The Future of Oil in a Carbon Constrained World

Daniel J. A. Johansson, Fredrik Hedenus and Thomas Sterner

Introduction

Global climate is changing. This fact is supported by robust scientific evidence, and there is no real doubt that the main reason is the increased concentration of greenhouse gases in the atmosphere caused by human activity, primarily related to the combustion of fossil fuels. Policies to handle the problems that a changing climate will bring about and what to do to limit the change in the climate are among the top issues in contemporary international politics. In connection with this, virtually all nations have ratified the UN Framework Convention on Climate Change (UNFCCC). The overarching aim of the UNFCCC is to avoid dangerous anthropogenic interference with the climate system (UNFCCC, 1992). Based on this the so-called 2°C target has, at least on paper, widespread political support as a target aimed at avoiding the most serious risks of climate change such as a potential dieback of the Amazon rainforest, melting of the Greenland ice sheet and increased global water stress problems (Fee et al., 2010). However, it is becoming more and more difficult to achieve this target given the difficulties in agreeing on any real international emission reductions.

Climate change policies have the potential to dictate the long-term prospects for the fossil fuel markets. Irrespective of the 2°C target it is clear that the use of fossil fuels (coal, natural gas and oil) cannot continue along historical trends. To avoid substantial climate change, the growth of anthropogenic carbon dioxide (CO₂) emissions needs to be reversed, for instance by a transition to other sources of energy complemented by technologies that capture and store CO₂ in sealed reservoirs and technologies that contribute to a more efficient use of energy. However, such a transition does not necessarily imply that the oil era is over yet.

In this chapter we outline how international climate policies to reduce emissions may affect long-term demand and supply of oil. In order to understand how the oil market will be affected we also have to understand the potential for CO₂ neutral alternatives to oil as well as how CO₂ from other fuels can be reduced. In doing this we primarily take a global perspective; climate change cannot be controlled in the long run unless the relevant policies are virtually global, or at least co-ordinated at a global level. The chapter will inevitably be somewhat speculative since it deals with the distant future, but the discussions and material presented will be based on available scientific literature. We will not cover issues related to the impact of climate change itself such as effects of melting arctic ice on the prospects for production or transportation of oil.
in that region. Such topics are outside the scope of this chapter. In section 2 we discuss some central aspects of international climate policies and in section 3 the relationship between cumulative emissions of CO₂ and the increase in global mean surface temperature. In section 4 we briefly outline the conventional view of the future of oil demand in a world where climate change is not a major issue and then analyze how it may change in response to climate policies. In section 5 we discuss alternatives to conventional oil, both fossil-based alternatives and renewable, as well as energy efficiency prospects, focusing mainly on the transport sector. In section 6 we discuss how OPEC and oil companies have approached the issue of climate change and analyse how oil producers may be affected by climate policies. Section 7 contains a final discussion on how policies in the short term may affect the oil market.

Global climate policies

The only long-term climate target that has gained some measure of universal acceptance within the international climate negotiations is the goal of stabilizing the global mean surface temperature at or below 2°C above the preindustrial level. This political target was re-emphasized in the outcome of the 16th Conference of the Parties (COP-16) meeting in Cancun 2010 (UNFCCC, 2010).

The climate problem is global; therefore, the relevant policies must be on the same geographical scale, at least in the long run. If merely a fraction of countries co-operate to reduce their emissions, the policy would be more costly and less effective. The countries outside the coalition have the opportunity to increase their consumption of relatively inexpensive fossil fuels to pick up the slack left by those within the coalition (Gerlagh & Kuik, 2007). This could become especially important in the long run if the coalition does not include a dominant share of global greenhouse gas emissions (Sterner, 2010).

Given the considerable difficulties in reaching and enforcing a global deal to reduce emissions of greenhouse gases that covers the majority of large countries, it appears improbable that a global climate regime with policies stringent enough to meet a 2°C target will come into existence sufficiently soon. It is generally accepted that limiting warming to less than 2°C reduces the risk of significant and irreversible changes in the climate system. However, this does not mean that there is any particular threshold at exactly 2°C. Significant negative impacts can occur already below 2°C, and if we were to miss the 2°C target, stabilizing the increase in the global average surface temperature at, say, 2.5 °C would still imply less severe consequences than risking an increase of 3°C (Smith et al. 2009; Harvey, 2007).

Reducing CO₂ emissions to levels discussed in this chapter will entail significant costs, although along with the benefits of increasing our chance of avoiding a range of costly climate impacts. There are considerable uncertainties but for instance the Stern Review mentions abatement costs on the order of a percentage of global GDP (Stern, 2007). In the perspective of a growing economy, this is not prohibitively costly; it does not mean that humanity cannot enjoy a good life. It does not mean that the poor cannot lift themselves out of poverty or even that the broad global middle class cannot continue to enjoy its welfare and economic standard (Azar & Schneider, 2002). However, the costs are high enough to warrant careful attention to economic efficiency in the design of climate policy. A cost-effective climate policy can never be achieved without relying heavily on an almost universal price-signal for CO₂ emissions, either generated by globally co-ordinated CO₂ taxes or a global cap-and-trade system.¹ However, such a policy is still a distant thought. Today greenhouse gas emissions are genuinely priced in only a few places, and there is little progress in international negotiations concerning climate mitigation. The reader should note that efficiency requires equalization of the marginal cost of abatement through a global CO₂ price. This does not imply that the cost of abatement should
be split equally among the world’s citizens. The distribution of costs can be separated completely from the efficiency issue and handled by a range of principles based on different perspectives of equity and responsibility, see Ringius et al. (2002) or Sterner (2002). The trouble is that the “scarcity rent” created by regulation of these emissions will generate very large sums of money, and there is genuine disagreement among countries how this rent should be shared. As shown by Sterner (2010), equal per capita shares would give India 16% of the global emission rights, while ‘grandfathering’ (emission rights based on historical emissions) would give India only 4% of total emission rights (since they currently emit about 4% of global emissions). The figures for the USA are roughly the mirror image: per capita rights would give the USA some 4% and grandfathering 16%. Naturally, when the disagreement implies such big differences in allocation, negotiations may be difficult and lengthy. The trouble is that we need a global agreement in order to make serious national policies possible, and we need it very fast if we are to reach targets such as the 2ºC target.

Essential climate facts

Up to 2010 the global average surface temperature has increased by about 0.7ºC above the pre-industrial level. Even if we immediately stop all greenhouse gas emissions, we would still witness an additional increase in the global average surface temperature of about 0.5º C. The reasons for this increase are threefold:

The full warming effect of the greenhouse gases is masked by the cooling effect of (primarily sulphate) aerosols. The majority of these aerosols are co-emitted with CO₂ when coal and oil are burned. If we cease to burn fossil fuels, we would also cut aerosol emissions significantly (Wigley, 1991). Hence, their cooling effect would rapidly lessen, since the aerosols have a short atmospheric life time, resulting in a temperature increase.

CO₂ and some other greenhouse gases have a long atmospheric lifetime. A kg of CO₂ emitted from combustion of fossil fuel would result in an elevated atmospheric concentration of CO₂ for a very long time. About 30 to 40% of the initial effect on the CO₂ concentration would prevail after 100 years, while about 20% would remain after 1000 years (Archer et al., 2009). The climate system responds slowly to changes in the warming generated by greenhouse gases due to the large thermal inertia of the oceans (Wigley, 2005; Johansson 2010).

The above applies to a complete and immediate cessation of fossil emissions, but that is not possible. These emissions are, in a baseline scenario, expected to grow a few percent per year. Just stabilizing emissions at the current level would require quite strong policy instruments. But this is a ‘stock’ problem: stabilizing emissions would still imply that the atmospheric stock continued to grow (although close to linearly rather than exponentially). This would still be entirely insufficient in meeting the 2ºC target; it would bring us above 600 ppm CO₂ and making temperature more than 3ºC warmer already this century.

Even though the science of climate change itself is robust, there are large uncertainties concerning how sensitive the climate is to emissions of greenhouse gases. Climate sensitivity is a measure of the change in the global mean surface temperature that would occur if we were to double the pre-industrial level of CO₂ concentrations in the atmosphere and wait for the full temperature effect to take hold. The global mean surface temperature would in this case likely increase by 2–4.5ºC, with a best estimate of 3ºC according to Meehl et al. (2007). This uncertainty about how much a given change in the concentration of greenhouse gases affects the global mean surface temperature results in large uncertainties in how much CO₂ the
world may emit and still keep the global mean surface temperature below a targeted limit. If climate sensitivity is low (i.e., \(\sim 2^\circ\)C), we can emit considerably more CO\(_2\) than if climate sensitivity is high (i.e., \(\sim 4.5^\circ\)C) for any given increase in global average surface temperature.

Because emissions of CO\(_2\) accumulate in the atmosphere, cumulative emissions are strongly correlated with the level of global warming, see Allen et al. (2009), Matthews & Caldeira (2008), Zickfeld et al. (2009) and NRC (2010). Hence, it is not of direct importance when emissions take place; what matters to the global average temperature is the cumulative amount of CO\(_2\) (within half a millennium or so), \textit{ceteris paribus}.

This relationship between cumulative emissions of CO\(_2\) and temperature change can be used to assess how much fossil fuels can be used while keeping the global average surface temperature below a certain level.\(^5\) The cumulative emissions of carbon emitted as CO\(_2\) from 2010 and onwards that are compatible with an increase in the global mean surface temperature of 2\(^\circ\)C and 3\(^\circ\)C have been estimated by the use of NRC (2010), CCC (2011) and the MiMiC model (Johansson, 2010), see Figure 29.1 for results. For example, in order to keep the global average surface temperature below 2\(^\circ\)C with a probability of about 50\%, we may emit about 550 Gton\(^6\) carbon (as CO\(_2\)) beyond 2010. For 3\(^\circ\)C, more CO\(_2\) may be emitted, about 1100 Gton carbon beyond 2010. However, there is a great deal of uncertainty in these numbers, beyond what the error bars in Figure 29.1 indicate. The error bars only include the uncertainty from the climate sensitivity and the carbon cycle. In addition, the cumulative carbon that may be emitted while reaching a specific temperature target also depends on how emissions of other greenhouse gases (methane, nitrous oxide, etc.) and aerosols develop. In addition, it is important to note that Figure 29.1 shows the cumulative \textit{net} emissions of CO\(_2\). If biomass with carbon capture and storage becomes a feasible option on a large scale, which would imply net negative emissions of CO\(_2\), the cumulative gross emissions of CO\(_2\) from fossil fuels could potentially be greater than those shown in Figure 29.1 (see Azar et al., 2006).

There are large uncertainties in the remaining recoverable resources of oil, natural gas, and coal.\(^7\) So as to be able to compare recoverable resources of oil and other fossil fuels with the cumulative emissions of CO\(_2\) that are compatible with different temperature stabilization levels, we have assessed a range of sources that provide estimates on proven reserves and recoverable resources.

The proved reserves of conventional oil amount to about 1,300bn. barrels according to BP (2010). In line with BP we include both crude oil and natural gas liquids (NGL) in the category conventional oil. Given standard conversion factors these reserves contain about 160 Gton carbon.\(^8\) The estimated additional recoverable resources, i.e., conventional oil left in reservoirs that are yet not classified as proven reserves and that may become economical to recover in the future, are uncertain. Estimates range from close to zero to about equal to the current proven reserves or even more (IEA, 2008; Aguilera et al., 2009; USGS, 2000; Kjärstad & Johansson, 2009; Sorrel et al., 2008). Setting aside the extreme estimates, we assume that the additional recoverable resources contain about 110 Gton carbon.

In addition to the recoverable resources of conventional oil, the recoverable resources of oil sands and heavy oil are estimated to be substantial, on the order of about 1,000 bn. barrel oil equivalent (boe) (Kjärstad & Johansson, 2009), corresponding to about 130 Gton carbon.\(^9\)

Proven reserves of natural gas amount to about 1,200 bn. boe (BP, 2010) and additional recoverable resources to about equally large, i.e., about 1,200 bn. boe (Aguilera, 2009; USGS, 2000), in total corresponding to about 220 Gton carbon.\(^10\) In addition, there is a substantial amount of unconventional gas. These resources may be several times larger than the proven reserves of conventional gas. The unconventional sources include shale gas, coalbed
methane, and tight formation gas. In addition, if methane hydrates stored in ocean sediments become recoverable, these could potentially add thousands of billion boe of gas, see Sims et al. (2007).11

The proven reserves for coal are larger (in energy terms) than those of conventional oil and natural gas, amounting to about 3,000 bn. boe and contain about 500 Gton carbon.12 In addition, the recoverable resources of coal are likely to be considerably larger than the proven reserves, estimated up to about an order of magnitude larger than the proven reserves (Thielmann, 2007; Sims et al., 2007), although much more conservative estimates of the recoverable resources of coal are also available (Höök et al., 2010).

The estimated recoverable resources (including the proven reserves) of fossil fuel contain considerably more carbon than can be emitted as CO2 with a maximum increase in global mean surface temperature of 2°C or any temperature level nearby, see Figure 29.1. Burning only the proven reserves of coal, oil and natural gas would foreclose the 2°C target, but would likely keep the increase in the global mean surface temperature below 3°C. However, if only the recoverable reserves of conventional oil and natural gas were used, but no other fossil fuels (i.e., no coal, oil sands, etc.), the amount of CO2 emitted would be compatible with meeting a 2°C limit, with a probability of roughly 50%.

The latter scenario may seem far from realistic today (2011). For the last few years, coal has been the most rapidly growing source of fuel globally. However, coal is the worst of the fossil fuels from a climate perspective; per energy unit, the CO2 emissions are higher than those of oil and natural gas.13 For this reason and since the recoverable resources for coal are estimated to be large, it is not uncommon to see suggestions that the most important strategy to combat climate change is to control the use of coal and to develop and rapidly deploy Carbon Capture and Storage (CCS) methods to minimize CO2 emissions from coal use (Kharecha et al., 2010).

The use of oil in a world with or without climate policies

Global demand for energy is expected to grow considerably over the coming decades. In a baseline scenario without strong climate policies, demand is expected to roughly double by 2050 (Clarke et al., 2009). Of the various energy sources oil is today the most important in energy as well as economic terms. Oil is used in virtually all sectors of the economy. The use and production of oil may grow by 1 to 2% per year in the coming decades (Dargay & Gately, 2010; EIA, 2010; IEA, 2010a). The growth will probably be strongest in rapidly industrializing countries such as China and India and for petroleum products used for transportation fuel and as feedstock for the petrochemical industry (Dargay & Gately, 2010; EIA, 2010; IEA, 2010a). For example, the consumption of light and medium distillates has grown about 8% per year in China in the past decade (BP, 2010).

In 2009, about 85m. barrels of oil were extracted per day (BP, 2010). About 60% of the global refinery output (measured in energy terms) was used within the transport sector (road, rail, aviation and shipping) and this share is expected to increase over the coming decades. Roughly 15% of the energy content of oil is used internally within the refining process; the use of crude oil directly as a fuel without any refining is rare (IEA, 2010b).

Growth of the energy system cannot be fuelled by fossil fuels if we are to avoid serious changes in the climate system. The use of fossil fuels without carbon capture and storage has to fall quite fast, and energy must be used more efficiently. In order to illustrate one possible transition path for the energy system, we use the Global Energy Transition (GET) model (Azar et al., 2003, 2006; Hedenus et al. 2010). This model makes assumptions on costs and energy conversion efficiencies for a large range of technologies, resource availabilities, and costs of extraction as
well as constraints on how fast technologies can expand. Given these assumptions, the model minimizes the total cost of meeting energy demand. In addition, an explicit constraint is included so that cumulative emissions beyond year 2010 are kept below 550 Gton carbon. This gives the world a ~50% chance of keeping the global average surface temperature change below 2°C.

A constraint of 550 Gton carbon can be met if global emissions peak by 2020 and then decline by about 2% per year. Such a scenario requires a rapid expansion of new energy sources, new infrastructure, and new end-use systems for higher efficiency. By 2050 more than 60% of the global primary energy supply would need to come from sources with virtually zero CO₂ emissions, see Figure 29.2. This can be compared to the situation in 2005 where about 20% of the primary energy supply came from renewable fuels. Similar results to those generated by the GET model and presented here can be found in a range of studies, see for example IEA (2010a) and Clarke et al. (2009).

Figure 29.1 Proven reserves and estimated additional recoverable resources of different fossil fuels, compared to cumulative emissions of CO₂ compatible with climate targets of 2 or 3°C above the pre-industrial level

Note: > 3000 G ton carbon
The feasibility of a large scale expansion of some of the new technologies necessary for an energy scenario such as described here needs to be proven and costs must come down before they will make a real dent within the energy system. For example, crucial technologies such as CCS or Biomass-to-Liquids (BTL) only exist in the demonstration phase today.

The transition of the energy system will involve major changes in all sectors of the economy. However, how much emissions will be reduced in the various economic sectors depends on both market forces and political choices. A related question is how emission of greenhouse gases should be reduced to minimize economic costs of abatement? This related question has been approached and analyzed in a number of studies; see for example Azar et al. (2003, 2006), Clarke et al. (2009) and Edenhofer et al. (2010). Although future costs and resource availability are very uncertain, some patterns emerge from such studies. It seems that reducing CO₂ emissions by reducing the use of petroleum products within the transport sector tends to be relatively costly while reducing emissions from coal tends to be relatively inexpensive. This is confirmed in Working Group 3 of the IPCC where the results of many model studies are assessed “… in all models, coal use is significantly reduced under the climate policy scenarios, compared to the baseline … In 2030, oil use is only modestly reduced by climate policies … ” (Fisher et al., 2007).

This is illustrated in Figure 29.3 where results from the GET model on the use of fossil fuels in the climate policy scenario presented above are compared with the use of fossil fuel in a baseline scenario. Coal is the fossil fuel that is reduced most. Coal is largely used for power production, for which less carbon-intensive alternatives are available, such as wind power, natural gas, or by using the coal with carbon capture and storage (Haszeldine, 2009). The substitution of natural gas for coal explains the increase in natural gas in the climate policy scenario. Oil is reduced in 2050 compared to 2030 in both the baseline scenario and the climate policy scenario due to resource depletion. However, the differences are small in both 2030 and 2050, mainly due to the limited low-cost abatement options in the transportation sector. In the baseline scenario Coal-to-liquids is the main substitute to petroleum products in the transport sector, while in the climate policy scenario a range of alternatives are used, including more efficient

Figure 29.2 A global energy supply scenario following an emissions path that limit cumulative carbon emissions to 550Gtons (post 2010)
vehicles (including hybrid vehicles), biofuel and natural gas. Petroleum products are considered less costly to substitute for in heating and electricity production than in the transport sector. However, the share of petroleum products in these sectors is already small, see Dargay & Gately (2010), EIA (2010) and IEA (2010a).

Options for reducing conventional fuel use

In this section we focus our attention on alternatives to petroleum products from conventional oil, especially for the road transport sector. This sector uses close to 50% of refinery output, a share that is likely to grow. However, all large scale substitutes for oil in the transport sector that has low CO₂ emissions have important limitations, at least in the short to mid-term (less than 20 years). This explains the results in Figure 29.3, namely that there is a relatively small difference between oil use in a baseline scenario and in a climate stabilization scenario. Given stringent climate policies, the main large-scale changes in the coming decades in the transport sector are likely to be more energy-efficient and smaller vehicles and perhaps biofuels. Still, in the long run (beyond 2020–30 or so), the transport sector cannot continue to rely on fossil fuels, and the choice seems to be between biofuels, electricity, and hydrogen (Hedenus et al., 2010). We will in this section present an overview of the different options.
Shifting fuel and propulsion technologies

In the transport sector, oil-based fuels have totally dominated for more than a hundred years. Still, several liquid alternatives may replace oil-based fuels when conventional oil becomes scarce, costly and/or is phased out due to policy concerns. These alternatives include fuels derived from extra heavy oils, oil sands, coal, natural gas, or from biomass. However, all liquid substitutes based on fossil alternatives have higher lifecycle CO₂-equivalent emissions than conventional oil, see Figure 29.4 and Brandt & Farrell (2007).

Other technologies may also yield important substitutes for oil in the transport sector, especially electricity in battery electric vehicles as well as hydrogen. To briefly assess these options, we describe their potentials and caveats.

Extra heavy oils and oil sands

Extra heavy oils and oil sands are extracted today in Venezuela and Canada, respectively, and are economically viable at current oil prices. Production costs are still higher than for conventional oil, around US$ 50–70 per barrel synthetic crude for oil sands, slightly lower for Venezuelan extra heavy oil, and higher for oil shale (IEA, 2010a). Moreover, the lifecycle CO₂ emissions per barrel synthetic crude are considerably higher than for conventional oil: for oil sands, 10–30 % higher (Charpentier et al., 2009) and higher yet for oil shale. In addition, there are severe environmental consequences of recovering oil sands and extra heavy oil that may prohibit larger-scale expansion of these fuels.

Coal and Coal-to-Liquids

The Coal-to-Liquids (CTL) technology was developed in the beginning of the 20th century and adopted large-scale during the Second World War in Germany and during the apartheid regime.
in South Africa. To produce liquid fuels, coal is gasified and thereafter synthesized to synthetic fuels. Considering the widely held view that coal is very abundant, see Figure 29.1, CTL could provide a large-scale oil substitute in the future. However the CO\textsubscript{2} emissions are around twice those from conventional oil-based fuels. On the other hand with the use of CCS technologies, the emissions would come down to comparable levels as those for conventional oil. This would come at an increased cost of around US$10 per barrel if the CCS technology succeeds in becoming a commercial technology with safe and permanent storage sites for the captured CO\textsubscript{2}. The oil price needs to be stable over $60 to $100 per barrel for CTL projects to be economical (IEA, 2008).

**Natural gas and Gas-to-Liquids**

Natural gas is sometimes mentioned as an alternative fuel to petroleum products in the transport sector. Natural gas would reduce the CO\textsubscript{2} emissions by about 30% if used to replace gasoline; but it would reduce CO\textsubscript{2} emissions by about 60% if used to replace coal in the power sector, and at a lower cost. Arguably, it is better to use the limited gas resources in the latter way, from a climate perspective. Natural gas can also be used to synthesize diesel or other synthetic fuels, i.e., Gas-to-Liquids (GTL). The process is rather costly and involves energy losses on the order of 40 to 50%, which results in slightly higher CO\textsubscript{2} emissions compared to conventional oil (IEA, 2005).

**Biofuels**

There has been considerable optimism about biofuels as an alternative to petroleum products. This optimism has declined in recent years, in part due to the dubious experience of public support for cereal-based ethanol. This is a costly source of biofuel, with rather large emissions of greenhouse gases, giving small or no carbon benefits compared to gasoline or diesel, see Figure 29.4. If biofuels are to make an important contribution in the future energy system, other sources have to be used, such as sugarcane or woody biomass, as both costs and potentials for greenhouse gas reductions are more promising (Hamelinck and Faaij, 2006).

Regardless of the feedstock, the production of biomass requires land, which globally is a scarce resource. Bioproductive land is essential for providing society with food, fibres, and bioenergy, and for preserving ecosystems and biodiversity. The demand for such land is currently increasing for several reasons, and there is little reason to expect that the demand growth will level off in the foreseeable future (Smith et al., 2010).

The increased scarcity of land and expansion of bioenergy have several important implications:

An increase in land use will increase land rents, and thereby both food and biomass prices (Johansson and Azar, 2007). The high food prices in 2007/2008 are believed to at least partly have been a result of the rapid expansion of cereal-based ethanol production in the USA and the EU. Higher food prices may have adverse social effects, and the increased land rents may also undermine some of the cost-effective potential of biofuels. Bioenergy will be a scarce resource and cannot, even in the long run, be used for all energy purposes. Biomass has competing uses as a source of liquid fuel, heat, electricity, and as feedstock to the chemical industry. Where the biomass will be used will be determined by cost differentials and policy design. Assuming an equal price on CO\textsubscript{2} from all sources, several studies have come to the conclusion that it is more cost effective to use the limited biomass resources for residential and industrial heat or for electricity production rather than for liquid biofuels, see Azar et al. (2003) and Gul et al. (2009).
Expansion of bioenergy requires additional land use. There may be large CO₂ emissions associated with land-use conversion from pasture or forests to agricultural land, see for instance Fargione et al., 2008. However, there is also the risk of indirect land-use change. Even though bioenergy itself is not grown on former forest land, the expansion of bioenergy crops may displace food production, so that food instead is grown on former forest or pasture land (Searchinger et al., 2008). The effect of indirect land-use change could be substantial and even totally negate the greenhouse gas benefits obtained if the biofuel replaces oil.

**Electric vehicles**

Electricity may be used in light utility vehicles, either in Battery Electric Vehicles (BEV) or in Plug-in Hybrid Electric Vehicles (PHEV). The first BEV was developed in the 1890s, but was later out-competed by the internal combustion engine. Since the 1990s there has been a renewed interest in the electric car. However, the electric car faces several obstacles to becoming more than a marginal contributor to the transport sector. BEVs are typically more expensive than their counterpart internal combustion vehicles, with roughly the same size, top speed, range, etc. The cost (and success) of BEVs depends critically on the cost of their batteries. Today these batteries cost around 700 US$/kWh (Brooker and Thornton, 2010). To become a cost-effective option given stringent climate policies, this cost would need to be cut by 80% (Offer et al., 2011).

The energy efficiency in an electricity motor is around three times higher than in the internal combustion engine. On the other hand, there are larger losses when electricity is generated and transmitted compared to when petrol is refined from crude oil. If coal is used to produce the electricity, the carbon emissions per km driven are roughly the same for a BEV as for a conventional car (Jaramillo et al. 2009). Thus, to make the electric car a viable option in the case of climate policy, the electricity system must first be transformed, and a large share of the electricity must be produced by renewables, nuclear, and/or coal and natural gas with CCS. Finally, the limited range of a BEV constitutes an important barrier.

The PHEV has both an internal combustion engine and a large battery that can be charged from the grid. This enables the internal combustion engine to work more efficiently, as in hybrid vehicles, but also enables a larger range compared to a BEV. PHEVs do not require as large a battery, which makes them cost-effective at a higher battery cost of around 300 US $/kWh (Hedenus et al., 2010; Offer 2011), significantly higher than for the BEV.

**Hydrogen**

Hydrogen cars are often perceived as the sustainable solution for the transportation sector, although the technical obstacles are probably even more substantial than for electric cars. Hydrogen is produced using an energy source that determines the carbon footprint. Producing hydrogen using fossil fuels does not make sense from a climate mitigation perspective. Instead, viable energy sources are renewables such as wind and solar, nuclear energy, or fossil fuel plants with CCS. Distribution and storage of hydrogen tend to be both costly and energy-consuming, since high pressure gas tubes have to be used in order to compress the gas into a manageable volume. Hydrogen may be used in both internal combustion engines and fuel cells. Fuel cells have higher conversion efficiency, but both the cost and the limited lifespan are presently prohibitive (von Helmolt and Eberle, 2007). Even so, if batteries turn out to remain rather expensive, and biofuels are constrained by land availability, hydrogen may become an attractive alternative in the future.
Reducing the use of liquid fuels

When the price of petroleum (products) goes up the use tends to go down (ceteris paribus). This reduction in demand is a result of two main factors; a decline in the use of the service the fuel provides (such as transport distance or heating) or a switch to a new technology using the fuel more efficiently. These two main factors are captured in the price elasticity of demand for liquid fuels. Hence, pricing of CO₂ emissions will not only result in a shift toward other sources of energy with lower CO₂ emissions as discussed above, it will also result in a reduction of demand for liquid fuels.

The demand price of liquid fuels is in general considered to be inelastic, although this is in part a function of the time horizon studied. In the short run (about a year) the price elasticity is very low, close to zero. The options for shifting to other energy sources in the short run are limited, and the energy services provided by the fuel in general rather essential. In the long run (about 10 years) the price elasticity is considerably larger. Given time to adjust the capital stock to a new price level implies that vehicles, burners, or other equipment with a more efficient use of the fuel become profitable to invest in given that the fuel price increases. As a consequence, if CO₂ emissions are priced, the consumer price (producer price plus emissions price) of oil will increase, thus reducing demand.

Sterner (2007) reports on a number of reviews of fuel price elasticities and concludes that they are about −0.3, in the short run, and about −0.7, in the long-run. However, this is the price elasticity for engine fuel (gasoline and diesel), not oil. The fuel price includes refinery margins, insurances, transport costs, taxes, etc. Therefore, the corresponding price elasticity of oil is lower. Studies that have focused explicitly on oil price elasticities find values around 0 to −0.1 in the short run and less than −0.5 in the long run (Gately & Huntington, 2002; Dargay & Gately, 2010).

An implication of the price inelasticity of oil demand is that CO₂ prices will only have a small effect on demand for oil as illustrated in Table 29.1, which shows relative reduction in oil demand for various CO₂ price levels. These price levels can be compared with the price in the EU Emissions Trading Scheme (EU ETS) which is about US$20 per ton CO₂.

However, we need to be cautious here, the estimates of price elasticities point to the fact that the demand for liquid fuels is not very price responsive. This does not mean that the fuel could not be used much more energy efficiently. There is a large technical potential for improved energy efficiency in the transport sector, see ICCT (2011) and Bandivadekar et al. (2008). However, it is well accepted that even if many energy efficiency measures tend to appear cost-effective on paper, the potential is often not realized, for a range of reasons, see Jaffé & Stavins (1994) and Brown (2004). This difference between the cost-effective technical potential and the realized outcome is sometimes referred to as the “energy efficiency gap.”

Historically, engine losses, the rolling resistance of tires, and air drag have all decreased, but these efficiency gains have to a large degree been balanced by an increase in the performance and size of the vehicle. By increased performance we mean increased acceleration, larger

<table>
<thead>
<tr>
<th>CO₂ price (US$/ton CO₂)</th>
<th>Reduction in demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>3 %</td>
</tr>
<tr>
<td>50</td>
<td>8 %</td>
</tr>
<tr>
<td>100</td>
<td>14 %</td>
</tr>
</tbody>
</table>

Table 29.1 The decline in demand for oil for three different CO₂ prices. In the calculations an untaxed world market price of oil of US$100 per barrel was assumed together with a long-run elasticity of −0.4
engine, air conditioning, increased passenger space and weight, among other changes requiring energy, see An & Di Cicco (2007) and Sprei et al. (2008). If the consumer desires these, it is “costly” to reduce fuel use.

Fuel economy and/or CO2 emissions from vehicles are regulated in the USA, the EU, China, South Korea, and Japan among other countries (ICCT, 2011). The proposed targets in these countries for the coming years would imply cuts in CO2 (or fuel use) per kilometre in the order of several percent per year. Hence, these fuel economy standards point to the fact that much of the potential for energy efficiency improvements must be realized together with a trend toward lighter and smaller vehicles if the standards are to be met. In addition, this increase in energy efficiency cannot be counteracted by increases in vehicle performance that require additional energy, as has been common in the past, if the vehicle manufacturers are to comply with regulations. However, regulation of fuel economy is far from being an optimal instrument from the viewpoint of fuel savings. It is not likely to cut fuel use as much as fuel economy is improved since only vehicle characteristics and not usage is regulated. As the vehicle becomes more energy efficient the marginal cost of an extra mile declines which acts as an incentive to increase driving distance. This effect is commonly dubbed the “direct rebound effect.” For example, Small & Van Dender (2007) estimate that 5–20% of the potential fuel savings from vehicle fuel economy improvements have been eaten up by the rebound effect. In addition, the fuel price would tend to fall if demand is reduced, encouraging all kinds of new use of fossil fuel. For these reasons we should not expect that fuel efficiency standards will cut petroleum product demand as much as fuel economy is improved.

**Oil producers and climate policy**

One major challenge in international climate policy negotiations has been related to the issue that energy-exporting countries, especially the OPEC member countries Saudi Arabia and Kuwait, claim that their oil resource rents will decline as a consequence of measures to reduce CO2 emissions. The concerns are understandable since many OPEC countries and other energy-exporting countries depend heavily on energy exports for their national income. Some energy-exporting countries push the claim that they either should be compensated for lost oil export revenues or be supported in their attempt to diversify their economies to be less dependent on oil export revenues (Barnett & Dessai, 2002; Aarts & Janssen, 2003; Depledge, 2008; Loumi, 2009). In order to get the energy exporting countries as signatories to the UNFCCC and the Kyoto protocol, article 4.8 in the UNFCCC and articles 2.3 and 3.14 in the Kyoto protocol state that these energy exporting countries should (at least in part) be compensated for losses in energy export revenues or obtain assistance in diversifying their economies (UNFCCC, 1992, 1997). In the Cancun Agreement, paragraphs 88–94 consider, among other issues, the concerns among the energy-exporting countries and the impact emissions-reducing policies may have on these countries’ national income (UNFCCC, 2010).

OPEC countries have in part based their concerns on energy-economic model studies that show that OPEC countries are negatively affected by measures to reduce greenhouse gas emissions. Such studies are plentiful, see for example Berg et al. (1997), Bernstein et al. (1999), Ghanem et al. (1999), McKibbin et al. (1999), Bartsch & Muller (2000), Radetzki (2002), IEA (2010a), Kitous et al. (2010) and van Vuuren et al. (2010). Briefly summarized, these studies suggest that policies and measures aimed at reducing CO2 emissions will reduce oil consumption, and push the producer price of oil down, and that both these effects cause a decline in revenue from oil export.

Echoing the concerns expressed by the oil nations, international oil companies have worried that climate change policies will erode their business, see van den Hove et al. (2002). Some oil
majors are also known for their intense lobbying campaigns against climate policies and for their support for campaigns to confuse the public about the science behind climate change, see Oreskes & Conway (2010).

Although the concerns expressed by countries rich in oil endowments and oil companies make intuitive sense, i.e., that climate policies will erode their rents and profits, many studies on climate policies point toward the fact that such policies alone may not put an end to the petroleum era, at least not in the transport sector. The reasons for this have been discussed above, but we summarize them here.

The carbon content in the estimated recoverable resources for conventional oil is smaller (less than half) than the cumulative emissions of CO₂ compatible with meeting long-term stabilization levels of the global average surface temperature in line with the targets discussed in international climate politics.

Most conventional oil is inexpensive to extract, according to the EIA (2008) less than US $20 per barrel in the Middle East, and less than US$40 per barrel in other places, see also Aguilera et al. (2009) and Brandt & Farrell (2007), for studies suggesting even lower production costs for conventional oil.¹⁸ Hence, even if the producer price of oil would drop below current levels (~US$100 per barrel) due to climate policies, most conventional oil would be used anyway, unless the CO₂ price is very high or alternative technologies inexpensive.

Oil is superior for production of liquid fuels, which are crucial in the transport sector, with few contenders. Oil used in other sectors than transport is easier to substitute, but transport is the major sector that uses petroleum products, and the share of petroleum products used within the transport sector is expected to grow.

The price elasticity of demand for liquid fuel has been low historically, and there is no obvious reason to believe the situation is different today or will be different in the coming decades. Recent studies have even estimated that the oil price elasticity has become even smaller over the last decade (Hamilton, 2009). Hence, an increase in the consumer price of petroleum would only imply a relatively small reduction in demand.

The lowest-cost substitutes for conventional oil are fuels derived from unconventional oil, coal (CTL), natural gas (GTL), sugar cane (ethanol), lingo-cellulosic biomass (second generation ethanol or BTL). The fuels derived from these sources involve greater lifecycle CO₂-eq emissions, with the exception of the biomass-derived fuels. This implies that the cost of producing and using these fuels will increase more than the cost of producing and using fuels derived from conventional oil if CO₂ emissions are priced. This would increase the relative advantage of conventional oil to the other fossil alternatives. This could result in an increased producer price for conventional oil (Manne & Rutherford, 1994, Person et al., 2007, Johansson et al., 2009). However, the relative advantage for conventional oil would be small if CCS expands large-scale and is used to capture and store upstream emissions from the production of synthetic petroleum products from unconventional oils, coal, and natural gas.

Although most studies suggest that oil resource owners will see a drop in their resource rent due to climate policies, no firm conclusions can be drawn. Based on the first four arguments presented above one may suggest that it is likely that most of the conventional oil in the estimated recoverable resources will be used even if globally and stringent climate policies are in place.¹⁹ Taking the fifth argument into account, one cannot rule out that the net present value oil rent for OPEC and other conventional oil owners may increase due to climate policies²⁰ that are stringent enough to allow the 2°C target to be met, as suggested in Persson et al. (2007) and
Johansson et al. (2009). Whether resource rent will increase or not will also depend on the pricing strategies adopted by OPEC, see Johansson et al. (2009) for an analysis of OPEC and climate policies.

Final discussion – policies in the short term

In the previous sections of this chapter we have taken a perspective that policies directed towards reducing emissions of greenhouse gases primarily have a close to global coverage and are driven by economic efficiency considerations. However, climate policies may predominantly in the short-run, take other routes. Existing and planned national policies aimed at reducing the use of petroleum are in a sense ambitious. More than 25 nations have biofuel blending mandates (REN21, 2010), and plans for fuel economy standards in the coming years are strong in many major countries (ICCT, 2011). A continuation of these policies aimed at reducing petroleum use in the transport sector is likely irrespective of the success of international climate negotiations. However, these policies are not the most cost-effective approach to cut emissions of greenhouse gases. As we have already mentioned, they depart from the ideal of a universal price on all greenhouse gas emissions in two different ways. Such policies may put a higher burden (in the form of a higher marginal cost of abatement of CO₂) on the transport sector than on other sectors, and they are not even cost-effective for the transport sector compared to policies that increase fuel taxes (Sterner, 2002).

Putting a higher burden on the transport sector may be motivated by a series of considerations. The domestic transport sector is not subject to international competition, and there is a strong inter-relationship with energy security issues. The distributional and political effects of transport fuel taxes are not easy to deal with but may be preferred to the corresponding effects related to fuels such as kerosene (used by the very poor) or fuels that are used by industry where fear of the loss of jobs is a dominant factor. Regulating and pricing greenhouse gas emissions from energy-intensive industries exposed to international competition would affect prospects negatively and lead to massive lobbying in favour of jobs. Dealing with emissions (of CO₂, nitrous oxides (N₂O), and methane (CH₄)) from soils, forests, and ecosystems may turn out to be administratively more complicated than dealing with transport fuels. Still taxing fuels is also very difficult politically (at least in some countries) and thus may increase the temptation to use other second-best policies such as fuel efficiency standards, biofuel blending mandates and subsidies for certain technologies. It is easy to see that there are powerful lobby groups in favour of these policies, but essentially no one lobbies for higher fuel taxes, see further Sterner (2002) and Anthoff & Hahn (2010).

For these reasons, the transport sector may have to undertake a larger share of mitigation than would have been the case if the policies were driven by global cost-effectiveness alone, especially as long as only a limited fraction of the world’s nations have binding emissions targets. This in turn will have an impact on the oil market (including the relative demand for different petroleum products) that may go beyond what we have presented in this chapter. Hence, the effect of climate worries and policies on the oil market will not only depend on the stringency of climate policy and the alternative technology solutions available but also on the strategies chosen with respect to policy instruments used and sectors targeted.

Acknowledgements

We would like to thank EON, Formas and the Swedish Energy Agency for funding and Jessica Coria, Paulina Essunger and Jonas Nässén for their helpful comments.
Notes

1 It can be noted that cost-effectiveness of policies is stated as a principle in the UNFCCC (1992).
2 The response on the global average surface temperature due to different CO₂ emission scenarios can be tested with the simple climate model Chalmers Climate Calculator (CCC) available online via www.chalmers.se/ee/ccc.
3 Estimated with the CCC model, using best estimates such as climate sensitivity being 3°C.
4 Note that likely means the probability is 66 to 90% that climate sensitivity is in this interval (Meehl et al., 2007).
5 See also Grubb (2001).
6 G stands for Giga. It is a unit prefix indicating multiplication of a unit by 10⁹ or 1,000 m.
7 By recoverable resources we mean resources left to be extracted. This includes both proven reserves and additional recoverable resources that may become extractable due to reserves growth, new findings and the impact of technological progress.
8 Based on 6.1 GJ/boe and 20 kg C/GJ. We use the same factors for NGL; this will overestimate the energy content and the weight of stored carbon in the conventional reserves somewhat, but the overestimation will be small since the share of NGL to that of crude oil within the proven reserves is rather small.
9 Based on 6.1 GJ/boe, and 22 kg C/GJ.
10 Based on 6.1 GJ/boe and 15 kg C/GJ.
11 The extraction of methane hydrates would involve large climatic risks related to the danger of methane leakage during the recovery of the hydrates.
12 Based on 6.1 GJ/boe and 25 kg C/GJ.
13 The ratio of CO₂ emitted per energy unit is about 3:4:5 for gas, oil and coal, respectively.
14 In the studies discussed here the oil price assumed was in general lower than in recent years (2007–2010) and lower than current price forecasts (IEA, 2010; EIA, 2010a). For this reason, abatement options may have been underestimated. See also van Ruijven & van Vuuren (2009) for an analysis of the importance of oil price on cost effective mitigation options.
15 The leakage of natural gas in production, transmission and distribution is substantial, on average 2–3% of the world’s gas production (EPA, 2006). As natural gas to a large degree consist of methane, this leakage causes additional global warming in addition to the CO₂ emissions from combustion of natural gas. As a result, the climate benefits of switching from gasoline to natural gas are relatively smaller than the reduction in CO₂ that such a switch results in.
16 The demand price elasticity measures the percentage change in quantity demanded divided by the percentage change in price.
17 Hypotheses about why the “energy efficiency gap” exists include costs not covered in the technical cost calculation that are real for the consumer (and/or investor), the consumer (and/or investor) lacking information about benefits of energy efficiency, and that he/she may irrationally undervalue the economic benefits of energy efficiency.
18 However, ultra-deep off-shore reservoirs and oil extracted by enhanced recovery may be more costly than the suggested numbers.
19 The so-called “green paradox” (Sinn, 2007; Gerlagh, 2010) is related. This paradox suggests that policy plans aimed at reducing the demand for fossil fuels cause the suppliers of the fuel to expect that future fossil fuel prices will be eroded as a result of the planned policies and as a result the suppliers extract their resource more rapidly with an acceleration of climate change as a result.
20 Unlike a carbon tax, other climate policies such as fuel economy standards, subsidies to biofuels, or hydrogen would not contribute to an increase in the producer price of oil, they would only contribute to cutting the demand for oil and in turn also its price.
21 Distributional consequences of fuel taxation are considered in Sterner (2011).

References


433
Daniel J. A. Johansson, Fredrik Hedenus and Thomas Sterner


