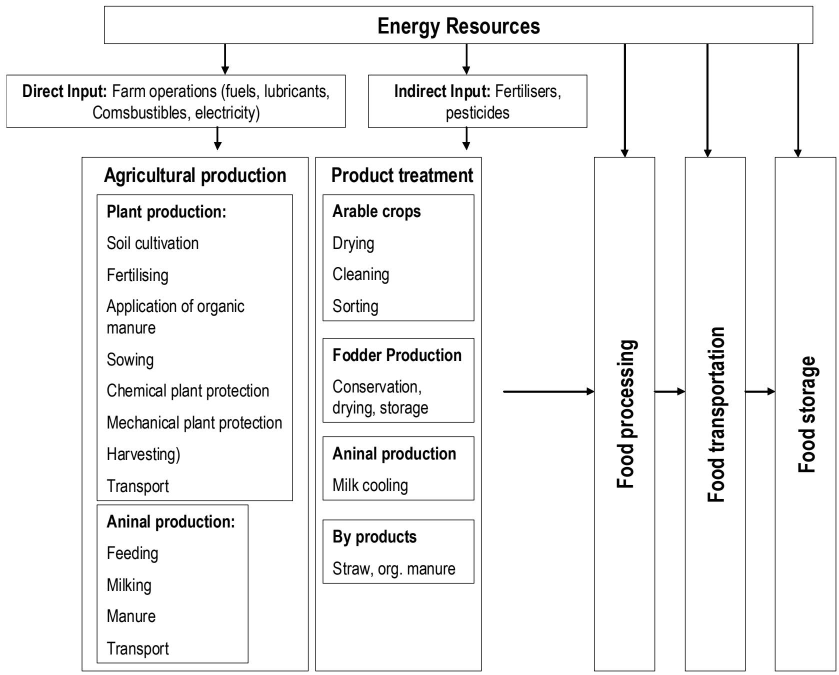
One of the reasons for the larger decline in energy prices could be that energy demand is probably more elastic than was previously thought (Van der Linde, personal communication). Recent developments show that the sharp increases in oil prices reduced US demand for oil, contributing to lower oil prices. Food demand remains quite price and income inelastic. The intensity of the impact on prices will depend on the intensity of the demand change as well as on the possibilities of adjustment of supply. Note that figure 4.2 presents aggregate data. In Section 3 we explain why some commodities (e.g. sugar and meat) did not undergo the same price developments.

To summarise, the first link is an indirect link: although it does not reflect an interaction between energy and food, the factors included in this link are major factors that affect price determination in both markets. This link has to do with common characteristics that affect both markets at the same time. First, macroeconomic developments exert a significant pressure on the demand side of both energy and food markets: an additional 2.5 billion people in 2050 will need food, housing and energy. Second, in both markets supply takes some time to adjust and sudden demand and/or supply shocks can be easily translated in the short term into large price movements; the level of stocks can play an important role by closing the gap between the demand for and the supply of food and energy. Third, speculation is a factor that affects both markets.

4.3 Impact of energy costs on food production and prices

The sharp upward trend in crude oil prices began in 2003, and immediately put a constraint on agricultural production. The sharp upward trend in food prices began in 2005. We come then to an additional link between energy and food markets that has to do with the fact that energy is a key input factor in the agrifood chain and that, therefore, changes in energy prices have a direct impact on agricultural and food production costs. The level of input prices (e.g. the price of energy) is a conditioning factor for agricultural production and in turn for agricultural commodity prices. Moreover, increases in input prices in the food industry can be more easily translated into higher consumer food prices. Energy is consumed at the various stages of the food chain (see figure 4.3).

Figure 4.3 Energy consumption in the food chain



Source: Based on representation of Kraenzlein (2009).

In our analysis we consider separately energy use in farm production activities and energy use in food processing, transportation and storage until the commodities reach the consumer. This distinction is relevant for the analysis because the transmission mechanisms of higher input costs, caused by for example higher energy costs, differ between the farm sector and the food processing and distribution sector.

4.3.1 Energy use in agriculture

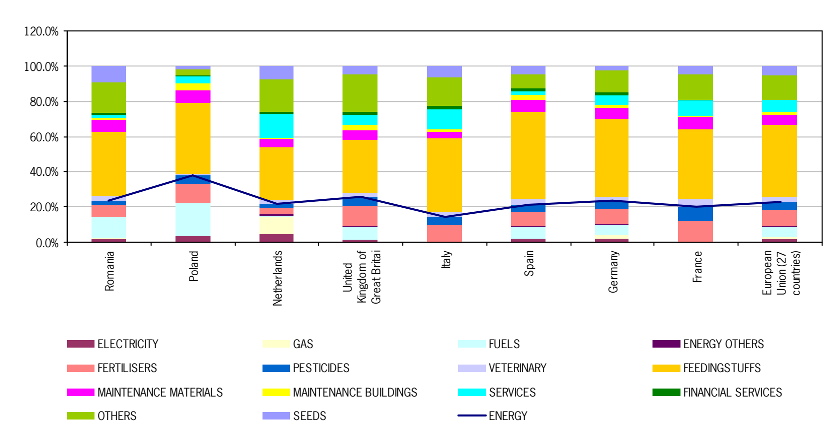
The share of the agricultural sector in world energy demand is relatively small. In OECD countries, the agricultural sector is responsible for an estimated 3–5% of total energy use (FAO, 2004). In the energy balances for the EU-25, the agricultural sector accounts for 2.27% of total energy use (including coal, crude oil, petroleum products, gas, nuclear, hydro, geothermal, solar, waste, electricity, heat and others) (Kraenzlein, 2008; OCDE-IEA, 2005). Even though the energy demand of the agricultural sector is small compared to other production sectors, agricultural production (i.e. crop and animal production) requires a significant input of fossil fuels and other energy sources. Increasingly mechanised agricultural production needs timely energy supplies at various points of the production cycle to achieve optimum yields (Schnepf, 2004).

Share of energy in agricultural production costs

Agricultural production costs are a combination of variable and fixed costs. Variable (or operating) costs can be directly attributed to the production decisions in the agricultural year, such as application of seeds, fertilisers, fuels, chemicals, etc. In contrast, fix costs are not directly related to annual production decisions and include land, machinery, ownership costs, taxes, interest, etc.

Knowing the share of energy in agricultural production costs is necessary for understanding the impact of energy prices changes on the production decisions of farmers. The following figure presents some data on the European agricultural sector in 2008.

Figure 4.4 **Agricultural intermediate expenses by type in the EU 2008**



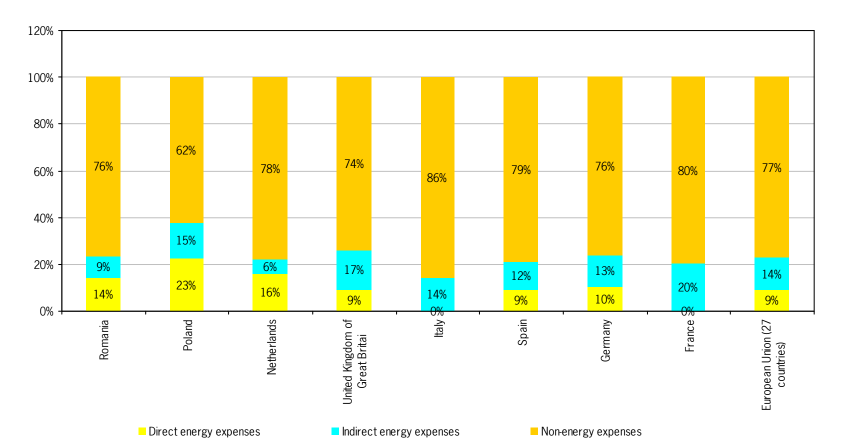
Source: Based on Eurostat data prepared by Verhoog, D. (LEI, 2010).

The agricultural sector consumes energy both directly and indirectly. Energy in agriculture is directly used as fuel or electricity to perform farm activities (to operate agricultural machinery, irrigation systems and pumps that run on electricity, diesel and other energy sources). Energy is also required in processing and conserving agricultural products and in their transportation and storage. Indirectly use of energy is found in the fertilisers and chemicals produced off-farm, which either are produced from energy or are heavy users of energy in their production process. Another indirect use of energy is the energy consumed by the steel foundries in producing the steel that will be used for producing tractors.

Some studies emphasise that the combined effect of direct and indirect energy use in agricultural production is small compared with the energy used beyond the farm gate: food processing, retail chain and food distribution (transport and storage), and then domestic storage and cooking. However, energy costs represent a significant share of agricultural production inputs.

Total EU energy expenses in agriculture account for 23% of total agricultural intermediate expenses (excluding labour and capital fix costs), varying among countries between 19% and 40%.

Figure 4.5 **Direct and indirect energy expenses in total farm intermediate expenses in the EU 2008**

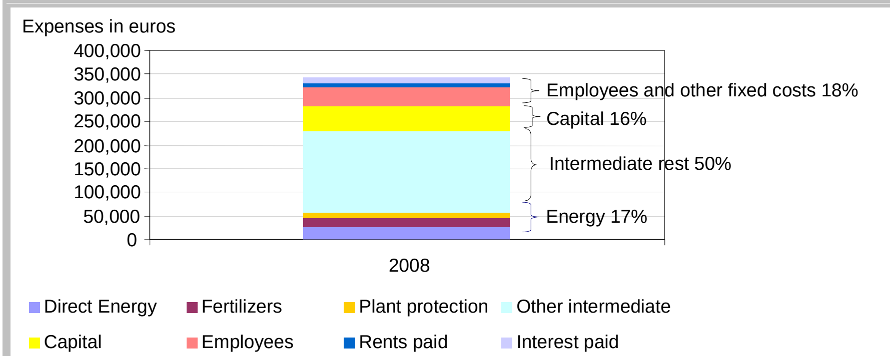


Source: Based on Eurostat data prepared by Verhoog, D. (LEI, 2010).

Looking at the indirect energy expenses in the EU agricultural sector, fertilisers account for 9% and plant protection products, herbicides, insecticides and pesticides account for the other 4%. The direct energy expenses at the EU level comprise electricity expenses (2%), gas (1%), and fuels and propellants

(6%). The direct energy costs are significant but small when compared to total production expenses. Total energy costs, including indirect energy expenses (use of fertilisers and pesticides), can play a much more important role in farm production costs and therefore in farm net revenues and production level. The share of energy costs in production expenses varies from year to year depending on the number of hectares planted, crop and livestock mix, energy prices (Randy Schnepf, 2004) and production technology. The following figure shows the share of energy in total agricultural production costs.

Figure 4.6 **Agricultural total expenses in the EU 2008**



Source: Based on Eurostat data prepared by Verhoog, D. (LEI, 2010).

In the US agricultural sector, the energy share in total crop production expenses is about 15%, of which 5% are direct and 10% are indirect energy expenses (USDA 2009).

In developing countries, mechanised agriculture and modern irrigation techniques are still largely underdeveloped. Mechanised agriculture includes the use of tractors and other equipment for land preparation, planting, cultivation and harvesting. The two main objectives of mechanising agriculture are to increase the productivity of agricultural production and to improve the quality of agricultural work. The further mechanisation of agriculture and the modernisation of irrigation techniques that are required for achieving the needed higher yields implies a higher energy need in the agricultural sectors of developing countries.

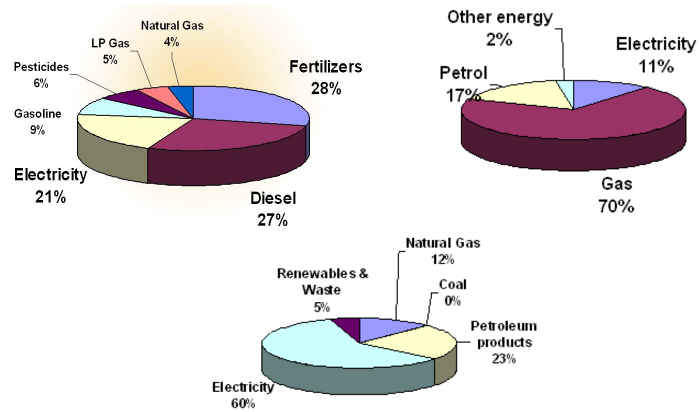
Energy use in agriculture by energy source and type of activity

The share of energy in agricultural production costs and the type of energy used vary widely according to production activity, management practice and location. In the following figure, energy consumption in agriculture is differentiated by energy source in different locations that might be also influenced by different activity types and production practices. In general this figure shows that agriculture is very dependent on fossil fuels.

Diesel, fertilisers, petrol and pesticides together represent 70% of the energy use in US agriculture. In the Dutch agricultural sector, gas and petrol represent 77% of total energy expenditure. As another example, in the UK, electricity represents 60% of total energy consumption and is produced from gas and coal (34% and 20%, respectively), which means that the UK agricultural sector also relies on fossil fuels. These data show that the agricultural sector is very dependent on fossil fuels and is therefore very sensitive to the high volatility of fossil fuels prices.

The largest share of fossil fuel usage in industrial farming is related not to transporting food or fuelling machinery, but to producing artificial fertilisers and pesticides. The fertiliser synthesising process is very energy intensive, and mainly uses gas. Producing and distributing fertilisers and pesticides also requires the consumption of liquid fuels.

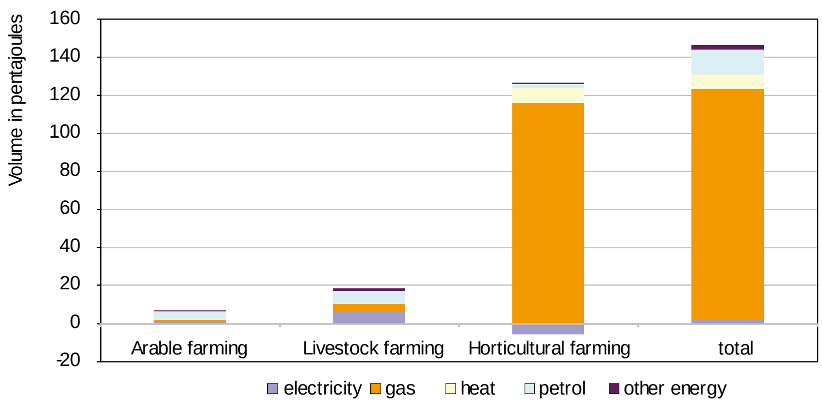
Figure 4.7 **Farm energy use by source (USA, 2002) (left), farm energy expenditure by source (Netherlands, 2007) (right), farm energy consumption by energy type (bottom) (UK, 2005)**



Source: Minarowski (2004), LEI Wageningen UR (2007), Warwick HRI the University of Warwick (2005).

Not surprisingly, energy costs affect some agricultural activities more dramatically than others. The energy type also varies with the activity.

Figure 4.8 **Dutch farm energy consumption by activity and energy type 2007**



Source: LEI Wageningen UR (2009).

Energy intensity and energy efficiency in agriculture (input/output)
Higher energy costs in the 1970s pushed all economic sectors to increase their energy efficiency. Agricultural producers responded by making trade-offs, replacing more expensive fuels with less expensive fuels, shifting to less energy-intensive crops and employing energy-saving production practices where possible. Energy intensity (i.e. energy consumed per unit of total output) in the agricultural sector has steadily declined over time due to gains in energy efficiency, and this trend will probably continue.

There are still potential energy savings that could be made in agriculture, especially in developing countries. Achieving this potential requires further investments in research and technology.

Trends in agricultural energy inputs and costs
According to the USDA, the production expenses of the agricultural sector declined in 2009 for the first time since 2002, but this came after the two largest year-over-year increases in expenses on record. The global recession has put downward pressure on markets for farm inputs as well as commodities. In particular, expenditures on fuels, fertiliser and feed are down from 2009.

Fertiliser prices rose steadily between 2002 and 2008 (annual average prices paid climbed by 264%). In 2009, prices paid for fertiliser dropped by 26%. Annual average prices paid for fertiliser are forecast to drop another 7% in 2010, although they are expected to rise from their present level as the price of natural gas (the primary source of nitrogen fertiliser) increases. Projected use of fertiliser is expected to grow slightly. Pesticide prices rose in 2007/2008 by 8.3%. Like fertiliser prices, prices paid for fuel rose dramatically between 2002 and 2008. In 2009, average prices paid for fuels fell 34%. In 2010, they are forecast to be up 13%.

Although the short-term projection foresees lower input costs, the further development of oil and energy prices is a critical issue for determining the future production costs of agricultural commodities. The recent energy outlook projects higher energy prices until 2030, which should lift future agricultural production and commodity prices to higher average levels in the future, but whether this would change the long-term downward trend in real agricultural commodity price remains uncertain. In Section 5 we project long-term commodity prices in two oil prices scenarios. The results are also discussed in Section 5.

Price transmission mechanisms: the impact of changes in energy costs on agro-commodity prices

As we have seen, energy is an important component of farm operating costs. The impact of higher agricultural input costs caused by higher energy prices on agricultural commodity prices depends on the responsiveness of agricultural producers. Individual farmers behave as 'price takers', which means that they do not have the ability in the short term to pass on higher input costs through the marketing chain. Therefore, increases in energy prices can only be translated in the short term into a reduction of farm income. How agricultural producers respond to expected lower farm incomes caused by higher energy prices depends on the time horizon under consideration. If farmers perceive the energy price change as temporary, their efforts will be directed to economising on fuel by, for example, applying smaller amounts of fertilisers and pesticides, or even switching between fuels if such makes economic sense. However, in the short term major inputs have already been purchased, so that the response of the farmer is limited and income losses are very likely. On the other hand, if farmers perceive energy price changes as permanent, they will try to modify the farm's activity mix and production practices (e.g. turning to less energy-intensive crops) to adjust to the new revenue-cost structure. A reduction in the amount of fertilisers and pesticides applied may be obtained by changing to extensive production methods. Exit from the market could be observed if variable costs are expected to be higher than revenues and agriculture becomes unprofitable. This type of adjustment could then lead to less productivity and less production, provoking higher agricultural commodity prices.

However, as a second-order effect, the higher agricultural commodity prices would encourage farmers to put more resources into agriculture and thus increase productivity, which would mitigate the initial commodity price increases. It is therefore important to consider that the negative effect on farmer's income of higher energy prices is also mitigated in a context of increasing agricultural commodity prices. The input/output price ratio at farm gate in one period normally serves as signal to agricultural producers to adapt their production decisions for the subsequent period. Therefore, higher commodity prices lead to more crops being sown in the subsequent period. Nevertheless, how good prices are in one period as a predictor for prices/production in the subsequent period is still under research (Bindraban, 2008). Higher commodity prices enable farmers to buy more inputs (e.g. fertilisers) to use in the subsequent period, leading to higher yields and higher supply, and higher supply of agricultural commodities will bring the commodity prices back to lower levers. Here, the adjustment mechanisms between input-output prices and production are a crucial issue. If the upward trend in energy prices becomes permanent, will the long-term downward trend in commodity prices in real terms be reversed? Section 5 presents a simulation of food prices in two crude oil price scenarios.

Input costs monitoring together with market food price monitoring are key issues for future developments of agricultural supply and prices. In other words, agrifood chain analyses and market information systems are needed.

Box 4.1	**Estimate of impacts of energy price scenarios on crop production costs in the USA**

The following crude oil and gas prices scenarios are considered:

	2007	**2020**	**2020**	**2020**
	reference	**baseline**	**scenario 1**	**scenario 2**
Crude oil price (USD/barrel)	67.0	93.9	119.4	128.3
Natural gas (USD/MBtu)	11.3	14.5	19.6	21.7

Results:

	Baseline	**S1**			**S2**		
	2020	**2020**	**change**	**%**	**2020**	**change**	**%**
Maize	289.75	330.08	40.33	14	345.00	55.25	19
Soybeans	139.60	146.42	6.82	5	150.23	10.63	8
Wheat	117.63	133.96	16.33	14	140.00	22.37	19
Cotton	524.09	548.97	24.88	5	557.86	33.77	6
Rice	559.21	638.71	79.50	14	666.91	107.70	19
Sorghum	154.28	176.51	22.23	14	184.81	30.53	20
Barley	134.10	147.45	13.35	10	152.26	18.16	14
Oats	136.44	159.12	22.68	17	167.29	30.85	23

The results show that the impact of oil and gas prices on the agricultural production expenses varies among crops, which partly reflects the relative importance of energy among the crops. However, this study does not make any further analyses of the impact on revenues or in production levels, considering also other variables.

Source: Doane Advisory services (2008).

Box 4.1 shows the results of a quantitative analysis of the impact of energy price scenarios on the crop production costs for the US agricultural sector.

Production costs are a driving factor for agricultural income and agricultural production level, which is a key factor in determining agricultural commodity prices. Therefore changes input costs such as energy costs could lead to changes in commodity prices.

4.3.2 Energy use in the food chain

We just have seen how energy prices can affect agricultural commodity prices, but the food system includes not only agricultural production but also the processing, distribution (transport and storage), sales, purchasing, preparation, consumption and waste disposal of food.

Much of the food production and processing occurs far from where the final consumers live and buy groceries. Environmental costs are also related to food production and transportation. Examples of external environmental costs are the increased amount of fossil fuels used to transport food long distances, and the increase in greenhouse gas emissions resulting from the burning of these fuels (Pirog, 2001).

Therefore, a sustained increase in energy prices could be translated into higher food prices, because energy use contributes to additional food production costs and higher food prices beyond the farm gate at three stages in the chain (Schnepf, 2004):

1. Food manufacturing, especially with energy-intensive technologies
2. Transportation of food products (e.g. in climate-controlled containers)
3. Storage and distribution of food items (e.g. in environmentally controlled facilities).

The percentage that energy represents in the total consumer price

According to ERS-USDA data, transportation plus energy costs represent 7% of the total consumer price, while farm value and labour represent 19% and 38%, respectively. Considering that energy consumed in farm production is around 20% of total production costs, energy used at the farm represents 4% of the total consumer price.

Ratio of energy input to food-energy output

Food production and distribution are energy- and water-intensive processes, and they also generate significant amounts of GHG emissions. One indicator of the energy efficiency of the contemporary food system is the ratio of energy outputs (the energy content of a food product, i.e. calories) to the energy inputs. For example, it takes many calories of energy to produce one calorie of energy in the form of meat.

It is not within the scope of this report to present a detailed study of the consumption of energy at the various stages of the food chain, but further analysis on this topic for several regions (Europe, developing countries, world) would be of interest both for understanding the relative importance of energy in the food chain as a factor shaping future food prices, and for giving a measure of energy efficiency.

Price transmission mechanisms: impact of changes in energy costs on food retail prices

The responses of producers and consumers to market prices determine future prices. An increase in the price of crude oil implies that food producing firms face increased energy costs and therefore increased input and producing costs. In the short term, firms cannot adjust their input use and consumers will not yet have adjusted to the change in food prices caused by higher energy prices. In this situation, the full increase in averages costs resulting from higher energy prices will be passed on to consumers in the form of higher food prices. Therefore, the increase in the average costs and the consequent increase in retail prices depend mainly on the importance of energy in food production and the ability of food firms to pass on higher costs to consumers. But if the energy price increase continues, in the medium/long term food prices may reflect the price responses of consumers and producers. Then in the long term the responses of producers and consumers mitigate the predicted short-term retail price increases. Producers may try to substitute the more expensive energy inputs, leading to smaller increase in costs and less impact on consumer prices. Furthermore, consumers may respond to higher prices by reducing their consumption of food products, mitigating the long-term impact of higher energy prices on retail food prices.

The increase in food prices has a more negative impact on consumers in low-income countries, since the percentage of food expenditure in total income is larger. The impact of increases in food prices caused by increases in energy prices would be more negative for developed that developing countries, because developed countries consume more processed food. But on the other hand, the impact of increasing agricultural commodity prices is more significant in developing than in developed countries, because in the former food is normally less processed than in the latter countries and therefore the share of the agricultural commodity price in the consumer final price is bigger.

4.4 Agriculture as an energy producer: impacts of biofuels on food markets

4.4.1 Introduction

The third link between energy and food is formed by the production of energy in the agricultural sector: wind, solar, and biomass energy can be harvested, providing farmers with an additional source of income. The first two links described were not new, but this third link, although not completely new, has been developing very strongly in recent years.

Farmers can benefit from wind energy in many ways, including generating their own power, leasing land to wind developers and becoming wind developers themselves. Solar energy is clean and unlimited. Capturing the sun's energy for light, heat, hot water and electricity can be a convenient way to save money, increase self-reliance and reduce pollution. Whether drying crops, heating buildings or powering water pumps, using the sun can make a farm more economical and efficient. [Biomass energy has to do with growing crops as feedstock for energy production, for example in the form of biofuels. In all three cases of energy production in the agricultural sector there is an important issue: land for energy or for food.

Biofuels are one of the few current alternatives to conventional fuels in the transport sector. Whereas high energy prices create incentives to develop biofuels production, at the moment the higher demand for biofuels is probably more related to targeted government policies (e.g. EU directive). Several developed and developing countries (e.g. China), moved by climate change mitigation aims or energy security issues, have implemented policies to stimulate the production of biofuels, leading to a higher demand for agricultural commodities and substitution effects in agricultural production. The share of biofuels in total energy supply is currently small and, according to recent energy world prognoses, will remain small at least until 2030, so that biofuels have a modest influence in energy markets. On the other hand, the impact of the increased biofuels production is enormous in agrifood markets.

4.4.2 What are biofuels?

The agricultural sector is a consumer of energy, but it is also increasingly developing the capacity to produce energy, primarily in the form of renewable biofuels. Biofuels are liquid fuels produced from biomass; they include mainly ethanol, biodiesel and methanol. According to the EIA descriptions, bioethanol production comprises the conversion of starch or sugar-rich biomass (corn/maize, other cereals, sugar cane, etc.) into sugar followed by fermentation and distillation to alcohol. Biodiesel production comprises the extraction and treatment of vegetable oils, used cooking oils and animal fats using alcohols. The resulting liquid fuel can either be blended with conventional diesel fuel or burnt as pure biodiesel. Biomethane is a biogas from anaerobic digesters and landfills used as compressed gas in natural gas vehicles. In this report we focus mainly on ethanol and biodiesel.

Biofuels are primarily used in the transport sector, that is, by cars, trucks, buses, planes and trains. As a result, their principal competitors are petrol and diesel fuel produced from fossil fuels. Unlike fossil fuels, which have a limited resource base that declines with use, biofuels are produced from renewable feedstock.

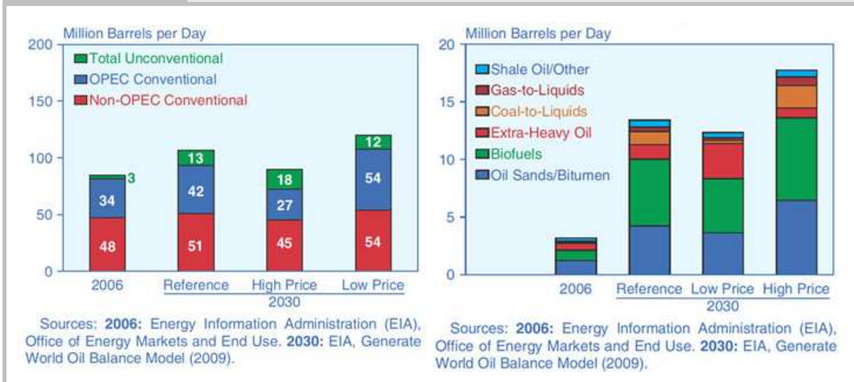
Biofuels currently represent the most visible energy–food link. Higher energy prices may have partly incentivised the production of biofuels during the last five years but other factors also related to energy - for example, climate change mitigation policies and policies concerning energy security - have had a stronger impact on biofuel production. However, until recently biofuels seemed to be an attractive alternative to fossil fuels, by contributing to climate change mitigation, reducing fossil fuels dependency, improving energy security and farm income, and promoting rural development. However, concerns about the induced land-use change, the smaller greenhouse gas savings than expected, and the impact on global food prices and food security, together with concerns about the economic viability of biofuels production, have dampened initial expectations. In the EU, for example, the initial targets for bioenergy use have been reduced and sustainability criteria are being introduced to prevent negative impacts on high-value nature areas (e.g. Amazon forest or high-peat soils) that would result from the production of biofuels. The interactions with the agricultural sector through competition for land and crops, indirect land-use effects and constraints on agricultural food production (e.g. the availability of phosphates; see section 3) are highly complex and therefore hard to control. The research community's study in this field and the discussion on appropriate biofuel policies continue (Stehfest et al., 2010).

4.4.3 Biofuels production: impacts on energy and agricultural markets

Biofuels production and energy supply

According to IEA data (Eisentraut, 2009), biofuels currently provide approximately 1.5% of global transport fuel. The share of biofuels in the total energy supply as well as in the total energy liquids supply is very small, and therefore the impact on energy markets is low and is expected to remain low until 2030 (IEO-EIA, 2009). But the share is growing and may get a more significant role in energy markets in the future. The following figure shows the share of unconventional liquid fuels in the total liquid fuel supply in 2006 and the expectations for 2030 in three oil price scenarios (left) and the share of biofuels in the unconventional liquid fuels.

Figure 4.9	World liquid fuel supply 2006-2030 (left) and world production of unconventional liquid fuels 2006-2030

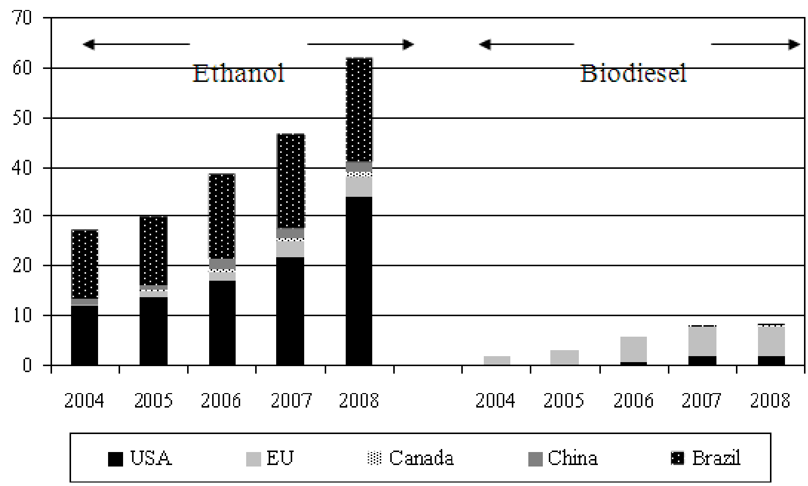


Source: IEO-EIA (2009).

Box 4.2 provides information about world biofuels production.

Box 4.2	Biofuels production

The production of biofuels is growing rapidly throughout the world. From 2004 to 2008, world biofuel production grew by more than 240%, namely from almost 30 million to 72 million litres (F.O. Licht, 2009). Ethanol dominates world biofuel production with a share of almost 90%. Amongst the ethanol producing countries, the USA became the largest producer in 2005 and has a current (2008) share of almost 55% (followed by Brazil: 34%) in ethanol production. The market share of the EU in total ethanol production increased from 1% in 2004 to 7% in 2008.



In 2004, biodiesel production was concentrated in the EU, which was responsible for almost 95% of world biodiesel output. Between 2004 and 2008, world biodiesel production increased from 2.2 million litres to almost 10 million litres. This increase, however, took place in the EU and the USA. In 2008, the EU produced 6.4 and the USA 2.2 million litres of biodiesel, respectively. This graph shows that world biofuel production is heavily concentrated in those regions that have strong policy mandates. In 2008, together the USA and the EU contributed almost two thirds of total biofuel output at global level. Brazil, a country where biofuel production is mainly driven by market forces (ethanol from sugar cane dominates the market), has a share of 30% in 2008 biofuel production.

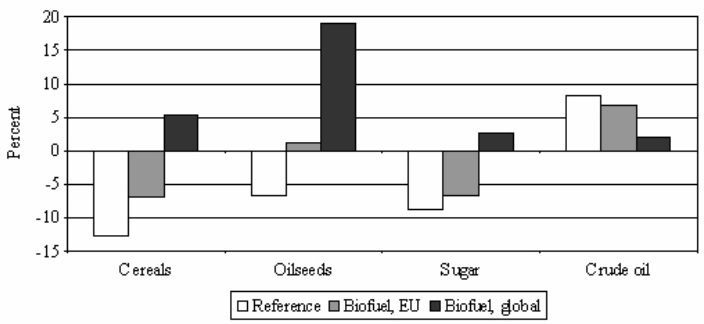
Source: LEI (2009).

Demand for biofuels crops and impacts on agricultural prices

In order to meet the ambitious future targets of the EU Biofuel Directive (in 2010 5.7% and in 2020 10% biofuels share in the transport sector under the condition that second-generation biofuel technology is available),[1] the large-scale production of crops used specifically for biofuel production will be necessary in Europe. Box 4.3 shows the results of Banse's study (2009), which analysed the impacts of increasing demand for biofuel crops in order to meet the requirements of the EU Biofuels Directive and other countries' biofuel mandates on world crop prices.

Box 4.3	**Impacts of biofuel production on demand for and prices of biofuel crops**

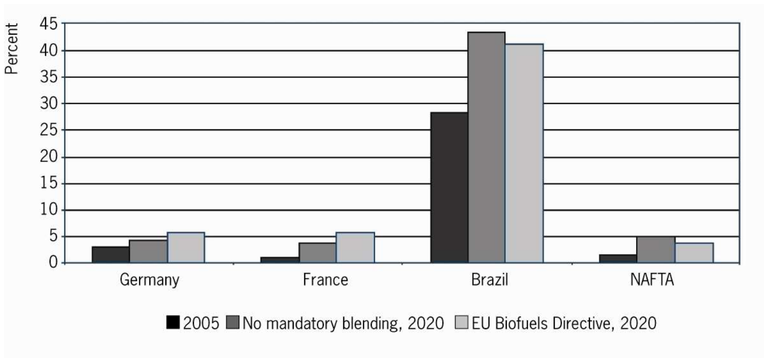
Banse (2009) points out that in a 'Global Economy Scenario' in 2020, which includes the EU Biofuels Directive, demand for biofuel crops is estimated to be USD7.3 billion (in 2001 dollars), 43% of the additional demand being domestically produced and 58% imported. The strong increase in imports for biofuel crops would affect the world prices of biofuel crops. Therefore, EU policies can originate changes in world crop prices. Banse, van Meijl and Woltjer (2008) show that under a scenario 'Biofuel, global', which includes biofuel policies in the USA, Canada, South Africa, Japan, Korea and Brazil, oilseed prices increase by 26% in contrast to the long-term trend projected in the reference scenario without mandatory blending, in which the real world prices of agricultural products decline and maintain their long-term trend (see following figure). The reason for that is the inelastic demand for food combined with a high level of productivity growth. Under an EU mandatory blending target, the oilseed sector has the highest price difference, because biofuels in EU transport are dominated by biodiesel from oilseeds.



[1] The EU Commission is currently discussing a 10% proposal for 2020, divided into 7% for first-generation biofuels and 1.5% for second-generation biofuels, the latter counting double towards a national biofuels target.

Box 4.3	Impacts of biofuel production on demand for and prices of biofuel crops (continued)

It is interesting to see that even without the enforced use of biofuel crops through mandatory blending, the share of biofuels in fuel consumption for transportation purposes still increases because the ratio between crude oil price and prices of biofuel crops is expected to change in favour of biofuel crops.



Source: Banse, LEI (2009).

There is another effect of biofuels production on farm prices that must be taken into consideration: the production of by-products, mainly oil cakes, gluten feed and dried distilled grains with solubles (DDGS). The use of crops in biofuel production could result in a lower availability of feeding inputs, making them more expensive. However, the residues of the biofuel production are rich in protein and fibre and will become available in considerable quantities for the feed industry. Protein has traditionally been the more expensive component of feed. A drop in feed prices resulting from the increased availability of this component can therefore be expected (Bindraban, 2009).

Economic viability, market trends and side effects

The IEA points out that even with considerable improvements in biofuel production efficiency (i.e. energy yields), the relatively high costs of biofuels in OECD countries is a critical constraint for the commercial sustainability without policy support. For first-generation biofuels, the technology is quite mature and costs are expected to steadily decrease, but without big changes. For ethanol and biodiesel, the cost of feedstock (crops) is a major component of the total cost. Therefore, the costs of biofuels production are highly affected by the volatility of crop prices; long-term contracts with farmers are needed to allow for sustainable production. Another important factor of the biofuel production costs is the size of the conversion plant. The normally larger US plants produce biofuels (i.e. ethanol) at lower cost than plants in Europe. The production costs for ethanol are much lower in countries with warm climates. Brazil is the world's lowest cost producer, mainly because of the sugar cane-to-ethanol technology. In addition to plant production costs, distribution costs also have an impact on retail prices, especially when biofuels must be transported over long distances to reach markets.

The crude oil price can also influence biofuel production, since both compete in the transport sector. The higher the crude oil price, the more competitive the production of biofuel crops versus petroleum production; therefore, biofuels form a link between food and fuel prices. On the other hand, low crude oil prices make biofuel production comparatively less competitive and less profitable, and high feedstock prices also make biofuels less profitable. Banse (2008) emphasises that even at crude oil prices of USD120 per barrel almost no biofuels are economically viable without support policies. With low petroleum prices, biofuels production needs to be subsidised. The OECD-FAO Agricultural Outlook 2009 points out that the development of biofuel markets depends not only on policies but also on technological advances. According to the Outlook, the IEA estimates that assuming significant investments in R&D, ethanol and biodiesel could become competitive by 2030 with a crude oil price of around USD100 per barrel (nominal). But expectations related to biofuels market developments are very reliant on assumptions on policy implementations (OECD).

Brazil (35%), the USA (43%) and the EU (9%) are expected to still be the main ethanol producers in 2018, as well as the main consumers of ethanol (Brazil 28%, the USA 48%, the EU 11%). According to this, Brazil will be a net exporter, while the EU and the USA will need to import to meet demand. African countries are not seen as emerging exporters during the coming decade. Columbia has become the second sugar cane-based ethanol producer, with most exports going to the USA. Expansion of Chinese ethanol is expected to remain less rapid than earlier projections would suggest, and the trade levels will remain low. The EU is expected to remain the main market for biodiesel, as well as the major producer (18 billion litres in 2018) and consumer of biodiesel. Domestic production will grow, as will biodiesel imports to meet the growing demand. In the USA, production of biodiesel will grow less than consumption but production (5 billion litres in 2018) is still expected to be higher than consumption and therefore the USA will be a net exporter. Biodiesel production in Brazil is assumed to grow (3 million litres in 2018) but most will be domestically consumed. In Argentina biofuels production is expected to grow very fast and the country could become the largest biofuel exporter with net exports of 3.4 billion litres in 2018. In Indonesia and Malaysia the expectations have not materialised - even though they are the two leading producers of vegetable oil and are potential powerhouses of biodiesel production. India is expected to grow significantly, reaching about 7 billion litres in 2018. The outlook for biodiesel production in Africa remains modest due to unresolved technological issues and an unfavourable economic situation.

The agriculture sector provides feedstocks for biofuel production, but the increased biofuel crops demand may have a strong impact on world agricultural markets particularly when biofuels are produced from crop commodities. The demand for biofuels affects agricultural markets through direct competition with other crop uses and through competition for scarce resources such as land. Higher agricultural prices can provide additional income opportunities for crop farmers, but may harm food security especially for consumers in low-income countries. In addition, the environmental impacts of higher biofuel production seem less beneficial than originally expected. The resources required for biofuel crops (land, water, etc.) have consequences for CO_2 balance, soil erosion and biodiversity. Second-generation biofuels might help to reduce the competition between feed, food and fuel (Meijl, 2009).

4.4.4 Biofuels second-generation technology

There is increasing criticism of the sustainability of many first-generation biofuels. This related to several concerns: food vs. fuel discussion, net environmental impacts, commodity prices economic viability, etc. For this reason, attention is now directed to second-generation biofuels. While first-generation biofuels are in an advanced state and have mature technologies, second-generation biofuels are not yet produced commercially, although pilot plants have been set up in recent years. The research activities are mainly taking place in North America, Europe and certain emerging countries, for example Brazil, China and India. The feedstock for second-generation biofuels would be agricultural and forest residues and other crops that are not used for food. Benefits from the second-generation biofuels would be the consumption of waste residues and the use of abandoned land; it would thus be possible to promote rural development and improve economic conditions in emerging and developing regions. But once the technology becomes commercially viable, the production of second-generation biofuels would require considerable amounts of biomass. Analysis of existing and potential biomass sources should be done before the start-up of second-generation biofuels.

However, even if the second-generation biofuels production technologies are more efficient and second-generation biofuel crops are not food crops, there could be still the problem of competition for food crop land and conservation areas. The sustainability of the second-generation fuels will depend on whether producers comply with the established criteria for avoiding undesired land-use changes.

In summary, it is clear that to ensure the sustainability of second-generation biofuels, more research is needed into the economic profits for developing countries, a road map for technology development must be drawn up, an impact assessment of commercial production must be carried out, and improved data must be gathered on available land and on social and environmental benefits and risks in developing countries (IEA, 2009).

4.4.5 Competing claims between food, feed and fuel

Assuming a growth in world population from the current 6.5 billion to 9 billion inhabitants, increasing welfare and the consumption of more animal products means that food production has to be doubled by 2050. Calculations by (e.g.) Wageningen University and Research Centre show that such production is technically possible (Diepen et al., 2009). However, will it be realised? The main concerns are economic and social feasibility, access to food especially for the world's poorest, impacts of climate change, increasing competition between food, feed and non-food use of biomass (especially bio-energy), and impacts on biodiversity and natural systems, for instance tropical rain forests.

The competition between food, feed and fuel has received increasing attention in recent years. Diepen and colleagues (2009) report from FAO balance sheets that in 2000, 50% of world production of food and feed crops was used for food and 50% was used for feed. This feed share may increase rapidly in the coming years, due to the increased consumption of animal products (see also Keyzer et al., 2005). Moreover, 2% of world arable area is currently used for energy crops, but this may also increase, due to biofuel stimulation policies.

Subsidy programmes in the USA may lead to more than 40% of coarse grain use (mainly maize) for bio-ethanol in 2015. The mandatory blending of 10% in transport fuels in the EU may lead to an additional land use of 20–30 million hectares, or 20-30% of all current arable land in the EU-27, if all the needed biomass were to be produced within the EU. OECD-FAO (2009) calculate that 24% of coarse grain production in OECD countries or 12% of world coarse grain production might be used in 2018 for bio-ethanol, against less than 10% and 7%, respectively, in 2006-2008, whereas 20% of world oilseed production might be used for biodiesel in 2018 against less than 10% in 2006-2008.

These increases have had already an upward effect on world market prices, and will have further effects in future. Estimates of these effects differ from below 30% to 75% for cereals and oilseeds (IFPRI, 2007, Banse et al., 2008 and Mitchell, 2008). Second-generation biofuels based on raw materials other than those also used for food (wood, other perennial crops, waste), if technically and economically feasible in future, may diminish these effects, but will also compete with current agricultural land use for other purposes. Moreover, they need large-scale investments.

Competing claims are not restricted to land use but also concern the use of water and fertilisers. Concerns are especially increasing about the availability of phosphate and other essential minerals. The conclusion is that the downward trend in world market prices in real terms over the past decade is likely to change into a horizontal or even upward trend in the future. An upward trend might even accelerate if climate change leads to temperature increases higher than 2 or 3 degrees. Smaller increases in temperature might lead to higher world production and hence to lower world market prices (see e.g. OECD-FAO, 2009).

Production in Europe will meanwhile continue to grow, due to further yield increases and efficiency gains in the supply chain, whereas human consumption is stabilising or even decreasing due to saturation, ageing, stabilisation or decrease in meat consumption, and even population decrease. Moreover, climate change may result in more production in northern parts of Europe, compensating for production losses in the southern part. The resulting further increase in self-sufficiency will cause a continued downward trend in European prices, so that these might even become lower than world market prices.

5 Long-term effects of energy prices on food prices

5.1 Introduction

In order to sketch the mechanisms involved in the interaction between oil price and food markets in the longer term, we calculated two scenarios with a general equilibrium model, called LEITAP (see Appendix 4 for a brief description of this model). We projected till 2030 developments in the world economy and focused on the effect of a change in crude oil supply on food prices. Here, we first we outline the way biofuels and energy are modelled in LEITAP. Section 5.3 discusses the results of a high and a low crude oil price scenario, and in this way provides insight into the long-term relationship between the crude oil market and food markets. It should be noted that the simulations concern only the long term; in the short term, the interrelationships generate much more severe effects.

5.2 Energy and biofuels in LEITAP

LEITAP allows for the substitution of biofuels for crude oil in the petroleum industry. Because biodiesel and ethanol are close substitutes for refined crude oil, it is assumed that substitution is easy, but not at current price levels. It is thus assumed that the differences in cost price between fossil fuels and biodiesel/ethanol are solved through a subsidy. This implies that the relationship between crude oil price and biofuel demand depends to a large extent on government behaviour. Because this relationship is very complicated, we assume that the government budget that is available for direct or indirect subsidies on biofuels remains constant. Therefore, the mechanism involved in the model is mainly an assumption about government behaviour.

The development of the crude oil price depends on demand and supply. The growth of the world economy and technological changes determine oil demand, while crude oil supply is determined by a tension between an increasing scarcity of crude oil as the consequence of the depletion of natural resources, and increased technological possibilities to extract the available natural resources. In the real world this is more complicated, because especially the political economy of OPEC countries is very complicated, where rent-seeking behaviour plays an important role. The assumption in our model is that this type of behaviour is mainly temporary in character.

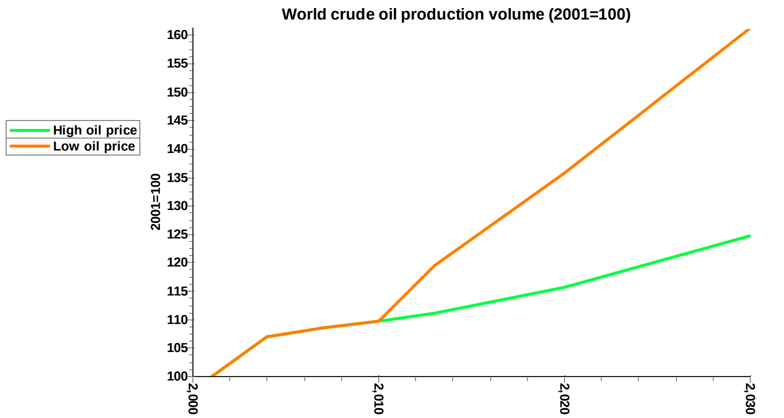
A large part of the fluctuations in crude oil prices are caused by the fact that crude oil production and refining takes a lot of time. Ten years is not much in this respect. At the moment the investment is done, the variable operating costs are very low. As a consequence, there is a tendency to use production facilities at full capacity, and the price elasticity of supply in the short term is very low. A small increase in demand or a small disruption of supply may have large effects on the crude oil price in the short term. This explains the recent experience on the crude oil market, but this type of behaviour is not in the LEITAP model, which is long term in character.

5.3 Food price projections in a high and low oil price scenario

In order to investigate the long-term effects of an increasing scarcity of crude oil, we ran two scenarios, one with a relatively large supply of crude oil and one with a very restricted supply. We compared the differences for especially food prices and farmer income.

Because we work with a database with 2001 data, we first projected till 2010 based on GDP and population data and short-term projections, and projections of crude oil production in this period. After 2010, we differentiate, where the low oil price scenario has an extra 10% increase in crude oil availability compared with the high oil price scenario.

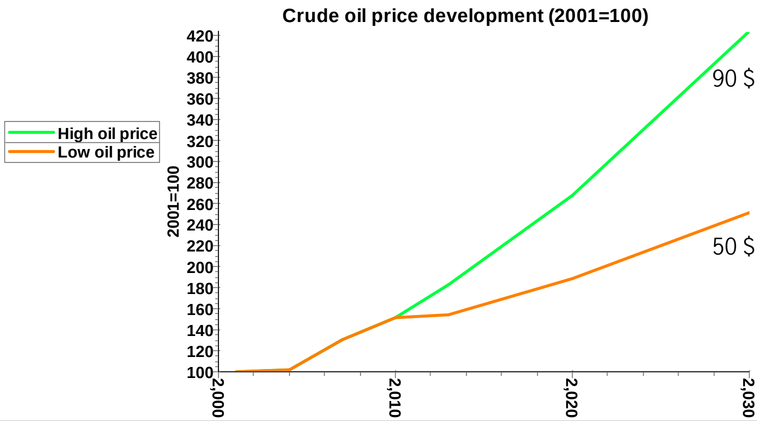
Figure 5.1 **Crude oil production**



Source: LEI.

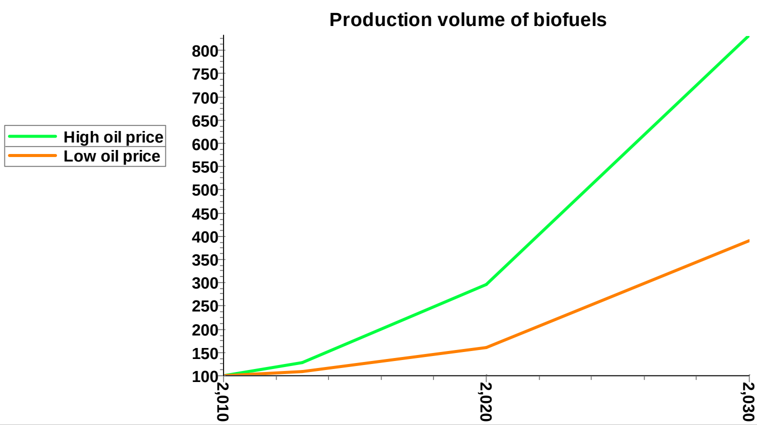
In the low oil price scenario, the crude oil price more than doubles compared with 2001 to about USD50 per barrel, while it rises more than fourfold in the high oil price scenario to about USD90 per barrel. Figure 5.2 shows that the model predicts a much smaller increase in crude oil price than happened during the last years. This is because the model describes long-term behaviour, while the current oil price development is mainly caused by short-term restrictions on oil supply, because in the period around 2000 investment in crude oil production and refining was very low as a consequence of the low oil price. The low oil price in this period was also not an incentive to invest in energy-saving means of production, including the cost of cars.

Figure 5.2 **Crude oil price**



Source: LEI.

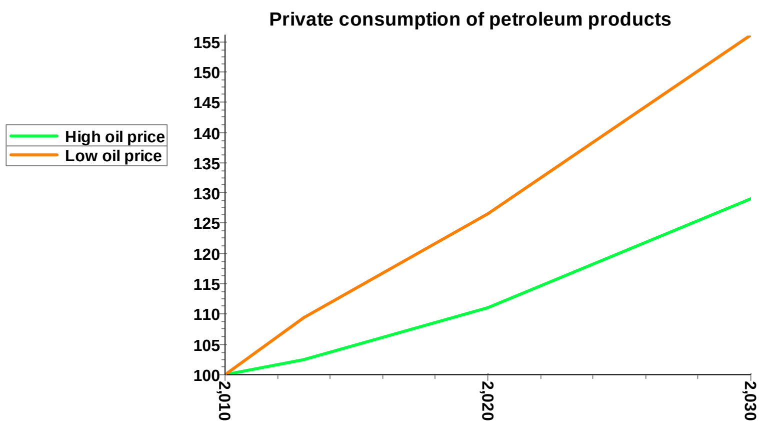
Figure 5.3 **Production volume of biofuels**



Source: LEI.

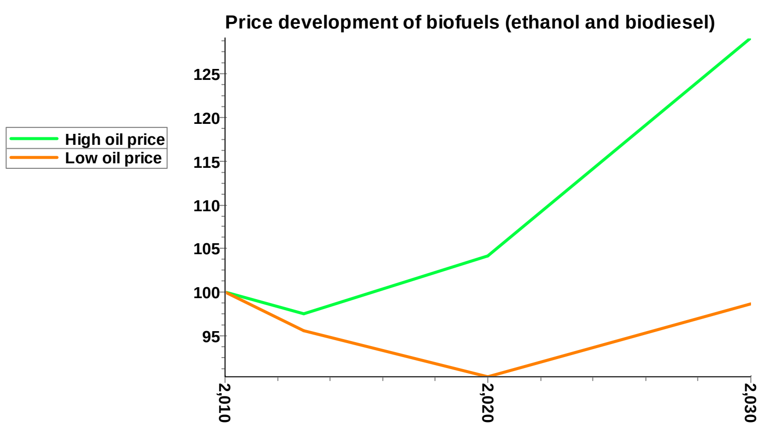
As figure 5.4 shows, the increase in crude oil price has a significant effect on the consumption of petroleum products. In the high oil price scenario, petroleum consumption is 18% lower. The increase in crude oil price makes biofuels more attractive. We assume that the budget available for biofuels remains the same, where with a higher crude oil price fewer subsidies per litre of biofuel is needed. As a consequence, biofuel production rises eightfold between 2010 and 2030 in the high oil price scenario, while the price of biofuels is about 30% higher in the high oil price scenario than in the low oil price scenario.

Figure 5.4 **Private consumption of petroleum products**



Source: LEI.

Figure 5.5 **Price of biofuels**

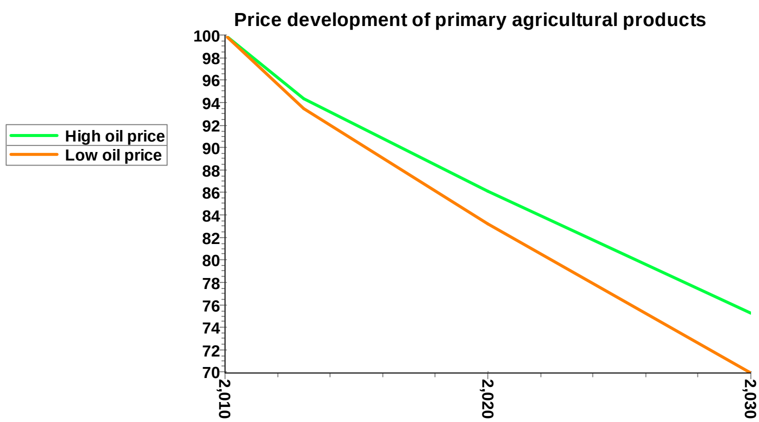


Source: LEI.

Despite the pressure from biofuels, in both scenarios the prices of agricultural products tend to decrease. This is a result of technological developments, where it is assumed that labour- and capital-saving technological changes are much faster in agriculture than in other sectors. This is consistent with the past, and was extrapolated to the current fast-growing countries.

According to the model, the high oil price scenario generates an 8% higher price of primary agricultural products in 2030 compared with the low oil price scenario. For products from arable land this is about 10%, while for animal products the rise is only 5%; especially for the poor countries this 10% increase in the price of, for example, cereals may be significant, but note that this higher price remains 20% lower than the current price.

Figure 5.6 **Real price of primary agricultural products**

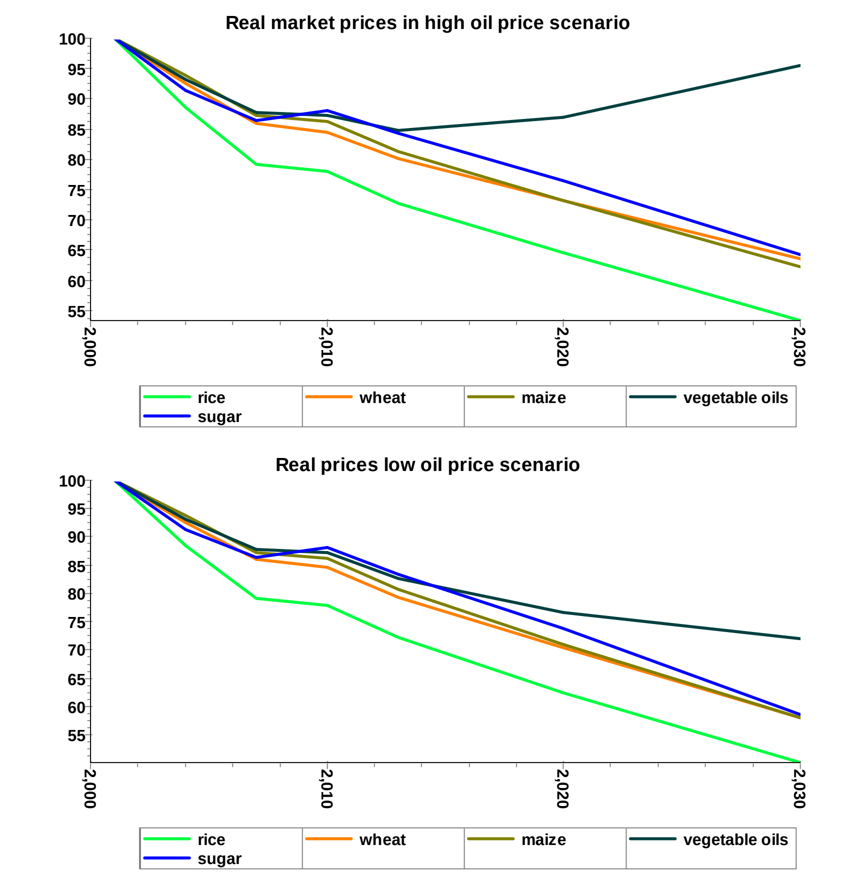


Source: LEI.

According to these results, the agricultural commodity prices are projected to continue the long-term downward trend in real terms. However, the results are very dependent on the assumptions made.

Figure 5.6 shows the results in an aggregate way. The following two figures present the results for individual agricultural commodities.

Figure 5.7	Real price of agricultural products; high (above) and low oil price scenario (below)



Source: LEI.

It is remarkable that the price of most commodities continues the long-term downward trend in both scenarios. The exception is vegetable oils, whose price changes the trend by 2013. The reason for this is probably that biodiesel production becomes in the high oil price scenario more competitive and demand for vegetable oils increases.

The mirror image of the higher prices of agricultural products is the higher income per worker in agriculture. Because the outflow of labour from agriculture is high, agricultural income per worker tends to be low compared with other sectors in the economy. This pressure is lowered when agricultural employment is reduced less, as a consequence of the production of biofuels. The difference in income in 2030 is about 8% on a worldwide level.[1]

Figure 5.8 **Price of primary agricultural products**

Source: LEI.

In summary, the crude oil price has long-term effects on food prices, but the effect is not alarming. A faster increase in the crude oil price is good for farm income and bad for food prices, but the effect is in the order of magnitude of 5–10%. With predicted increases in farm income and reductions in food prices, we are probably talking about less improvement rather than deterioration compared with the current situation.

5.4 Comments

The simulations presented here give a rough idea of the effect of the crude oil price on agricultural prices. Note that biofuel inputs remain relatively small compared with crude oil inputs in the petroleum industry: about 10% in the high oil price scenario. This is because only in Brazil are biofuels becoming com-

[1] Note that the dynamics of the labour market is one of the few markets where short term and long term makes a difference in the current model. This implies that if the faster growth of biofuels were tod end, the difference in income development would gradually diminish towards zero in the long term.

petitive (a 75% share), while in other countries biofuels remain expensive compared with fossil fuels. We have also assumed that productivity developments in agriculture follow the pattern of the past and that land productivity follows FAO projections.

The results of the simulation for 2030 show that with a crude oil price increase in real terms of 80% (low to high oil price scenario), food prices will increase in the long term in real terms by only about 8%, and remain in both scenarios below 2000 levels. Behind this result there is a projected volume of biofuels production and there are assumptions concerning economic and population growth, technological developments in the agricultural sector, and productivity developments following the pattern of the past and the FAO projections.

The model simulations are long-term simulations. In LEITAP only the labour and capital markets make a difference between short-term and long-term behaviour. In order to investigate the effect of short-term fluctuations in crude oil price, we need to build dynamics into the energy and agricultural markets. This is possible in the long term, but not within the current project. It is obvious that because demand and supply in both energy and agricultural markets are very inelastic, that the interdependencies are much higher. Especially when high crude oil prices are caused by an unexpected increase in economic growth, agricultural markets will be influenced by the same forces. As a consequence, common driving forces combined with extra demand for biofuels may drive up agricultural prices much more than suggested. This section mainly shows that long-term behaviour is fundamentally different from short-term behaviour.

6 Conclusions

There are three main links between energy markets and food markets. The first is formed by the common drivers on the demand side, namely demographic and economic developments. The second link is related to the energy costs of agriculture and of food production and distribution. The third link is the role of agriculture as a producer of energy. In assessing the effects of these three links, it is crucial to distinguish between long-term and short-term effects. In the short term, supply and demand in both markets are very inelastic. As a consequence, small changes in either supply or demand will have large effects on prices. In the long term, supply and demand can adjust; therefore fundamentals of the markets determine prices.

Long-term developments
The quantitative analysis in Section 5 shows that in the long term the price of agricultural commodities will be on average 8% higher in the high crude oil price scenario (USD90/barrel) than in a low crude oil price scenario (USD50/barrel). In both scenarios, all commodities except vegetable oils will continue the long-term downward trend in real prices. The projections show that the prices of vegetable oils start an upward trend from 2014 on, but remain in 2030 under the 2000 bottom line. It must be stressed that these results are strongly dependent on the underlying assumptions about economic and population growth, yield increases, technology development and share of biofuels on the fuels market.

In the long term, population and welfare growth determine demand growth on both agricultural and energy markets. The effect on prices of these long-term tendencies depends on the ability of supply to adjust. The depletion of oil fields plays a fundamental role in energy markets; however, the reduction of scarcity as a consequence of technology is competing with that depletion. In the long term, the increasing scarcity as a consequence of depletion seems to win, generating an expected increase in real crude oil prices. An important background to this expected increase in crude oil price is the concentration of available oil in unstable and rent-seeking OPEC countries. The market share of these countries will increase because oil reserves are used up almost everywhere.

With respect to agricultural markets, the OECD-FAO Agricultural Outlook 2009 assumes that the long-term upward production trend will continue thanks to the achievement of higher yields. Cost price of agricultural products will decrease because of improvements in general productivity. The expected rise in crude oil prices has some influence on agricultural and food prices, because crude oil is used as an energy source and is also a source of artificial fertilisers. But the general productivity increase may be expected to be stronger. This implies a decline in real prices, although nominal prices may rise as a consequence of inflation. Recommendations concerning expected rising energy prices are to promote energy efficiency in the agricultural sector as well as in food production, transport and storage (e.g. adopt minimum efficiency standards for equipment, vehicles, buildings), and to identify alternative and efficient renewable energy sources and promote their sustainable development.

Biofuel policies may have an effect on long-term agricultural prices. Both developed and developing countries have implemented policies that support biofuels production as an alternative source of energy in the transport sector. The initial expectations that biofuel production will contribute to energy security and a better environment have been dampened, as recent studies have shown uncertain effects on land-use change, food prices and the reduction of greenhouse gas emissions. They suggest that these objectives cannot be met with first-generation biofuels, namely biofuels produced through the currently commercialised processing of agricultural feedstock. With increasing biofuel production, demand for agricultural products will increase and their prices will tend to increase.

Promoting second-generation biofuels - which means converting into ethanol cellulosic material from sources other than edible agricultural commodities - offers potential benefits. Nevertheless, most of the biomass for second-generation biofuels (apart from waste and residues) needs to be produced on land, which means that agricultural and energy markets will continue competing for scarce land resources. The availability of these land resources (depending on, for example, deforestation policies, which also have an influence on the greenhouse gas balance), and especially the technological improvements, will determine the long-term effect of biofuels on agricultural markets.

Projections of future prices depend to a large extent on assumptions about productivity increases. This is more relevant for developing economies, since most of the world population and economic growth is foreseen to happen there, indicating a need for policy reform and additional investments in production technologies. Investments in improving the overall environment in which agriculture operates (e.g. basic governance systems, macroeconomic policies, basic infrastructure, education, health) would be the most suitable measures due to their likely multiplier effects on the agricultural sector. But the ability to invest in the low productivity regions of the world depends much on political and economic stability.

Short-term developments

In the short term, both energy and agricultural prices may fluctuate a lot. Because both energy and agricultural supply are very inelastic in the short term, an unexpected increase in demand or an unexpected disruption of supply may generate large changes in price. The recent price increases may be explained by unexpected growth in especially India and China, combined with underinvestment in both energy and agriculture as a consequence of very low prices in the previous period. If prices start to fluctuate heavily, releases of intervention stocks and/or speculative behaviour can play an important role in narrowing or widening, respectively, the gap between food or energy demand and supply.

The energy costs of food production are an important factor in the determination of the short-term production costs of agricultural commodities (in the EU: 23% of the total variable agricultural expenses). Farmers are not able to pass on energy price increases to consumers. As a consequence, an increase in energy price will be at the cost of agricultural income in the short term. But when demand in the agricultural sector is also high, the level of agricultural incomes may not be a serious problem.

If more biofuels than expected are produced, perhaps generated by a higher crude oil prices without adjustment of biofuel subsidies, demand for agricultural products may rise unexpectedly. Supply cannot be adjusted in the short term, which implies an increase in both agricultural prices and agricultural income.

Commodity speculation has been identified in Sections 2 and 3 as a driving factor for the demand for energy and agricultural commodities. Most major primary commodities, such as energy and agricultural products, are actively traded on futures markets. Commodity speculation affects both energy and agricultural markets and has probably contributed to the price boom of recent years. It is not necessarily a major factor, but it is possible that some of the effects have been substantial and some persistent. Further economic analysis of the effects of speculation and a discussion about the need to prevent destabilising 'excessive speculation' would add to this study.

Recommendations for further research
This study provides a preliminary assessment of the links between energy markets and food markets. It shows that the effects of the links are quite different in the short term than in the long term. More research is needed to gain a better understanding of the complexities and interrelations between the sectors. Future research could be focused on:

- Impact assessment of climate change, land availability, water and phosphates availability, environmental regulations, biofuel policies and agricultural policy reform on agricultural production potentials
- Analysis of energy consumption at the various stages of the food production and distribution chain
- Improving the simulation model in order to assess price effects of short-term changes in demand and supply
- The risks of speculation in agricultural and energy commodity markets and the options for international regulation.

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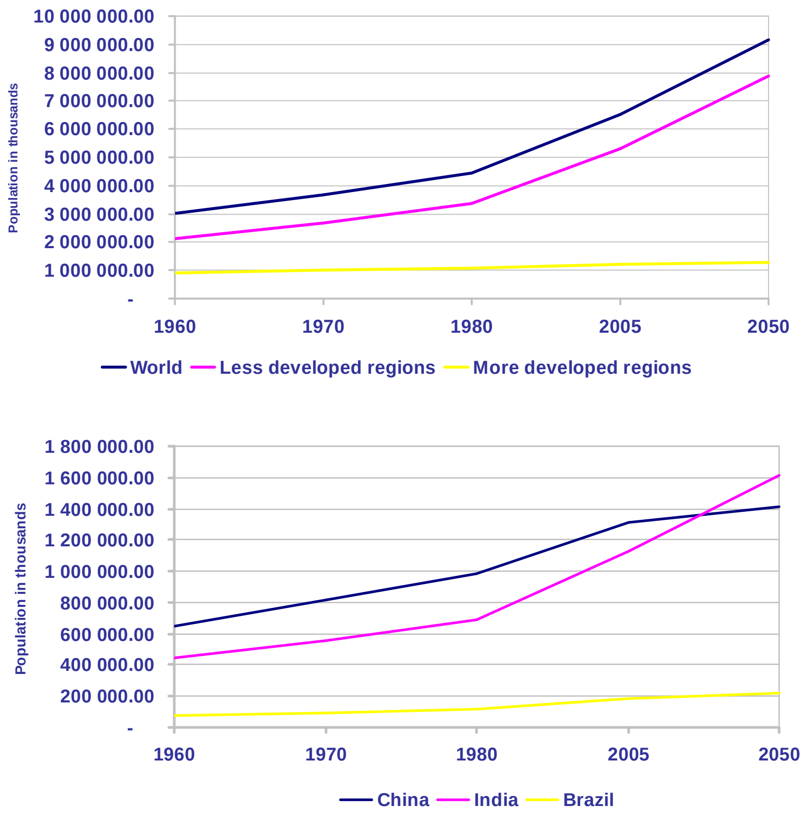
Appendix 1

Population and economic developments

Figure A1.1 provides historical data and estimates from the United Nations until 2050 for population growth in several regions.

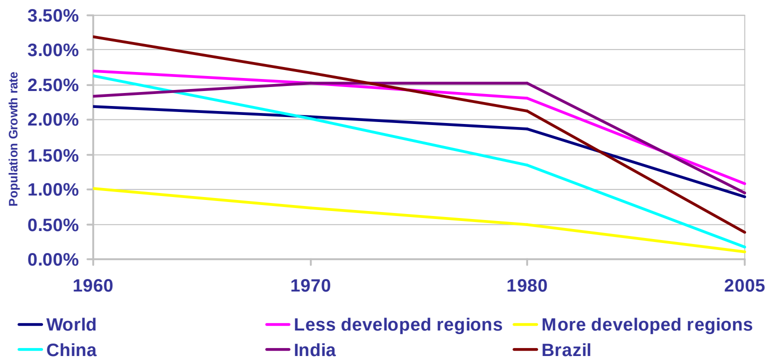
Figure A1.1 **Population development in several world regions 1960-2050**



Source: UN Data.

We can observe that most of the population increase will occur in developing countries, which are thirsty for energy; therefore energy demand will probably grow even faster than population growth. The following figure shows that even if populations continue to grow significantly, growth rates are declining in all regions.

Figure A1.2	Population growth rates in several world regions 1960-2050



Source: UN Data.

The following table shows historical and recent projections for world gross domestic product (GDP) growth.

Table A1.1 Real GDP projections for world regions and several countries

(Annual percent change)

	Average 1991–2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2014	Fourth Quarter[2] 2008	2009	2010
Real GDP															
Advanced economies	**2.8**	**1.4**	**1.7**	**1.9**	**3.2**	**2.6**	**3.0**	**2.7**	**0.6**	**–3.4**	**1.3**	**2.4**	**–2.2**	**–1.3**	**1.7**
United States	3.4	1.1	1.8	2.5	3.6	3.1	2.7	2.1	0.4	–2.7	1.5	2.1	–1.9	–1.1	1.9
Euro area	. . .	1.9	0.9	0.8	2.2	1.7	2.9	2.7	0.7	–4.2	0.3	2.1	–1.7	–2.5	0.9
Germany	2.1	1.2	0.0	–0.2	1.2	0.7	3.2	2.5	1.2	–5.3	0.3	1.8	–1.8	–2.9	0.8
France	2.0	1.8	1.1	1.1	2.3	1.9	2.4	2.3	0.3	–2.4	0.9	2.3	–1.6	–0.9	1.4
Italy	1.6	1.8	0.5	0.0	1.5	0.7	2.0	1.6	–1.0	–5.1	0.2	1.9	–2.9	–3.2	0.8
Spain	2.9	3.6	2.7	3.1	3.3	3.6	4.0	3.6	0.9	–3.8	–0.7	2.1	–1.2	–3.5	0.5
Netherlands	3.1	1.9	0.1	0.3	2.2	2.0	3.4	3.6	2.0	–4.2	0.7	2.6	–0.8	–3.2	1.2
Japan	1.2	0.2	0.3	1.4	2.7	1.9	2.0	2.3	–0.7	–5.4	1.7	1.8	–4.5	–1.3	1.4
United Kingdom	2.5	2.5	2.1	2.8	3.0	2.2	2.9	2.6	0.7	–4.4	0.9	2.9	–1.8	–2.5	1.3
Canada	2.9	1.8	2.9	1.9	3.1	3.0	2.9	2.5	0.4	–2.5	2.1	2.1	–1.0	–1.5	3.0
Korea	6.1	4.0	7.2	2.8	4.6	4.0	5.2	5.1	2.2	–1.0	3.6	4.5	–3.4	4.3	3.5
Australia	3.4	2.1	4.2	3.0	3.8	2.8	2.8	4.0	2.4	0.7	2.0	3.0	0.7	1.4	2.8
Norway	3.7	2.0	1.5	1.0	3.9	2.7	2.3	3.1	2.1	–1.9	1.3	2.1	0.5	–2.1	2.6
Singapore	7.6	–2.4	4.1	3.8	9.3	7.3	8.4	7.8	1.1	–3.3	4.1	4.6	–4.0	2.5	4.3
Denmark	2.6	0.7	0.5	0.4	2.3	2.4	3.3	1.6	–1.2	–2.4	0.9	2.3	–3.7	–0.5	2.0
Israel	5.8	0.0	–0.7	1.5	5.0	5.1	5.3	5.2	4.0	–0.1	2.4	4.4	2.1	0.3	2.8
New Zealand	2.9	2.6	4.9	4.1	4.5	2.8	2.0	3.2	0.2	–2.2	2.2	3.3	–2.0	–0.6	2.8
Iceland	2.5	3.9	0.1	2.4	7.7	7.5	4.3	5.6	1.3	–8.5	–2.0	4.0	–1.5	–11.9	–5.0

(Annual percent change)

	Average 1991–2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2014
Africa	**2.4**	**4.9**	**6.5**	**5.4**	**6.7**	**5.7**	**6.1**	**6.3**	**5.2**	**1.7**	**4.0**	**5.3**

	Average 1991–2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2014
Central and eastern Europe[4]	**2.0**	**0.2**	**4.4**	**4.8**	**7.3**	**6.0**	**6.6**	**5.5**	**3.0**	**–5.0**	**1.8**	**4.0**
Commonwealth of Independent States[4,5]	. . .	**6.1**	**5.2**	**7.8**	**8.2**	**6.7**	**8.4**	**8.6**	**5.5**	**–6.7**	**2.1**	**5.3**
Russia	. . .	5.1	4.7	7.3	7.2	6.4	7.7	8.1	5.6	–7.5	1.5	5.0
Excluding Russia	. . .	8.9	6.6	9.1	10.8	7.4	10.2	9.9	5.4	–4.7	3.6	5.9

	Average 1991–2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2014
Developing Asia	**7.4**	**5.8**	**6.9**	**8.2**	**8.6**	**9.0**	**9.8**	**10.6**	**7.6**	**6.2**	**7.3**	**8.5**
Afghanistan, I.R. of	. . .	. . .	. . .	15.1	8.8	16.1	8.2	12.1	3.4	15.7	8.6	8.9
Bangladesh	4.9	4.8	4.8	5.8	6.1	6.3	6.5	6.3	6.0	5.4	5.4	6.5
Bhutan	5.0	6.8	10.9	7.2	6.8	6.5	6.3	21.4	7.6	8.5	5.3	6.8
Brunei Darussalam	. . .	2.7	3.9	2.9	0.5	0.4	4.4	0.6	–1.5	0.2	0.6	1.7
Cambodia	. . .	8.1	6.6	8.5	10.3	13.3	10.8	10.2	6.7	–2.7	4.3	6.3
China	10.4	8.3	9.1	10.0	10.1	10.4	11.6	13.0	9.0	8.5	9.0	9.5
Fiji	5.0	2.0	3.2	1.0	5.5	0.7	3.3	–6.6	0.2	–2.5	1.2	3.0
India	5.6	3.9	4.6	6.9	7.9	9.2	9.8	9.4	7.3	5.4	6.4	8.1
Indonesia	4.0	3.6	4.5	4.8	5.0	5.7	5.5	6.3	6.1	4.0	4.8	6.3
Kiribati	5.2	–5.1	6.1	2.3	2.2	0.0	3.2	–0.5	3.4	1.5	1.1	1.1
Lao PDR	6.3	5.7	5.9	6.1	6.4	7.1	8.4	7.5	7.2	4.6	5.4	7.3
Malaysia	7.1	0.5	5.4	5.8	6.8	5.3	5.8	6.2	4.6	–3.6	2.5	6.0
Middle East	**4.0**	**2.5**	**3.8**	**6.9**	**5.9**	**5.5**	**5.8**	**6.2**	**5.4**	**2.0**	**4.2**	**4.8**
Bahrain	4.6	4.6	5.2	7.2	5.6	7.9	6.7	8.1	6.1	3.0	3.7	5.0
Egypt	4.4	3.5	3.2	3.2	4.1	4.5	6.8	7.1	7.2	4.7	4.5	6.0
Iran, I.R. of	3.7	3.7	7.5	7.2	5.1	4.7	5.8	7.8	2.5	1.5	2.2	3.2
Iraq	. . .	. . .	. . .	. . .	. . .	–0.7	6.2	1.5	9.5	4.3	5.8	6.8
Jordan	4.7	5.3	5.8	4.2	8.6	8.1	8.0	8.9	7.9	3.0	4.0	5.5
Saudi Arabia	2.7	0.5	0.1	7.7	5.3	5.6	3.2	3.3	4.4	–0.9	4.0	5.0
Syrian Arab Republic	4.8	3.7	5.9	–2.1	6.7	4.5	5.1	4.2	5.2	3.0	4.2	5.7
United Arab Emirates	4.4	1.7	2.6	11.9	9.7	8.2	9.4	6.3	7.4	–0.2	2.4	5.2
Yemen, Rep. of	5.7	3.8	3.9	3.7	4.0	5.6	3.2	3.3	3.6	4.2	7.3	4.7

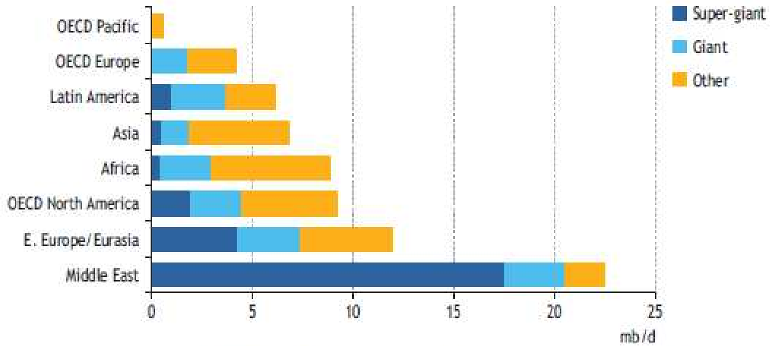
	Average 1991–2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2014
Western Hemisphere	**3.3**	**0.7**	**0.6**	**2.2**	**6.0**	**4.7**	**5.7**	**5.7**	**4.2**	**–2.5**	**2.9**	**4.0**
Antigua and Barbuda	3.4	1.5	2.0	4.3	5.2	5.5	12.4	6.9	2.8	–6.5	–1.5	3.9
Argentina[6]	4.2	–4.4	–10.9	8.8	9.0	9.2	8.5	8.7	6.8	–2.5	1.5	3.0
Bahamas, The	2.1	0.8	2.6	–0.9	–0.8	5.7	4.3	0.7	–1.7	–3.9	–0.5	1.8
Barbados	1.0	–2.6	0.7	2.0	4.8	3.9	3.2	3.4	0.2	–3.0	0.0	2.5
Belize	6.0	5.0	5.1	9.3	4.6	3.0	4.7	1.2	3.8	1.0	2.0	2.5
Bolivia	3.8	1.7	2.5	2.7	4.2	4.4	4.8	4.6	6.1	2.8	3.4	3.7
Brazil	2.5	1.3	2.7	1.1	5.7	3.2	4.0	5.7	5.1	–0.7	3.5	3.7
Chile	6.5	3.5	2.2	4.0	6.0	5.6	4.6	4.7	3.2	–1.7	4.0	5.4
Colombia	2.7	2.2	2.5	4.6	4.7	5.7	6.9	7.5	2.5	–0.3	2.5	4.5
Costa Rica	5.2	1.1	2.9	6.4	4.3	5.9	8.8	7.8	2.6	–1.5	2.3	5.2

Source: World Economic Outlook, October 2009, IMF.

Appendix 2

Crude oil production by region and size of field

Figure A2.1 **Crude oil production by region and size of field, 2007**



Note: For fields covered by IEA field-by-field oil production database. See footnote 3 for definitions of super-giant and giant fields.
Sources: IHS and Deloitte & Touche databases; other industry sources; IEA estimates and analysis.

Source: WEO 2008-Oil and Gas production prospects.

Appendix 3

Results of some studies on agricultural and forest land availability

Table A3.1 **An overview of the literature on global agricultural and forest land availability**

Source	Base year and use (Mha)	Study of year and potential change (Mha)	In 2020 (Mha) (linear interpolation)
UNEP 2007	**2000** • Cropland and pasture: 4,920 • Forest: 4,700	**2025** • Cropland and pasture: +440-990 • Forest: -/- 340-570	**2020** • Cropland and pasture: +350-790 • Forest: -/- 270-460
MNP 2007		**2020** • Cropland and pasture: +0-600	**2020** • Cropland and pasture: +0-600
CE Delft 2007	**Current** • Cropland: 1,500 • Pastures: 3,500 • Forest: 3,900	**2020** • Cropland: +200 • Pastures: 0 • Forest: -200	**2020** • Cropland: +200 • Pastures: 0 • Forest: -200
Smeets et al. 2007	**Current** • Cropland and pasture: 5,000 • Forest: 3,900	**2050** • Cropland and pasture: +729-3,585	**2020** • Cropland and pasture: +290-1,400
Hoogwijk et al. 2005	**1970** • Cropland: 3,000 • Forest: 3,000	**2020** • Cropland: +0-800 • Forest: +100-300	**2020** • Cropland: +0-800 • Forest: +100-300
FAO 2002	**Current** • Cropland: 1,500 • Pastures: 3,460 • Forest: 3,870	**2030** • Cropland: +1,120	**2020** • Cropland: +750
Hoogwijk et al. 2003	**Current** • Cropland: 1,500 • Pastures: 3,500 • Forest: 4,000	**2050** • Cropland: +0-3,700 • Degraded: +430-580	**2020** • Cropland: +0-1,480 • Degraded: +170-230
Fischer et al. 2000	**1990** • Cropland: 1,520 • Pastures: 3,380 • Forest: 3,980	**2050** • Cropland: +220 • Pastures: -/- 80 • Forest: -/- 110	**2020** • Cropland: +90 • Pastures: -/- 30 • Forest: -/- 45

Source: Kampman (2008).

Appendix 4

The LEITAP model

LEITAP2 was developed at the Dutch agricultural research institute LEI, which forms part of Wageningen University and Research (WUR). The name comes from the model from which it is derived (GTAP) and the name of the institute where the current model was developed. It is programmed in GEMPACK. Compared with the original version of the GTAP model at LEI, the LEITAP1 model has been extended and stylised considerably.

The LEITAP2 model is based on the general equilibrium model GTAP, which was developed at Purdue University, USA. LEITAP2 integrates three variants of the GTAP model: it uses the rough characteristics of the production structure of the energy variant of GTAP (GTAP-E), the international capital flow accounting system of the dynamic GTAP model (GTAP-DYN) and includes large parts of the agricultural variant of GTAP (GTAP-AGR).

The standard GTAP model is a global computable general equilibrium model that covers the whole economy, including factor markets. The model uses a consistent database of world trade and production, the GTAP database. The regional aggregation is on a country level, where some countries are aggregated into larger regions (in the GTAP7 database 108 countries and regions are available for the year 2004). The database distinguishes 54 sectors and 5 endowment sectors (skilled/unskilled labour, capital, natural resources, land). In order to have a model that can be calculated within a day, sectors and countries have to be aggregated (in the current setting: 45 regions and 28 sectors). A program has been developed to create these aggregations from the original database.

The GTAP model is a multi-regional, static, applied general equilibrium model based on neoclassical microeconomic theory. The standard model is characterised by an input-output structure (based on input-output tables of nations and groups of nations) that explicitly links industries in a value added chain from primary goods, over continuously higher stages of intermediate processing, to the final assembling of goods and services for consumption. A representative producer for each sector of a country or region maximises profits by choosing outputs and inputs of labour, capital, natural resources, land and intermediate goods. Each sector produces one type of output. The producer has a nested CES production function with constant returns to scale, where in the standard GTAP model only endowments have elasticities of substitution that are different from zero. Perfect competition is assumed in all sectors within a country. On an international scale, goods from the same sector are not homogenous, which is represented by Armington elasticities for import of goods. Primary production factors land, labour and capital cannot move between sectors. Supply of labour, capital and natural services is exogenous and these production factors are always fully employed.

The LEITAP2 model includes a lot more extensions than the standard GTAP model. The various extensions of the model can be switched on or off easily. First, an integrated production structure, with energy nesting (including biofuels), feed and fertiliser nesting is included. Second, there is a possibility to include dynamic international investment in the model. This will probably be extended towards a model of sectoral investment in the near future. Third, production quota can be implemented. Fourth, EU policy, including first- and second-pillar measures, can be switched on. Fifth, land supply is modelled, based on biophysical model outcomes from the land allocation module of the model IMAGE. It distinguishes between marginal and average land productivity. Sixth, substitution between types of land is modelled in a dynamic way. Seventh, dynamic mobility of capital and labour between agricultural and non-agricultural sectors can be switched on. Eighth, income elasticities of consumption are modelled as a function of PPP-corrected real GDP per capita.

In summary, the LEITAP model is a general equilibrium model of the world, with a special focus on the agricultural and energy markets.

LEI Wageningen UR develops economic expertise for government bodies and industry in the field of food, agriculture and the natural environment. By means of independent research, LEI Wageningen UR offers its customers a solid basis for socially and strategically justifiable policy choices.

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