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On the effects of fossil fuel prices on the transition
towards a low carbon energy system

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On the effects of fossil fuel prices on the transition towards a low carbon energy system

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Abstract: The purpose of this paper is to shed light on the role that fossil fuel prices have in bringing about a transition to a low carbon economy. This is a very broad, complex and potentially ambiguous question. It requires a good understanding of the factors that can shape long run fossil fuel price trends as well as an understanding of how energy transitions take place, and more specifically how an unprecedented policy-driven global energy transition can be orchestrated. The paper starts with the theory and historical evidence of resource and energy prices with a key message that over the very long run prices of energy services have shown a steady decline. The paper explains why a focus on oil is warranted, discusses the key determinants of oil prices and presents a brief history of recent oil price patterns. It also considers the connection of oil prices with recessions, what the future might bring for fossil fuel prices, and the potential implications of an end to cheap oil for the transition to a low-carbon economy. Finally, it looks into some facets of the interaction between fossil fuel prices and climate policy with a special focus on the role of carbon prices and how these must ultimately be part of a much broader strategy for an effective transition to a low carbon economy that is robust to alternative oil price trajectories.



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1. Introduction

According to conventional wisdom fossil fuels will supply nearly three-quarters of global primary energy for many decades (IEA 2012b, 2013c, 2014b). Oil still represents the single largest fuel. Sustained growth for oil and increasing or continued high prices are seen as the most likely trend based on projections of population growth, prosperity and the desire for car ownership.

Clean energy (hydro, other renewable energy technologies and nuclear power) increased its share in primary energy from 1973 to 2008 from 12.4 to 18.7 per cent as a result of the expansion of nuclear and hydro. Biomass, solar, geothermal and wind just kept pace with growth in energy demand. Technology and market support policies have been changing this picture with energy supply from solar photovoltaic and wind growing respectively at around 35 and 20 per per cent per year since 2005 (REN21 2014).

The climate change imperative and conventional wisdom on energy developments could not be further apart. The target of limiting the increase of temperature to 2°C above that reached at beginning of the twentieth century requires that carbon emissions from energy-related activities worldwide be cut in half. This can only be achieved with drastic reductions of fossil fuel use. In spite of the slowdown in world economic growth global CO₂ emissions continue to grow at record highs and without a change in present energy and climate policies can be expected to lead to a long-term temperature increase of 3.6°C or more (IEA 2013c, 2014b).

Following the Stern Review (2007) many modeling exercises were undertaken to understand what such a low carbon revolution would require in terms of technologies and policies (Caillé et al., 2007; Greenpeace/EREC 2010; IEA 2010a, 2010b, 2013b, 2014b; OMA/AMO 2010). The overall message of these studies is that the transition can be attained, yet there is considerable variation regarding the assumptions made about policies, technologies, diffusion speed, costs and competition. The range of scenarios and pathways can be illustrated with two of these studies. The IEA (2010b) 450ppm scenario sees a 'no growth' or slightly shrinking oil industry within the next 25 years and oil price

stabilizing at \$90. Greenpeace/EREC (2010) sees a one third drop in oil output with a price of \$150 per barrel by 2030 (Haug 2011).

Trends in fossil fuel prices (and especially oil) are perhaps the most visible indicator of potential sustained changes in the global energy sector. They are both a reflection of changes that are taking place and can act as precursors to change. When looking at price of oil over the long run two facts stand out: for most of its history the price of oil has been steady and low and since 2005 we have seen the longest sustained increase. This second fact gave rise to increased concern for energy security, energy poverty, renewed discussions about peak oil or the end of cheap oil, and the potential role of high energy prices in propelling a transition to sustainable energy. As the oil price was moving towards its peak of \$147 in July of 2008, and following a decade of record global high temperatures and extreme weather events, the world was increasingly discussing the interrelated crises of energy, water, food and climate change. The global financial crisis that took on gale force after the collapse of Lehman Brothers, led to an initial dramatic fall in the oil price, and a shift of attention to the more immediate threat to human welfare. Despite the depth of the financial crisis the oil price rebounded and remained at historically high levels (around or above \$100/barrel) up until the very recent decline in the price briefly dipping below \$80/barrel in November of 2014.

The purpose of this paper is to shed light on the potential role that fossil fuel prices have in bringing about a transition to a global sustainable energy system or a low carbon economy. This is a very broad, complex and potentially ambiguous question. It requires a good understanding of the factors that can shape long run fossil fuel price trends as well as an understanding of how energy transitions take place, and more specifically how an unprecedented policy-driven global energy transition can be orchestrated. Do we have reason to believe that fossil fuel prices will remain high or could they revert back to their long run trend, or some other pattern? How might different price trajectories affect investments in low carbon alternatives? Is it actual price trends that matter or expectations and forecasts that shape business investments and government planning? Is

a high carbon price or tax a key to a low carbon energy transition? Could such a policy backfire as oil producing countries increase production of oil before the tax regime toughens and threatens to strand their resources?

The discussion will start with a look at the theory and historical evidence of resource and energy prices. What does theory have to say about expected trends in fossil fuel prices? What has been the long term historical pattern of fossil fuel prices? Are fossil prices really what we should be looking at or should we be focusing instead on prices of energy services? The key message here is that energy service prices over the very long run have shown steady decline. Fossil fuel prices have been largely low and steady over the last century. In this context the 1970s oil shocks and the recent upturn in fossil fuel prices look like blips. Yet there are reasons to suggest that 'this time may be different'. Despite the importance of energy service prices analysts tend to focus on oil over other fossil fuels so this section also looks at the reasons for this and presents a brief history of oil price.

Continuing the focus on oil, section 3 will present the key determinants of oil price trends from the perspective of 'oil-market fundamentals' (or more simply supply and demand) with a closer look on the recent cycle of rising or relatively high oil prices. It will briefly distinguish between short run volatility and medium or longer term price trends and acknowledge the growing financialization of oil and the debate about the role of speculation in price formation.

From the first major oil shocks in early 1970 oil prices have been closely linked to the macroeconomy and recessions. Section 4 briefly looks into this connection. Section 5 considers what the future might bring for fossil fuel prices. There has been much discussion on the implications of a new era of the end of cheap oil for the interrelated issues of energy security, economic growth and climate change. Section 6 will present the main arguments in this debate along with potential evidence.

The last section (section 7) will look into some facets of the interaction between fossil fuel prices and climate policy. Economists have espoused setting an adequate price on CO₂ emissions as the most important element in attaining mitigation targets. This section will

examine arguments that suggest that this policy may be self-defeating (known as the Green Paradox) and arguments that suggest that some form of carbon pricing must be part of a much larger policy mix or broader societal transition. It also emphasizes the importance of considering the interaction of fossil fuel prices and climate policies for the transition to a low carbon economy.

2. Theory and evidence of resource and energy prices

2.1. Theory of resource price paths

In the physical world all resources are finite. In economic analysis resources are characterized as effectively unlimited when the extraction or production of a resource is either small relative to the resource base or the producers perceive the resource as limitless. In perfectly competitive market conditions the price will tend to the lowest long run average cost. With unlimited resources, capital, and labor, any increase in demand will be met with adjustments in supply and price changes will only be temporary. With advances in technology or production processes the time profile of prices would be that of fluctuations around a downward trend (Fouquet 2011b).

In a perfectly competitive economy, limited but renewable resources (fisheries, forests) will be extracted up to the point where the natural growth rate of the resource will equal the discount rate (the return on investments elsewhere). A constant flow of the resource is supplied to the economy over time. Increases in demand for the resource through population growth or rising incomes would be reflected in rising prices unless countered by improvements in production technology or increases in the renewable resource stock.

Hotelling's (1931) elegant theory of exhaustible resources characterizes the dynamics of resource extraction and price over time showing how a perfectly competitive market can theoretically ensure a welfare maximizing pattern of exploitation. The incentive for producers is to extract resources up to the point where the expected increase in future net prices (net of marginal production costs) is equal to the discount rate. If producers keep

the resource in the ground they can expect to profit from selling in the future at a higher price. This they compare to extracting the resource and investing the revenues at the rate of interest. Through this profit maximizing motivation the perfectly competitive market ensures that extraction of the resource over time follows an optimal or welfare maximizing path such that the net real price of the resource rises at the rate of the discount rate. The economy balances the welfare gains from immediate consumption against welfare gains from future consumptionⁱ. Even in a zero growth economy with demand for the resource remaining stable over time, the price will rise as the limited resource is depleted. Growth of the economy will enhance the tendency of the price to rise as demand increases (higher incomes or larger population) and as the expected price of the resource stock has to match the higher rate of return on capital. The net price is both a measure of the scarcity of the resource and the market signal that ensures the welfare maximizing time profile of depletion.

Extending this basic model to incorporate more variables like technological advances, backstop technologies that become 'attractive' at higher prices, and new discoveries of resources, can lead to very different paths for prices and depletion of resources.ⁱⁱ For instance, technological progress reducing the costs of extraction would lead to a fall in the initial price but raise the rate of increase in the price over time. New discoveries of resource stocks will reduce the rate of increase in prices as well as the range. These new price profiles will still be socially optimal under the perfectly competitive market assumptions. Extensions to the basic model that involve imperfect market structures (cartels, monopolies), environmental and security externalities, uncertainty in property rights, and regulations to address these, further alter price and depletion profiles as well as the welfare properties of these. In theory, and depending on a multitude of factors, all kinds of resource price trajectories can be envisaged. Resource prices may fall, rise, remain stable over time or exhibit some other pattern.

2.2. Evidence of price paths

Concern over the exhaustibility of resources and the implications for an economy have a long history, with Malthus' vision of a 'dismal' future being the most prominent. Long-run trends in price trajectories for commodities, resources and energy have been examined to test for increasing scarcity. The first systematic studies of long-run resource price trends were conducted by Potter and Christy (1962) and Barnett and Morse (1963). They examined the real prices for a number of mineral, agricultural, and renewable resources in the US over 87 years (1870-1957) and found that all but three remained constant or had fallen. Similar findings were made for nonrenewable resource price over periods greater than one hundred years by Nordhaus (1974), Smith (1979), Slade (1982), Berck and Roberts (1996). Pindyck (1999) looked at 127 years of U.S. oil, coal and natural gas prices. He found a U-shape that fit well when ending with the oil crises of the 1970s. The last two decades of the twentieth century saw prices reverting to historic lows only to rise up again in the last ten years. In real terms the price of oil dropped continuously from 1900 to 1970 and despite episodes of higher prices in the 1970s and 2000s the price of oil in real terms remained below the level reached in 1920 (Hamilton 2013). Literature reviews have found that the limited nature of renewable and exhaustible resources has not been reflected in increasing scarcity over time. Discoveries of new deposits, development of substitutes and technological progress in extraction, exploration and use seem to keep scarcity at bay (Hamilton 2013; Krautkraemer 1998; Livernois 2009). Another argument that 'reconciles' Hotelling's theory with this evidence is that while many resources are in principle exhaustible they are perceived to be so vast, with the date of depletion so far away, that they are treated as unlimited (2013).

Much of the empirical evidence on resource price trends have tended to focus on periods of up to a hundred or so years. It could be that this is too short a time frame to observe the impingement of scarcity. There are a number of methodological difficulties in finding and manipulating data to generate very long time series. Hausman (1987) created a series of consumer and producer prices from 1450 to 1988 and found that fuel prices were not

rising over the long run or in individual cases of fuel price increases consumers found less expensive fuels to switch to. Fouquet (2003) found little evidence of substantial systematic increases in real average price of energy from 1500. On this scale they did find that the twentieth century was characterised by an increase which they attribute to the dramatically altered energy systems and large-scale substitution towards more expensive fuels. They suggested that this was not the result of increasing scarcity but the rising value associated with higher quality energy services.

2.3. Focusing on service prices

A more radical departure in the understanding of resource scarcity but that is actually more in tune with economic theory, is to focus on prices of energy services rather than energy prices per se. After all, energy resources are inputs into services and the more relevant question is whether limited resources impinge on flows of services or make them more expensiveⁱⁱⁱ. Consumption of energy is driven by the demand for services like transportation, powering of lights and appliances, and space and water heating (Goldemberg, Johansson, Reddy, & Williams, 1985). Energy resources are inputs combined with other inputs and technologies to provide services "be it a hammer with muscular strength, a harness with horse power, sails with wind, or a train with steam, diesel or electricity" (Fouquet 2011a, p. 197). Even if the price of energy remains unchanged the price of the service may fall when the efficiency of the technology improves (Haas et al., 2008; Howarth 1997). Over long periods of time the price of energy and energy services may diverge substantially.

Though this insight is not new relatively little empirical work has been undertaken to examine the trend in the price of energy services and the broader implications involved. Nordhaus (1996) looked at energy prices and energy service prices for lighting over the last two hundred years. Using the price of energy rather than the energy service

dramatically underestimated the welfare gains to consumers and the fall in the cost of lighting.

Fouquet (2011b) extends this analysis to all main energy services for very long periods of up to seven hundred years to examine whether it is more generally the case that using energy prices underestimates the decline in costs of energy services. Energy service prices are calculated by finding the energy efficiency of the equipment used for the services and then translating from energy prices to energy service prices. If a unit of coal placed in a traditional fireplace costs \$100 and provides 10 per cent of a unit of coal in useful heat the price of the one unit of coal in useful heat is \$1000. As coal fireplaces increase in efficiencies to 20 percent the price of one unit of coal in useful heat becomes \$500. More generally, the cost of an energy service can be found by multiplying the energy price of the resource used by the efficiency of the particular technology used for the service. Fouquet (2006) developed a model of growth in the adoption of each principal technology and its share of the energy service market through evidence of energy consumption. "By combining the share of the market with the cost for each technology, a relatively reliable average heating or lighting price can be estimated, comparable across various waves of technological development" (Fouquet 2011b, p. 201). With some difficulties in data reliability a similar methodology was applied to power and transportation and an average price of energy.

Trends in the average price of fuels used for heating (woodfuel, coal, natural gas, electricity) along with trends in the average price of household heating (energy service provided) in England are presented in Figure 1. Specific fuels used vary by consumer and through time so the average heating fuel prices are weighted by consumer expenditure on the fuels. Woodfuel prices dominate between 1300 and 1550. After that coal prices increasingly dominated as the transition to coal intensified. Their lower prices relative to woodfuel and their increasing use, providing 90% of heating by 1800, explains the downward trend in energy price as well as energy service price. Efficiency of heating equipment began to improve with the widespread adoption of the Rufmord fireplace in the

nineteenth century (Crowley, John E. 2001). Cleaner and highly efficient natural gas and electricity central heating boilers in the twentieth century substantially boosted efficiency gains. The introduction of the Clean Air Act of 1956 led to a rapid substitution away from coal to more expensive natural gas and electricity. Despite the substantial increase in energy prices associated with meeting environmental standards, the efficiency of the new technologies meant that heating service continued their long run decline. Focusing on energy prices rather than energy efficiency in the twentieth century would give a false sense of increasing scarcity with regard to heating services.

The general message is that a focus on the service being provided rather than the resource used for the service can lead to different results in long term trends, with different implications of underlying drivers and policy tools, is further corroborated when looking at the other services of energy examined by Fouquet (2011b). In the case of power, animal fodder was the main source of energy and animals were the main technology providing the service up to the Industrial revolution. A transition to coal and the steam engine was followed by a rising dependence on petroleum and natural gas in the twentieth century. The overall long term trend since the seventeenth century has been a fall in the price of energy services, particularly dramatic after the Industrial Revolution. The divergence in service and resource prices is even greater when looking at freight and passenger transportation with a similarly dramatic continuous downward trend in transportation service prices from the eighteenth century onward. In the second half of the twentieth century energy prices (increasingly associated with oil) were generally stable (rising in the 70s) though improvements in vehicle efficiency led to continued reductions in the cost of transport services. Fouquet (2011b) also examined the average price of energy and an average price of energy services in the UK with a similar broad message: the long run decline in the average energy price after the 1700 was accompanied by an even greater decline the average energy service price. Table 1 gives a synoptic account of this information for the different energy categories.

A lesson to draw from this analysis when it comes to a transition to sustainable energy systems is that the prices that are likely to have a more important bearing on a move to low carbon energy sources are the prices of energy services associated with fossil fuel inputs. Though efficiency gains in fossil fuel based energy services must be an important part of the transition, if this is to lead to reduced use of fossil fuels it must not be fully reflected in lower service prices. The rebound effect^{iv} refers to the tendency for any efficiency gains in energy technologies to be reflected in falling prices of energy services that then stimulate new demand for these services. So while resources are used more efficiently, the actual reduction in resource use may be less or even insignificant. The substantial efficiency gains in vehicle transportation meant that the real price of this service was falling despite a stable (or sometimes rising) oil price inducing higher demand for cars, allowing greater distances travelled and feeding into urban sprawl.

2.4. Focusing on oil

Though there is good reason to study energy service prices, most discussions to date have focused on fossil fuel prices and especially oil. Since much of the debate concerning the potential role of fossil fuel prices on climate policy and the transition to sustainable energy systems have had a narrower focus on oil it is useful to see why this is so.

In 2013 oil accounted for 32.9 per cent of global energy consumption remaining the leading fuel (see Figure 2). This share is the lowest in BP's dataset (that starts in 1965) following a continual decline over the last 14 years. Natural gas accounts for 23.7 per cent and coal 30.1 per cent (BP 2014a). It is a highly convenient fuel in that it is liquid and achieves large technical economies of scale at various stages of production and transportation. It has the highest energy content (on a weight or volume basis) compared to fuels like gas and coal. Measured either by volume or value, crude oil together with its refined products is the most widely traded physical commodity. Oil prices are determined in a global market while natural gas and coal prices are determined regionally.^v The

transport and aviation sectors remain nearly totally reliant on refined products from crude oil (Allsopp & Fattouh, 2011).

The oil sector is central to the economic growth and development of the oil producing countries with these economies being vulnerable to oil-price instability and protracted periods of declines in oil price (2011). Oil markets have also been associated with large macroeconomic effects on OECD countries and the global economy, with oil price shocks preceding 10 out of 11 recessions in the US (Hamilton 2013).

An important reason that oil is deemed special is because of its intimate and dominant role in the transportation sector (see Figure 3. While energy security concerns and the rising price of oil in the 1970s led to substitution away from oil in the power and heating sectors, the potential difficulties of substituting away from oil in the transport sector is seen as a key challenge to a transition to a low carbon economy and a likely cause of continuing high oil prices.

Given the dominance of oil and its being a global commodity crude oil prices are potentially a critical indicator of factors affecting energy and fossil fuel markets. Both natural gas and coal are subject to longer term contracts and retain stronger regional characteristics.

Natural gas prices can diverge markedly across different regional markets due to differences in pricing mechanisms^{vi}, limited arbitrage options, cost of transport between regions, and local gas market conditions (IEA 2012b, 2014b). The recent growth of shale gas production in North America has kept prices low and has markedly increased the divergence across regional markets. Still oil and gas prices have often been treated as coupled or linked based on the fact of competition in final energy consumption primarily in the industrial and electricity sector (see Figure 4). Gas delivery contracts often contained price clauses with oil price indicators in order to maintain competitiveness. This resulted in a close relationship between gas and oil prices. Also, the relatively undeveloped spot market in gas in the EU has helped maintain the oil price indexation. With the poor state of gas trading, indexation is perceived to give greater certainty on future profit margins.

More recently gas delivery contracts include coal price indexation, keeping it competitive vis-a-vis coal in the electricity market. In the very long run as switching capabilities between gas and oil decrease and gas markets become more liquid it is likely that decoupling will take place (Bakker et al., 2009).

The recent increase in sea-borne trade in LNG has led to greater equalization of gas prices across regions through arbitrage. The great increase in unconventional gas production in the US has meant that it has stopped importing LNG and may become a net exporter of gas. In 2012 natural gas prices in the United States briefly dipped below \$2 per million British thermal units which at that time were 20% of import prices in Europe and around 12% of import prices in Japan. These marked regional price differentials reinvigorated a debate about gas prices moving away from oil indexation and whether this will bring about a global convergence of gas prices at a lower level than oil prices (IEA 2012b).

A relatively small fraction of coal consumption is traded internationally with international prices affecting some domestic prices while in other regions domestic prices more closely related to domestic production. The most important factor affecting the outlook for coal price is the competition between natural gas and coal in the power sector (2012b). Up till the 1970s while coal prices were generally lower than oil prices they followed the same pattern. Following the oil shocks of the 1970s while oil price became increasingly volatile the coal price remained relatively flat. Unlike gas and oil, coal consumers are less able to make short-term switches to other fuels and this might explain the lower volatility. Another (related) explanation for the lower responsiveness of coal prices to oil price change is that coal is sold under long term contracts (over 30 years). There has also been a large increase in coal sector productivity relative to oil. Finally, the 'dirtiness' of coal makes the move to gas a more likely response to rising oil prices (Bakker et al., 2009).

The extent of coupling of coal with oil or gas will depend on the extent to which these energy carriers serve as substitutes on consumer markets in the long run. In the electricity market competition with oil will decrease as it leaves the electricity generation

stage. No large changes in competition between coal and oil are expected in the industrial sector, while the transportation sector is likely to see greater competition with the increasing penetration of coal-to-liquids. Large remaining coal reserves suggest that sudden increases in coal prices are unlikely though volatility may increase due to increasing short-run switching capability for transport fuel (2009).

2.5. A brief history of oil price

The superior product characteristics of oil (and not price initially) were a crucial factor in its adoption. Two other drivers were also critical: (a) the adoption of the internal combustion engine for individual and collective mobility, itself the outcome of technological progress and entrepreneurial decisions and (b) decades long country-specific policies and investments supporting oil use, e.g., Churchill's decision to have the British Navy switch from coal to oil, public investments in roads in Europe and the U.S., to public support of exploration, production and RD&D for oil companies (Haug 2011).

Figure 5 shows the precipitous drop in oil price after a couple of decades since its adoption in the late 1800s. From 1900 to 1970 the price of oil (in real terms) continued to drop and spiked with the oil shocks of the 1970s, then stabilizing at a low till early 2000 after which a sustained increase in oil price led to a historic high of \$147.5 in July 2008. The global financial crisis brought a collapse of the price to \$30.28 followed by a remarkable recovery of the oil price in 2009. The West Texas Intermediate (WTI) spot price increased by more than 160 per cent in one week (from \$30.28 on 23 December to \$79.39 on 31 December 2009).

Drastic reductions in oil demand followed the oil shock of the 1970s and early 1980s with carbon intensity in IEA countries dropping by 24% between 1974 and 1986 (IEA 2004). Diversification policies (support of nuclear, natural gas) and efficiency policies (incentives, regulations and standards for cars, appliances and buildings, and industrial equipment) played an important role in this transition and the fall in oil prices to a low \$10 per barrel

by 1986. Following consistently low oil prices and nuclear accidents of Three Mile Island and Chernobyl, the substitution of oil tapered off and RD&D funding for alternative energies reached an all time low (Haug 2011). But oil did not regain its lost market shares. Global oil intensity is half that of the early 1970s.

In the period preceding the Global Financial Crisis annual average price increased for seven years in a row. This sustained rise differed from the earlier dramatic price rises that were associated with shifts in the power structure between producers and consumers (as was the case when OPEC took over the pricing system in 1973) or big supply shocks (as happened with the Iranian revolution of 1979). Producer power did not appear to be a cause of the recent upswing nor was it used to dampen the rise in prices. OPEC appeared to have a passive role largely responding to 'market determined' oil prices (Allsopp & Fattouh, 2011). Instead, the unprecedented increase in demand from non-OECD countries appears to have been the main driver; especially the demand from China and India associated with economic growth, industrialization and higher per capita income. In conjunction with growth in world demand for oil, the price rise has been associated with an inability for supply to keep apace.

The combination of a projected continuing increase in demand for oil (and fossil fuels) with questions about the capacity of oil supply to keep apace have given rise to arguments that this time may indeed be different. An important factor in the discussion has to do with the extent that there can be substitution away from crude oil, especially given the almost complete reliance of the transport sector on oil. In a sense the question turns on how 'special' is oil (2011). While the very recent drop in oil price (to around \$80/barrel since the summer of 2014), associated in part with the shale revolution has given rise to talk in the industry of a new 'age of abundance', the most recent World Energy Outlook (2014b) continues to project historically high oil prices based on that the underlying recent trends. It acknowledges the role of the shale gas and oil but does not find that these will bring enough supply at low enough cost to alter the general picture.

3. Key determinants of oil price trends

When it comes to interpreting oil price trends and attempting forecasts of future trajectories most analysis relies on oil market fundamentals. This is essentially the study of the various determinants of demand and supply, the behavior of market players, as well as uncertainty about the role of policy and technology. Key factors affecting global oil demand dynamics and long term demand include oil prices, taxation policies, the relative price of competing energies, growth in population, economic growth and potential for demand side technological innovation (limitations on increases in efficiency or reductions in consumption). Important supply side factors include geological physical constraints, technology constraints, costs, investments in exploration and production, market structure or political instability.

3.1 Demand factors

3.1.1. Growing demand

One of the main determinants of oil demand persistently found by the literature is economic activity measured as GDP or household income. The acceleration of oil consumption in non-OECD economies in recent years has been one of the most important shifts in oil-market dynamics, with oil demand growth in non-OECD outpacing that of OECD countries in every year. The Asia-Pacific region accounted for more than 50 per cent of the incremental change in demand during this period (Allsopp & Fattouh, 2011).

China's high energy demand growth should not be taken as a given. Chinese growth has been export driven sustained in large parts by loose monetary fiscal policy in the US with its widening internal and external deficits. The global financial crisis has shown the limitations of this model. Even though the global economy recovered as a result of radical monetary policy and Keynesian boosting of demand, this expansion will eventually be replaced by fiscal consolidation as has already happened in Europe (Helm 2011).

Nevertheless, the growth in population (expected to reach 9 billion by 2050) and in the per capita incomes are likely to have a strong impact on future energy demand.

Global oil demand projections are very reliant on assumptions made about economic growth and the oil-price trajectory. For instance the US Energy Information Administration (EIA) projections made in 2010 vary by more than 25 mb/d for the year 2035 in the low growth and high growth scenarios and by 27 mb/d in the low oil price and high oil price scenarios. The assumption made about income elasticity of oil demand has an even greater influence on diverging projections found in different studies. Two stylized facts about income elasticity are that (a) it tends to change with the level of economic development, e.g., as the share of manufacturing to non-manufacturing GDP rises, and (b) there is a threshold effect when per capita income reaches a certain level so that car ownership grows twice as fast as income growth (Allsopp & Fattouh, 2011).

3.1.2. Substitutability in transportation (prime movers)

A key reason why oil is seen as special or difficult to substitute is its role in transportation. Most forms of transport are almost exclusively reliant on oil. As long as oil retains its dominant role in transportation, and given projected growth of transportation, especially car ownership in China, demand for oil will likely outstrip supply and thus lead to sharp price rises (Helm 2011). The long run trend in the demand for transport fuels will be determined by the growth in the vehicle fleets and the overall efficiency gains. The first effect is likely to dominate initially with the rise in demand from emerging economies with efficiency gains and technological advances eventually outweighing the growth in numbers (Allsopp & Fattouh, 2011).

Fuel prices are not likely to slow the rapid growth in car ownership in rapidly growing developing economies. The evidence suggests that gasoline prices do not significantly affect car ownership (Johansson & Schipper, 1997; Storchmann 2005), though they do

encourage a shift towards smaller and more efficient vehicles and affect the number of vehicle miles travelled.

The impact of technology advances and policy on oil demand in transportation are hard to measure and predict. Without a dramatic shift in policy, the internal combustion engine will likely remain the dominant technology in the transport sector with technology advancing incrementally with increasing market shares of hybrids, plug-in-hybrids, electric vehicles, flex-fuel cars, and CNG vehicles. These vehicles remain uncompetitive without government support but can make inroads with advances in technology, economies of scale and investment in infrastructure along with relatively high oil prices (Allsopp & Fattouh, 2011).

The main challenges for electrification of motor vehicles are batteries and infrastructure for charging them. On a more optimistic note Helm (2011) points out that the problem for batteries of weight and range for transportation parallels that of the development of mobile phones and portable computers which became mass consumer goods because of the revolution in battery technology.

According to Allsopp (2011) oil is special but not so special that substitutes won't be found at higher prices. Relative prices of different sources of energy have changed substantially. The impressive near replacement of oil by gas and coal in power generation and space heating that took place in industrial countries in the 1980s testifies to the potential influence of relative price changes, linked also to discoveries of gas and energy security policy. While up to 1990 gas was conserved primarily for petrochemicals and Europe effectively made it illegal to use it for power stations, the North Sea gas and Russian supplies made it the fuel of choice for power (Helm 2011).

Yet some argue that the easy substitutions have already taken place. Bio-fuels like ethanol and (controversial) corn ethanol have shown some potential to provide a substitute for oil in transport but their impact remains small though technological developments could change that. A more obvious way to substitute oil in transport comes from the potential to convert coal, oil and gas into each other. Gas-to-liquids (GTL) and coal-to-liquids (CTL) are

economic at high oil prices so they would certainly be good candidates as backstop technologies limiting further increases in the price of oil and its products. They are however extremely bad in terms of CO₂ emissions. Other potential sources of substitution include further penetration of gas and coal in power generation in non-OECD countries, direct use in transport of compressed natural gas (CNG) and liquified natural gas (LNG), and the use of electricity in end-use-fossil-fuel-burning applications like electric cars and heat pumps (Allsopp & Fattouh, 2011).

3.2. Supply factors

3.2.1. Supply factor in recent cycle

Several possible explanations for real or perceived oil supply restrictions playing a role in the post 2000 rise in oil price have been considered. Mature oil fields were seeing rapid declines in their extraction rates (Kjärstad & Johnsson, 2009). There were concerns about global reserve limits, about the willingness and capability of national oil companies to develop reserves at an adequate pace, and about increasing costs of exploration and development (Allsopp & Fattouh, 2011). In the last few years there has been an increasing pessimism about the potential supply from non-OPEC countries. The high oil price between 2001 and 2008 saw a weak response from non-OPEC supply outside the Former Soviet Union. Many mature basins witnessed rapid declines with the average annual observed decline rate of 4.6 per cent per annum over the period 2000-2008 (OPEC 2009). Many oil companies in non-OPEC countries have been pushed by high oil prices and limited access to reserves to explore new frontiers, e.g., deep and ultra-deep waters in places like the Gulf of Mexico in the US, and the potential for development of unconventional oil and liquids (oil sands, bitumen, extra heavy oil, shale oil, CTL and GTL). Yet many analysts focus more on 'above-ground' factors as the supply constraint, e.g., adequate and timely investments in extraction, rather than depleting resources (IEA 2013c).

Peak oil advocates claim that total world physical supplies are well researched and are reaching a peak in production soon (around 110m barrels a day) and that there is limited substitutability between the various sources of energy so that oil is 'special'. According to Hubbert as oil fields mature (move past their peak) the costs of recovery increase dramatically making an oil field economically unexploitable once past 50% of its capacity. Even though there is considerable uncertainty about estimates of present reserves, what can be discovered, and potential recoverability of estimated reserves, Helm (2011) argues that the peak oilers 'certainty' relies on the fact that there were no big new finds in the 1980s and 1990s. In fact most of the world's super-giant fields were discovered before the 1970s, the exception being Lula in Brazil found in the last decade. This fails to take into account the low price of oil over that time span that made exploration and production uneconomic. Higher prices may confound this theory as new discoveries are made. The fall in rate of discoveries have levelled off since the 1990s mostly as a result of higher oil price (IEA 2012b). According to the International Energy Agency it is not the size of the resource base that will affect the future of oil but investment conditions, costs to develop fields and price of oil in conjunction with energy and climate policies (IEA 2012b, 2013c, 2014b).

3.2.2. New discoveries key driver of past increases in oil production

Hamilton (2013) draws on the history of oil production in the US to argue that the key to expanded oil supply has been new discoveries rather than advances in extraction technology. "In 2010 -- with the truly awesome technological advances of the century and a half since the industry began, and with the price of oil 5 times as high (in real terms) as it had been in 1891--Pennsylvania and New York produced under 4 million barrels of crude oil. That's only 12% of what had been produced in 1891--120 years ago--and about the level that the sturdy farmers with their spring-poles were getting out of the ground back in 1868" (2013). When focusing on production within each state production increased



then eventually declined. The uninterrupted increase in U.S. oil production over a century was primarily due to the fact that new fields came into production as mature fields died out. "The rise and fall of production from individual states seems much more closely related to discoveries of new fields and their eventual depletion than to the sorts of price incentives or technological innovations on which economists are accustomed to focus" (2013, p. 9).

While U.S. production peaked in 1970 world oil production reached 60% higher than it had been in 1970 but the mechanics of growth are similar, i.e., the main driver of growth came from new fields as mature fields entered decline. Episodes of declining production in OPEC countries, however, reflect dramatic geopolitical events such as the OPEC embargo of 1973-74 or the Iranian revolution of 1978-79, or deliberate decisions from Saudi Arabia to mitigate price movements. Yet, the decline in Saudi Arabian production since 2005 may be due to the maturing of the magnificent Ghawar field. A number of factors have contributed to stagnating production from other OPEC members such that total production has essentially been flat since 2005. Furthermore, despite increases in oil production in other countries (China, Canada, Brazil, central Asia and Africa), "overall, global production of oil from all sources was essentially constant from 2005 to 2010" (Hamilton 2011, p. 13). Hamilton (2011) suggests that the historical pattern of oil prices and production are best interpreted as the result of (1) oil being priced by the industry as if it were inexhaustible, (2) technological progress providing temporary and limited boosts but (3) the primary determinant of annual production rate increases being the exploitation of new geographic areas and (4) the potential for further increases in new geographic areas is limited to the point that exhaustion of oil will start playing a bigger role in price determination.

The phenomenal increase in demand for oil from emerging economies will accelerate the date of transition. Even with phenomenal success in discovering new oil fields it will be difficult to outpace the growth rate in demand. "One has only to compare China's one passenger vehicle per 30 residents today with the one vehicle per 1.3 residents in the

United States, or China's 2010 annual petroleum consumption of 2.5 barrels per person with Mexico's 6.7 or the United States' 22.4" (2011).

3.2.3. R&D, E&P and oil price (implications)

Ultimately, if substitution of oil remains difficult, the combination of a declining supply and a growing demand for oil would seem to make rising prices and increased volatility unavoidable. A rising oil price, however, will lead to increased R&D and E&P. "The history of discovery of reserves and greater extraction from existing reserves has been driven by price--as, indeed, has the development of unconventional gas and shale oil. The current major R&D programmes in renewables reflect this, too--with the added incentives of a carbon price and subsidies" (Helm 2011, p. 75).

Horizontal drilling and injection of fluids to induce small fractures are the most important recent technological developments bringing new fields into play. New technologies are unlocking new types of resources like light tight oil (LTO) and ultra-deepwater fields while improving recovery rates in existing fields. Estimates of amounts of oil that remain to be produced are expanding but "this does not mean that the world is on the cusp of a new era of oil abundance" (IEA 2013c, p. 25). A high or increasing price of oil is what will make such technologies and the expansion of supply economically viable.

Technological developments on the natural gas front are also having important impacts on fossil fuel prices. The development of liquified natural gas has released the constraints of pipelines. Important technological breakthroughs in recovering shale gas (horizontal drilling, IT capacity to seek out pockets of gas at great depths and the ability to fracture rocks to release gas flows) have led to recent supply breakthroughs. The US is the first to commercially exploit these opportunities and the price implications are already being felt globally. With these newly available sources of domestic gas the US no longer imports gas. As a result of abundant gas the US increasingly exports coal putting downward

pressure on coal prices in other regions. In the EU the low coal prices in 2011 along with the low CO₂ prices led to a dramatic increase in coal use (2012b).

3.3. Short-term price volatility and financialization

Day to day oil price volatility may be related to new information rather than fundamentals but longer term price swings are of greater concern to producers and consumers and generally do reflect fundamentals. They often reflect supply and demand shocks or transformations in the oil supply chain. A fundamental feature of the oil market is the wide range in which the oil price can clear so this also affects price swings (Mabro 1991). The cost floor of oil production in key OPEC countries sets the price floor while the potential entry of substitutes and expectations of behavior of financial markets sets the upper boundary (Allsopp & Fattouh, 2011). When there is excess capacity the oil price approaches the lower bound while when the market is characterized by excess demand most of the market adjustment occurs through sharp price rises in the short run. Potential substitutes or demand patterns aren't affected in the short run but they do put a cap in the long run.

In 1986-88 there was a shift towards a market-related pricing system from a system of prices administered initially by large multinationals in the 1950s and 1960s and then by OPEC from 1973-88. With the increased financialization of oil^{vii} and the extreme swings and increased volatility of prices in 2008-9, doubts have been raised as to whether prices reflected fundamentals or were influenced by speculation and financial flows. A polarized debate followed the volatility of prices in 2008-9 between those that viewed price swings as reflecting fundamentals, e.g., tightening of market, low price elasticities, rigidities from long periods of underinvestment, and changes in behavior of key players, to those that focused on the increasing involvement of financial players in poorly regulated oil derivatives markets. The increased involvement of financial players can be attributed to numerous factors: tight market conditions increase upside of speculative bets; the historic

low correlation of commodities with financial assets increased their attractiveness; positive correlation with inflation provide a hedge against inflation risk and a weak dollar; expectations of relatively high returns. Despite the growing theoretical and empirical literature on the role of financial players, firm conclusions have not arisen (Fattouh 2010). Some analysts have also put forward the role of the increased 'financialization' of crude oil in determining prices through 'speculative' financial flows (Singleton 2011; Turner, Farrimond, & Hill, 2011).

3.4. Player behavior

3.4.1. Modelling OPEC behavior

There are many conflicting theoretical interpretations of the behavior of OPEC. Studies have suggested that the budgetary needs guide decisions, others that the transfer of property rights led to production cuts in 1970s as governments tend to have lower discount rates than oil companies, others focus on the different models of coordinated action of OPEC members (textbook cartel, 'two block' cartel, 'clumsy' cartel, dominant firm, loosely competing oligopoly, residual firm monopolist and a 'bureaucratic' cartel). Empirical evidence has not helped narrow the range of views.

The standard way of modelling OPEC supply does not to rely on some behavioral model but simply assumes that OPEC always closes the gap between anticipated oil demand and non-OPEC supply. This approach relies on the 'highly questionable' assumptions that OPEC is interested only in expanding output and its market share and that it can and will increase investment in capacity as needed (Allsopp & Fattouh, 2011; Gately 2004). Yet, expanding output can lead to lower prices and thus hurt revenues, and investments in increased capacity may not be forthcoming, inter alia, due to concerns about long-term oil demand and geopolitical factors. Simplistic assumptions about OPEC supply are inadequate so anticipating OPEC behavior remains a critical factor affecting the oil price (2011).

3.4.2. Models feeding back into behavior of players

The global demand and supply factors discussed give a broad sense of the kind of analyses that may inform forecasts and assessment of likely oil-market conditions. Longer term assessments rely on scenarios and models that incorporate assumptions or estimates about these factors and other important parameters. Government agencies and market actors simultaneously form their 'models' of the oil market and oil price and these shape their behavior and feed into the very models they use such that this collective assessment itself shapes the real outcomes. Whether oil prices thus determined reflect the 'fundamentals' in some 'deeper' sense is itself a matter of much controversy (2011).

4. Oil price, recessions and a novel explanation of the centrality of oil

Five events over the last half century have led to significant disruptions in production of crude oil (closure of Suez Canal in 1956, OPEC oil embargo in 1973, Iranian revolution in 1978, Iran-Iraq War in 1980, the first Persian Gulf war in 1990). World oil production following each of these events fell by between 4-9%. There have also been some other less significant episodes of supply disruption. Abrupt oil price increases have also taken place since World War II without a significant physical disruption of oil supply with the most notable being the upswing beginning in 2004. The strong demand for oil from emerging economies appears to be the principal cause of this cycle (Kilian 2008). Of the 11 episodes in oil price spikes identified 10 were followed by a recession in the United States (Hamilton 2011). The only postwar recession in the US not preceded by a spike in the price of crude oil is the recession of 1960.

A large empirical literature has looked into the connection between oil prices and real economic growth and many studies have found a significant negative correlation. Hamilton (2013) (who also provides a survey of this literature) shows that an oil price increase takes some time to show up in real GDP (a drop appearing a full year after initial oil price increase) but the size of the effect is quite large, e.g., a 10% increase in the price of oil

(over the three previous years' high) GDP growth would be 0.42% slower (at quarterly rate). This is somewhat puzzling given that the energy expenditure share is a small number (4% of total GDP in the US in 2010) and the short run price elasticity of demand is also small. So the significant observed response to oil price increases cannot be attributed to the direct effects of decreased energy use on productivity. Another explanation suggested relates to the demand for motor vehicles. Data show that the decline in expenditures on motor vehicles is large and immediate and this could lead to idled capital and labor resulting from Keynesian frictions in adjustments of wages and prices (though the results can also be derived with a neoclassical model). The role of shifts in motor vehicle demand in recessions that followed several historical oil shocks is also demonstrated by Ramey and Vine (2010). US real GDP would have grown by 1.2% in the first year of the 2007-8 recession had it not been for the oil price induced decline in demand for domestically manufactured vehicles (Hamilton 2011).

The link between oil price and economic growth or recessions is important in considering oil price's role in the transition to a sustainable energy system partly because emissions are intimately linked to growth but also because of the potential link between economic growth and innovation, the investment climate as well as policy priorities.

5. Whither oil price: Is this time different?

There is a long history of false projections about fossil fuel prices, wrong 'conventional wisdoms', or 'peak' theories that have been found at least premature. Attempts at long term analyses of oil have often been spectacularly off the mark. Concerns over resource scarcity in growing environmental movement of the late 1960s led the 'Club of Rome', extrapolating from the 1950s and 1960s, to predict unaffordable prices and unsustainable growth. The high oil prices of the 1970s and first half of the 1980s led credence to their position. This 'conventional wisdom' was confounded by the world recessions of 1982 and 1991, the substitution of natural gas for oil in space heating and power generation and increases in supply such as North Sea and Alaska. Far from a protracted period of high



prices and resource scarcity by 1985 oil prices collapsed and remained low for nearly two decades. Once again, this 'new' period of low prices influenced extrapolations about future price developments as illustrated by the *Economist's* prediction in 1999 that the world was awash with oil with prices possibly heading to \$5 per barrel. Instead, the longest sustained rise in oil prices was just ahead (Allsopp & Fattouh, 2011).

Helm (2011) points out that energy policy has been greatly influenced by assumptions made about future oil prices. In the 1970s, the success of OPEC and the fear of running out of oil made it the conventional wisdom that prices would continue to rise in the future. During the two decades of cheap oil from 1980 to 2000 energy security was not much of a concern, abundance was taken as the norm. IEA's 2000 forecast for the year 2010 was that fuel production would reach 95.8 million barrels per day with an average daily oil price of \$28.25 per barrel. The actual numbers were 87.1 mbpd and \$79.61. At the time it's rosy picture of oil supply and prices were partly a reflection of the two decades long low price of oil and their view that the 'revolution' taking place in deepwater drilling technology would substantially augment future oil supply ^{viii(Cobb n.d.)}.

This conventional wisdom began to change after 2000 in part because of the neglect of energy security and the collapse of exploration and production by oil companies that had also wrongly assumed that oil prices would remain low (Helm 2008). With the price of oil gradually reaching a peak of \$147 by 2008 energy security once again became a top priority. Europe's growing gas dependency on Russian supplies heightened concern. Gas was not physically but politically constrained and this dependency drove Europe to seek to loosen the dependency through a combination of nuclear, renewables and new coal generation. The economic crisis has already changed the picture by lowering the projections of future demand. Gas prices have gone down and the link between gas and oil prices has weakened. The production of shale gas in the US has also reduced Europe's dependency on Russian supplies (2011).

When considering the long or very long run it may not even matter that some resource like oil may no longer be economically exploitable. What is more relevant for purposes of

public policy is whether the pattern of oil and fossil fuel prices are likely to be significantly different for a long enough time to require some step change or even more radical shift in energy policy widely construed (energy security, climate change, and macroeconomic policy). It is not just the prices per se that really matter for policy formation but what the price patterns are signalling. Ultimately the question about future price patterns of fossil fuels turns on the more fundamental question of the nature of underlying causes of a sustained change in the energy market and system. This question acquires special urgency in view of the very limited time frame for a needed transition to sustainable energy systems along with how this interacts with other energy policy objectives.

Though there is some common ground in interpreting the history of oil and fossil fuel prices there remain substantially contrasting views about whether the recent climb in the price of oil is ushering in a more sustained phase of higher prices and greater volatility. The viewpoint depends on how much weight is given to the various factors seen to be involved in the recent higher oil price plateau. Those that see this as a more lasting trend focus on one or several of the following factors: the specialness of oil for transport so that the kind of shift from oil to gas in the power sector that began in the 1970s cannot be replicated for transport easily, that discoveries rather than technological breakthroughs have been the key driver of increases in oil supply in the past, that world oil production from existing reserves have not been adequately responding to higher oil prices, that there have been no substantial new discoveries, that exploration has moved into higher cost sources (including unconventional oil), that technologies for alternative transport fuels will take time and remain relatively expensive for the near future, that demographics and world economic growth will bring about unprecedented increases in demand for motor vehicles and transportation services.

Though the increases in world petroleum production over the first 150 years have been impressive a close look at the details of this growth (driven largely by new discoveries rather than technological innovation) still suggests that we might be entering a period of 'rocky plateau' in total production (Hamilton 2011). "[T]he world could soon reach a point

from which continuous decline in the annual flow rate of production could not be avoided, and inquire whether the transition to a pricing path consistent with that reality could prove a fairly jarring event" (2013, p. 17). "The world has entered the phase of substituting a relatively cheap-to-extract barrel with a relatively expensive-to-extract one" (Allsopp & Fattouh, 2011).

A dramatically different reading comes from Helm (2011) who places greater weight on the prospect for electrification of transport along with the potential for gas and coal to fill in for missing oil.^{ix} "Electricity can be produced by abundant gas (and coal), and shale gas pushes aside any serious notion of 'peak gas'. The implications is not just that peak oil claims should be largely dismissed, but rather a very different perspective. It is wrong to assert that we do not have enough oil--or fossil fuels. On the contrary, we are awash with fossil fuels; we have too much, not too little" (2011, p. 79).

It should be noted that despite the starkly contrasting emphasis on the likelihood of higher or lower fossil fuel prices present in these views, both authors recognize the great uncertainty in these conjectures. Despite the consistent failings of 'conventional wisdom' it seems inevitable that forecasts continue to be made (if only for the need to consider alternative scenarios) and that new 'conventional wisdoms' take shape whether a result of 'animal spirits', the need for coordination, or just a reflection of our uncertain but evolving state of knowledge. Though conventional wisdoms are often seen as such after they have been disproved it is worth looking at the latest World Energy Outlook forecasts or scenarios of future fossil fuel prices as indicative of a the present dominant view. In general oil price is projected to stay high and to gradually increase if climate change policy is not ramped up. The forecasts are put in context with their statement: "History has shown that energy prices are notoriously difficult to predict" (IEA 2012a). There is not much documentation about what goes behind their long term forecasting of prices which are initially exogenous inputs into their World Energy Model. "The assumed paths for each form of energy reflect our judgment of the prices that would be needed to encourage sufficient investment in supply to meet projected demand over the *Outlook* period" (2012a,

p. 40). Though the recent surge in unconventional oil (along with downgrading in global growth prospects) has been associated with the recent drop in oil prices from September through November of 2014 this has not significantly altered these projections (2014b).^x Taking the very long term view of energy service prices it would seem reasonable to expect that irrespective of resource prices the services will continue to fall in real terms and that potential spikes in resource and energy service prices will be temporary. Still "temporary" spikes in resource price can have profound economic impacts and can influence political priorities and thus affect public policies with longer term implications. With respect to the imperatives of a transition to a low carbon economy the oil price in the coming years may be particularly important given how energy policy can lock-in energy system choices for decades.

5.1. Oil, Gas and Coal forecasts

The World Energy Outlook (2014b)^{xi} forecasts are related to scenarios about climate change policy and their impact on carbon prices. Three main scenarios are used. The Current Policies Scenarios assume that only existing and planned climate policy programmes are executed and the CO₂ price is low and gradually rises. The New Policies Scenario assumes investment decisions in the power sector are made with an implicit shadow price for CO₂ and that China introduces a carbon price covering all sectors from 2020. Finally, the 450 Scenario assumes that CO₂ prices are established in all OECD countries with convergence taking place from 2025 and the price reaches \$140/tonne in most OECD countries by 2040 (IEA 2014a)}. Based on these and other assumptions projections are made about the energy mix as well as fuel prices. Table 2 shows fuel price projection assumptions by scenario.

According to the International Energy Agency (2012b) the rising trend in prices since the financial crisis reflects the mounting cost of producing oil from new sources in order to satisfy increasing demand and while existing fields are being depleted. Higher prices are needed to balance supply with faster growth in demand. Oil price is forecast to reach

\$155/barrel in 2040 in the Current Policies Scenario but only \$100/barrel in the 450 Scenario as demand for oil will be lower with less need to develop high cost oil fields (see Figure 6) (2014b).

Gas prices are forecast to follow the trend in oil prices with the ratio of gas price to the average oil price remaining below historical averages (see Figure 7) (2012b). A relatively small fraction of coal consumption is traded internationally with international prices affecting some domestic prices while in other regions domestic prices more closely related to domestic production. The most important factor affecting the outlook for coal price is the competition between natural gas and coal in the power sector. Coal production costs are not expected to rise as fast as gas and oil costs, and demand for coal is expected to level off around 2025 so coal prices are projected to increase less in percentage terms than gas and oil prices (2012b).

6. Implications of high fossil fuel prices for the transition to a sustainable energy system

As difficult it is to project future fossil fuel prices it is highly contentious to draw insights about what would happen if we were entering a prolonged period of higher fossil fuel prices or swings from a higher plateau. A look at past economic responses to oil price spikes may suggest that if we are entering a phase of 'peak' and the 'future decades look like the last 5 years, we are in for a rough time' (Hamilton 2011). A persistently high oil price, or recurring spikes associated with supply disruptions, would impact negatively on economic growth. The lower energy intensiveness of Western economies in the last decades means that the negative impacts may be expected to be less pronounced than that during the crises of 1970s and 1980s. To the extent that the global economy is slow to reduce its dependency on oil in the transport sector as it managed in the power sector after the oil shocks of the 1970s then a stark scenario is one of potentially sluggish economic growth and heightened energy insecurity. If this picture also implies the kind of shift in political priorities that has followed the Financial and Economic Crisis, with

economic growth and employment rising on the political agenda and climate policy receding, then the news for a transition to sustainable energy may also be bad.

On a more positive note higher long term energy prices could be expected to decrease energy use and emissions as economic growth decreases, to lead to increasing energy efficiency and enhance substitution towards alternative energy options (Ruijven & Vuuren, 2009). The higher prices of oil during the oil crises of the 1970s and 1980s coincided with a period of 1-2% lower economic growth, though economies are much less oil intensive now and more alternatives are available. A strong historical relationship between fuel efficiency and fuel prices has been found across regions (Schipper 2008). The transport sector is likely to see the greatest efficiency gains. (Rout et al., 2008) found strong efficiency increases in scenarios with high oil prices combined with climate policy and/or high coal prices suggesting that high oil prices can lead to substitution toward dirty fuels.

We don't have a long enough history of climate policy nor any prior policy-guided global energy transitions to draw some initial inferences from. There have been important national policy guided transitions mostly induced by the oil shocks of the 1970s and the desire to address energy security, e.g., the move to nuclear in France, biofuels in Brazil (see Solomon (2011)). These do suggest that far reaching policy driven energy transitions can be attained with adequate sustained political and administrative resolve but there are limitations on drawing lessons from national to a global system wide transition. Even in these instances the driving force was a need to ensure energy security and ultimately the availability of cheap energy. The latter being a far easier political sell than expecting voters to accept higher prices to mitigate emissions.

There are some lessons to be drawn from the pre-crisis sustained surge in fossil fuel prices. However, with our present knowledge that the upswing was associated with deep macroeconomic imbalances, an associated financial bubble and its ultimate collapse, it may seem more appropriate to treat the impressive growth phase as the unavoidable flip side of the present ongoing fragile and slower growth. The rapidly rising fossil fuel prices after 2005 did much to heighten energy security concern and precipitate a sense of

impending multiple crises of peak oil, rising food prices and extreme weather. Energy security and climate change agendas appeared to be finding some common ground, though important tensions remained. The rising price of oil stimulated investments and supportive policies for clean fuel production and end-use technologies. It also incentivized higher exploration and production investments in unconventional oil and gas as well as deep-sea oil. In macroeconomic terms, the fact that the surge in oil price had not already put a damper on growth (though it eventually contributed to the downturn) was a kind of an anomaly that fed into the sense that we had already entered into a world of ongoing high rates of growth with widespread resource limitations symbolized most starkly by the capacity of the atmosphere to regulate global temperature.

The heightened concern for climate change added a new twist: high oil prices related to depletion strains may be a boon to a much needed transition to sustainable energy. While this might be the case, (Helm 2011) argues that a peak oil narrative describing a world of high and rising oil prices, tight market with high price volatility has been exploited by non-government organizations and vested interest groups to capture public policy. The imminence of an "energy Armageddon" provides a compelling case for strong government action in the form of targets and investments to bring about a rapid switch from oil and gas to renewables and nuclear energy. If the price of fossil fuels are going to be high anyway then the costs of a switch will not be that onerous and could even end up being negative, i.e., saving us money. The International Energy Agency (2011, 2012a, 2013c, 2014b) suggests that greater reliance on renewables would dampen the future prices of fossil fuels as is reflected in the scenarios discussed above. (Helm 2011) says that these arguments have been made by advocates of strong climate action in conjunction with 'optimistic assumptions about cost levels and trends for particular preferred technologies'. More specifically, according to (2011) the assumption of high fossil fuel prices allowed the Stern Review (Stern & Treasury Great Britain, 2007) to claim a low cost of decarbonization (1% GDP per annum) and made the 2008 EU 'catchy 20-20-20 targets' politically acceptable. Helm (2011) is essentially making the separate points that (a)

projections of future high prices are most likely wrong, (b) are convenient to generate support for more aggressive climate action, and (c) are being used to misguide clean energy policy towards special interests.

Though the energy security agenda has often been seen as ally to the climate change agenda, and certainly this could be the case, the policies pursued to address each challenge are often in conflict. Expanding the potential substitutes for oil will only be helpful to the climate change agenda if the substitution is away from fossil fuels. Yet coal, not oil, is the largest and fastest growing sources of CO₂ emissions. Coal, coal-to-liquids and gas-to-liquids may help the energy security agenda but they are extremely bad in terms of GHG emissions. Electrification of transport would not be of help to the climate change agenda if it relied on power produced from coal (Allsopp & Fattouh, 2011).

With the Great Recession the political agenda and public attention shifted dramatically. The new picture is one of potentially prolonged economic fragility and lower paced growth, but enough growth to keep oil prices at a new plateau. Lower growth could mean lower emissions if global climate policy remained in place and strengthened in the emerging markets. Despite the depth of the recession, after a small dip emissions surged to new heights in line with the highest emission scenarios.^{xiii} Coal, the relatively cheaper but dirtier fuel increased its share in power production. Energy security coupled with a priority on economic growth over climate change may not bode well for a sustainable energy transition, though energy security has also diminished as a concern. In the case of coal, the absence of rent, the availability of substitutes and its market structure have meant fewer international security concerns. With natural gas, security concerns relate to over-dependence on supplies from specific countries and pipeline issues where a transit country could disrupt the flow, e.g., Ukraine. Natural gas used to have regional market structure (like coal) with different pricing systems in different regions or countries. The growing sea-borne trade in LNG has internationalized the market for gas making it more like oil. Also expanded supply may dampen security concerns which has certainly been the case with the great increase in production of unconventional gas in the US and the

potential for production in other countries (2011). On the other hand the recent ongoing crisis in Ukraine that has led to international sanctions on Russia and the very volatile situation in the Middle East have provided renewed security concerns, despite the concurrent temporary oil supply glut.

A shift to cheaper energy options is likely to be a significant impact of higher oil and gas prices, with a shift to coal being a major consequence if climate policy is not in place (IEA 2008; Rout et al., 2008; Vielle & Viguiet, 2007). Half the rise in global energy demand over the last decade was met by coal, growing at a rate faster than renewables (IEA 2012b). There are many alternative sources of energy for transportation that can lead to significantly higher CO₂ emissions such as creating synthetic crude from surface-mined Canadian oil sands, enhanced recovery, or conversion of natural gas, coal and oil shale to liquid fuels. So while higher oil prices may propel investment in cleaner energy a timely transition to sustainable energy will ultimately depend on a robust climate policy capable of inducing transition whichever way oil price moves.

The pace and rate of oil price hikes may also be an important factor determining the technology choices made. For instance, an early and rapid rise may propel the use of electric vehicles with existing infrastructure while a gradual rise may allow for forward planning for more large-scale system innovations (Ruijven & Vuuren, 2009).

7. Fossil fuel and climate policy interactions

Effective climate policy in whatever form it takes will have a significant impact on fossil fuel prices. If regulation is put in place to fit all new coal based power plants with Carbon Capture and Sequestration, the price of coal would be expected to rise though the final impact will depend on policies and developments affecting other fossil fuels and alternative energies. Up to this point we have touched on the implications of fossil fuel prices on the transition to sustainable energy systems largely independently of climate policy, though some points were raised on the potential interactions. Clearly, if the targets

set to decarbonize most of the energy system by mid century are to be achieved, climate policy will play a critical if not dominant role in the shaping of the prices of fossil fuels. Gaining a better understanding of the potential interactions between fossil fuel prices and climate policy is a complex but essential task.

The following sections will consider a few of the many potential interactions of fossil fuel prices and climate policy. It will first look at what is known as the 'Green Paradox' which suggests that climate policy attempts to lower the future demand for fossil fuels are futile because of the way that oil exporting countries can 'neutralize' these policies. The next section will look at some recent models that have attempted to incorporate market imperfections in assessing the role and limitations of carbon pricing. They suggest why carbon pricing on its own is inadequate and why climate policy needs to go beyond fossil fuel pricing if it is to be effective. Finally, in a similar spirit the last section puts fossil fuel prices and carbon prices in an even broader context than markets by referring to a burgeoning transition literature. These last two sections highlight why, as important as fossil fuel prices may be for a transition to sustainable energy systems (with or without carbon pricing), they must be part of a far broader transition strategy. Ultimately a robust climate policy must take into account the many possible trajectories of fossil fuel prices and the complex ways these interact with elements of a transition strategy.

7.1. Green paradox

Carbon taxes on emissions, or the use of fossil fuels according to their carbon content, have been a favorite climate policy instrument of economists. As marginal harm resulting from CO₂ emissions increase over time, so too must the announced tax increase through time. A theoretical argument dubbed the 'green paradox'^{xiii} by Sinn (2008a) generated a stir by showing that instead of abating emissions a carbon tax or any policy that attempts to suppress the demand for fossil fuels, will actually bring the release of emissions forward while having no affect on cumulative emissions. The gist of the argument is that as producers become aware that future demand for their resources will wane they will



increase fossil fuel output (and thus emissions) earlier before climate policy damages their returns. Sinn (2012) even suggests that the supply side reaction by the producers may explain the falling fossil fuel prices (in real terms) between 1980 and 2000 coinciding with the "green" movement and demand restraint energy policies. He acknowledges, however, that there is yet no empirical evidence that the green paradox was behind the falling real prices. It is rather a conjecture based on his surprising theoretical result which was a direct application of Hotelling's rule. Therein has lied its strength as an idea and its potential weakness as a guide to practical policy (or explanations of historical trends). More specifically, adjustments to the model that add realism can easily counter the incentives for producers to bring production forward. For instance, it has been shown that if a greener backstop technology is relatively cheap, subsidizing the backstop will lead to less climate damage (van der Ploeg & Withagen, 2012). Also, taking into account that new oil production requires investment expenditures in exploration and development will lead firms to reduce these expenditures in view of falling prices, which is the opposite effect of the green paradox (Cairns 2013).

Besides its purely theoretical interest, the green paradox is also useful in highlighting that price and output strategies of oil resource owners (and more generally their behavior or the supply side) should not be taken as given. Wei et al. (2012) look at how fuel-producing economies can counteract climate policy and find that while a tax on fuel consumption reduces climate damage OPEC may retaliate by subsidizing oil and increasing domestic consumption. OPEC is keenly aware of what is at stake. Energy-exporting countries have already lodged a claim for compensation^{xiv} based on studies^{xv} that show how they will incur losses from carbon-reducing policies. Johansson et al. (2009) argue that as OPEC countries have low extraction costs so demand reduction need not lower their rents and may even lead to increases. It is unconventional and synthetic oils that will be disproportionately affected.

The effect on oil demand and OPEC revenues from backstop technologies and three different sets of climate/energy policies on oil demand are explored by the IEA World

Energy Model. Due to the price-inelastic oil supply response high cost, unconventional and non-OPEC deep-sea resources have to be developed to meet any oil demand change. Oil prices (along with a carbon price) range between \$90-135 per barrel in 2035 (in 2009 terms). Despite carbon policies and increasing market share of clean energy, OPEC is shown to triple oil revenues in the next 25 years as compared to the last 25 years (IEA 2010a).

7.1.2. Energy assets and revenues impact from climate policy

In a recent report the International Energy Agency (2013a) also considers the impact of climate policy (specifically that associated with it's 450 Scenario) on energy sector assets and revenues. Implicitly this provides an appraisal of the potential of a green paradox, i.e., the extent to which oil exporters will react to a carbon price in a way that will counter any potential benefits.

Energy sector assets can become "stranded" for any number of reasons, such as the impact on LNG import terminals in the United States following the shale gas boom. Climate policy can lead to stranded assets resulting from market or regulatory changes. For instance, power plants may be retired early because of new emissions regulations or discovered gas or oil fields are not developed as a result of climate policy induced reductions in demand. In the IEA's 450 Scenario, without wide deployment of CCS, more than two-thirds of current proven fossil-fuel reserves are not commercialised before 2050. Coal is the most affected with only 20% of today's coal being exploited while more than 50% of oil and gas reserves are developed and consumed (2013a).

Despite the higher rates of stranded assets in the 450 Scenario relative to the New Policies Scenario, gross revenue in the power sector is higher in the former as a result of the combined impact of higher electricity prices and lower electricity demand. This overall gain masks the distribution of benefits and losses, with coal power plants without CCS bearing losses as the costs of carbon prices outweigh the lower fossil fuel prices. New

generation capacity (renewables, nuclear and fossil-fuel plants fitted with CCS) all enjoy higher revenues.

The decarbonization of the power sector means that many of the older, inefficient fossil-fuel power plants (about 50% of which are subcritical coal-fired plants) are idled or retired before their anticipated technical lifetime, though most of them still recover their investments.

Oil and gas revenues in the 450 Scenario are lower than in the New Policies Scenario but are also three times higher than the level of the last two decades. The policies associated with the 450 Scenario do not introduce any significant risks for currently producing oil and gas fields. However, investments may not be justified in some of the fields that have not yet started to produce or have not been found yet. Assets further downstream like refining, LNG plants and transportation may also become stranded. New pipeline utilisation rates may also decline in some regions.

The risk of losses on sunk investments is relatively low for coal mining since coal prices only need to be slightly above variable costs to generate an adequate return on investment.

7.2. Beyond carbon prices

Most economists view carbon pricing as the central plank of any effective policy to combat climate change. Though there is substantial controversy over the specific means of attaining a global price on carbon emissions, e.g., whether to tax CO₂ emissions or to set up markets in emission permits, some form of carbon price is deemed essential for a transition to a low carbon economy. This draws on the theory of market failure and the view that greenhouse emissions are a global externality reflecting the fact that climate's temperature regulating function is a key service that goes unpriced in the market. If the damage associated with climate change is adequately priced than all actions contributing to climate change will be penalized in line with the potential damage they cause. Fossil fuels associated with larger carbon emissions would see their full social prices (market

price augmented with a carbon penalty) rise and the system would be pushed to alternative less damaging activities. In the ideal theoretical construct, carbon prices would adjust with fossil fuel prices accounting for the marginal damage of an extra unit of carbon emissions. If oil prices increased as a result of biting reserve constraints then total emissions would recede and the marginal damage associated with an extra unit of CO₂ emission would be reflected in a lower carbon price. If oil is very cheap because new resources or technologies make it so, then the carbon price would rise. Even in more realistic settings, e.g., the EU ETS system, carbon price would be expected to be sensitive to the price of fossil fuels. Indeed, this kind of sensitivity may be among the attributes making carbon markets an attractive policy instrument.

There is a large modelling literature that looks at the appropriate trajectory of a global carbon price needed to attain specific targets of accumulated greenhouse gases. In part, given the complexity of climate-economic models, these models tend to abstract from the many non-carbon-price policy tools often used in practice or supported in theory. For instance, developing new technologies require targeted support to help them attain economies of scale. This is certainly the case for renewable energy technologies, electric vehicles and smart grids, all of which also require supporting infrastructure. Non-price policies may also be needed to discourage investment in long-lived energy infrastructure that would not be responsive to price changes (2013a). The standard model used to assess the effectiveness of carbon price patterns over time are general equilibrium models of different degrees of complexity, but they generally abstract from non-price policies.

A tendency to view carbon pricing as a silver bullet policy to decarbonize the economy derives from traditional welfare economics that treat failures as primarily missing markets or prices. In the theoretical world of frictionless (and institutionless) market economies many market failures can be addressed by establishing a market or price where it is otherwise missing. Most of the scenarios exploring the costs of technologies for mitigating greenhouse gases use unrealistic assumptions such as that there is global agreement to mitigation policies and that all relevant technologies are available.

Technology is often treated as exogenous though there has been a growing and substantial literature on endogenizing technology in models. Many imperfections are widely ignored like inertia, path-dependencies of infrastructure investments, and the role of myopic behavior on the costs of mitigation. More generally there has been very little research on the implications of imperfect economies or second-best settings for climate policy including, and perhaps more ambitiously, the political economy of the design of policy instruments (Edenhofer, Carraro, & Hourcade, 2012). The next section will briefly look at ways in which introducing imperfections can have significant implications on the effectiveness and limitations of policy that relies too heavily on carbon pricing, or that ignores important aspects about how technology evolves or how market imperfections may prevent a transition to a low carbon economy.

7.2.1. Imperfect markets

The RECIPE Project (Report on Energy and Climate Policy in Europe) is one attempt to consider decarbonization scenarios that incorporate imperfections like constraints in the availability of mitigation technologies or the impact of delayed and incomplete participation in global action (Edenhofer 2012).^{xvi} A specific application of second-best modeling within the RECIPE Project is particularly relevant in revealing the potential limitations of too singular a reliance on a carbon price as a means of decarbonization. Waisman et al. (2012; 2013) use a hybrid computable general equilibrium model to examine the policy needed to make the transition to low carbon economies in the presence of technical inertia and imperfect foresight influencing investment decisions. The focus is on the transportation sector which is particularly oil dependent and the most difficult to decarbonize. In addition to a reduction of energy intensity of transportation modes and the carbon content of fuels, low-carbon modes must be promoted and the overall volume of mobility must be reduced. Most energy-economy-environment (E3) models focus only on technology and do not incorporate the behavioral determinants of transportation dynamics

(Schafer & Victor, 2000). Waisman et al. (2013) attempt to fill in this gap by including policies that complement carbon pricing that can influence behavioral determinants of transportation: "(1) spatial reorganization at the urban level and soft measures towards the use of less mobility-dependent agglomeration, (2) reallocation of investments in favor of public modes for a constant total amount for transportation infrastructure, and (3) adjustments to the logistics organization to both decrease the transport intensity of production/distribution processes and optimize the use of vehicles" (Waisman et al., 2012, p. S107).

There are a number of obstacles to reducing the carbon intensity of fuels in transport, like problems with large scale expansion of biofuels^{xvii} or intermittency of renewables. There are also technical and behavioral limitations to reducing the energy intensity of mobility (purchase decisions undervalue future energy savings).

Energy prices are just one of many factors influencing the patterns of transportation. Important additional factors include income, spatial organization, housing costs, and availability of transport infrastructure. In transportation sector "energy prices are swamped by other determinants (e.g., real estate markets, political bargaining behind infrastructure policies and just-in-time processes in industry)".

Promoting a switch in modal structure of mobility from carbon-intensive (e.g., air, passenger cars) to low-carbon (e.g., public transport and non-motorized modes for passengers, rail, shipping) requires dedicated investment in the latter forms to improve speed, reliability and flexibility. Network externalities in long-lived infrastructure generally make it cheaper to expand one network rather than maintaining two in parallel (e.g., rail and road) making path dependency and lock-ins in energy intensive mobility more likely. The volume of mobility is another key determinant of decarbonization and is influenced by the interplay between several factors affecting consumer and industry choices that all impose inertia on the dynamics of mobility. The spatial distribution of housing, transport, and industrial infrastructures (characterized by strong inertia) determine commuting distances and transport intensity of production. Location choices

involve a trade-off between transport and housing expenditure, with the fall in transport prices being at the root of urban sprawl. There is evidence that households devote a given time to mobility so that any infrastructure improvements that make higher speeds possible lead to greater distances travelled or shift to faster modes (e.g., aviation) (Metz 2008; Schafer & Victor, 2000; Zahavi & Talvitie, 1980). The total time traveled for production/distribution of a given volume is determined by the tradeoff between inventories and just-in-time organizations (*Green Logistics : Improving the Environmental Sustainability of Logistics* 2012; Piecyk & McKinnon, 2010).

Two feedback effects also impact the volume of mobility. First, improvements in infrastructure for a given mode (enhanced accessibility or improved services) may trigger increases in mobility (Noland 2008). Second, reductions in marginal costs of travel can lead to a 'rebound' effect like increases in mobility after improved fuel economy measures (A Greening, Greene, & Difiglio, 2000).

Though many studies acknowledge the important role of reducing the carbon intensity of energy or the energy intensity of transport modes, the majority of them also point to the need of changes in modal structure and volume of mobility. Demand for transportation services and fuel consumption from vehicles appear to be weakly sensitive to energy prices. This suggests that in the absence of other measures, only high and increasing energy prices, or carbon prices, sustained over the long run would be able to bring about significant changes in transport-related carbon emissions (Waisman et al., 2013).

Carbon pricing needs to be complemented by measures, inter alia, that affect the spatial organization of the economy so that firms' production/distribution processes and households' patterns of consumption are compatible with lower overall demand for transportation or less carbon intensive modes of transportation. Infrastructure, fiscal and land-use policies, industrial regulation and policies that affect the location of firms can play a critical role in reshaping demand patterns for transportation. In addition, policies like those that replace physical mobility with telecommunications should be considered (2013).

The hybrid dynamic general equilibrium model (IMACLIM-R) incorporates explicit representation of passenger and freight mobility in a way that allows an assessment of measures affecting modes and volume of transportation (in addition to carbon intensity of energy and energy intensity of transport modes). Non-price determinants like urban organization, infrastructure and spatial organization are included along with their interactions with the rest of the economy.

The key conclusions reached are that emissions are weakly reactive to energy price increases so that a very high carbon price needs to be imposed to attain mitigation targets when only carbon pricing policy is used. Three non-price measures were analysed: urban reorganization lowering mobility (e.g., commuting and shopping), deployment of infrastructure to favor low-carbon transportation modes and changes in logistics organization (to lower freight mobility intensity of production/distribution). With these additional measures emission reductions are achieved with significantly lower carbon prices thus reducing macroeconomic costs of mitigation. The macroeconomic losses associated with high carbon price "can be explained by (1) inertia of infrastructure, location choice, and urban forms embedded in models; and (2) the rebound effect of mobility, which requires a very high carbon price in the second half of the century if stringent emission targets are to be met" (2013, p. S124).

In a carbon price only scenario the major determinant of reducing emissions is the diffusion of vehicle energy efficiency while in the scenario that allow for appropriate transport policies, emission reductions are achieved predominantly from a modal shift and mobility reduction. Essentially, energy prices are inadequate to bring about the kinds of modal choice or volume of mobility changes that can be less expensive means of reducing emissions. A carbon price only policy ultimately relies on fewer and more expensive ways of achieving emission reductions. When accounting for political realities this also means that an energy price only policy will be more likely to fail in delivering the needed goals.

7.3. Beyond markets: transition literature

Carbon prices can only be part of a broader strategy, whether this involves additional support for research and development in clean technologies or deployment of infrastructure to favour low carbon means of transportation. This is apparent from economic modelling exercises that make departures from simple general equilibrium market dynamics. These models could be viewed as restricted in that their departure is an ideally functioning market economy confronting different degrees of imperfection, or as a step in a direction towards a much broader analysis that looks at energy transitions beyond the narrow confines of market dynamics.

Innovations in clean energy differ in that users do not get a better, cheaper or more pleasing product or service, nor does clean energy meet some unmet need that will make consumers willing to pay a higher price. "Instead, the lack of obvious demand impetus and unprecedented system complexity characterize the evolutionary dynamics of clean energy" (Haug 2011). This is in part a reason why higher fossil fuel prices on their own provide no guarantee of the direction of an energy transition. Carbon prices in part address this by inducing the demand for clean energy (or penalizing 'dirty' energy), but cannot bring about a system wide energy transition on their own. A growing systems transition literature [references] has been looking at the causes of past energy transitions and drawing lessons on the kinds of changes required for a low carbon revolution. The analysis moves far beyond market dynamics.

Clean energy transitions face great challenges as they require changes of large technical systems. Firms tend to adopt routines and rules and focus on incremental innovation conducive to gradual change (Nelson 1994). Path dependencies arise from the cumulative nature of RD&D and sunk costs of prior investments. Technology, organizational and investment choices reinforce each other leading to lock-in of dominant products and systems (Haug 2011). Innovation is not enough. What is needed is a dynamic co-evolution of technologies, markets and institutions. Prices and incentives can change the pace of technical change but it will be bound by the nature of incumbent technology (Dosi & Grazzi, 2009). In this perspective, the unsustainability of our energy system is not a matter

of scarcity but of staying within the confines of self-perpetuating technological trajectories. "Prices and regulatory measures...have limited 'inducement effect'. Only the development of new technological paradigms will meet the objectives of sustainable energy systems" (Haug 2011, p. 100).

The market failure approach as a basis of policy action has been seen as overly narrow by the systems innovation literature which identifies a broader concept of 'system failure' or 'system problems' in the co-evolution of technologies, markets and institutions. The speed, direction and success of innovation processes depend largely on the environment in which innovations are developed. Many system failures (besides market failures) may exist that prevent or hamper the development and diffusion of innovations. Large technological systems like the energy system are characterized by inertia due to the strong interrelatedness between the energy system and the economy. In transforming the energy system all part of the economy will be affected.

A "lock in" characterize complex and large scale socio-technical systems more generally (with the transportation network being an important component of the broader system), and there is "a stronger mutual feed-back loop between individual energy choices and the system's organizational principles and characteristics" (Goldthau & Sovacool, 2012, p. 234). The energy system and the interrelated transportation system exhibit 'path dependency' in that initial historical events can lead to a self-perpetuating process. Within a socio-technical system, when a specific technology is selected, positive feedback loops among different elements lead to a situation of "lock in" in which the chosen technological solutions remain dominant while resistance remains strong against new competing technologies.

Geels (Geels 2004) broadens the the frame of analysis even more with his multi-level perspective that considers three interlocking levels: 1. The socio-political landscape refers to cultural and political values and socio-political trends that are deeply routed and beyond the control of actors. 2. The socio-technical regime within which a technology is embedded includes the normative and cognitive rules of the sector, the material, technical

and scientific knowledge, and network of public and private actors and social groups. 3. The niches where new technologies and products are developed include the actors involved in more radical innovations along with their social networks, incentives and learning space.

Seven functions of innovation systems need to work together for a sustainable energy system transition to occur: entrepreneurial activity, knowledge creation, knowledge diffusion through networks, institutional guidance in the search process, market formation, resource mobilization, and advocacy coalitions to create legitimacy. Over time, these functions interact to form "virtuous cycles" of change or 'vicious cycles' of disillusion among actors (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008; Hekkert, Suurs, Negro, Kuhlmann, & Smits, 2007).

Negro et al. (2012) identify five 'systemic problems' to systems innovation with a focus on a clean energy transition. (1) Market structure problems refer to the organization of the current market and the criteria used to select innovations (this category include traditional market failures and the advantages that incumbent technologies have from reaping increasing returns and network externalities). Instances of these problems are the incompatibility of the RETs with the paradigm of the large-scale centralised generation. In wind energy, for instance, the first choice was to develop large-scale wind turbines. This premature convergence to large-scale led to poor technological design. (2) Infrastructure problems refer to the absence of infrastructures for the new technology trajectories, both physical (like electricity grids) and non-physical (like scientific and applied knowledge). (3) Institutional problems refer to formal institutions (hard) like technical standards and labor law, and soft institutions like social norms and values, entrepreneurial spirit, which form the environment within which firms, knowledge institutes and the government are embedded. In the case of renewables one of the most cited problems relates to 'stop and go' policies of regulation and subsidy schemes. (4) Interaction problems can occur when individual actor are guided in the wrong direction by network actors that are part of a broader set of relationships between firms, governments, public knowledge institutes and

third parties (such as specialized consultants). They can also occur when connectivity among complementary technologies and actors is poor. (5) Capability problems arise when firms simply lack the competence, capabilities or resources to make the leap to a new technology or regime. Negro (2012) develop this classification in order to organize a broad literature on systems innovation and consider case studies that reveal instances of these systemic problems in understanding the slow diffusion of renewable energy. The point here is to reveal the extent to which there is a need to go beyond a traditional market failure approach which tends to overemphasize the role of prices and underemphasize broader institutional problems. Table 3 below provides a categorization of systemic problems for clean energy from case studies according (2012).

8. Conclusions

There are a number of general lessons that can be drawn from the history of oil prices. With low oil prices substitution is less likely to take place and support policies for alternatives will be perceived as expensive and will be less likely to be pursued or sustained. The implications for a low carbon transition are that it will be politically more difficult to garner support if future fossil fuel prices revert to their historic normal or come down from their present high levels. Climate policy will appear more expensive and there wont be the added pressure of concern for energy security. Though the present mainstream view is that oil prices will remain relatively high and their intimate connection with transportation will make substitution away from oil difficult, climate policies must be ready to address the possibility of low fossil fuel prices including the possibility that this results from a strategic reaction to climate policy from oil exporting countries.

High fossil fuel prices can make climate policy easier to pursue but it cannot be taken as a given that they are boon to a low carbon energy transition. The high oil prices of the 1970s did lead to a substitution away from oil, lower energy intensity, and a dramatic shift in energy mix in some countries, e.g., France and Brazil. The relative ease of substitution,

including the ability to use the existing infrastructure and technology (power generation), the existence of mature technologies that were easy to scale, made the transition from oil to gas, coal and nuclear relatively swift and smooth. The existing power regimes, industry structures and public sector approaches were well suited for nuclear power, natural gas and coal. "Nuclear power offered a seamless, perceived low-cost substitute for fossil-fuel base load power. Natural gas offered attractive technical and economic characteristics for consumers. It fitted well in the technology portfolio and with the strategies of international oil and national energy companies. The dominant public sector thinking of the time fostered national gas champions and supported the required pipeline and LNG infrastructure" (Haug 2011, p. 96). Early attempts at renewables, very much in a niche phase, faltered as support policy were short lived which was partly the result of the eventual decline in oil prices. The demands of a low carbon revolution are very different from the kind of shift that took place as a result of the oil shock of the 1970s. High oil prices can just as easily induce new exploration and development of oil fields or technologies that either increase supply like unconventional fuels or substitute oil with other fossil fuels in transportation. Without a strong climate policy in place, these are the more likely outcomes given that they are a more natural extension of the existing socio-technical energy system.

There is still much controversy about the likely trajectory of future fossil fuels. The recent drop in the price of oil (September - November 2014) associated with relentless US shale gas production, weak global demand and higher than expected OPEC supply has raised talk about a new era of abundance. Still the present 'conventional' wisdom (as reflected in the most recent World Energy Outlook (2014b)) seems to be that 'this time is different' and that oil prices will remain at a higher level, for a longer time, than has been the norm over the last 150 years. The key determinants for future oil prices are the potential to substitute oil in transportation, the extent to which high prices induce major new discoveries and development of oil fields, and the pace of growth in world demand for transportation. Unconventional oil and gas are already having an impact and are likely to dampen future

price rises but are not likely to bring about a era of abundance (IEA 2013c, 2014b). Yet the possibility that this time is not different is far too great to disregard. It may turn out that we are awash with oil, gas and coal. Whether energy markets drive fossil fuel price up or down in the future, it is clear that climate policy will have to ensure that fossil fuel prices remain above their historic norm if there is to be any hope for attaining a timely transition to a sustainable energy system. The Great Recession has negatively affected the resolve for climate action, while advances in extraction technologies and the hope of a new 'golden age of gas' have partly allayed the concerns for energy security.

"Modeling fossil fuel prices is a daunting challenge... [but] an essential part of the puzzle, required for a complete economic analysis of the costs and benefits of climate policy" (Ackerman & Stanton, 2013, p. 130). Most modelling efforts have treated fossil fuel prices as exogenous relying on scenarios of their trajectory over time. Effective climate policy will require a much better understanding of the interaction of climate policy with fossil fuel prices or the underlying determinants of fossil fuel prices. This is largely uncharted ground and a critical area of research for forming effective and robust policies for a transition to a sustainable energy system.

One of the few modelling exercise that has considered the interaction of climate policy with fossil fuel prices has showed that high hydrocarbon prices in the absence of climate policy would reduce CO₂ emissions in the short run but increase them in the long run (Ruijven & Vuuren, 2009). With climate policy higher fossil fuel prices may facilitate the transition. Among the many complexities of modelling fossil fuel prices endogenously one needs to account for the potential reaction of oil exporting countries to climate policies. The Green Paradox is a surprising instance of how the long standing theoretical centrepiece of modelling resource prices could have completely missed the potential role of the supply side. Sinn's (2008b) initial presentation of the Green Paradox was striking in that it showed that in theory climate policy could be totally neutralized by oil exporting countries. The growing literature responding to this challenge raised doubts about the presence of a Green Paradox. Oil exporting countries have already filed for compensation

for losses arising from climate policy, scenario analysis undertaken by the IEA (IEA 2013a) suggests that the losses from stranded assets will not be as big as might be expected. Still, considering the reactions of oil exporting countries has to be an important component of climate policy analysis and formation.

Carbon prices have been the policy most advocated by economists for a transition to a low carbon economy. As important as it is to ensure higher fossil fuel prices through a carbon price component, this can only be effective as part of much broader strategy. Recent developments in models that account for market imperfections and endogenous technology emphasize the need to complement carbon price policies with other policy instruments including direct encouragement of development of clean energy technologies, infrastructure investments, fiscal and land-use policies, industrial regulation and policies, especially as these affect demand for transportation. A growing transition literature that takes an even broader perspective from market correcting analysis, identify the sea change required in the socio-political landscape and the socio-technical system for a low carbon transition to become a reality. When we better understand the the way that policy and system changes affect the price of energy services rather energy prices we will be able to forge effective climate policy. When energy services associated with low carbon become cheaper or more attractive than their high carbon counterpart we will have forged the road to a low carbon economy.

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Figures and Tables

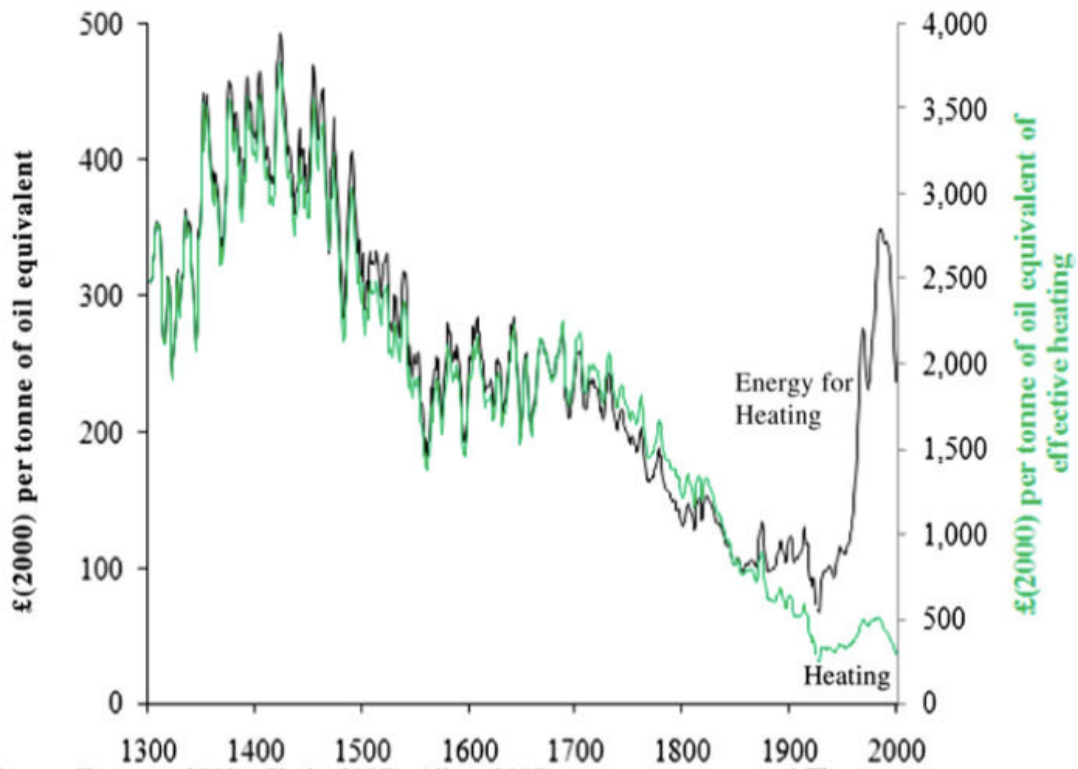


Figure 1: Prices of energy (for heating) and price of household heating in England (1300-2000)

Source: (Fouquet 2011b)

Table 1: Divergences in prices of energy and energy services (1700-2000)

	X-fold decline in price of energy	X-fold decline in price of service
Heating	1.1	5.1
Power	12.5	16.1
Transport (freight)	3.0	20.1
Transport (pass.)	2.9	11.7
Lighting	9.0	5,830
Average	3.7	37.4

Source (2011b)

World consumption
 Million tonnes oil equivalent

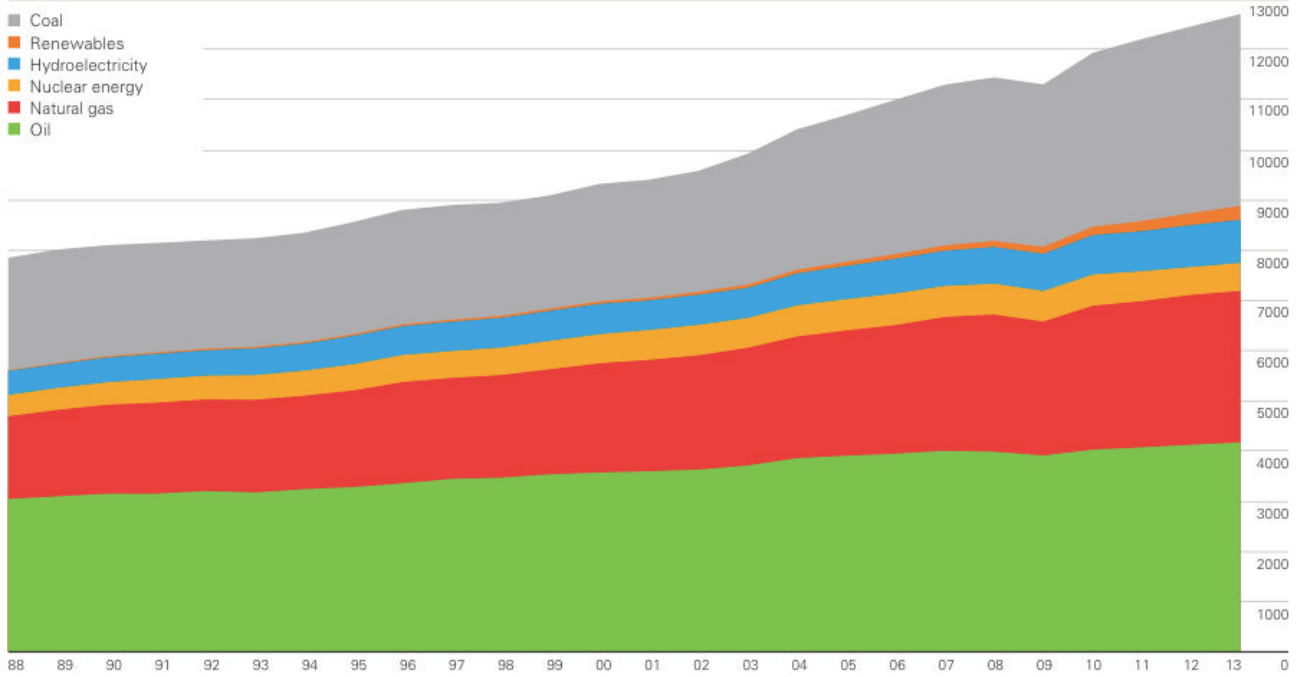


Figure 2: World consumption of primary energy by source

Source: (BP 2014)

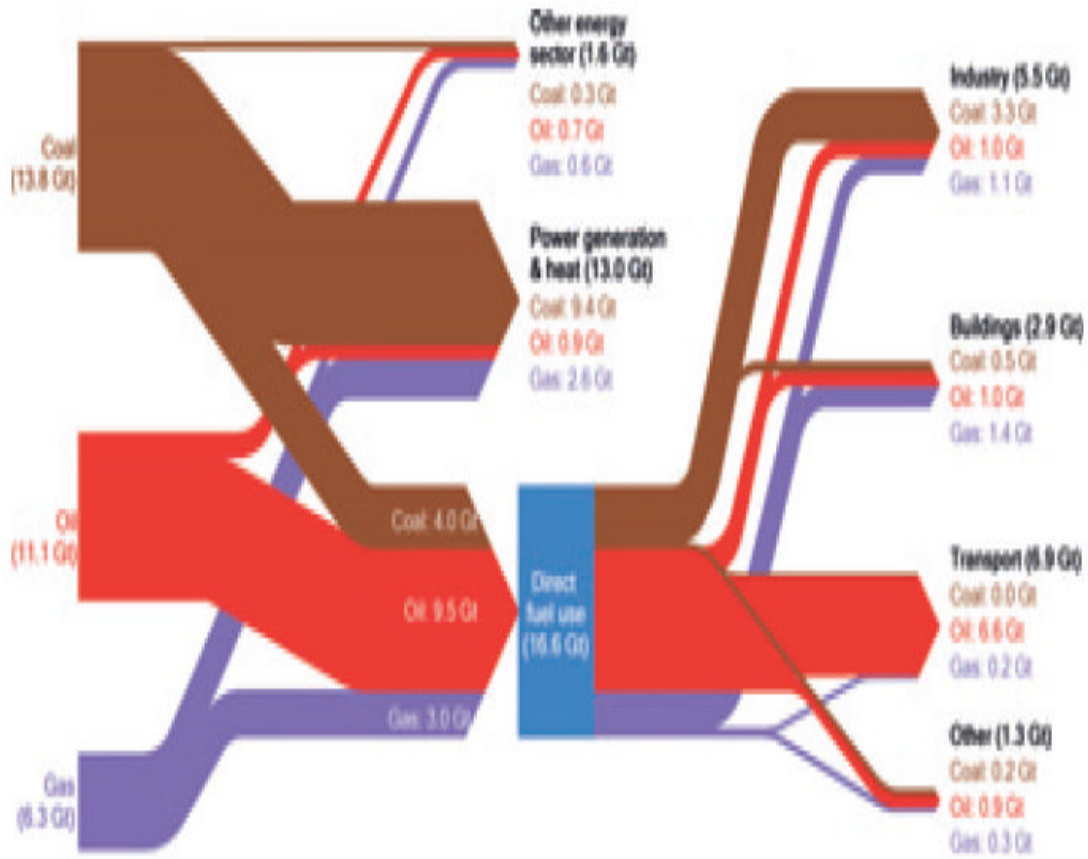


Figure 3: World energy related CO2 emissions by fuel and sector, 2011.

Source: (IEA 2013a, p. 32)

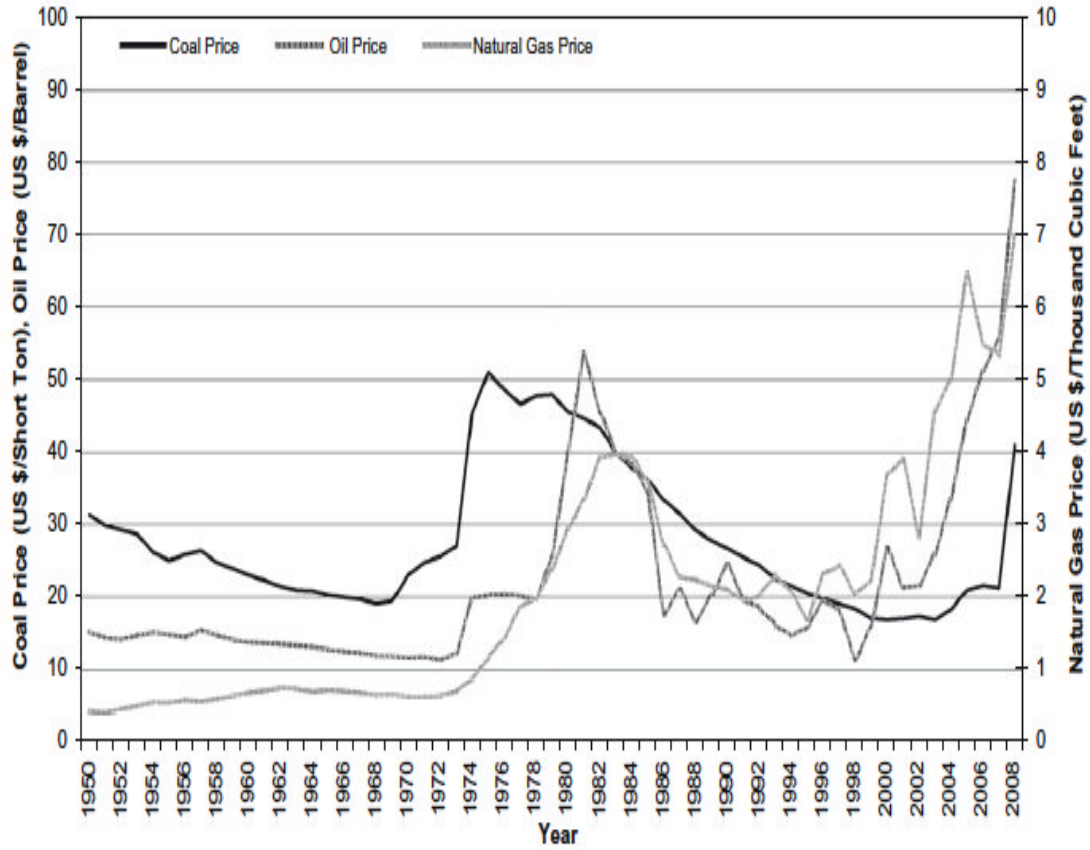


Figure 4: Historical trend in prices of coal, oil, and natural gas

Source: (Shafiee & Topal, 2010)

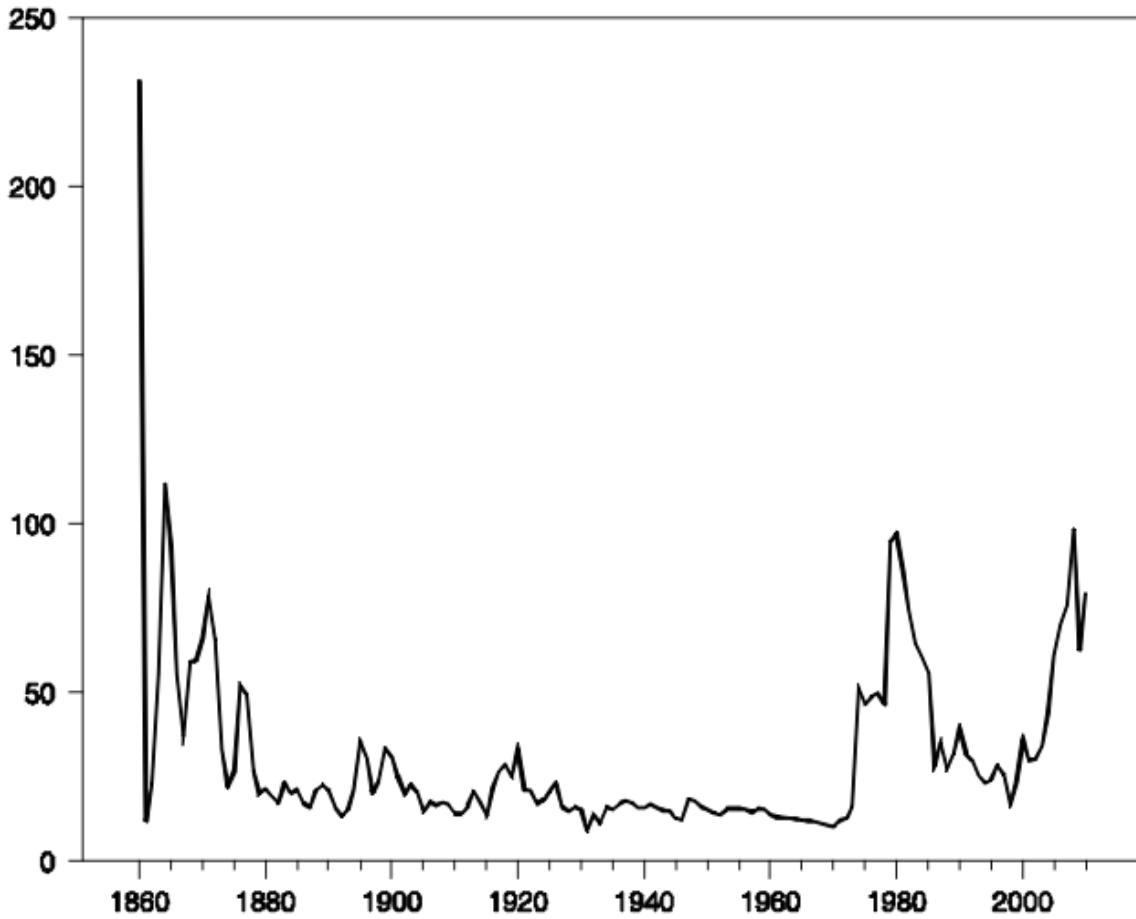


Figure 5: History of oil price

Price of oil in 2010 dollars per barrel, 1860-2010. Data source: 1861-2010 from BP, Statistical Review of World Energy 2010; 1860 from Jenkins (1985, Table 18) (which appears to be the original source for the early values of the BP series) and Historical Statistics of the United States, Table E 135-166, Consumer Prices Indexes (BLS), All Items, 1800 to 1970.

Source: (Hamilton 2013)

Table 4: Fossil-fuel import price assumptions by scenario (dollars per unit)

Source: (IEA 2014b, p. 41)

	Unit	New Policies Scenario						Current Policies Scenario					450 Scenario				
		2011	2015	2020	2025	2030	2035	2015	2020	2025	2030	2035	2015	2020	2025	2030	2035
Real terms (2011 prices)																	
IEA crude oil imports	barrel	107.6	116.0	119.5	121.9	123.6	125.0	118.4	128.3	135.7	141.1	145.0	115.3	113.3	109.1	104.7	100.0
Natural gas																	
United States	MBtu	4.1	4.6	5.4	6.3	7.1	8.0	4.6	5.5	6.4	7.2	8.0	4.4	5.5	6.9	7.6	7.6
Europe imports	MBtu	9.6	11.0	11.5	11.9	12.2	12.5	11.2	12.1	12.9	13.4	13.7	10.9	10.8	10.4	10.0	9.6
Japan imports	MBtu	14.8	15.0	14.3	14.5	14.7	14.8	15.3	14.7	15.2	15.6	16.0	14.9	13.5	12.9	12.5	12.2
OECD steam coal imports	tonne	123.4	108.5	112.0	113.0	114.0	115.0	110.0	115.0	119.2	122.5	125.0	105.3	97.5	89.0	78.0	70.0
Nominal terms																	
IEA crude oil imports	barrel	107.6	127.0	146.7	167.6	190.4	215.7	129.7	157.4	186.6	217.4	250.3	126.3	139.0	150.0	161.2	172.6
Natural gas																	
United States	MBtu	4.1	5.0	6.7	8.7	11.0	13.8	5.0	6.7	8.8	11.1	13.8	4.8	6.7	9.5	11.7	13.2
Europe imports	MBtu	9.6	12.1	14.1	16.4	18.8	21.6	12.3	14.9	17.7	20.6	23.6	11.9	13.2	14.3	15.4	16.6
Japan imports	MBtu	14.8	16.4	17.5	19.9	22.6	25.5	16.8	18.1	20.9	24.0	27.6	16.3	16.6	17.7	19.3	21.1
OECD steam coal imports	tonne	123.4	118.8	137.4	155.4	175.6	198.5	120.5	141.1	163.8	188.7	215.7	115.3	119.6	122.4	120.2	120.8

Notes: Gas prices are weighted averages expressed on a gross calorific-value basis. All prices are for bulk supplies exclusive of tax. The US price reflects the wholesale price prevailing on the domestic market. Nominal prices assume inflation of 2.3% per year from 2011.

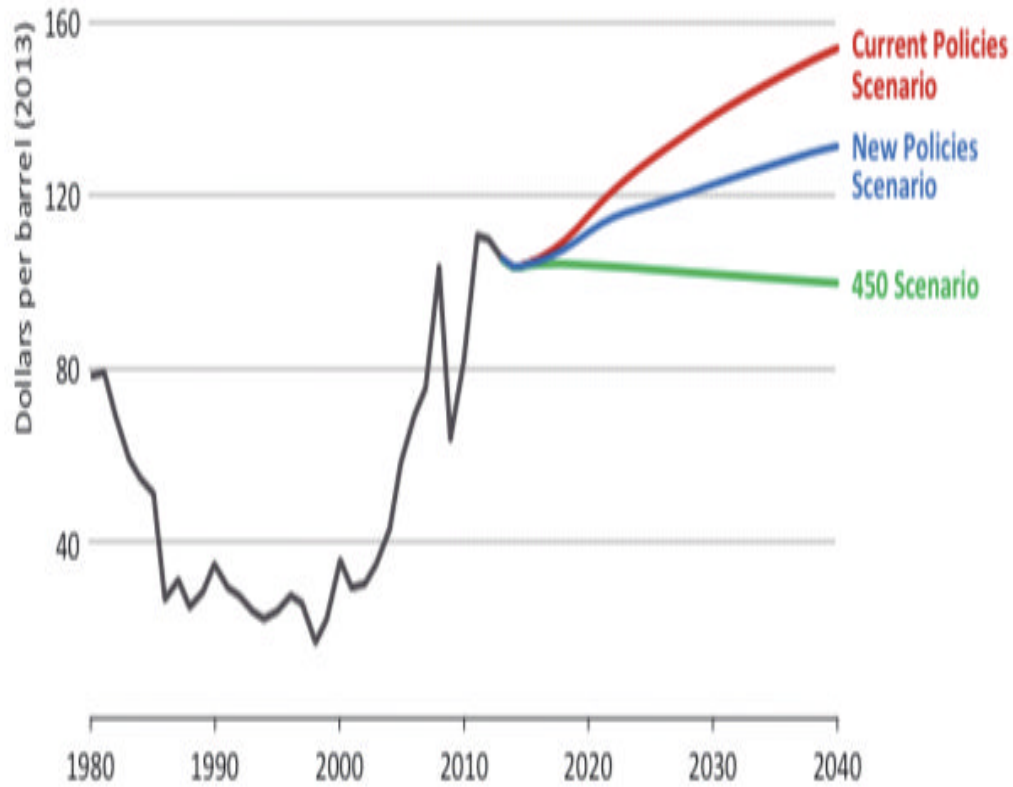


Figure 8: IEA forecast of future average crude oil price depending on scenarios

Source: (2014b)

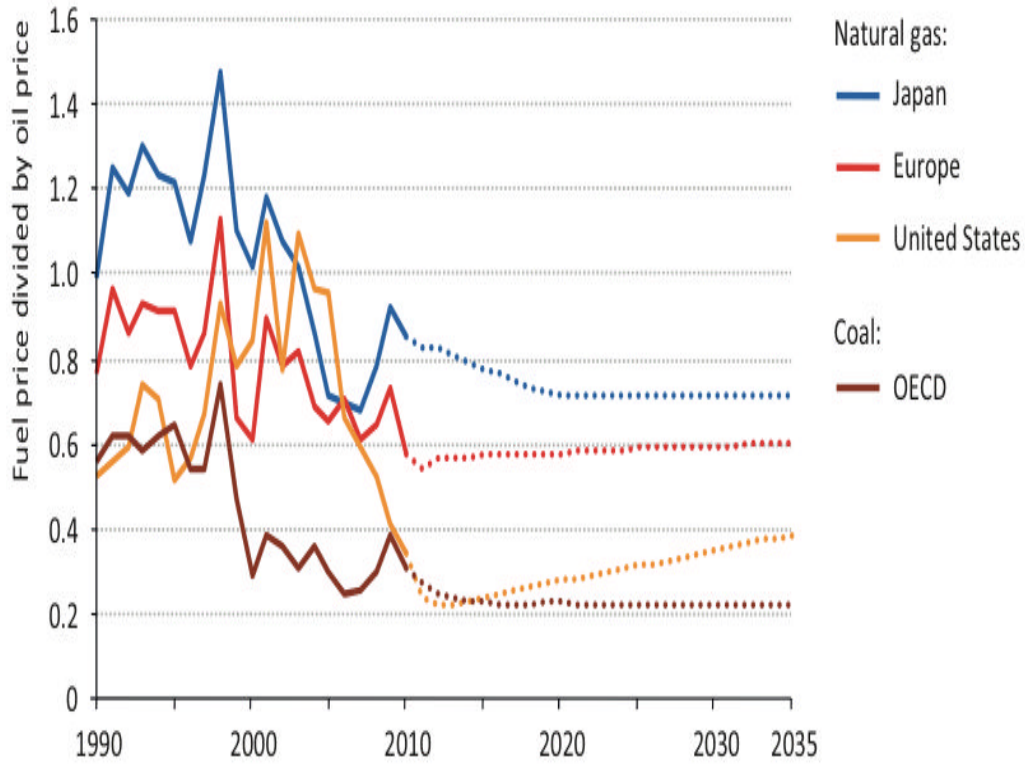


Figure 7: Ratio of average natural gas and coal prices to crude oil prices in the New Policies Scenario

Source: (2012b)

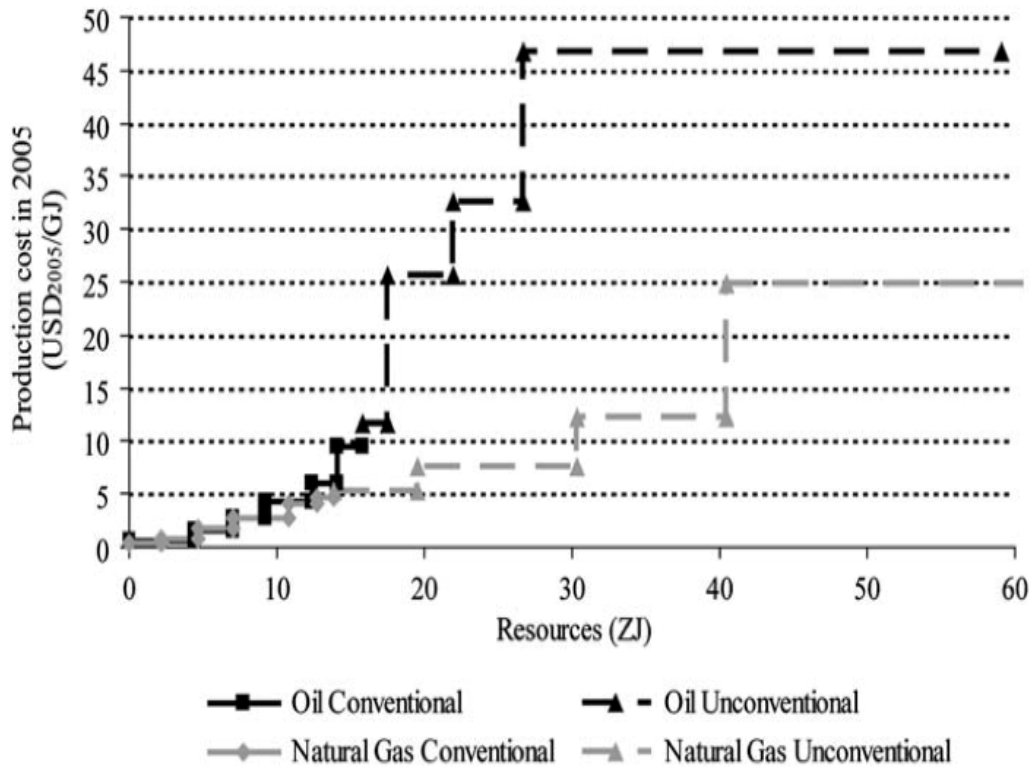


Figure 9: Long-term supply cost curves in the TIMER model

Source: (Bakker et al., 2009)

Table 5: Allocation scheme of systemic problems

Systemic problems	Empirical sub categories	No. of cases
Hard institutions	<ol style="list-style-type: none"> 1. 'Stop and go policy': lack of continuity and long-term regulations; inconsistent policy and existing laws and regulations 2. 'Attention shift': policy makers only support technologies if they contribute to the solving of a current problem 3. 'Misalignment' between policies on sector level such as agriculture, waste, and energy, and on governmental levels, i.e. EU, national, regional level, etc. 4. 'Valley of Death': lack of subsidies, feed-in tariffs, tax exemption, laws, emission regulations, venture capital to move technology from experimental phase towards commercialisation phase 	51
Market structures	<ol style="list-style-type: none"> 1. Large-scale criteria <p>Incremental/near-to-market innovation Incumbents' dominance</p>	30
Soft institutions	<ol style="list-style-type: none"> 1. Lack of legitimacy <p>Different actors opposing change</p>	28
Capabilities/capacities	<ol style="list-style-type: none"> 1. Lack of technological knowledge of policy makers and engineers <p>Lack of ability of entrepreneurs to pack together, to formulate clear message, to lobby to the government Lack of users to formulate demand Lack of skilled staff</p>	19
Knowledge infrastructure	<ul style="list-style-type: none"> - Wrong focus or no specific courses at universities and knowledge institutes - Gap/Misalignment between knowledge produced at universities and what needed in practice 	16
Too weak interactions	<ul style="list-style-type: none"> - Individualistic entrepreneurs - No networks, no platforms - Lack of knowledge diffusion between actors 	13
Too strong interactions	<ul style="list-style-type: none"> - Lack of attention for learning by doing - Strong dependence on government action or dominant partners (incumbents) - Network allows no access to new entrants 	8
Physical infrastructure	<ul style="list-style-type: none"> - No access to existing electricity or gas grid for RETs - No decentralised, small-scale grid - No refill infrastructure for biofuels, ANG, H2, biogas 	2

Source: (Negro et al., 2012)



ⁱ This does not account for sustainability that in the best of cases requires that the resource rents are all invested in order to increase the future productivity of man made capital.

ⁱⁱ See Livernois (2009) for comprehensive review of how economists have adjusted Hotelling's assumptions, modelled the reality of the oil market and empirically tested the results.

ⁱⁱⁱ One could draw on Lancaster's (1966) theory of characteristics of products which points out that consumers are interested in specific characteristics of products (flows of services these provide) rather than a product per se. In this sense even 'final' products are 'inputs' in the provision of ultimate goods (services flows). For instance, what matters to the consumer may be the calorie value, taste, texture, etc. of food with different food products providing different packages of this. A more relevant example for the present discussion is the demand for transport services.

^{iv} There is a large literature on the rebound effect. Sorrell (2009) provides a good introduction to this literature.

^v See Mohammadi (2009) for an empirical analysis of the long and short-run dynamics among the three energy prices (oil, natural gas and coal) in the US. Despite the importance of understanding the relationship between these energy prices it has not received the attention it deserves (2009).

^{vi} Hub-based pricing in North America, UK and Australia (moving in line with local supply and demand), longer-term contracts with oil-price indexation in Europe (though this is changing), oil price indexation in Japan and Korea.

^{vii} Financial innovation made it easier and cheaper for investors to increase their exposure.

^{viii} Who also points out that a similar "supply shock" is being predicted now with hydraulic fracturing.

^{ix} "Suppose for a moment that we are about to enter an age of cheap gas and the electrification of transport, backed up by the continuing upward trend in the share of coal in world energy demand (based on practically limitless supplies). The gas price would decouple from the oil price, and unconventional gas would provide a price ceiling. The oil price would ease back as gas competition intensified for chemicals, electricity generation, and industrial uses, while the gradual electrification of transport would eat away at oil's premium market. Coupled with increased supplies from Iraq in the short to medium term, limited by the availability of tar sands, and undermined in the medium to long term by the abundance of Arctic and other new supplies, the oil price might remain weak, perhaps even falling away in a couple of decades or so. Current conventional oil and gas forecasts,

like those made by the famous peak coaler, Jevons, in the nineteenth century about the prospect of running out of coal, may turn out to be very wrong (Jevons, 1865)"(2011, p. 86).

^x The World Energy Outlook (2013c; 2014b) provides a more in depth appraisal of the role of unconventional oil and gas and more generally about oil market developments.

^{xi} The more recent World Energy Outlook (2013c; 2014) forecasts are very similar. They do also consider a "low oil-price case" with prices reaching \$80/tonne by 2035.

^{xii} Though the 2012 and 2013 growth has been below the trend in the past decade.

^{xiii} A less charged term is 'intertemporal emissions leakage' since in effect the green paradox is showing how some policies may not be effective because of the way they alter the time profile of emissions. The more familiar use of leakage is for interregional interactions such that reduced emissions in one region are countered by increases elsewhere, e.g., a carbon intensive activity migrating to a more lenient jurisdiction.

^{xiv} A claim has been lodged based on article 4.8 of the UNFCCC and articles 2.3 and 3.14 of the Kyoto Protocol.

^{xv} See Johansson (2009) for a literature review of a series of economic modelling studies that provide the theoretical underpinnings of these claims including estimates of the damage of the negative impact of the Kyoto Protocol.

^{xvi} Edenhofer (2012) provides an overview of the special issue on the RECIPE Project and the various attempts to incorporate imperfections that add realism to decarbonization modelling and policies.

^{xvii} In the cases of biofuels there are large uncertainties regarding yield improvements, climate change feedback and the production potential of degraded land (Chum et al., 2012). The life cycle impact of biomass on GHG emissions may be less positive than expected (Searchinger et al., 2008; Tilman et al., 2009) and competition for land may pose problems for large-scale biomass production.



Financialisation, Economy, Society and Sustainable Development (FESSUD) is a 10 million euro project largely funded by a near 8 million euro grant from the European Commission under Framework Programme 7 (contract number : 266800). The University of Leeds is the lead co-ordinator for the research project with a budget of over 2 million euros.

THE ABSTRACT OF THE PROJECT IS:

The research programme will integrate diverse levels, methods and disciplinary traditions with the aim of developing a comprehensive policy agenda for changing the role of the financial system to help achieve a future which is sustainable in environmental, social and economic terms. The programme involves an integrated and balanced consortium involving partners from 14 countries that has unsurpassed experience of deploying diverse perspectives both within economics and across disciplines inclusive of economics. The programme is distinctively pluralistic, and aims to forge alliances across the social sciences, so as to understand how finance can better serve economic, social and environmental needs. The central issues addressed are the ways in which the growth and performance of economies in the last 30 years have been dependent on the characteristics of the processes of financialisation; how has financialisation impacted on the achievement of specific economic, social, and environmental objectives?; the nature of the relationship between financialisation and the sustainability of the financial system, economic development and the environment?; the lessons to be drawn from the crisis about the nature and impacts of financialisation? ; what are the requisites of a financial system able to support a process of sustainable development, broadly conceived?

THE PARTNERS IN THE CONSORTIUM ARE:

Participant Number	Participant organisation name	Country
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2	University of Siena	Italy
3	School of Oriental and African Studies	UK
4	Fondation Nationale des Sciences Politiques	France
5	Pour la Solidarite, Brussels	Belgium
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