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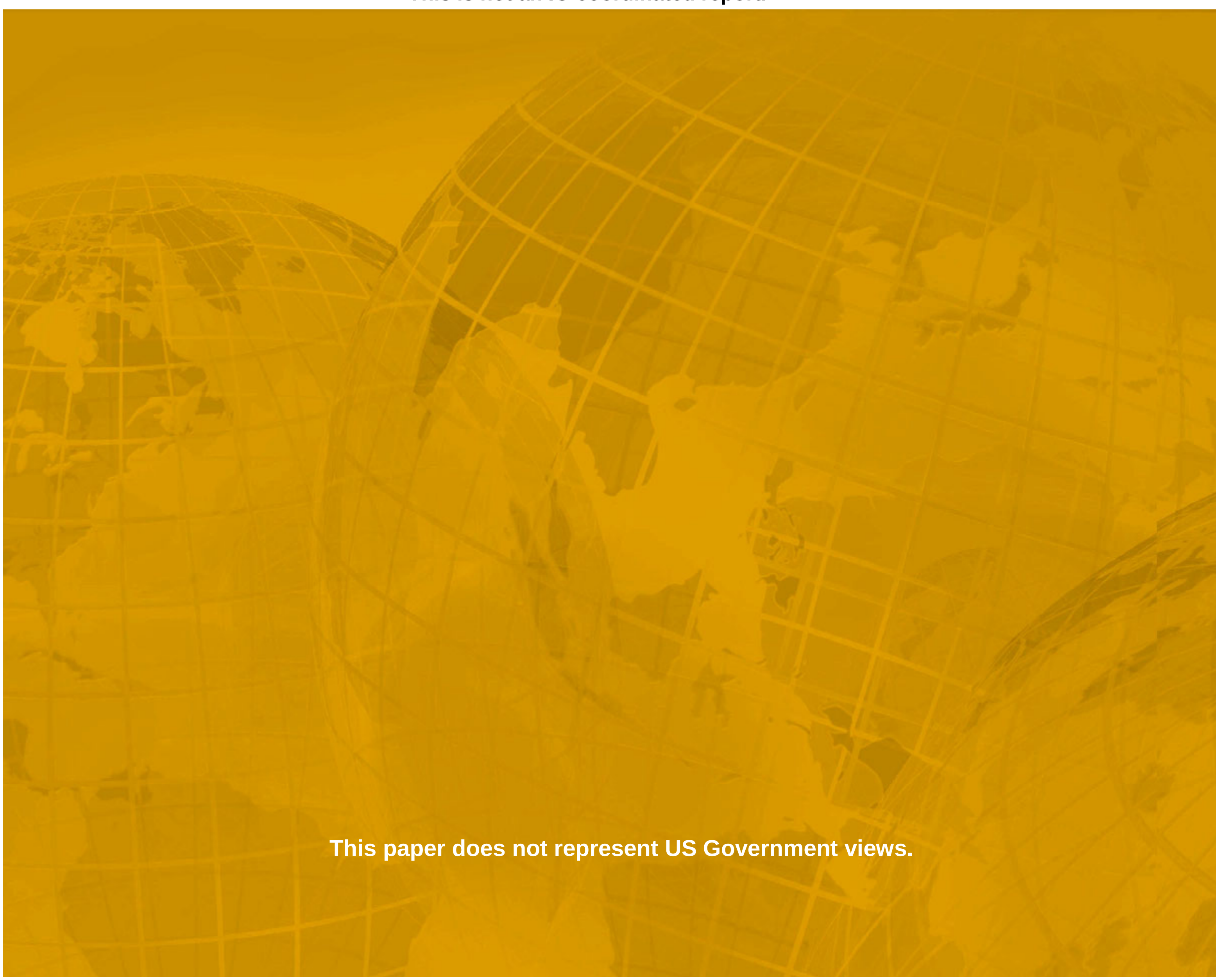
Natural Resources in 2020, 2030, and 2040: Implications for the United States

NATIONAL INTELLIGENCE COUNCIL REPORT

NICR 2013-05, 25 July 2013

This is not an IC-coordinated report.



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This report was prepared by Chatham House under the auspices of the Director, Strategic Futures Group. It was reviewed by the National Intelligence Council and other members of the Intelligence Community (IC), but was not formally coordinated.

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Scope Note

US National Security Impacts of Natural Resources in 2020, 2030, and 2040

This is not an IC-coordinated report.

The cut-off date for information used in the report was July 2012.

Based on the general contention that the world is entering an intensified period of resource stress, the National Intelligence Council (NIC) asked Chatham House in July 2011 to conduct research to identify the most important natural resource trends affecting US national security over a 2020, 2030, and 2040 time horizon. The requested analysis covers water, fuel, food, and metals (also referred to as materials). The identified trends—which include patterns of demand, supply, availability, price levels, and price volatility—are shaped and influenced by emerging climate changes, evolving demographic patterns, increasing economic development, and human induced environmental degradation. The result is this report which considers how local and global availability of natural resources will affect US security interests in the medium term (to 2020) and long term (specifically 2030 and 2040). The 2020 date was selected to identify the most pressing policy relevant issues; 2030 was selected to support development of the NIC's longer-range Global Trends series; and 2040 to support ongoing NIC projects exploring the national security impact of global food, water, and energy security.

The major assumption underpinning this analysis is that mounting prosperity in both the developed and the developing world will continue to drive increased consumer demand for key resources. At the same time, constraints in energy, water, and other critical natural resources and infrastructure, together with socio-economic shifts, will bring new and hard-to-manage instabilities. There will be an increasing risk of discontinuous and systemic shocks to 2040 as a consequence of these factors.

This report identifies potential natural resource stresses (in terms of aggregate availability, absolute prices, or rapid price changes) and analyzes their likely impact on the United States and states/regions of interest to the United States. The report also explores how these stresses will interact with one another and other pre-existing conditions, including poverty, social tensions, environmental degradation, ineffectual leadership, and weak political institutions. Summary tables (Annex A) provide an overview of key resource-related threats and their potential impact on the United States and other major economies. The risk assessments are based on a continuation of today's practices and trends; alternate policy choices, market actions, and technology developments will likely change future risk assessments.

Annex B provides fuller description of the tasking given to Chatham House and the results it produced.

Resource trends including future consumption, production, prices, and availability are subject to large uncertainties and for many types of resources detailed forecasts are not available (Annex C).

Threats to States of Interest to the United States					
Generic Threats	**States of Interest**	**Type of Threat**	**Trigger Event(s)—Timeframe**	**Underlying Pressures**	**Risk of Occurrence**
High and Volatile International Food Prices	Import-dependent countries with poor, urbanized populations: Mexico, Pakistan, Azerbaijan, Syria, Iraq, Egypt, Democratic Republic of the Congo, Philippines, North Korea Producing countries that may impose export restrictions in response to high prices: Argentina, Brazil, Russia, Ukraine, Thailand, Indonesia	Riots and political instability Regime collapse High inflation Further destabilization of global food markets Panic buying by consumer countries	Natural disasters or water shortages in producer countries (2020, 2030, 2040). Export restrictions by producer states (2020) Oil price spikes (2020, 2030)	Rise in consumption in emerging economies Water shortages Climate volatility Oil price volatility Population growth	High
High and Volatile International Energy Prices	Developing countries with high import-dependence: Eastern European countries, Caribbean Islands, Chile, India, Turkey	Riots and political instability Regime collapse Deteriorating public finances as subsidies expand High inflation and economic crises	Conflicts or social disruptions in energy producing regions (2030, 2040) Terrorist attacks on critical energy infrastructure (2020, 2030, 2040) Water shortages in producer countries (2020, 2030, 2040) Critical infrastructure damage from extreme weather events (2030, 2040)	Weak governance of resource producers Climate volatility Rise in consumption in emerging economies Water shortages	High

(Continued on page iv…)

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Resources in 2020, 2030, and 2040: Implications for the United States

Executive Summary

The Bottom Line: At the aggregate level, there are significant scarcity challenges for a number of key natural resources with potential impact on US security. Markets for agricultural commodities will remain tight through to 2020 and probably to 2030, with maize experiencing the largest increase in prices. Significant wheat production occurs in water-stressed and climate vulnerable regions in Asia (China, India, Pakistan, and Australia); markets therefore will remain susceptible to harvest shocks. Markets for oil likely will remain tight to 2020, and natural gas markets in certain regions may have constrained supplies. Commodity price shocks will afflict a wide range of consuming countries with weak governance regimes or high income inequality (Afghanistan, China, Egypt, India, Indonesia, Kenya, Pakistan, Somalia, and Ukraine).

The demand for resources is likely to continue to grow in the coming decades. **Energy demand is set to grow by 50 percent by 2030 according to the International Energy Agency. According to the United Nations Environment Program (UNEP), the amount of minerals, ores, fossil fuels, and biomass consumed globally per year could triple between today and 2050. Global growth in water demand for all uses is also set to increase by 50 percent over the same period compared with current consumption.**

Intensified resource stresses will bring new risks and uncertainties to international relations in an already turbulent world. Resource risks are coming atop socio-economic pressures created by rapid urbanization as well as shifting global economic power, adding another layer of uncertainty.

- Resource consumption patterns are driven by a range of factors: demographics and economic development are increasing demand, technology influences costs and the nature of both supply and demand, while environmental and social pressures increase the burden on both producer and consumer countries.
- No one knows whether today's domestic and transnational institutions, market systems, and multinational arrangements will be able to cope with these rising resource stresses.
- Distortive subsidies and a failure to price in other, indirect social costs increase complexity. A further layer of interconnection among resources emanates from their joint dependence on stable transportation infrastructure.

At the aggregate level, there are significant scarcity challenges for a number of key natural resources with potential impact on US security. Although these impacts may not directly affect the United States, they may adversely affect US economic partners, military allies, or regions important to US national

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(…continued) **Threats to States of Interest to the United States**					
Generic Threats	**States of Interest**	**Type of Threat**	**Trigger Event(s)—Timeframe**	**Underlying Pressures**	**Risk of Occurrence**
Disruptions of Physical Access to Critical Metals or Minerals	High-tech manufacturing sectors in import-dependent countries: Germany and other European manufacturers, Japan, South Korea, Taiwan	Disruption of supply chains and loss of income Diplomatic tensions with producer states Panic buying and creation of stockpiles exacerbating disruptions	Disruptions to Sea Lanes of Communications (SLOC) (2030, 2040) Export restrictions (2020) Natural disasters/ extreme weather (2030, 2040)	Climate volatility Weak governance of resource producers Tight supply conditions	Low
General Commodity Price Volatility	Developing countries that rely on commodity exports for a large share of GDP: Iraq, Democratic Republic of the Congo, Uganda, Algeria, Guinea	Spending increases when prices are high lead to fiscal pressure when prices fall Increasing reliance on foreign aid Political instability	Economic crises (2020, 2030, 2040) Political instability in major consuming countries (2020, 2030) Extreme weather events (2040)	Weak governance of resource producers Climate volatility	Medium
Water Shortages	Water-stressed regions and countries with high inequality and/or weak governance: Middle East, North Africa, Caucasus, and Central Asia; Mongolia, Pakistan, India, Afghanistan, South Sudan	Famines and increased migratory pressures that can result in country or regional destabilization Increasing dependence on foreign aid Increased diplomatic conflict over trans-boundary water resources	Droughts in the US (2020, 2030, 2040) Extreme weather events (2030, 2040) Groundwater contamination with shale gas extraction (2020)	Water shortages in specific states Unsustainable consumption	High

security. Price volatility will likely continue, with tight and rigid commodities markets for many commodities.

Food. **Markets for agricultural commodities will remain tight through to 2020 and probably to 2030.** By 2040, demand growth should slow, and new technologies and investments may have begun to deliver returns.

- **Among cereals, maize is likely to demonstrate the strongest international price rises, on the likely order of 20 percent by 2020, 80 percent by 2030, and 100 percent by 2050 (in real terms).** Rising demand for biofuels and animal feed exerts particular pressures on maize prices, and extreme weather will cause episodic deficits in production. From 2030, climate change will exert a significant drag on maize yields.

- Wheat is likely to exhibit growing demand and high price volatility through to 2040 as developing country consumers switch from rice. **Significant wheat production occurs in water-stressed and climate-vulnerable regions in Asia (China, India, Pakistan, and Australia); markets therefore will remain susceptible to harvest shocks.** A near-term supply disruption could result when stem rust arrives in South Asia, something that is quite likely to happen within the next few years. Wheat production is growing in Eastern Europe, but output is variable and governments have already demonstrated a readiness to impose export controls.

Energy. **Markets for oil likely will remain tight and volatile to 2020.** In the absence of ambitious policies on efficiency and deployment of new technology, or significant production from unconventional sources, severe shortages of oil between 2025 and 2030 would prompt emergency measures to reduce demand and to switch fuels in major importing countries. **In natural gas markets, a confluence of factors could constrain supplies to certain regions by 2020,** including lack of investment in global liquid natural gas (LNG) due to the expectation of North American shale gas development; failure of Russian Arctic gas projects and pipelines to materialize; rising domestic demand in the Middle East, and a failure of unconventional gas to compensate for the above because of investment and regulatory obstacles. **Although there are abundant coal resources, a combination of massive demand from planned Asian power plants and coal mine closures could cause intermittent scarcities through shipping and transportation bottlenecks.** This is likely to worsen as the effects of coal mining and coal-cleaning compete with increasing demand for water resources by 2030. By 2020, the prospect of cost-competitive renewable energy could become a destabilizing factor for fossil fuel-based investments in countries with sufficient renewable resources.

Prices for oil will likely remain above $100 average to 2020, with potential to go much higher as a result of a crisis or supply disruptions. The prolonged impact could send prices down by 2030 as consumers respond, and they could potentially fall further by 2040 as substitute technologies take hold.

Minerals. **Depending on how rapidly China's metal demand growth slows over the next ten years, metals markets may experience less tight market conditions compared to the past decade.** Prices may ease from their record levels, but are likely to remain at elevated levels due to upward shifts in producer cost curves. This medium-term easing is contingent on a number of large development projects coming into production over the next decade, despite significant technical, economic, and political challenges.

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- Especially for copper, the combination of declining average ore grade and reliance on new projects in countries such as Mongolia, the Democratic Republic of the Congo (DRC), and Afghanistan could keep markets under pressure. Continued high prices and volatility may also encourage lasting substitution, especially between copper and cheaper aluminum.

- Although light rare earths[1] are likely to continue to be in surplus over most of the next decade, heavy rare earth supplies will remain tight until at least the middle of the current decade, relaxing only after a second generation of non-Chinese rare-earths producers emerges.

- Beyond 2020, pressures on metal markets will be determined mainly by the growth of other emerging economies and the ability of industry to keep replacing depleting mines and responding to growing demand. Given the large investments needed either way, high prices are likely to persist for a considerable time to come.

Commodity price shocks will afflict a wide range of consuming countries with weak governance regimes or high income inequality (India, China, Pakistan, Afghanistan, Indonesia, Ukraine, and countries in sub-Saharan Africa including Kenya and Somalia). In developing countries where the energy price is set by the market, a further substantial increase in oil prices could quickly lead to social disruptions (demonstrations and riots). Countries with artificially low consumer prices will face longer-term structural problems that eventually will prove unsustainable.

[1] Rare earth minerals are a set of seventeen chemical elements in the periodic table, specifically the fifteen lanthanides plus scandium and yttrium. See Annex D for full description of light and heavy rare earth elements.

Contents

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Discussion

Introduction

Access to and control of natural resources has long underpinned the growth of human societies, determining not only the locations of civilizations but also the shape of economies and political institutions. Many have also argued that the struggle for the control of resources has been a major driver of conflicts across the ages. **Today, intensified resource stresses are anticipated to bring new risks and uncertainties to international relations in an already turbulent world. Resource risks are coming atop of socio-economic pressures created by rapid urbanization as well as shifting global economic power, adding another layer of uncertainty.**

Resource consumption patterns are driven by a range of factors: demographics and economic development are increasing demand, technology influences the costs and nature of both supply and demand, while environmental and social pressures add to the burden on both producer and consumer countries. **No one knows whether today's domestic and transnational institutions, market systems and multinational arrangements will be able to cope with these rising resource stresses.**

Resource pressures interact in a complex but often self-reinforcing manner. There are common factors of production—energy, water, and land in particular—which affect many other resource categories. A rise in energy prices, for example, influences food prices via fertilizer and distribution costs, and substitution via biofuels. The macro-economic consequence is either inflation—greatest in poorer countries where food is a larger component of overall spending—or a hit on government budgets where subsidies shield the consumer from food price rises. In other cases the resources are in competition. Land that could be used for food production may be given over to urbanization and biofuels, while power generation, agriculture, industry, and an emerging middle class put pressure on limited water resources. **Distortive subsidies and a failure to price in other indirect social costs, increase complexity. A further layer of interconnection among resources emanates from their joint dependence on stable transportation infrastructure as well as the trading and political relations required to maintain them.**

Key Drivers and Trends

The general contention is that today the world is entering an intensified period of resource stresses due to a number of factors. Globally, more resources will be needed by 2040 unless there is a radical deviation from the business-as-usual trajectory. The Table on page 2 summarizes mainstream projections for the supply and demand of key resources by 2020, 2030, and 2040.

Projections for Availability of Key Resources in 2020, 2030, and 2040			
	By 2020	**By 2030**	**By 2040**
Food	• Average prices to increase by 15-20 percent against long-rate average but lower than 2008, 2011, and 2012 spikes • Global production growth 1.3-1.5 percent per year until 2030 • Stocks to use ratios remain at crisis thresholds	• Crop demand reaches 2.7 billion tons, from 1.9 in the 1990s • Meat demand growth between 2001 and 2030 estimated at 1.7 percent per year. • Price increases of 70-90 percent compared to 2010 up to 130-170 percent if climate change	• Beyond 2030 demand growth for most crops and meat is projected to slow considerably
Energy	• Demand for energy increases by 18 percent (from 2008) by 2020 • To meet oil supply in 2020 over $3 trillion of investment in the oil sector is needed • Prices for oil range between $90-110	• Demand for energy grows by 50 percent by 2035 • By 2035 a total of over $8 trillion of investments in the oil sector is needed • Prices for oil are at $90-140 in real terms for 2035	• Demand growth slows in China and India beyond 2030, slowing down global demand growth
Metals	• Demand for major metals grows between 30-50 percent, rare earth demand doubles from 2010 levels • Copper will face a 30 percent supply gap in absence of considerable additional investment • Heavy rare earths will remain in deficit until 2020	• Compared to 2010 levels, demand for steel grows by 90 percent, copper by 80 percent. Aluminum, nickel, and zinc demand more than double • By 2030 the copper supply gap may widen to 50 percent of projected demand • Recurrent supply bottlenecks for specialty metals as new technologies are widely deployed	• Demand growth for steel slows as the current infrastructure and construction boom in large emerging economies slowly subsides

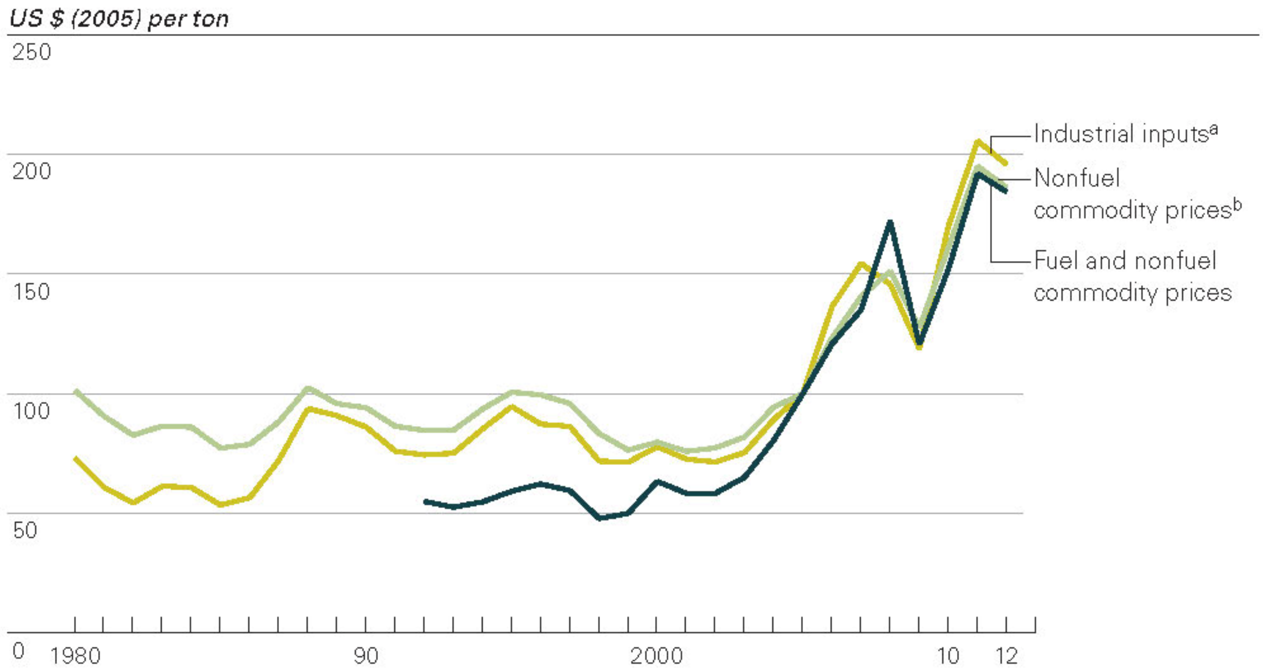
Sources: Data from Food and Agriculture Organization (FAO), International Energy Agency (IEA), and industry sources; compiled by Chatham House

The demand for resources is likely to continue to grow in the coming decades. **Energy demand is set to grow by 50 percent by 2030 according to the International Energy Agency. According to the United Nations Environment Program (UNEP), the amount of minerals, ores, fossil fuels, and biomass consumed globally per year could triple between today and 2050. Global growth in water demand is also set to increase by 50 percent over the same period compared with current consumption.** Consequently, most analysts are not projecting a collapse in prices in the short to medium term. **McKinsey**

and Company argues that barring a major macroeconomic shock, prices are likely to remain high and volatile for at least the next 20 years.

The markets for energy, food, water, metals, and other resources have remained tight and rigid in the past decade. This is reflected in the rise in resource prices since around the year 2000. IMF data shown in the figure below shows a broad correlation in price increases across food, fuels, and metals when presented as an annual average. According to McKinsey, the correlation between resource prices is higher than it has been for at least a hundred years.

Commodity Price Indices 1980-2012: Fuels, Food, Raw Materials and Metals



[a] Agricultural raw materials and metals.
[b] Includes industrial inputs and food and beverages.
Source: IMF commodity price database.
http://www.imf.org/external/np/res/commod/External_Data.csv

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Overall Drivers for 2020, 2030, 2040

Projections of global supply and demand in resources are underpinned by assumptions about population and economic growth, which have historically had a close relationship with resource growth. Although short-term trends are unlikely to change the 2020 picture dramatically, this is a major source of uncertainty between 2020 and 2040: latest UN population projections range from 8.1 to 9.7 billion in 2040, up from 7 billion today. In the low scenario the population will have plateaued by this time, and declines in later decades, relieving pressure on resources. But in the high scenario the population will continue to climb to over 15 billion by the end of the century.

In real terms global GDP is expected to double between 2010 and 2030, according to the IMF. Projections of GDP per capita in different countries vary widely for 2030, 2040, and 2050—and there may be profound discontinuities in current growth pathways. However, there is wide agreement on a general trend towards a 'great convergence' of per capita incomes after a 'great divergence' of per capita incomes over the past two centuries. China is currently driving this trend, but India and other developing countries are expected to follow.

Driven by population and GDP growth, at the global level, significant rates of growth are expected across the critical commodities such as fossil fuels, steel, food, and water out to 2040. This demonstrates that although technological improvements, changing economic structures and other factors have reduced the material intensity of the economy, an absolute decoupling is some way off.

Intensive industrialization, and especially associated infrastructure and urbanization, often results in a rapid increase in resource consumption. Energy-intensity and steel consumption, for example, grew rapidly in China post 2002 after a long period of decline. Energy intensity has been climbing at 1 percent per year in Saudi Arabia over the past decade.

Growing wealth also brings changes in consumer behavior. Between 1960 and 2004, individuals in the middle and upper classes increased resource consumption by more than 200 percent. Shifting diet patterns, for example, are key contributors to the growing demand for key commodities and resources. Average per capita consumption of meat in high-income economies increased from 55.9 kg per annum in 1990 to 93.5 kg in 2002. Over the same period, China's annual meat consumption per capita went from 3.8 to 52.4 kg and Brazil's from 27.8 to 82.4 kg. Whereas producing a kilogram of potatoes requires just 500 litres of water, producing a kilogram of beef requires 15,000 litres.

Increasing globalization of supply chains—combined with higher incomes and population growth in particular in the major developing countries—has seen both processing and consumption shift increasingly to developing countries. A study by Deloitte and the US Council on Competitiveness points to a "new world order for manufacturing competitiveness" in less than a decade. Its Global Manufacturing Competitiveness Index highlights the rise in the manufacturing competitiveness of three countries in particular—China, India, and the Republic of Korea (Korea). **The continued growth of manufacturing and consumption hubs around the world, in particular in the BRIC (Brazil, Russia, India, and China) countries, is likely to lead to a consolidation and expansion of regional production networks. With this diffusion of demand and production centers, the market power of the Organization for Economic Co-operation and Development (OECD) countries' consumers will be diminished.**

The challenge of meeting the demand for resources increases hugely when environmental constraints are taken into account. Water and land are already scarce in many parts of the world, and are coming under pressure from competing uses, as urbanization and industrial development continues. Climate change is expected to change the seasonality but also the amount of precipitation, while extreme events such as heat waves and storms are set to be increasingly common by 2040, according to the Intergovernmental Panel on Climate Change (IPCC).

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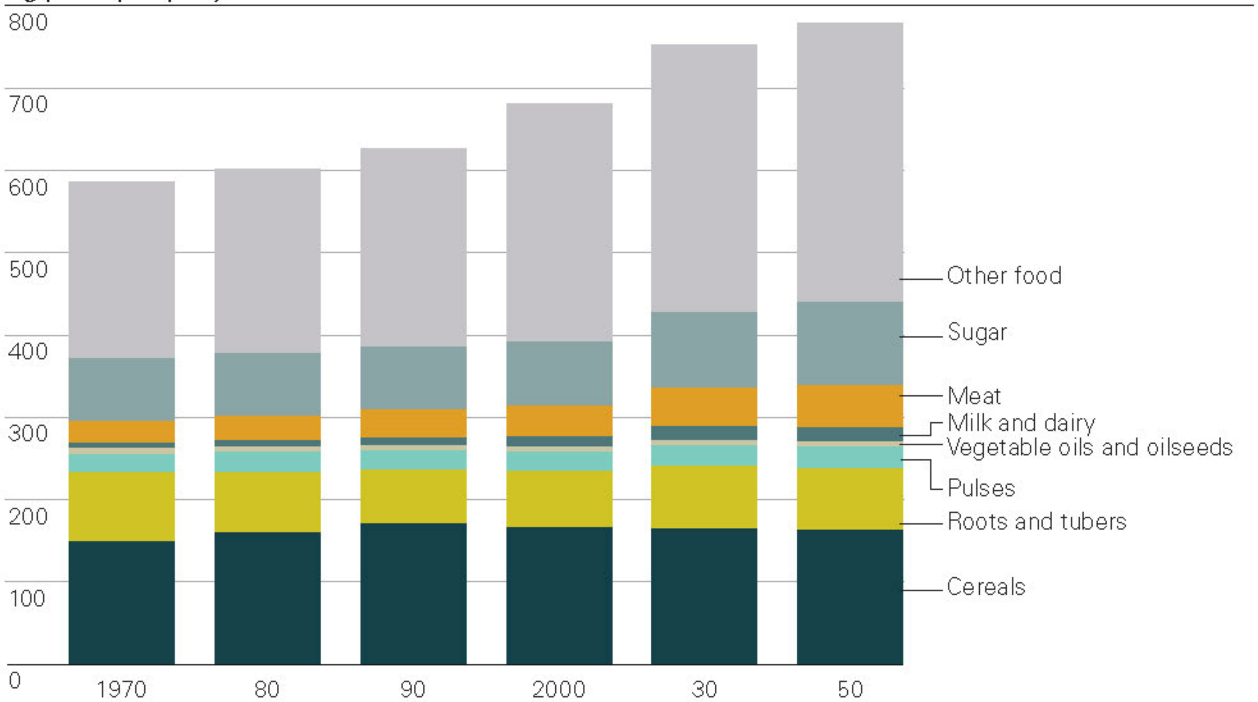
Food

Demand for food is set to rise. For staple crops, it will grow by 1—1.5 percent per year to 2040. Between now and 2020, demand for cereals will increase by around 15 percent and for oilseeds and sugar by 25 percent, according to the latest United Nations Food and Agriculture Organization (FAO) projections. By 2030, crop demand is expected to reach 2.7 billion tons—compared to an average of 1.9 billion tons in the 1990s.

Projected Per Capita Global Food Demand to 2050

Kg per capita per year



Source: Organization of the United Nations.

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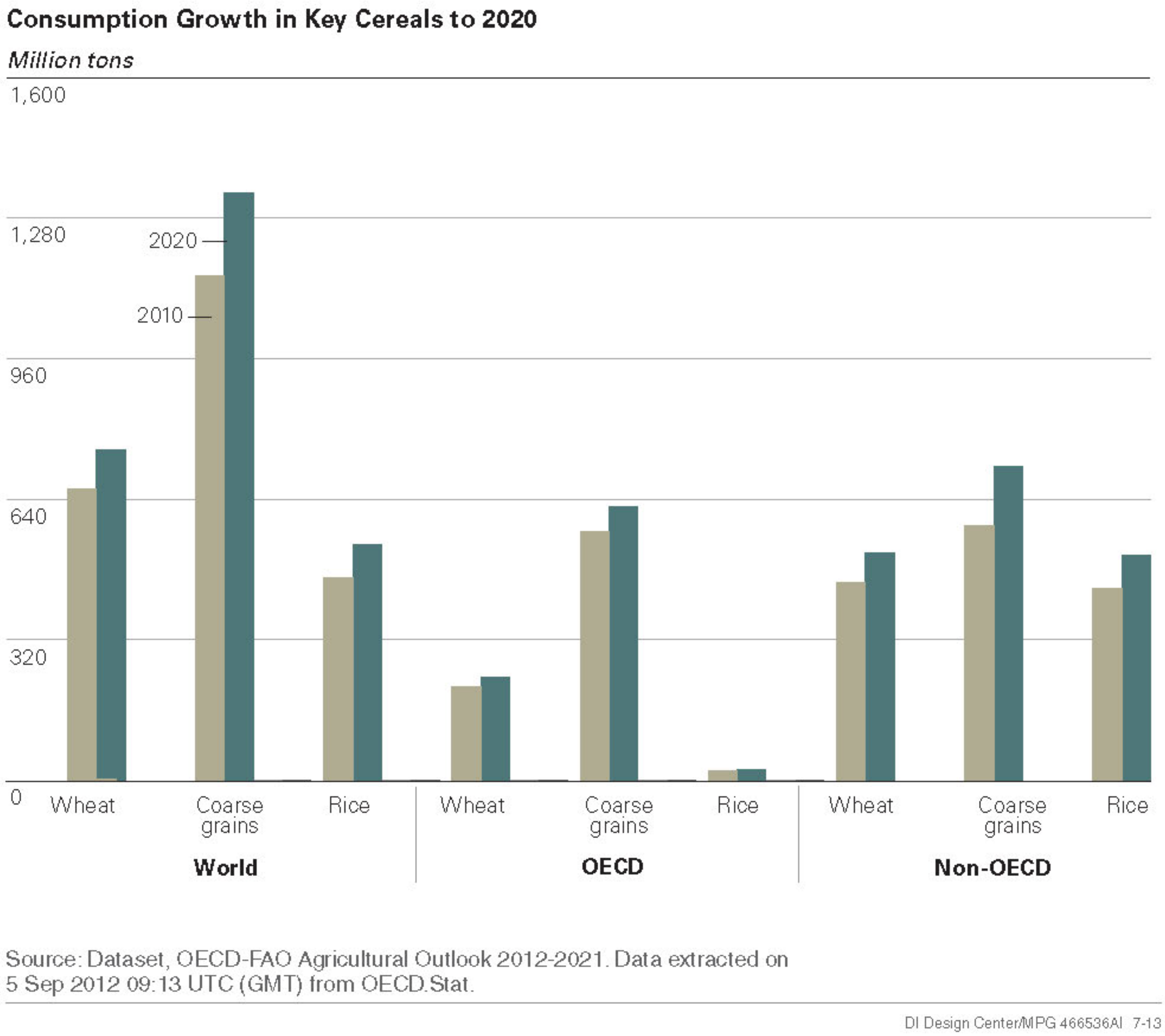

Based on growth rates over the last decade, in percentage terms the current major consumers of wheat and maize will change little over the next 10 years. For soybeans and palm oil, however, China's share of global consumption could double. Generally speaking, demand growth is concentrated in commodities associated with rising incomes and non-food uses.

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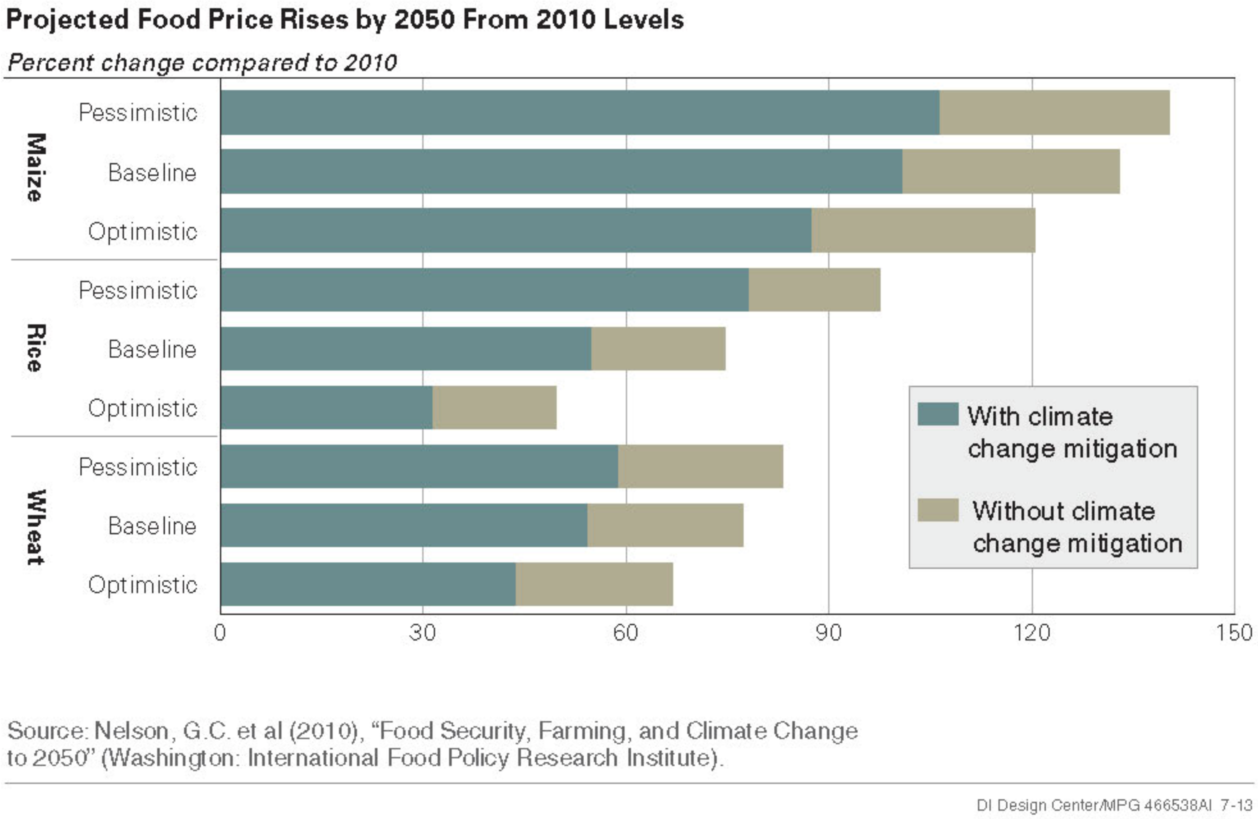
Food Commodity Growth Rates 2001-2030 and 2031-2050		
	Growth Rate 2001-2030	**Growth Rate 2031-2050**
Oilseeds	2.2 percent	1.6 percent
Meat	1.7 percent	1.0 percent
Coarse Grains	1.4 percent	0.8 percent
Wheat	1.1 percent	0.5 percent
Rice	0.9 percent	0.2 percent

Demand for processed foods as well as animal feed and biofuel uses explain the rapid forecast growth for oilseeds. Coarse grain is the fastest growing cereal class again because of use for animal feed and biofuels. Rice is expected to exhibit the least demand growth due to dietary shift with rising incomes, which tends to see consumption shift to wheat and other food sources.

Agricultural forecasts assume that agricultural markets clear, i.e., that international market prices ensure that supply and demand balance. As demand growth is expected to be stronger than production growth, which will be constrained by the availability of land and water and declining yield growth for cereals, prices will rise to curtail demand.

Food prices are expected to increase significantly due to rising demand and climate change. Using the IMPACT partial equilibrium model, the International Food Policy Research Institute (IFPRI) forecasts of cereal prices suggest that the price of maize may double by 2050 in real terms, once the impact of climate change has been taken into account. Price rises for wheat and rice were in the region of 60 percent under baseline assumptions (see figure on page 8). Similar work by the Institute of Development Studies (IDS) using the GLOBE general equilibrium model forecast price rises for cereals in the region of 70 percent to 90 percent by 2030 before climate change, the impact of which was to push price rises into the range of 130 percent to 170 percent (see figure on page 8). The IDS modeling generated higher price rises because it took as its baseline a modeled equilibrium price, rather than actual prices, which were well above equilibrium levels. Climate change has the most pronounced effect on maize, due to the vulnerability of maize yields to temperature rise.

Out to 2020, average prices of agricultural commodities are expected to decline from recent peaks, but remain well above the previous decadal average. This is captured in the most recent OECD-FAO Agricultural Outlook, which predicts nominal price rises for maize and rice in the region of 40 percent by 2020 against long-run averages, but shows nominal prices flat (maize) or declining (rice) against average prices over the period 2008-10 (see figure on page 9).


Projected Food Price Rises by 2050 From 2010 Levels
Percent change compared to 2010
Maize
Rice
Wheat
Pessimistic
Baseline
Optimistic
With climate change mitigation
Without climate change mitigation
0
30
60
90
120
150
Source: Nelson, G.C. et al (2010), "Food Security, Farming, and Climate Change to 2050" (Washington: International Food Policy Research Institute).
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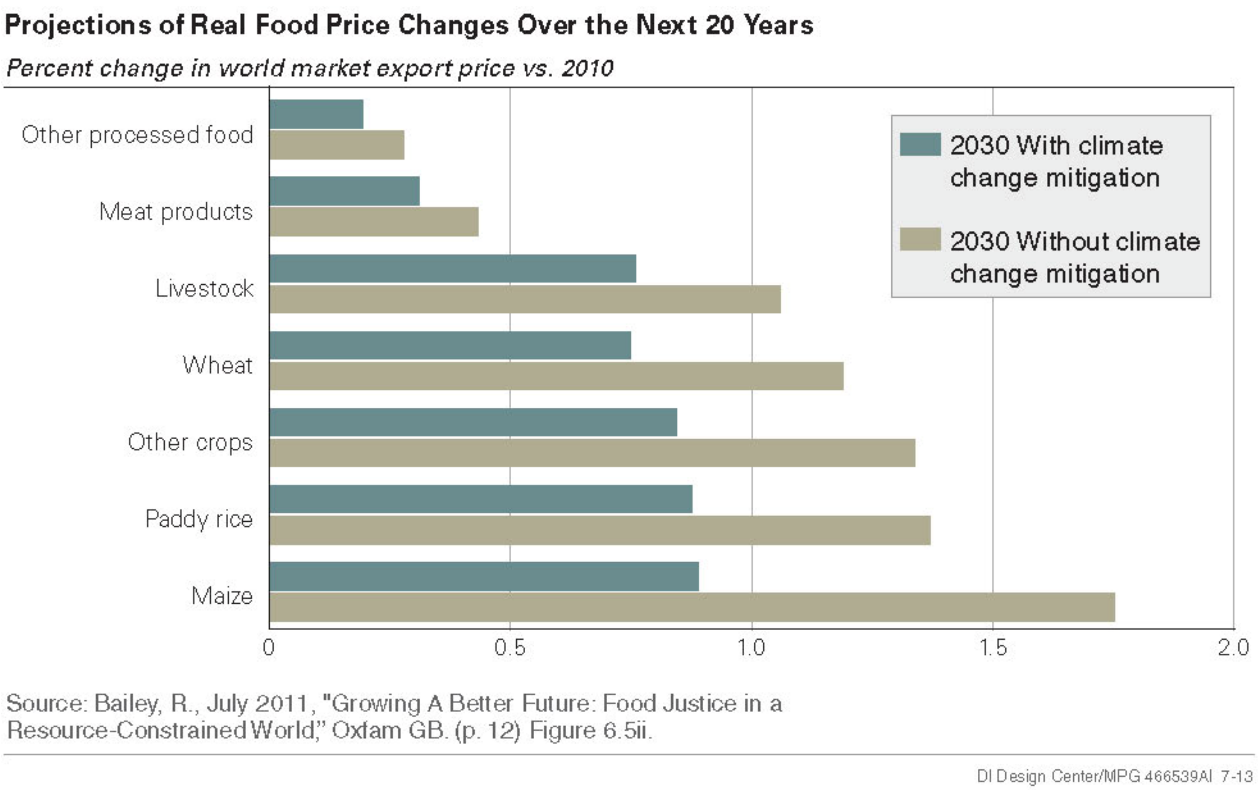
Projections of Real Food Price Changes Over the Next 20 Years
Percent change in world market export price vs. 2010
Other processed food
Meat products
Livestock
Wheat
Other crops
Paddy rice
Maize
2030 With climate change mitigation
2030 Without climate change mitigation
0
0.5
1.0
1.5
2.0
Source: Bailey, R., July 2011, "Growing A Better Future: Food Justice in a Resource-Constrained World," Oxfam GB. (p. 12) Figure 6.5ii.
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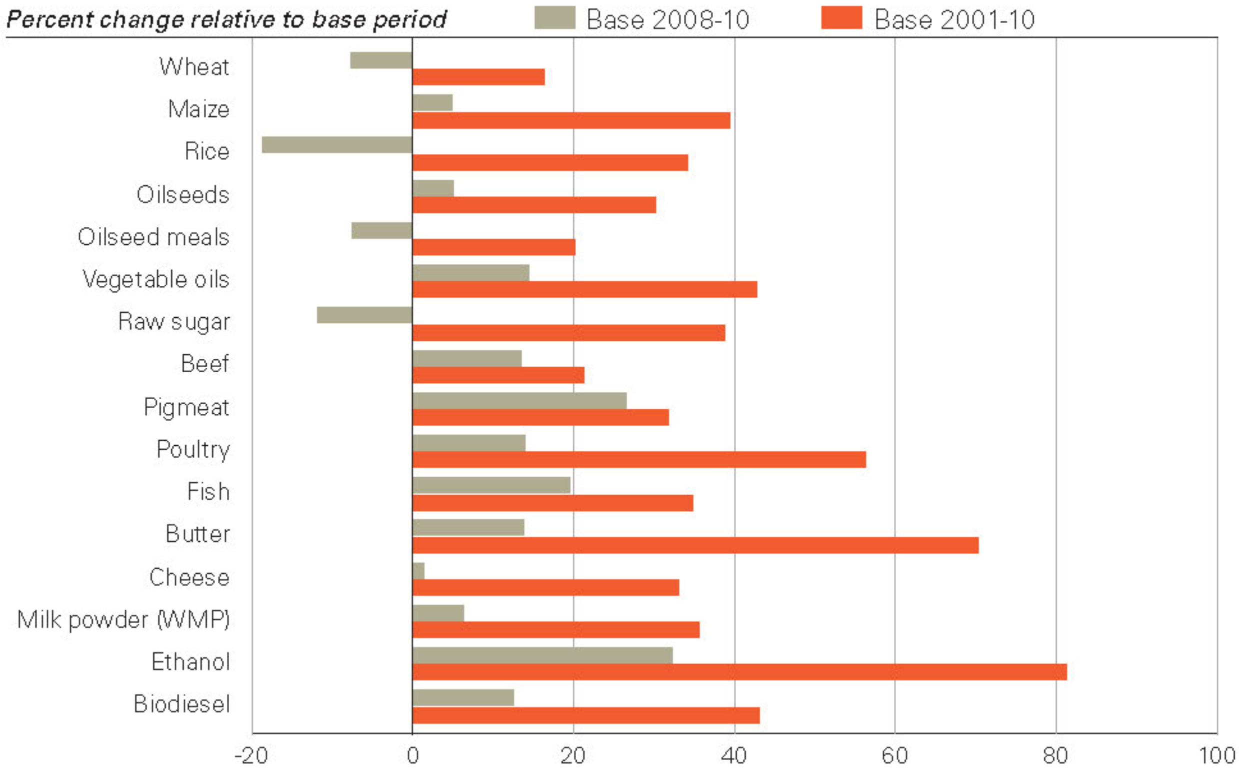
Projections of Average Nominal Prices in 2011-20 Against Different Baselines



Source: Organisation for Economic Co-operation and Development and Food and Agriculture Organisation (2011), 'OECD-FAO Agricultural Outlook 2011-2020'.

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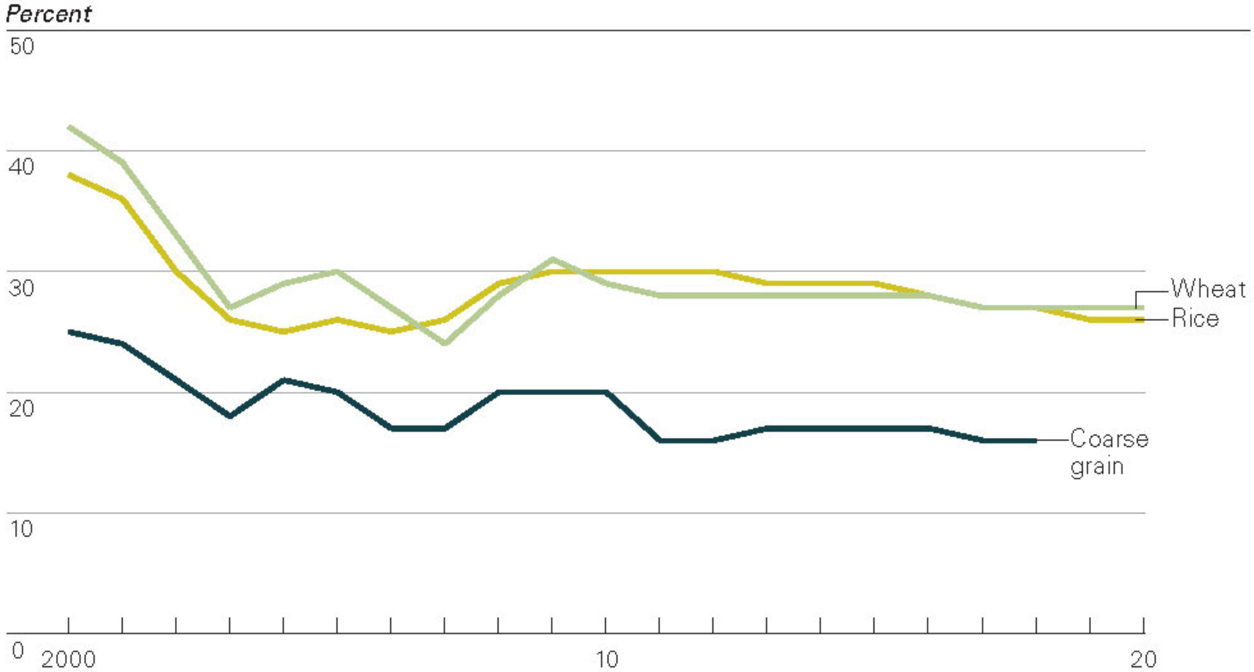
Price volatility is expected to persist. Cereal production is likely to remain constrained by land availability and declining yield growth, while demand growth will be strong. As well as exerting upward pressure on prices, this also means that stocks will struggle to recover, and stock-to-use ratios[2] will remain at crisis thresholds through to 2020 (see figure page 10). Other factors likely to exacerbate volatility are biofuel policies—which generate inelastic demand and render agricultural commodities substitutable with petroleum products—and, in the medium to longer term, climate change. Export controls helped magnify price spikes in 2008 and 2011, but no rules-based system exists at the international level for dealing with this issue.

[2] The stocks-to-use ratio is a convenient measure of supply and demand interrelationships of commodities. The stocks-to-use ratio indicates the level of carryover stock for any given commodity as a percentage of the total demand or use.

Global Stock-to-Use Ratios for Wheat, Grains, and Rice Will Remain at Dangerous Levels



Source: Organisation for Economic Co-operation and Development and Food and Agriculture Organisation (2011), 'OECD-FAO Agricultural Outlook 2011-2020'.

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Commodities most prone to volatility include maize and wheat. Continued reliance on maize as a biofuel feedstock into the near and medium-term will increase volatility due to inelastic demand and price transmission from oil markets. Maize is a staple crop in a number of Latin American countries. This volatility will also affect feed prices and so therefore meat prices. However, consumer price rises for meat are likely to be dampened as the livestock industry absorbs some of the higher feed prices, and meat consumers are likely to be richer and so less vulnerable to price hikes than consumers of staple crops. Due to substitution among cereals in production and consumption, price volatility will also transmit to other crops. In particular, volatility may transfer to white maize, the staple of Mexico, through the intermediating effect of feed markets if livestock producers switch from yellow maize to white maize in response to price rises for the former. Such an effect may have contributed to the 2007 'Tortilla Crisis' in Mexico.

Wheat is likely to exhibit high price volatility through to 2040. As for maize, stock-to-use ratios are low and will struggle to recover. Productivity growth has been slowing rapidly and technology has so far been unable to reverse this trend. Volatility is likely to transmit from maize to wheat as wheat is substituted for maize in animal feed. Meanwhile, demand growth for wheat is expected to outstrip production growth due to population growth and rising incomes that typically see consumers switch to wheat from rice. Significant production occurs in water-stressed and climate vulnerable regions (China, India, Pakistan, and Australia) susceptible to harvest shocks. A further potential supply disruption could result when Ug99 stem rust disease arrives in South Asia, something that is likely to happen within the next few years. Production is growing in Eastern Europe, but output is variable and governments have already demonstrated a readiness to impose export controls.

As a result, short-term, localized scarcities will affect wheat, due to weather-related or disease-related shocks in key producer regions. India and Pakistan are vulnerable to domestic production shocks, while the countries of the Middle East and North Africa are particularly vulnerable to price-related shocks. Import dependent countries are increasingly vulnerable to food price spikes or supply disruptions. In some cases this may lead to political instability which may have implications for US interests. For example, analysts have linked high wheat prices in 2011 with social unrest in North Africa and subsequently the Middle East.

Though rice exhibited the most extreme volatility during the 2008 price spike, this has largely been attributed to the collapse in confidence around a very thinly traded commodity, and the subsequent imposition of export controls. ASEAN efforts to increase transparency on stocks and avoid unilateral export measures will be crucial to avoiding this happening in the future.

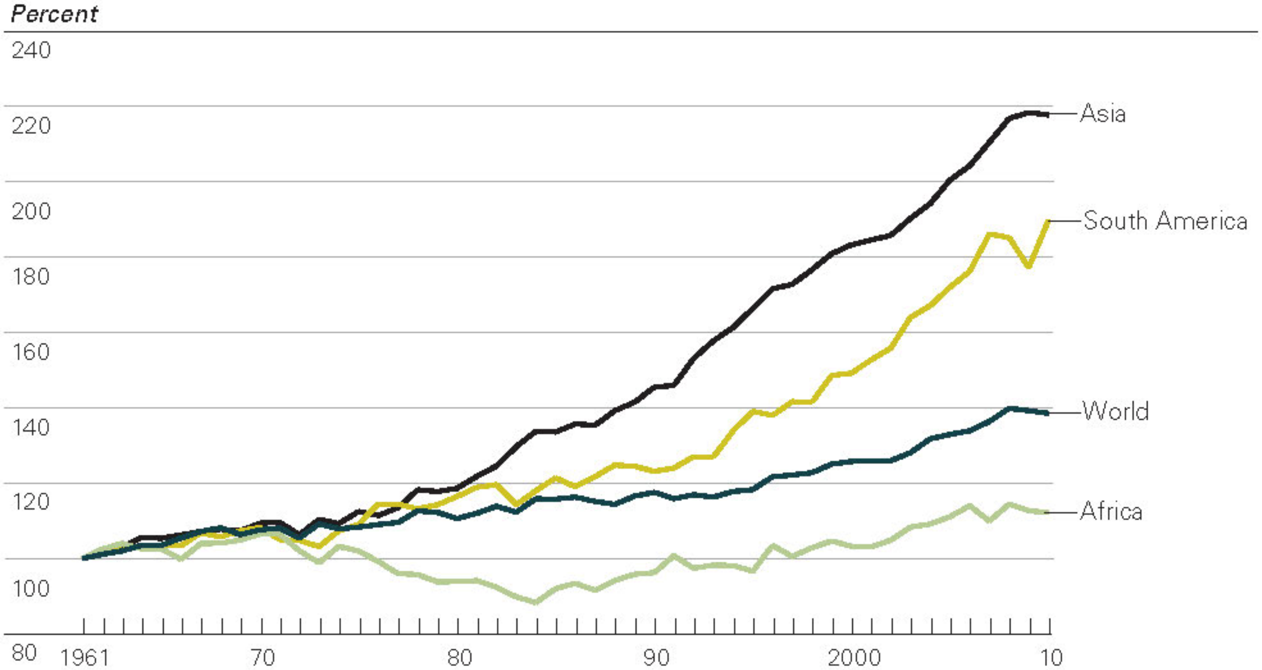
Agricultural production must increase rapidly in developing countries. By 2050, FAO predicts that global demand for food will have increased by 70 percent. Some analysts argue that properly addressing global hunger will require a production increase closer to 100 percent. Given existing constraints on land, meeting future demand at acceptable price levels will depend on increasing agricultural production in developing countries. FAO projects relatively consistent global rate of growth in production—at about 1.3-1.5 percent per year—out to 2030. However, developing countries are expected to grow at much faster rates—2.5 percent in sub-Saharan Africa, for example—while the major developed country producers (shown as industrial countries in table below) are in a slow decline.

Projection of Crop Production Growth by Region and Development Category

Annual Crop Production Growth (percent)	1969-99	1979-99	1989-99	1997/99 -2015	2015-30	1997/99 -2030
All developing countries	3.1	3.1	3.2	1.7	1.4	1.6
excl. China	2.7	2.7	2.5	2.0	1.6	1.8
excl. China and India	2.7	2.6	2.5	2.0	1.7	1.9
Sub-Saharan Africa	2.3	3.3	3.3	2.6	2.5	2.5
Near East/North Africa	2.9	2.9	2.6	1.8	1.5	1.6
Latin America and the Caribbean	2.6	2.3	2.6	1.8	1.6	1.7
South Asia	2.8	3.0	2.4	2.1	1.5	1.8
East Asia	3.6	3.5	3.7	1.3	1.1	1.2
Industrial countries	1.4	1.1	1.6	0.9	0.9	0.9
Transition countries	-0.6	-1.6	-3.7	0.7	0.7	0.7
World	2.1	2.0	2.1	1.5	1.3	1.4

Source: FAO (2002)

Changes in Per Capita Agricultural Production, 1961-2010



Source: Royal Society 2009, recreated with data from FAOSTAT Production Indices. http://faostat.fao.org/site/612/default.aspx#ancor

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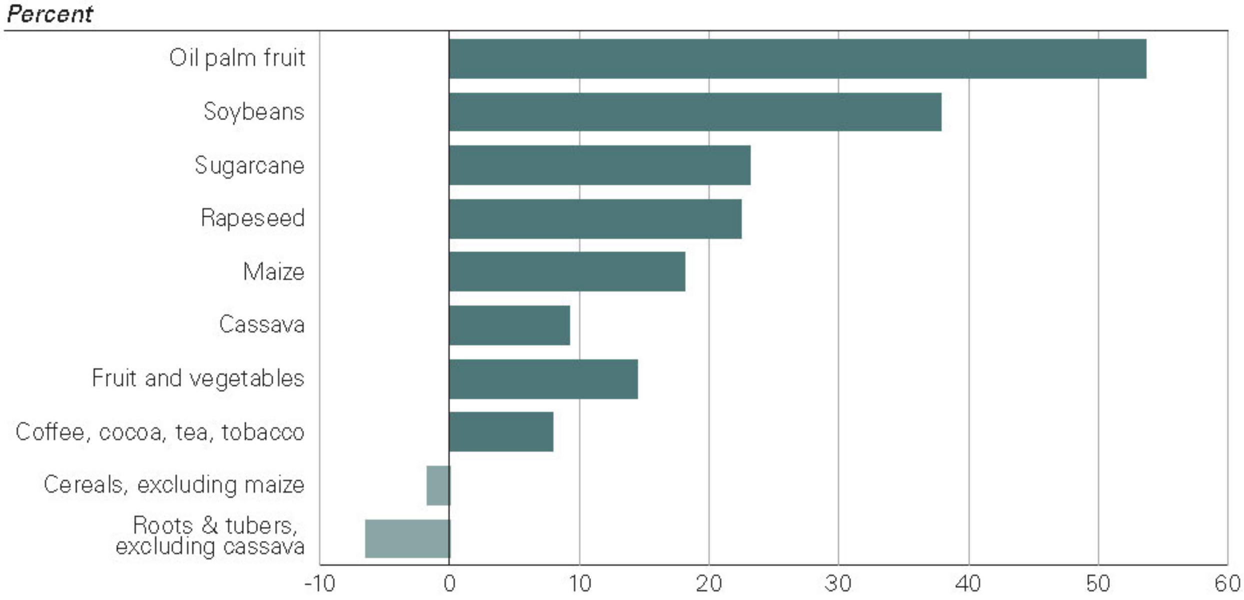
To meet the growing demand would require a significant increase in agricultural performance in Africa. Over the last half a century, Asia (200 percent) and South America (150 percent) have significantly improved production per capita, while Africa has only recently returned to 1970s levels. Though increasing agricultural productivity in Africa presents a significant opportunity to boost and diversify global production, as well as address regional poverty and food security, it also brings significant challenges and risks. Many African countries have poor enabling environments for agricultural development: rural infrastructure is lacking and governance and institutions may be weak. Without rapid investment in adaptation, climate change is also expected to result in sharp declines in African yields.

Closing the yield gap in Africa presents significant challenges and will take time and money. One estimate places the investment shortfall in developing country agriculture at $90 billion a year. US policy and investment will be key in determining to what extent Africa is able to make significant improvement in productivity required. Key policy levers include trade and investment agreements, the Feed the Future program and related aid spending, and agricultural R&D policy and spending.

In the short term, the production gap provides a significant opportunity for countries with lower intensity production than developed countries or potential reserves of arable land, such as those in Latin American and Eastern Europe.

Growth in Global Area Harvested for Selected Crops, 2000-10



Source: FAOSTAT, data accessed 9 September 2012.

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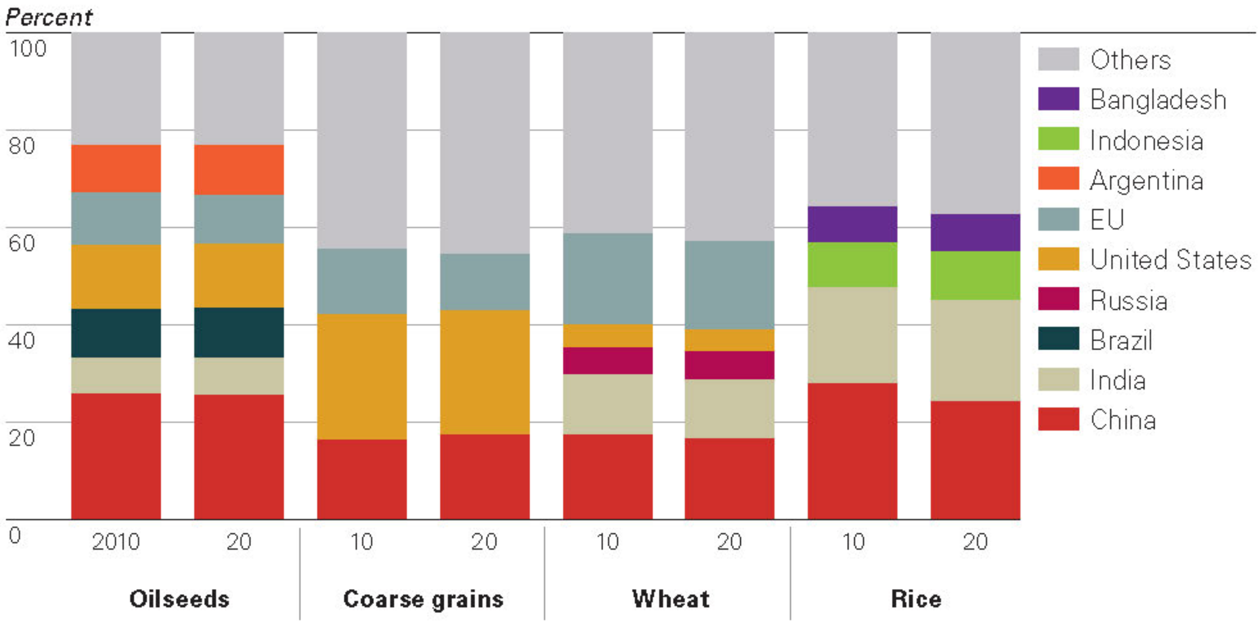
Share in Global Consumption for Key Staples, 2010 and 2020



Source: OECD-FAO Agricultural Outlook 2012-2021.

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At the global level, acreage of basic staple food crops such as cereals (including rice, wheat, barley, and sorghum) and roots and tubers (potatoes, cassava, yam) has been declining, while the area used to produce oilseeds (palm oil, soybeans, and rapeseed) and maize and sugar—which are increasingly used as animal feeds or biofuel feedstock—is expanding. This displacement is particularly affecting acreage in South and North America, Europe, and parts of Southeast Asia. There are currently two principal food export regions: North and South America. Australia and Southeast Asia are the only other net-exporting regions; the rest of the world is net-importing. Production of key agricultural commodities is concentrated in a handful of key countries: the United States, Brazil, China in soybeans and maize; Malaysia and Indonesia for palm oil; and France, India, Russia, the United States and China in wheat. Based on recent trends, the dominance of these players will continue until 2020. The text box below describes how global markets have reconfigured around China's demand for soybeans.

The Potential Impact of Changes in China's Self-Sufficiency Policy for Other Agricultural Commodities—The Case of Soybeans

A change in the grain self-sufficiency strategies of China and India would have major consequences for international food security. Both countries' cereal production faces significant challenges from environmental stresses relating to water scarcity, soil depletion and climate change, together with pressures on land availability from urbanization and industrialization. Both are major producers of wheat, and China is the second biggest producer and consumer of corn after the United States.

Through to 2020, neither China nor India is likely to abandon these totemic policies. Yet by 2030, both countries may be forced to liberalize their policies and increase imports due to demographic vectors and hard environmental constraints. The pace and scope of these transitions will determine the impacts on international cereal prices. A rapid shift in China's net-trade position for maize (or a decline in stock-to-use ratio), for example, coupled to US ethanol policy, could trigger a significant price run-up.

China does not pursue self-sufficiency in soybeans, and there has been rapid growth in imports to meet growing demand for feed and to build a strategic reserve. The implications for global soybean production and trade have been profound. Soybean markets have completely reconfigured around Chinese growth between 1990 and 2009 and the trend is set to continue to at least 2020.

Although the EU and East Asian countries such as Japan were the most important customers for soybeans in the 1990s they play a negligible role compared to China today.

Brazil has emerged as the most important exporter of soybeans and its leading role in global soybean trade will further grow towards 2020. Argentina too has grown rapidly, but rapidly rising domestic consumption is likely to increasingly constrain further export growth.

Although it is an extreme example, the soybean case shows how uneven consumption and production growth across the world is reshaping global trade patterns for key natural resources. In particular, it underlines the importance of China's net trade position for global patterns of production and trade. Because of its strong policy support for maize ethanol, the US has been unable to fully respond to Chinese demand for soybeans. In effect, the US ethanol program, which was designed to reduce the energy leverage of Middle Eastern states over the US, has ceded US agricultural leverage over China to Latin America.

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Food: Key Uncertainties to 2020, 2030, and 2040			
Timeframe	**2011-2019**	**2020-2029**	**2030-2040**
Demand	*Policy* • Rate of expansion of biofuel production. Will oil prices drive consumption beyond mandated levels? • Evolution of Chinese stock policy. *Consumer Trends* • Stabilization level of Chinese per capita meat consumption. • Extent of shift from rice to wheat and other cereals in developing countries.	*Policy* • Action to address food wastage. • Sustainability of Chinese and Indian self-sufficiency in grains. *Technology* • Second generation biofuels reducing demand for food feedstocks. *Consumer Trends* • Changes in developed country diets due to health and sustainability concerns. *Economic Development* • Growth in the next generation of emerging economies.	*Economic Development* • Development trajectory of current developing countries especially in terms of demographics, diet, and incomes.
Supply	*Policy/Investment* • Impact of investment rush into developing country agriculture (especially Sub-Saharan Africa and Asia): to close the yield gap or crowd-out productive investment. • The extent to which investments will begin to address post-harvest losses in developing countries. *Technology* • Potential of next-generation GMOs in delivering significant yield improvements. *Environmental* • Impact of increasing importance of less predictable Eastern European exporters on global supply. *Biological* • Supply disruptions due to pests/diseases (crop or livestock).	*Policy/Investment* • Extent of OECD farm support reform affecting production. • Impact of global climate mechanisms for REDD/REDD+ and agriculture on production and price. • Ability of regulatory changes to speed-up the delivery of pipeline technologies to market. *Technology* • Ability for next generation biofuels to decouple food production from oil and gas. *Environmental* • Level of environmental degradation and resource depletion. • Water shortages.	*Technology* • Disruptive technologies (for example lab-grown meat) ease supply constraints. *Environmental* • Total availability of land. • Impacts of climate change on food production.

This paper does not represent US Government views.

Fuels and Other Energy Sources

Consumption of energy commodities is also set to grow, albeit at an uneven pace across the world. The energy sector is facing a generational challenge; supply needs to simultaneously expand rapidly and decarbonize. Even the normally conservative IEA noted in 2010 that a business as usual (BAU) path would have 'alarming consequences' for energy and climate security. Shell's 'scramble' scenario describes what such a world would look like: a flight into coal and heavier hydrocarbons, followed by a supply crisis; reactions by governments that result in sudden domestic price increases or severe restrictions on energy use, disruptions to supply chains, and a slowdown in the economy.

The IEA suggests under existing policies demand for energy is set to increase by 50 percent by 2035. Fossil fuels would provide 80 percent of supply at this time, with the coal sector seeing the largest growth. This growth, according to a wide range of forecasts, is driven by demands from emerging economies. Over a 2035 horizon, uncertainties over the energy mix in the emerging economies will result from efforts to diversify away from coal to gas, deploy low carbon technologies, boost energy efficiency, and make adjustments to the industrial structure, especially in China.

Despite overall growth, energy consumption per capita globally remains grossly unequal but developing countries are catching up (see figure on page 17). Some 2.7 billion people around the world still rely on traditional biomass fuels for cooking and heating, and 1.3 billion people do not have access to electricity. The majority of people in energy poverty live in rural areas in South Asia and sub-Saharan Africa. Meanwhile, parts of the developing world—China, India, and Indonesia, in particular—are undergoing rapid industrialization, urbanization, population growth, and rising consumer demand. These trends will drive unprecedented power capacity additions and growth in demand for transportation fuel over the next 20 years. Much of the new and planned generation will service urban and industrial regions, further widening the gap between rich and poor.

Even in the coal sector—in which China is the world's largest producer—small percentage changes in the import balance in recent years have had a major effect on the regional and global markets. The IEA (2011) expects China to maintain a 50 percent share of global coal consumption for the energy sector to 2035 and India 15 percent--more than the United States' (10 percent) at that time. Domestic extraction, processing and transportation constraints coupled with significant growth in electricity production will lead to unprecedented levels of coal imports to China and India during this period. Net imports to China could more than double by 2020, but fall back below the current import volume by 2035 due to a further ramping up of domestic production. India, with its depleting domestic production and planned increases in coal-fired power generation, could overtake China's volume of imports after 2020, accounting for almost 30 percent of global trade—five times its current net imports and more than Australia currently exports—by 2035.

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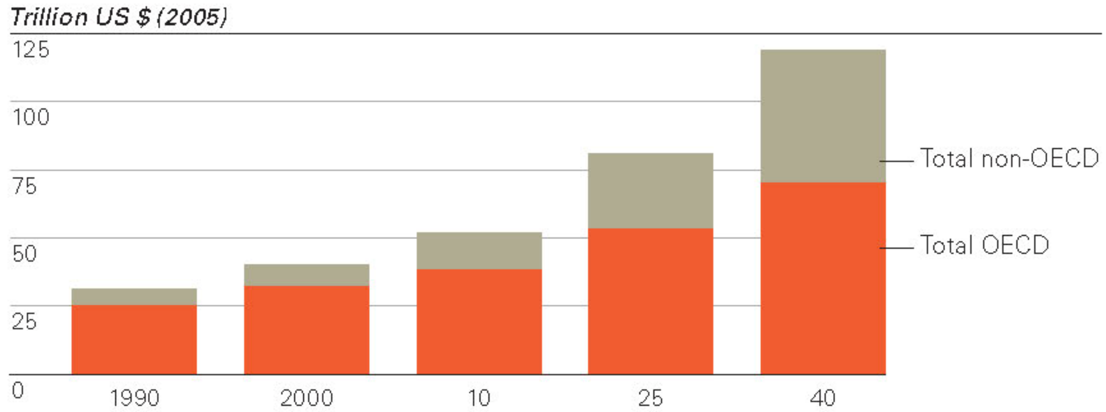
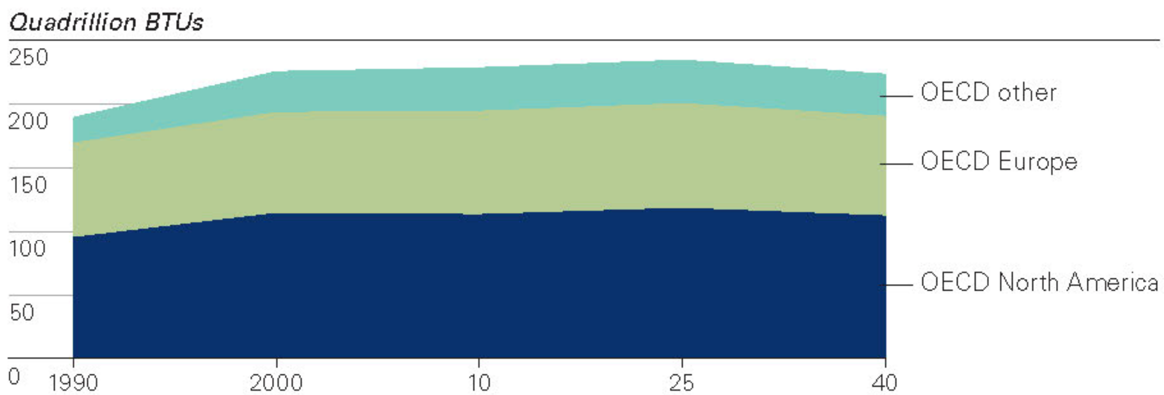
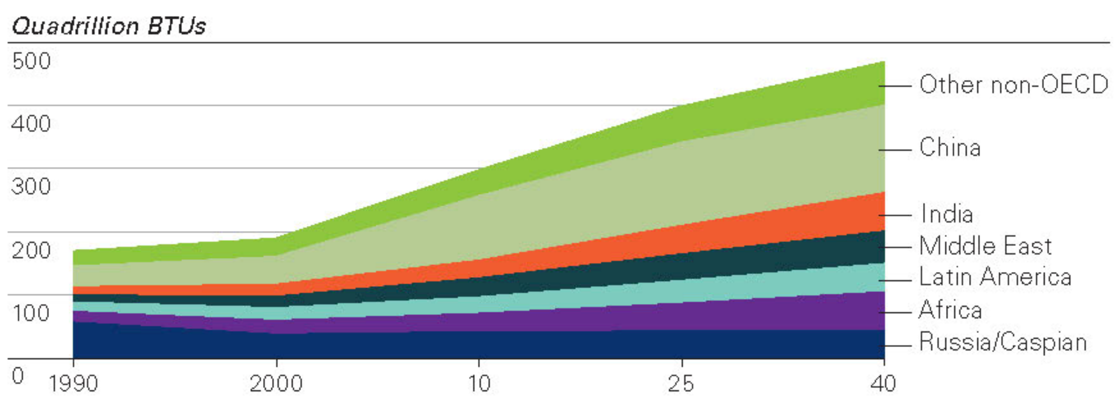
Global GDP



OECD Energy Demand



Non-OECD Energy Demand



Source: http://www.exxonmobil.com/Corporate/energy_outlook_datacenter.aspx

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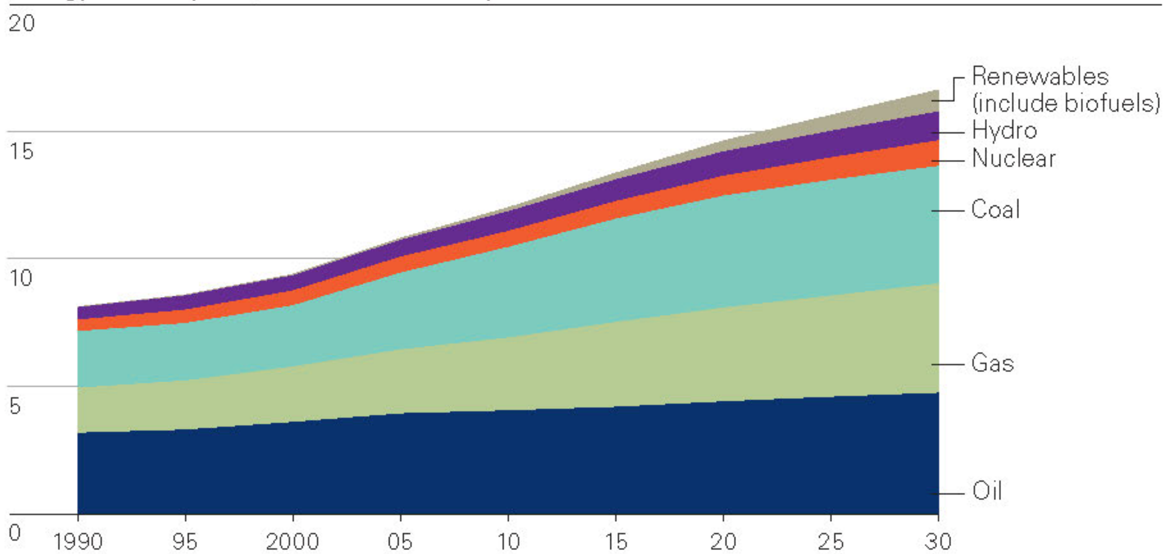
Energy Demand Mix, 1990-2030

Energy consumption, billion tons of oil equivalent



Source: BP (2011), "BP Energy Outlook 2030," BP Statistical Review. (London: British Petroleum), January 2011. http://www.bp.com/sectiongenericarticle800.do?categoryId=9037134&contentId=7068677

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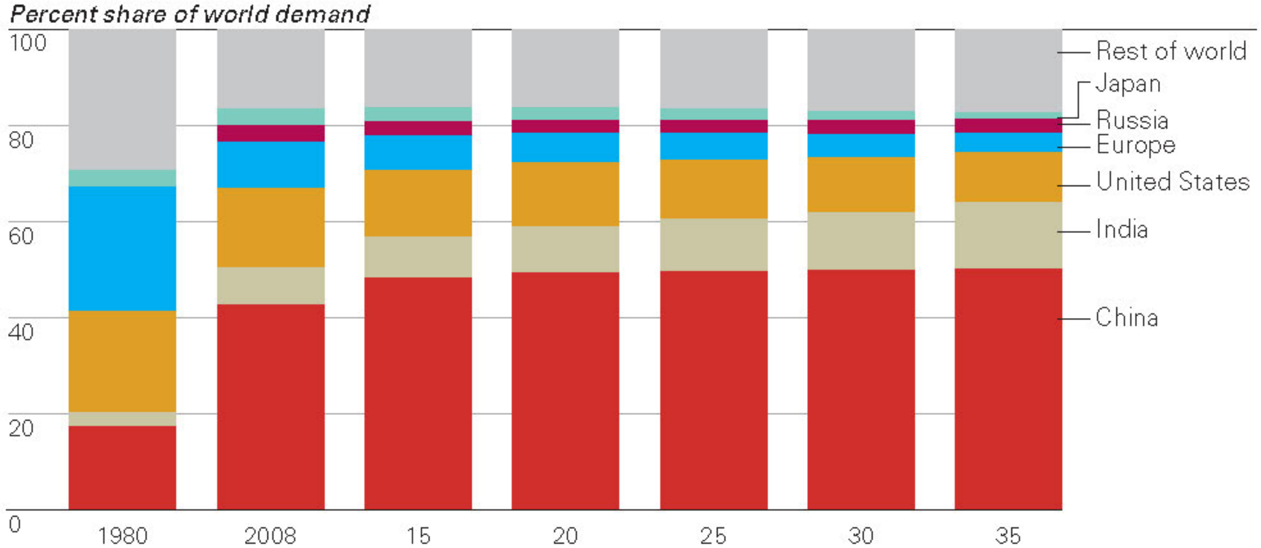
Coal Demand Shares, 1980-2035

Percent share of world demand



Source: IEA (2010), World Energy Outlook, Paris: IEA, p. 202.

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The future availability of energy resources is uncertain, despite rises in investments. **The security of energy supplies has been a critical security concern since the 1970s oil price spikes; it has returned as a policy priority for large importers since the price of oil reached $147 per barrel in 2008. There is much debate about whether the decline of conventional oil supplies will lead to a serious liquid supply crunch between now and 2030, or whether unconventional sources, coal- and gas-to-liquids, and biofuels will be able to meet growing demand in the emerging markets.**

Increased investment and technological advances redefine what is economical to extract and therefore what counts as a 'proven' reserve, and poor data availability in some of the major producer countries hampers any assessment. Furthermore, unproven and unidentified reserve figures are probabilistic in nature. The table below shows the remaining proven economic reserves for the major fuels according to British Petroleum (BP).

Proven Reserves for Oil, Gas and Coal		
	Years remaining at current production levels	
	World	US
Oil (conventional)	46	11
Gas (conventional)	58	13
Coal	118	241

Source: BP (2011)

It seems clear that conventional oil is the most geologically constrained of the three fossil fuels and that for which the United States has the least domestic conventional reserves—although the US oil picture is changing with the development of unconventional oil. However, with higher production and exploration costs associated with unconventional and frontier oil, it is now commonly accepted that the era of cheap conventional oil is over. Since the 1960s, discoveries of oil have dwindled and new fields have tended to be smaller and more expensive (see figure on page 20). Meanwhile, existing major fields have increased their production to meet growing demand.

According to the IEA, upstream investment more than quadrupled between 2000 and 2008, but most of this increase was due to increased costs of labor, exploration, construction materials and equipment. Yet most of the oil that will be produced in 2035 will come from new fields—those that have been found but are undeveloped (see figure on page 20), but also those that have yet to be discovered. Many of these are expected to be complex and expensive to develop (see figure on page 21).

The IEA projections indicate an increasing supply gap for liquid fuels will arise if discovery and investment in new fields is unable to compensate for declining production at currently producing fields together with rapidly increasing demand. This view—and the prospect of much higher prices accompanying a supply crunch—is leading to an acceleration of investment in conventional oil, unconventional oil, and other fuels which may be used in transport.

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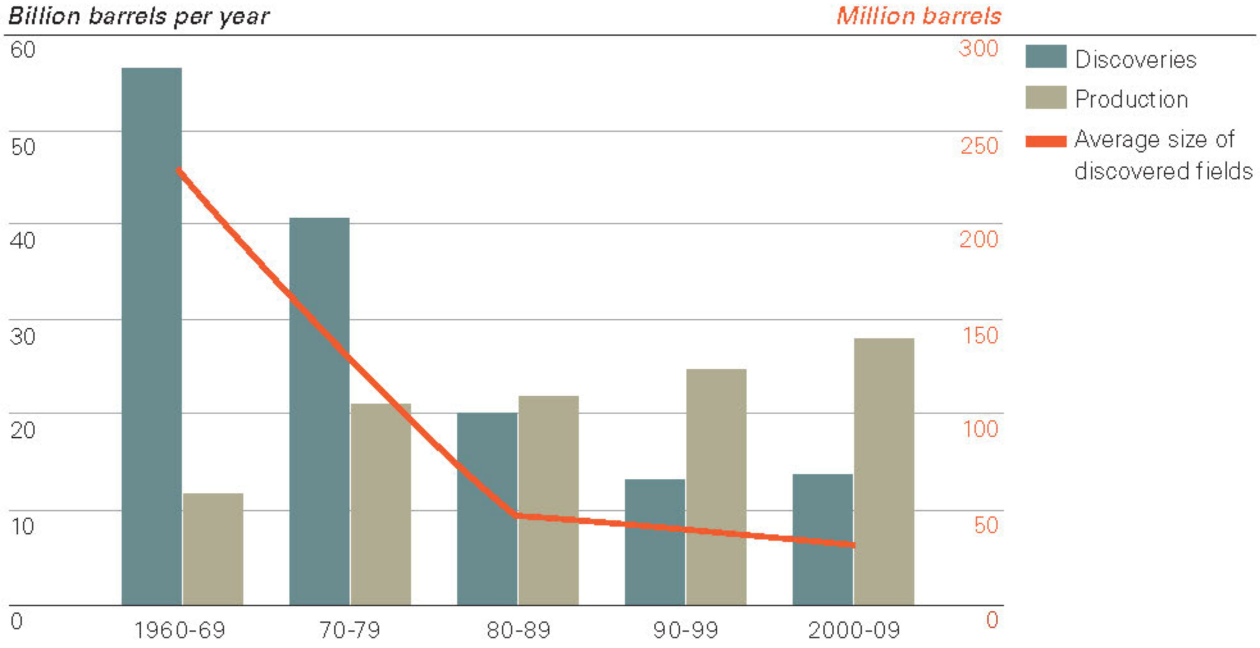
Size and Number of Oil Conventional Discoveries 1960-2009



Source: IEA (2010), 'World Energy Outlook 2010' (Paris: IEA).

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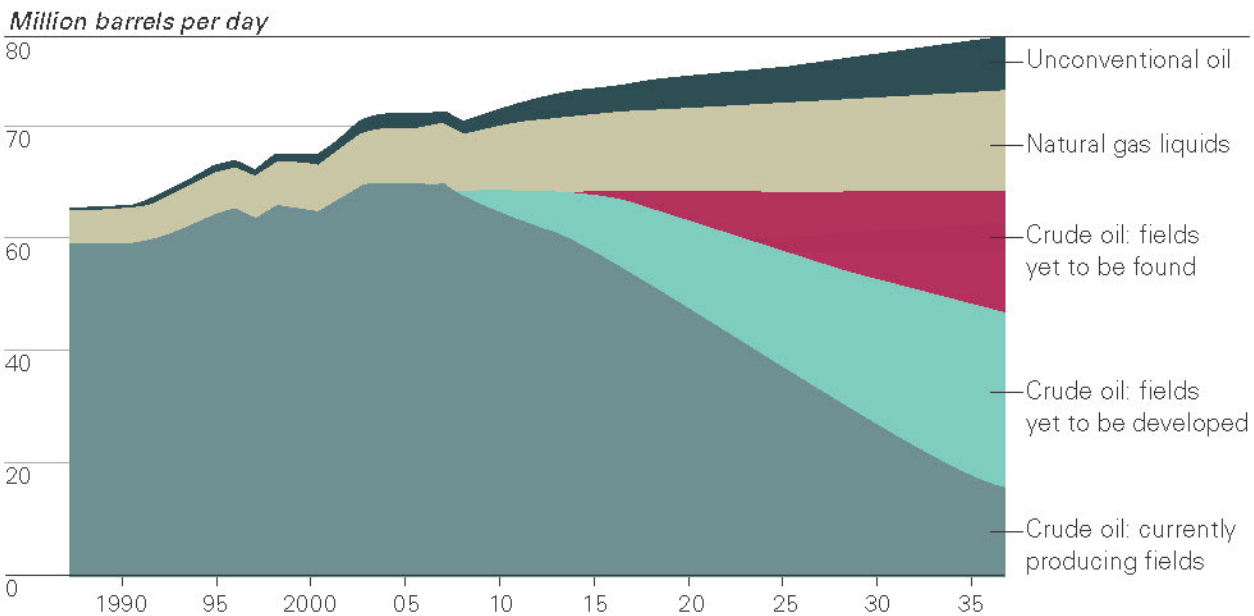
World Oil Production In the IEA New Policies Scenerio, 1990-2035



Source:IEA (2010), 'World Energy Outlook 2010' (Paris: IEA).

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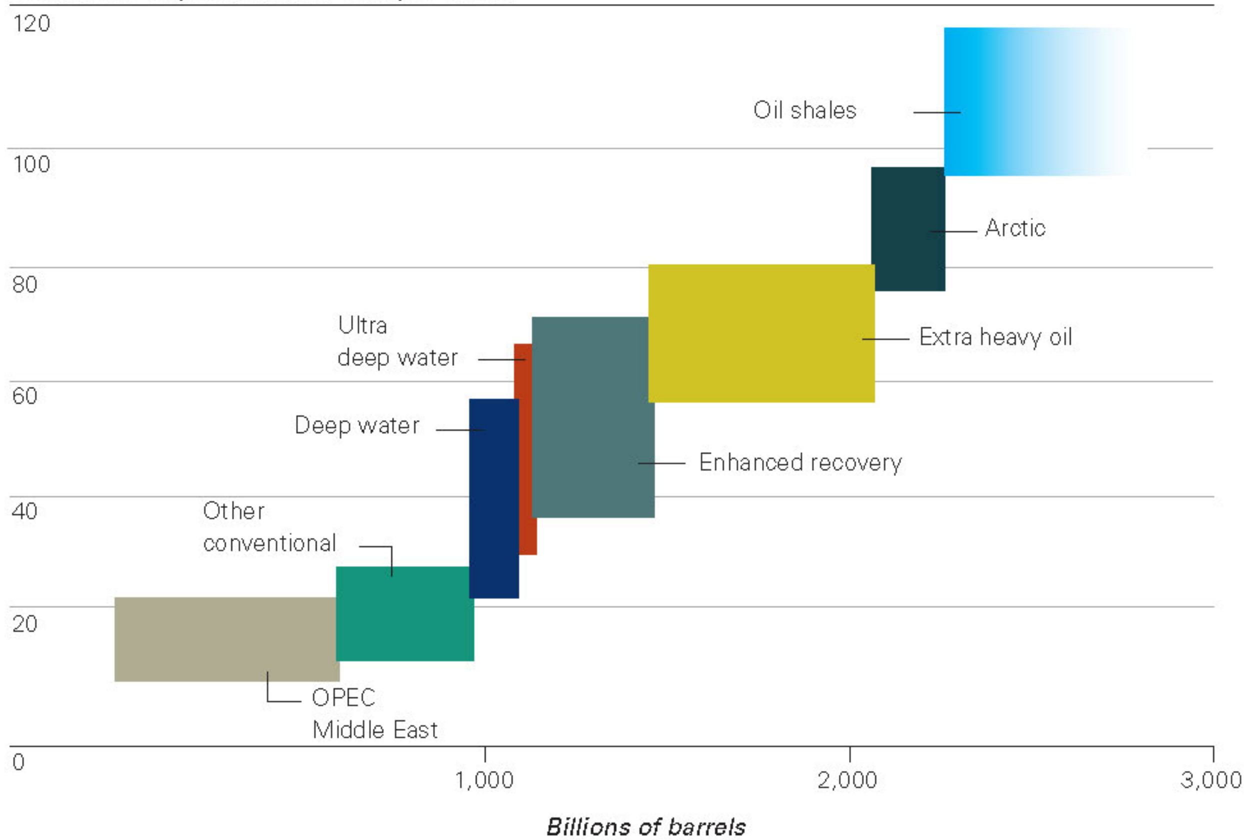
Differences in Production Costs of Oil From Various Sources

Break even oil price in 2012, US $ per barrel



Source: Mauriaud, P., 'Total's View on Future Oil Production'. Presentation at the 9th Annual ASPO Conference, 27-29 April 2009, Brussels.

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To meet oil supply in the IEA's new policies scenario by 2035, about $310 billion of investment is needed every year, 85 percent of which will be in exploration and production. For natural gas, the figure is $270 billion per year. The cost of oil production varies significantly by region—lowest in the Middle East, and highest in Europe and North America. Policy and investment frameworks in producer countries and demand-side policies in consuming countries make the prospects for delivering upstream investments highly uncertain in the short term. The potential for an oil supply crunch is discussed in a text box on the following page.

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A Coming Oil Supply Crunch?

According to the IEA, the global market will rely on OPEC to meet increasing global oil demand with the greatest expectation on Iraq and Saudi Arabia. But production and capacity to export in these countries are far from assured. Although holding the world's third largest proven conventional oil and second largest gas reserves, Iraq remains in political turmoil with the status of producing regions and the legislative environment contested. While the Kurdish Regional Government (KRG) is relatively stable and several major oil companies have signed extraction and production (E&P) contracts with its government, the federal government continues to challenge the legality of these in the absence of a nationwide petroleum law. In the future, with rapid population growth and poor power provision, domestic pressures for energy resources in Iraq may also lead to unexpected declines in oil and gas export flows as resources are diverted for domestic use.

Saudi Arabia is the world's largest exporter of oil, with a production capacity of 12.5 million barrels per day (mb/d). It produces 9–10mb/d of crude oil and natural gas liquids (NGLs). It currently exports 6–7mb/d of crude oil, refined products, and NGLs and maintains at least 1.5mb/d of spare capacity which has historically enabled it to release additional oil onto the global market to quell price spikes. However, rapidly growing domestic energy demand could affect Saudi Arabia's ability to maintain this cushion as the call on its oil for the global market increases. A rough estimate shows that current consumption trends in Saudi Arabia could deprive the world market of 1 to 2 mb/d by 2020 compared with the IEA's 'New Policies' supply scenario. National assessments appear to support this. The national oil company, Saudi Aramco, has warned that Saudi Arabia's crude export capacity would fall by about 3 mb/d to under 7 mb/d by 2028 unless the domestic energy demand growth is checked.

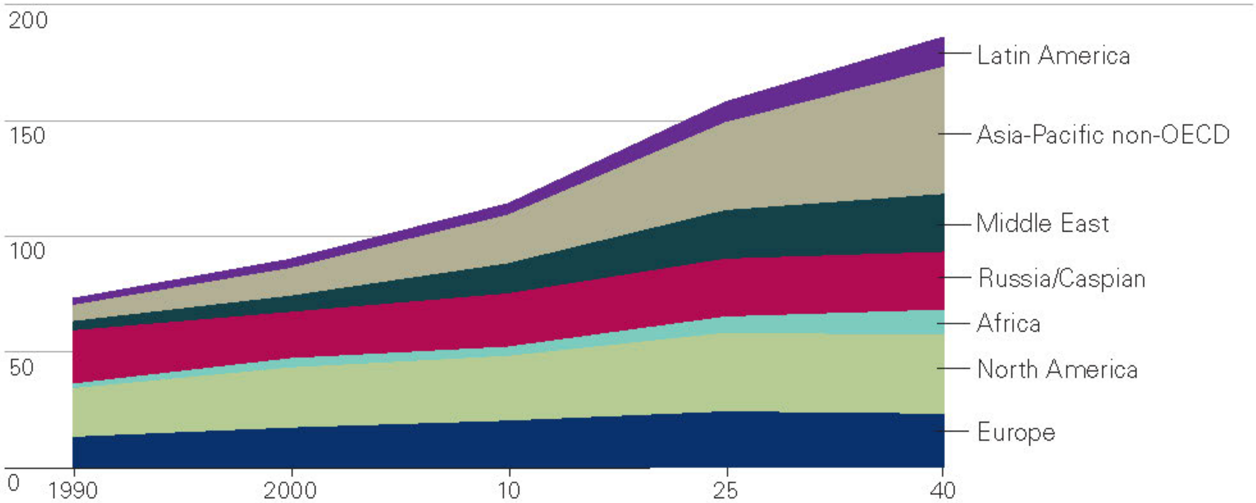
Average lead times between initial investments in surveying and exploring for oil and commercial production are 10-15 years. The delays in investment in Iraq coupled with under investment during the period of low oil prices in the 1990s could lead to a crunch period any time after 2015 as global demand continues to rise and before new fields come into production. Countries such as Kuwait and Iran have consistently failed in the past to achieve targeted production capacity increases. If Saudi spare capacity is eroded, and if other oil reserve holders such as Iran and Iraq fail to invest adequately in upstream capacity, an oil supply crunch leading to major and difficult to control price spikes on the world market is likely.

Source: Stevens, Chatham House (2008) and Lahn & Stevens (2011)

Recent years have seen considerable changes in the gas market, as a result of a number of factors. The widespread development of unconventional gas, particularly in the United States, has not only changed the short-term supply-demand balance in North America, but also affected the global Liquid Natural Gas (LNG) market. The US experience has also triggered many assessments and explorations for shale gas reserves in other parts of the world. In parallel, the development of LNG infrastructure and capacities has increased confidence in supply security and interlinked regional markets. Increased de-linkage between oil and gas prices has enabled greater price competitiveness in the power sector among gas and coal and nuclear.

Natural Gas Demand by Region

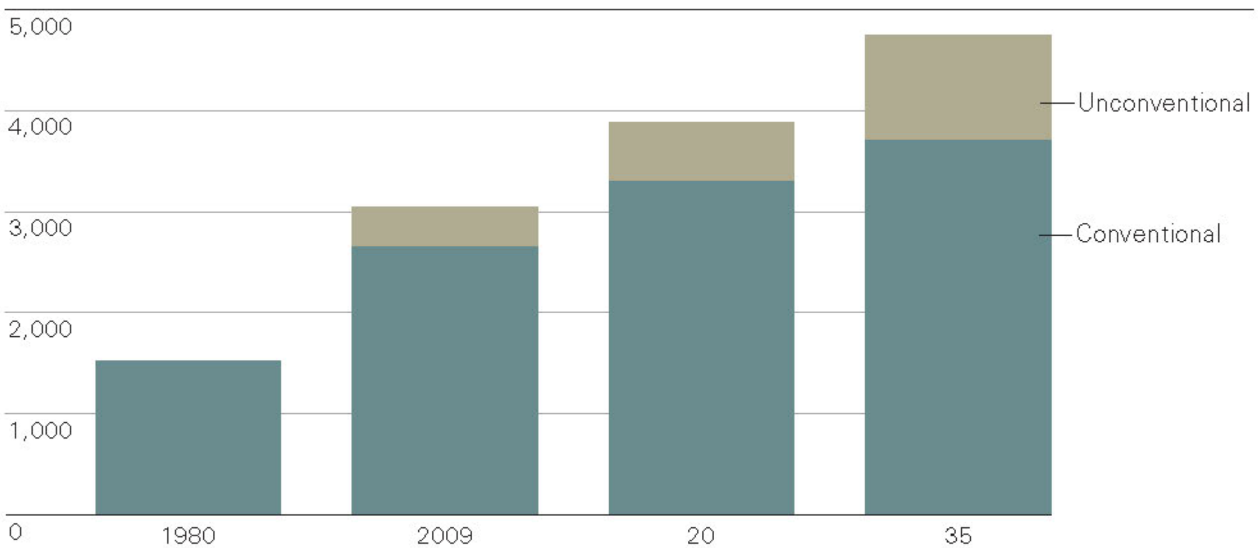
Quintillion BTUs



Source: ExxonMobil (2012), '2012 The Outlook for Energy: A View to 2040'. Graph 2: p.44
http://www.exxonmobil.com/Corporate/files/news_pub_eo.pdf
http://www.exxonmobil.com/Corporate/energy_outlook_datacenter_eonaturalgas.aspx

Natural Gas Production by Type

Billions of cubic meters



Source: IEA 2011, World Energy Outlook

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Prices and costs of energy are likely to remain high and volatile. Energy price predictions are naturally hostages to the uncertainty of future supply and demand. On the one hand there is increasing depletion of conventional reserves coupled with rising demand in Asia, and on the other the promise of tapping huge unconventional reserves in the face of OECD demand decline and renewable market breakthroughs.

Energy scenarios can explore some, though not all, of the uncertainties. For oil, the estimated import price ranges between roughly $90 per barrel and $140 per barrel in 2035 across the three IEA ***scenarios (in real 2010 dollars).*** The ***differences are due to assumptions on*** economic growth, the strength of government policies ***towards fuel efficient vehicles, the pace of the switch*** to alternative vehicles and biofuels production, and the development of ***conventional and non-conventional resour***ces. This highlights one of the problems of using economic drivers for low carbon development, as successful low carbon policies radically reduce the price of fossil fuels (due to lower demand) and therefore make the alternatives less competitive. The heightened uncertainties about future demand and unconventional recovery are likely to be an increasing source of price volatility.

Another important factor in keeping the oil price high is the expansion in rigid budget costs in oil exporting countries as the global oil price has risen. Since 2007, government spending in several OPEC countries has risen in the region of 50-60 percent. Budget cuts could be politically damaging, so governments will work to support the necessary international market price, and what is considered a ‘fair’ or ‘preferred price’ is likely to rise. For example, the Saudi Minister of Petroleum stated that $35/b was a fair price for oil in 2004–05; by 2010, this had risen to $70-80/b and in 2012 it was around $95/b. Saudi Arabia has much more export flexibility than some other OPEC countries (such as Iran, Venezuela, and Algeria) and will act to support a lower oil price given its interests in avoiding long-term demand destruction. However, Saudi domestic consumption of fossil fuels could constrain this flexibility between 2020 and 2030, increasing the likelihood of higher prices.

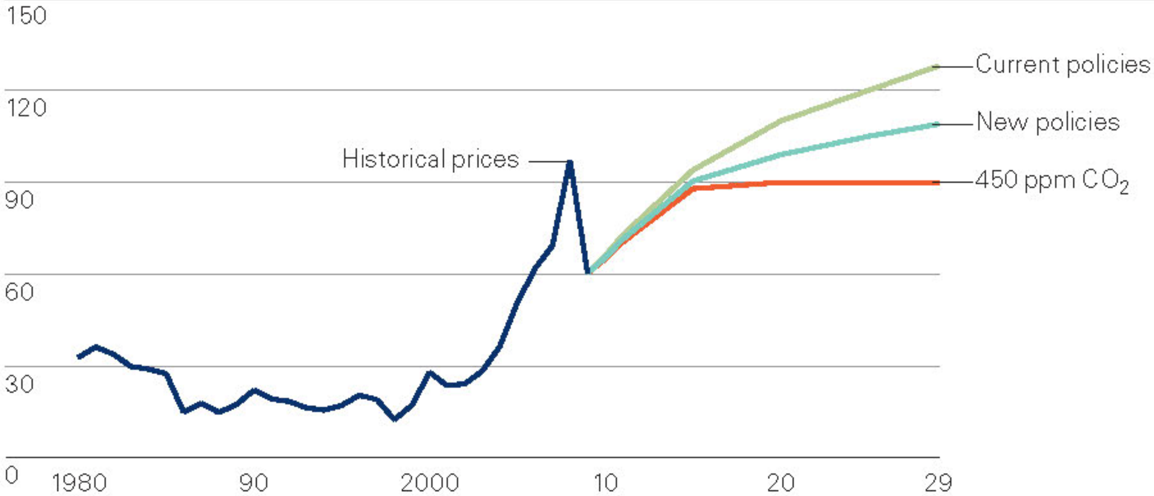
There is variation between producer countries’ required price (see estimates in the figure on page 25), but it is possible to discern a consensus building around the $100 mark in the next two to five years. OPEC could in theory agree to production cuts should the international price fall below this consensus level.

Sustained higher prices for fuel have an impact on consumer behavior, but also make it more likely that measures to rein in consumption and encourage a switch to alternatives (in the case of oil: biofuels, electric vehicles) will be put in place. A price spike of perhaps $160/b, if sustained for more than a few weeks, would prompt national policy changes in many of the importing countries.

The pressure to attract investment often succeeds in overcoming weak governance structures in some developing countries, even where there are significant risks. For example, capacity building at a range of scales is needed to address land management and the protection of major ecosystems.

Average Oil Import Prices in OECD, IEA Scenarios to 2035

US $ (2009) per barrel



Source: IEA (2010) "World Energy Outlook 2010," (Paris: IEA) p. 72, January 2011.
http://www.oecd-ilibrary.org/energy/data/spot-market-and-crude-oil-import-costs/iea-crude-oil-import-costs-by-type-of-crude_data-00448-en?isPartOf=/content/datacollection/ene-oil-data-en

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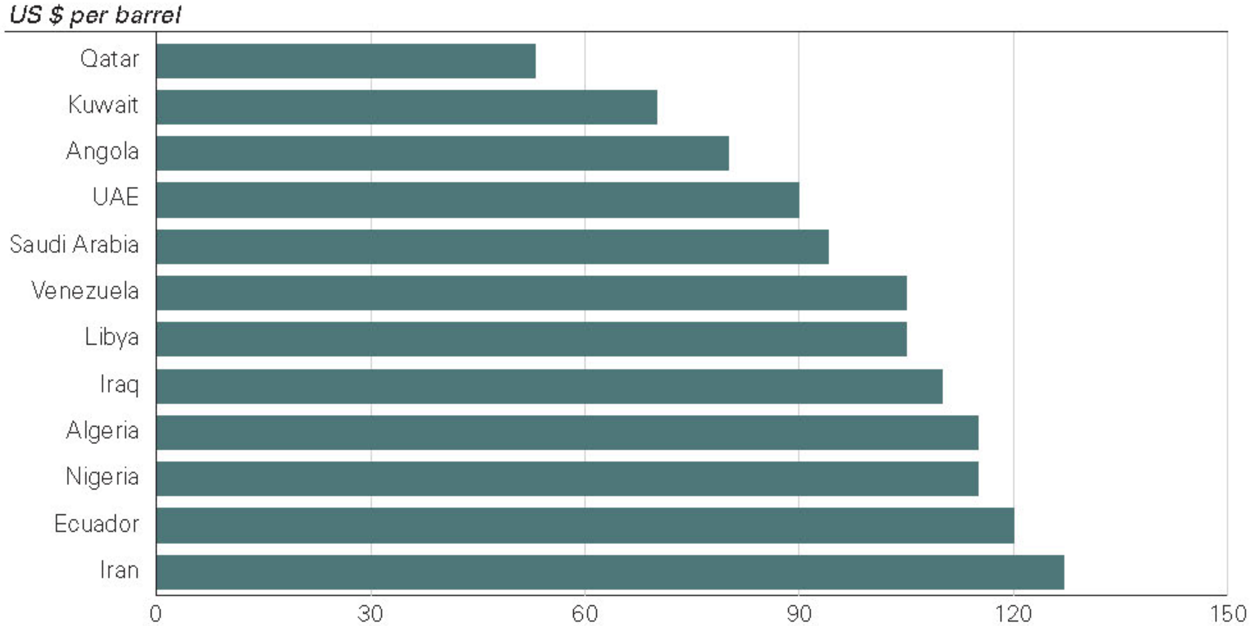
Estimate of Oil-Producing Countries' Fiscal Break-Even Prices

US $ per barrel



Source: Ali Aissaoui Apicorp Economic Commentary, Vol. 7, No. 8-9, August-September 2012.

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The energy sector could be facing a pivotal moment with the discovery of large shale gas reserves in the US and China, together with the rise of alternative energy sources. In general, change is slow in the energy sector due to long investment horizons in the upstream and lock-in to infrastructure and equipment on the demand side. But the rapid expansion of shale gas in the United States, enabled by advances in fracking technology and historical government investment incentives, is a reminder that sudden system changes in the energy sector are possible. Policy changes can also be disruptively fast, such as the German Government's reaction to Fukushima or the EU's renewable energy target (which, if achieved would, lead to over 30 percent of the EU's electricity coming from renewables, a three-fold rise in a decade). In the last five years, medium-term projections for the United States have shifted it from an LNG importer to an exporter, and reserve numbers for gas around the world have grown by over 15 percent. Prospects for exploitation of shale oil are also reducing import projections. There are questions in the United States and the rest of the world about some of the more optimistic projections, not least due to potential environmental legislation regarding the fracking process and, in the case of shale oil, the burning off (flaring) of associated gas.

According to the Chinese Ministry of Land and Resources, a preliminary study indicates China has the largest reserves of unconventional gas, as 25.08 trillion cubic meters of technically recoverable deposits. If true, this would be double the estimated US reserves. The government has signaled its commitment to reduce import dependence by developing domestic resources and expects coal-bed methane (CBM) and shale production in the range of 80-130 billion cubic meters by 2020. But the lack of equipment and experience, complicated geological structure, low domestic gas price, and potentially the necessary extraction resources may inhibit or slow down development.[3]

In Europe there is uncertainty about the geology, political and public acceptability, environmental impact, and financial viability of shale gas. The clearest example of these problems at even the first stage of development is the difference between the approaches of Poland and France which, according to the US EIA, have the two largest reserves in the EU. In Poland, the government sees shale gas as an important resource for diversification away from dependence on Russian gas and has been granting exploration licenses. In France, the Senate has banned hydraulic fracking, but not the extraction of shale gas.

There are important differences between North America and Western Europe about the potential extraction of shale gas, notably relating to:

- The availability of exploration equipment and the prevalence of existing extraction activities. In 2008, at the height of the gas boom in America, 1,600 rigs were in operation. In Europe now there are only 100.
- The ownership of the resources. In North America subsurface resources are owned by the landowner, in Europe, by the state.
- The density of the population.
- The national authorization processes, which vary considerably in member states and are thought to be generally stricter in the EU.

Policies on climate change and resource insecurity can also reshape future energy demand. By the 2020s, progress on subsidy reduction or removal in key growth markets such as the Middle East and China could also have a substantial impact on demand. A mix of policy instruments has successfully boosted

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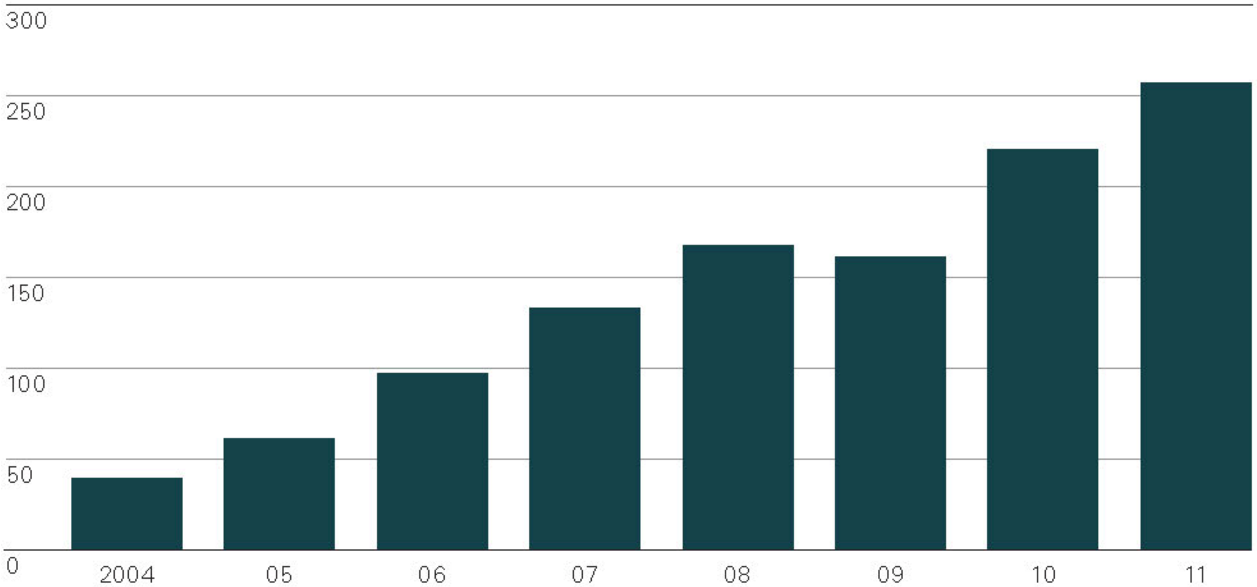
[3] Water is often listed as a limiting resource, however shale gas fracking technology is rapidly changing and new methods to recycle water, use brackish water, or even substitute other gasses and fluids are being developed.

investment in renewable energy and, to a lesser degree, nuclear power in European countries, Japan, the United States, and China—the latter now accounts for the lion's share of both investment and technology deployment. The graph below shows the recent rapid growth in global investment in renewable power generation. This has bounced back after the financial crisis to be close to the trend of the last decade.

Investments in research and development today are helping to shape the commercial technologies of the 2020s and beyond. Chatham House analysis of 68,000 low-carbon energy patents found that new technologies have historically taken 20 to 30 years to reach mass-market application, but innovation rates can be faster, as shale gas has shown. Technology deployment generates learning and cost reductions, and so to an extent the support policies for renewable and electric vehicles in key markets will shape the future costs of these supply options.

New Investment in Renewable Energy, 2004-11

Billion US $, adjusted for reinvested equity, includes estimate of undisclosed deals



Source: Bloomberg New Energy Finance (2012), 'Global Trends In Clean Energy Investment'. Presentation 11 July 2012, available: www.bnef.com/free-publications/presentations/. Slide 3.

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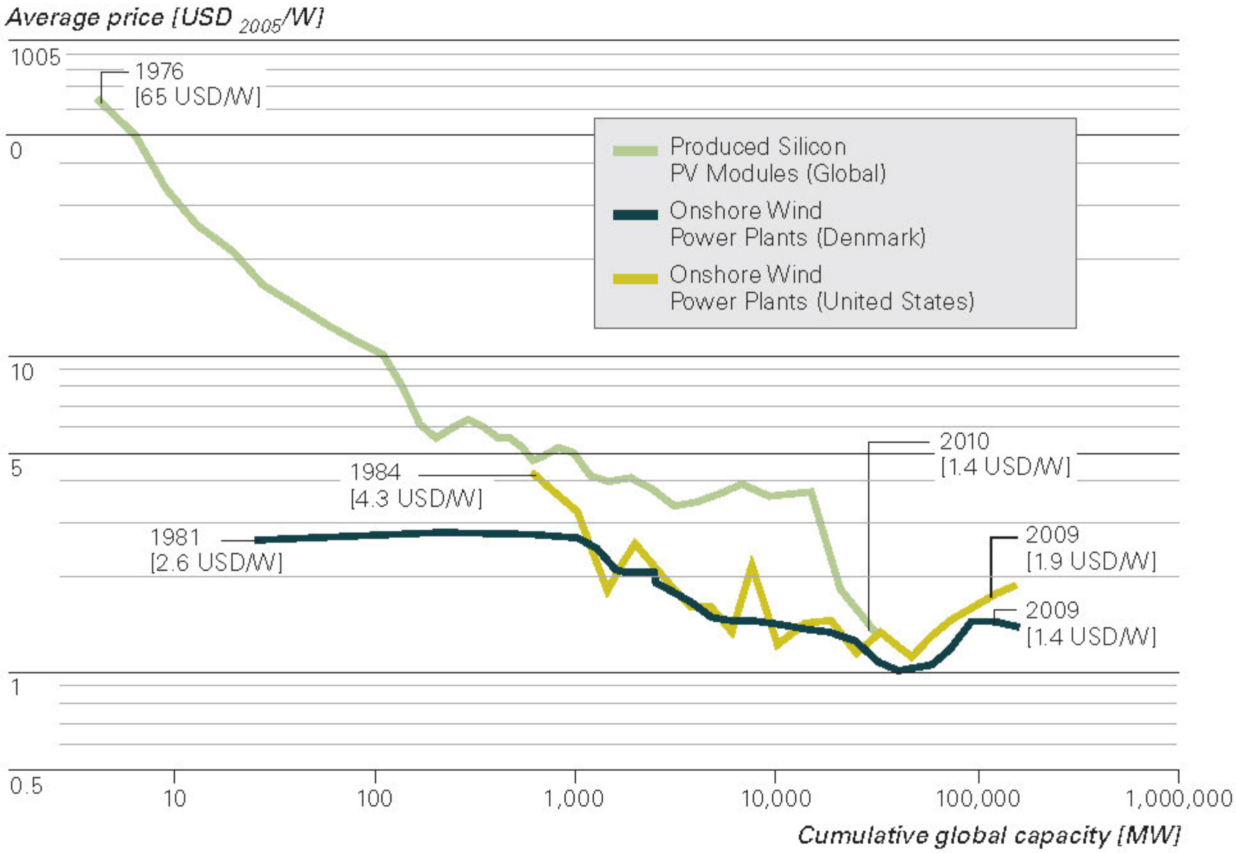
Cost-Curves for Renewable Energy



Selected experience curves in logarithmic scale for the price of silicon PV modules and onshore wind power plants per unit of capacity Depending on the setting, cost reductions may occur at various geographic scales. The country-level examples provided here derive from the published literature. No global dataset of wind power plant prices or costs is readily available. Reductions in the cost or price of a technology per unit of capacity understate reductions in the levelized cost of energy of that technology when performance improvements occur.

Source: IPCC, 2011: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1075 pp.

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Looking to the future, critical thresholds to watch include the break-even points between renewable (solar, wind, and wave) and coal power generation (grid parity) and between electric vehicles and the internal combustion engine. If these arrive by 2020, as some analysts expect, they could have a large disruptive effect on energy systems by 2030. The figure above shows the rapid decline in the cost of solar panels and wind power.

This paper does not represent US Government views.

Fukushima and the Future of Nuclear Power

Prior to Fukushima there were more nuclear reactors under construction than there had been for a decade. However, active construction programs with more than two reactors under construction in 2011 were found in only four countries (China, India, Russia, and South Korea), with China responsible for 40 percent of the global total. The short-term prospects for the further deployment of nuclear power depend on a number of factors, which include:

- The availability and costs of conventional fuels, particularly natural gas, coal, and hydropower resources.
- Current market and finance conditions, which would favor the large upfront costs and long lead times of nuclear power.
- An acceptable long-term regulatory, political, and public support environment.
- Active government support through technology-specific market measures.
- Climate change policies that would encourage the use of nuclear power.

Given the current environment, in which several of the above criteria are not met, it seems unlikely that nuclear power will undergo a significant global revival in the near term. Assuming CO2 emissions constraints are placed on the energy sector, nuclear energy's main competitors over the longer term are likely to be renewable energy or some CO2 capture/atmospheric removal technology.

Second generation biofuels also have the potential for fast growth in the 2020s, not least because they do not depend on a change in end-use technology and are in less direct competition with food crops. Shale gas has grown phenomenally fast in recent years in the United States, but its future remains uncertain elsewhere. Rapid development of carbon capture and sequestration (CCS) would allow for greater fossil fuel use and industrial production in a carbon constrained world. In the wake of Fukushima (see text box above), there are uncertainties over nuclear power expansion at the global level and associated uranium demand, but more importantly Fukushima could have large secondary effects for coal, gas, and renewables.

This paper does not represent US Government views.

Energy: Uncertainties to 2020, 2030, and 2040			
Timeframe	**2011-2020**	**2021-2030**	**2031-2040**
Demand	*Policy/investment* • The prospect of sustained policies to incentivize public and private investment in resilient energy infrastructure. • Impact of potential energy price reforms in China, India, and the Middle East. *Technology* • The growth rate of new vehicles in China. If vehicle deployment grew 1 percent faster than 5 percent forecast by 2035 demand will be 2mb/d larger. *Consumer behavior* • A sustained spike in oil prices could accelerate fuel switching to biofuels or gas, particularly in the US. *Economic development and political stability* • The pace of urbanization in emerging economies and attendant rate of energy demand growth due to resource transfers and competition. *Policy* • The impact of Fukushima on global nuclear power deployment. • Impact of budgetary concerns on fiscal support schemes for renewable energy. • Level of public pressure/ environmental regulations affecting development of unconventional fossil fuels including tar sands, shale oil and gas, and Arctic oil and gas.	*Policy/investment* • Impacts of emissions reductions targets on global energy demand and the energy mix. • Likelihood of radical policies to constrain energy demand in response to supply crunches and sustained high prices. *Technology* • Impact of 'smart grids' on electrical efficiency. *Consumer behavior* • Deployment of electric vehicles, affecting oil demand. *Economic development and political stability* • Potential political crises and fragmentation in emerging economies, e.g. political unrest in China and India could rock markets and lower demand trajectories. *Investment and development* • Whether the 30 mb/d of new oil capacity needed to replace depleting reserves (between 2020-35) is introduced in time. • Lock-in to gas-fired power generation capacity coupled with supply under-investment leading to power shortages, particularly in Europe and China. • The potential of unconventional gas production to grow in other regions, particularly China and Russia.	*Policy/investment* • Policies responses to environmental crises effecting fuel markets (including uranium and biofuels). *Technology* • Innovation and deployment in mobility and power prompting terminal decline in fossil fuel energy demand. *Economic development and political stability* • The rate of growth of the current low-income developing economies, e.g., in Sub-Saharan Africa and South Asia.

(Continued on next page…)

(…continued) **Energy: Uncertainties to 2020, 2030, and 2040**			
Timeframe	**2011-2020**	**2021-2030**	**2031-2040**
Supply	*Technology* • Whether and where renewable technologies achieve grid parity. *Investment and development* • China's ability to meet the projected 30 percent increase in domestic coal production. • Potential development of Russian high north, e.g., Yamal and Shtokman, enabling supply to both European and Asian markets • Whether the 17 mb/d of new oil capacity needed to replace depleting reserves is introduced in time. *Economic development and political stability* • Increasing accountability of governments in the Middle East and resulting impact on oil production. • Major crises in exporting countries, e.g., Iran, Iraq, Nigeria, causing oil price spikes. • Rising budgetary pressures in oil exporting countries continuing to drive up oil prices.	*Technology* • Degree to which intermittency issues for renewables are addressed/reduced, e.g., through infrastructure, IT, and storage solutions. • The cost-effectiveness of carbon capture and storage. *Environmental constraints* • Conflicts over resources, e.g., water, and infrastructure affecting the extraction of unconventional oil/gas and coal. • The impact of melting permafrost on the delivery of Arctic oil and gas. *Economic development and political stability* • Rising domestic consumption of oil and gas—especially from the Middle East—constraining exports.	*Infrastructure* • Vulnerability of energy infrastructure to climate change, volatile weather, and supply disruptions. *Environmental constraints* • The impact of climate change undermining some existing energy infrastructure.

Energy implications for the US: The United States was until 2009 the world's largest energy user (having been overtaken by China). However, US per capita energy consumption is well above the world and OECD average. Although this offers opportunities for energy efficiency, achieving parity with other countries would require large structural changes in society. The high per capita US energy use makes the US economy more vulnerable to changes in the global energy markets. Although this is well known and discussed in the United States in context of supplies from the Middle East, the real threat to the US economy is higher prices driven by growing demand from emerging economies. Although increased production of domestic unconventional fossil fuels will offer the United States some assurances of physical access to energy, it will only marginally reduce the vulnerability of the United States to global price shocks or increases. Globally, in the absence of an acceleration in the deployment of non-fossil fuel energy technologies and systems, increasing demand for energy will aggravate future climate change and increase the energy security risk in countries and regions of interest to the United States.

- The United States has considerable coal reserves and a significant increase in natural gas production from unconventional sources—which has begun—will lower energy costs for US businesses, allow the substitution of natural gas for coal for electrical power production (reducing GHG emissions), and allow for the possible export of liquefied natural gas and/or coal.
- The development of domestic unconventional fuels offers the United States an important opportunity to create local economic activity and an orderly transition of its long-term energy policy. However, in the absence of other policy actions, continued high reliance on domestic fossil fuels will not significantly reduce US GHG emissions and may create additional local environmental problems.

Energy Technology Wild Cards

The energy sector has been slow to change historically because of the high capital costs and complex infrastructure required. The shale gas revolution in the United States was an exception and provided an example of how compelling market forces and new technologies resulting in part from government-funded research can enable a fast change even in the energy sector. With continued government basic energy research and policy to discourage the buildup of CO_2 in the atmosphere, several “game changing technologies” are plausible in the next thirty years. These include:

- Inexpensive carbon capture and sequestration that would make the continued use of fossil fuels—especially coal—environmentally and economically acceptable.
- New energy storage technologies—heat storage, electricity storage, vehicle batteries—and radical improvement of renewable technologies—especially solar—that would challenge the expected dominance of fossil fuels. The development of low-cost high performance batteries would transform the use of electric vehicles.
- An affordable “closed carbon cycle”—where CO_2 is removed from the atmosphere and combined with solar-derived hydrogen from water—to manufacture hydrocarbons on site that would make fossil hydrocarbon fuels obsolete and allow for direct control of the global biosphere.
- Micro-generating renewable technologies would accelerate the development of zero energy and energy plus buildings, radically changing the energy requirement of cities.

Minerals

Demand growth for metals is expected to remain relatively brisk even though there are few reliable estimates. Unlike energy, comprehensive long-term demand projections are mostly unavailable outside the realm of resource companies and commercial consultancies. The few publicly available forecasts rely on approximations based on GDP growth estimates; they typically provide an aggregate estimate for all metals or just for a selected few. On the whole, publicly available analysis anticipates demand growth to continue. The OECD, for example, has estimated metal demand to grow by 250 percent on 2005 levels by 2030, or 5.1 percent per year. The Ellen McArthur Foundation estimates that global ore extraction will grow from an estimated eight billion tons annually to eleven billions tons by 2020, an increase of 37 percent, or 3.2 percent per year.

Forecasts for individual metals differ both in the results and the timeframe considered. For steel, McKinsey estimates imply demand growth of an average of 3.8 percent between 2010 and 2020 and a subsequent slowdown to 2.2 percent for the 2020 to 2030 period. Similarly, BHP Billiton estimates 3.6 percent average growth until 2025. For copper, industry experts estimate an average growth rate of 2.5 percent until 2035, while the Chilean copper commission forecasts 3.4 to 3.9 percent until 2020. Sources differ substantially on nickel and zinc long-term demand growth rates, but industry estimates in recent years range anywhere between three and six percent growth over the next decade. A recent United States Geological Survey (USGS) exercise put aluminum demand growth until 2025 at 4.1 percent per year. It is difficult to assess the reliability and robustness of these forecasts because the underlying assumptions in terms of growth projections or country breakdowns are generally not publicly available and may at times be influenced by commercial interests.

China has dominated demand growth for metals over the past ten years, and it will continue to be the most important factor in shaping global metals demand until at least 2020. China's metal consumption has overtaken the consumption of the entire OECD, up from just 20 percent of OECD consumption ten years ago (see figure on page 34). This is much larger than its share for most other commodities. Even thought the metal intensity of China's economy is unusually high given its level of development, there is considerable scope for further growth, especially in the Western provinces where per-capita metal consumption rates are comparable to many other developing countries. According to BHP projections, China's consumption will grow by 473 million tons until 2020, only slightly less than the 512 tons it added over the past ten years and nearly half of projected global consumption growth.

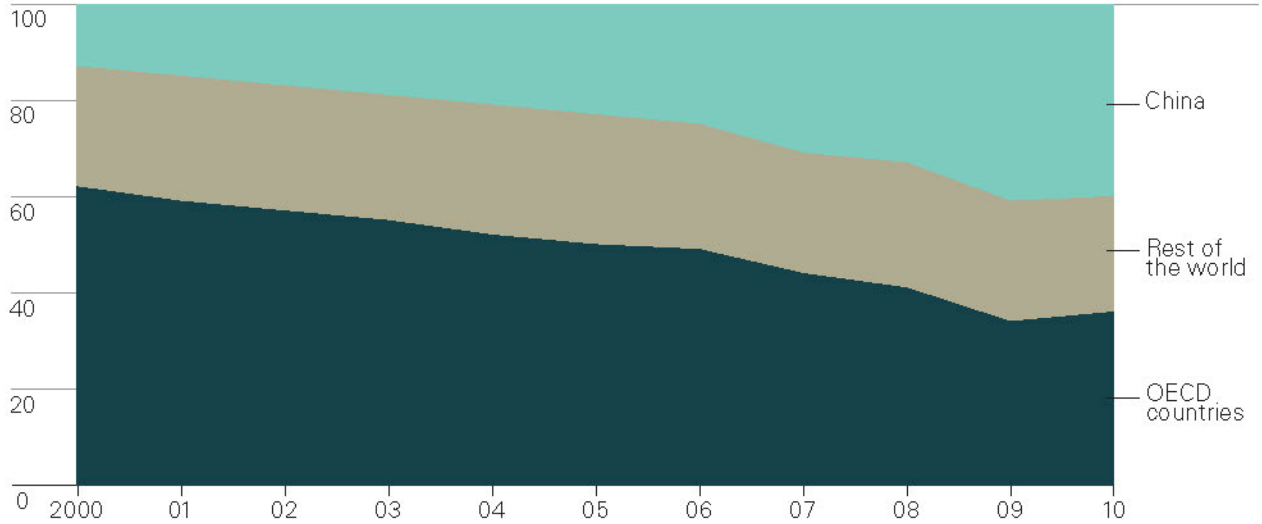
China has also become increasingly dependent on imports. Despite rapid increase in mine output, it is now able to meet only roughly half of its metals consumption from domestic sources (see figure on page 34).

As a result, China has already become the single largest importer of metals worldwide, importing more than Japan, the United States, Germany, and South Korea together. This makes China heavily dependent on imports, especially from Australia and emerging economies such as Brazil, Indonesia, and Peru.

Towards 2030, other emerging economies are likely to gradually replace China as the driving force of global consumption growth. In India or Brazil, for example, demand is not only much lower than in China, but also has been growing at much lower rates. But metal consumption in all the emerging economies will have to accelerate over the coming decades to meet infrastructure and construction requirements. India's contribution to global steel consumption growth, for example, is projected to make up nearly 30 percent over the next decade.

China's Share in Global Metals Consumption, 2000-10

Percent of world total



Source: Chatham House analysis of World Bank data.

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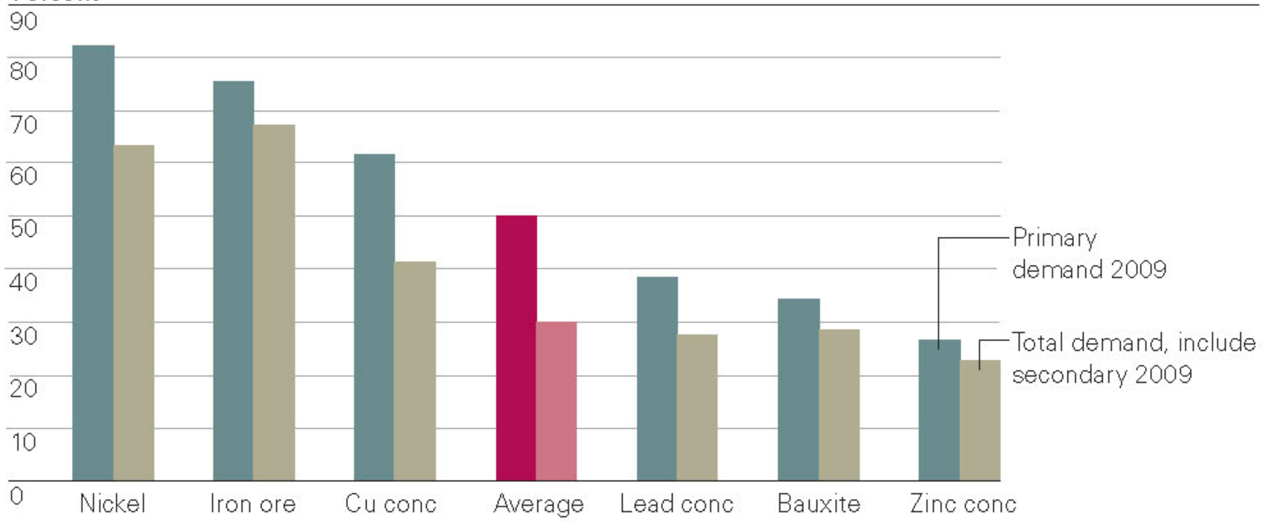
China's Import Dependence on Various Metals in 2009

Percent



Source: Presentation, Trench, Allan, 2010 "The China Influence–Commodity Markets to 2012 and Beyond" Australian Resources Chinese Investment Conference, Adelaide, July 2010, slide 14-crugroup.com.

Note: Primary demand is demand in an unprocessed state, such as ore extracted and requires minimal processing before use. Secondary demand is for scrap material, which is composed of new and old scrap.

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The combination of growing Chinese import dependence and increasing demand in other emerging economies will lead to heightened tensions over access to resources. These could arise, for example, between China and large exporters such as Brazil or Peru, over the extent and conditions under which these countries make supplies available. In a recent example, China has expressed concerns over an Indonesian export ban on unprocessed nickel. India is also likely to become increasingly import dependent by 2030, placing it in competition with China for supplies from exporting countries such as Australia.

The mining sector faces enormous challenges in delivering future supply of metals and minerals. Mining activity and significant mining reserves exist in many countries, however, in contrast to fossil fuels. Exploration is continuing on all five continents, making a concentration of reserves unlikely over the timeframe of this report (see map below).

Nonferrous Exploration Expenditure in 2011

Top Destinations for Nonferrous Exploration, 2011

country or region — **United States** 8 — *percent*

Other locations account for about 6 percent.

Source: Metals Economics Group (2012) "World Exploration Trends 2012: A Special Report from the Metals Economics Group for the PDAC International Convention".

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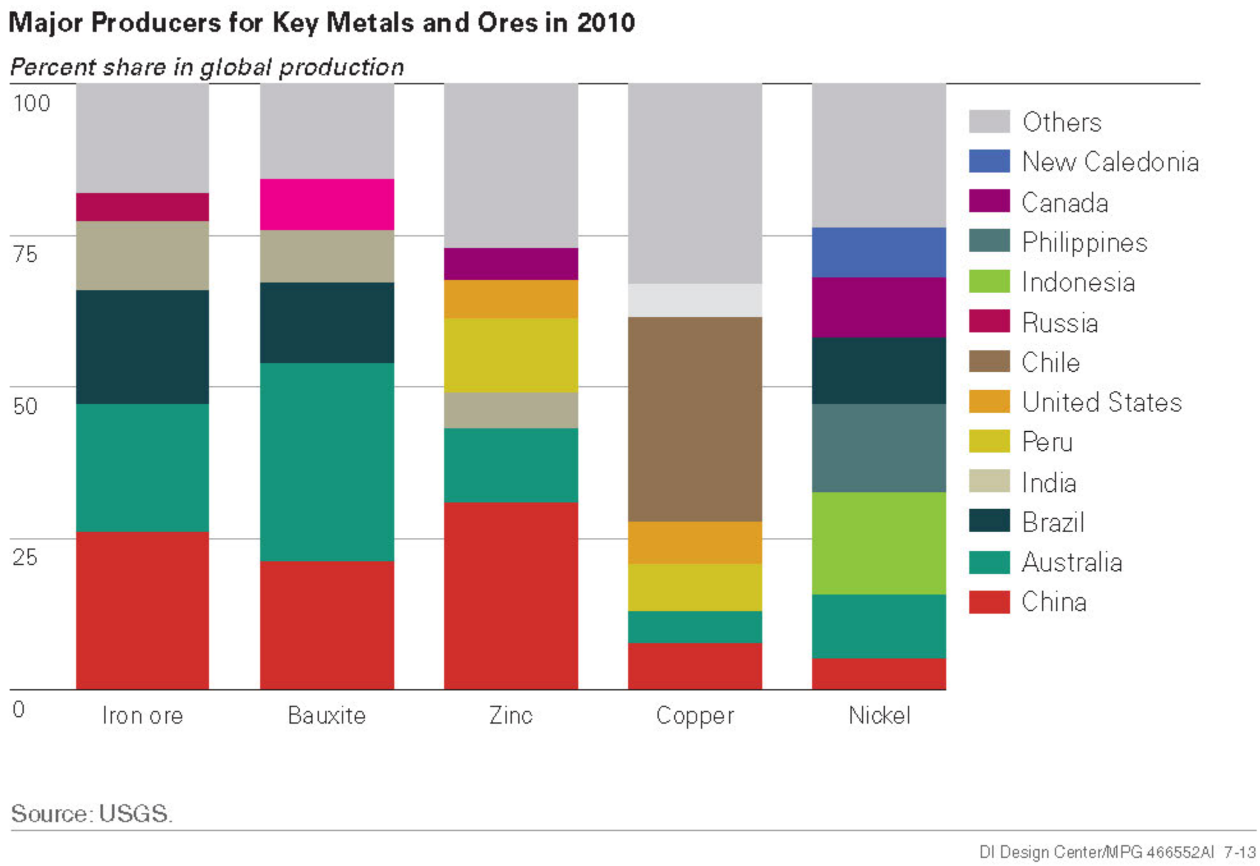
The production of individual metals is however typically dominated by a handful of countries, with iron ore and bauxite production being particularly concentrated (see figure below).



This paper does not represent US Government views.

If reserve ranges (i.e., the ratio of proven reserves over annual production) are considered, there are no major new concerns about metal resources compared to ten years ago. Intensified exploration in response to rising metals prices has led to significant additions to proven reserves over the past decade (see Table below). Known deposits in the less certain resources categories are even larger, typically exceeding proven reserves by one order of magnitude. As in energy, technological innovation can affect the extent of economic mineral reserves considerably.

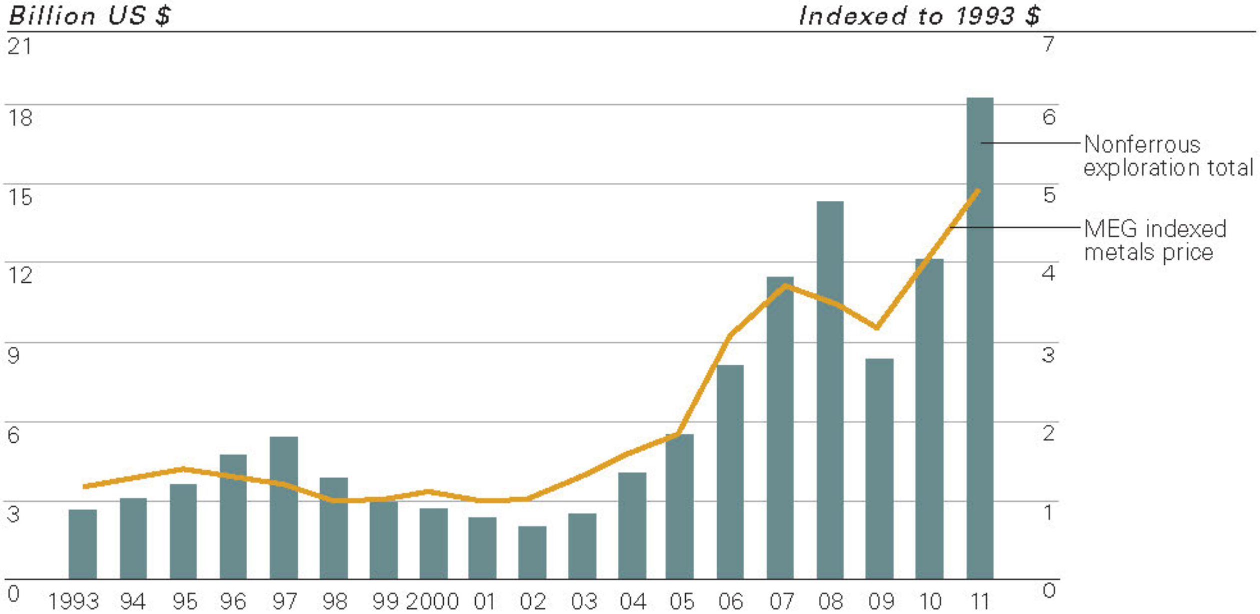
Production Reserves and Reserve Ranges 2000-2010

	Mine Production			**Reserves**			**Reserve ranges**	
	2000 (K tons)	*2010 (K tons)*	*growth*	*2000 (K tons)*	*2010 (K tons)*	*Growth*	*2000 (years)*	*2010 (years)*
Iron Ore	1,060,000	2,590,000	144 percent	140,000,000	170,000,000	21 percent	132	66
Bauxite	135,000	209,000	55 percent	24,000,000	29,000,000	21 percent	178	139
Copper	13,200	15,900	20 percent	340,000	690,000	103 percent	26	43
Zinc	8,730	12,000	37 percent	190,000	250,000	32 percent	22	21
Nickel	1,250	1,590	27 percent	58,000	80,000	38 percent	46	50
REEs	84	133	59 percent	100,000	110,000	10 percent	1198	827

Source: Chatham House calculations based on USGS data

But reserves do not determine future supply, and high prices and tight markets have led to growing anxiety over the future availability of metals and minerals. Copper supplies have been extremely tight over much of the past decade. However, because of exploration in developing countries and expansion of discoveries in existing mines, proven copper reserves have more than doubled between 2000 and 2010. In contrast to this, bauxite reserve ranges have been considerably reduced, but supply has gradually expanded. At current consumption levels, rare earth reserves would last for centuries, but the world has experienced a severe supply shock in the past few years. Additionally, reserves ranges do not indicate anything about the quality of reserves. Despite intense exploration efforts, discoveries of large scale, high quality reserves have become less frequent (see figures on page 38).

Non-Ferrous Exploration Spending Against an Index of Metal Prices 1993-2011



Source: Metals Economics Group (2012) "World Exploration Trends 2012: A Special Report from the Metals Economics Group for the PDAC International Convention," p.2.

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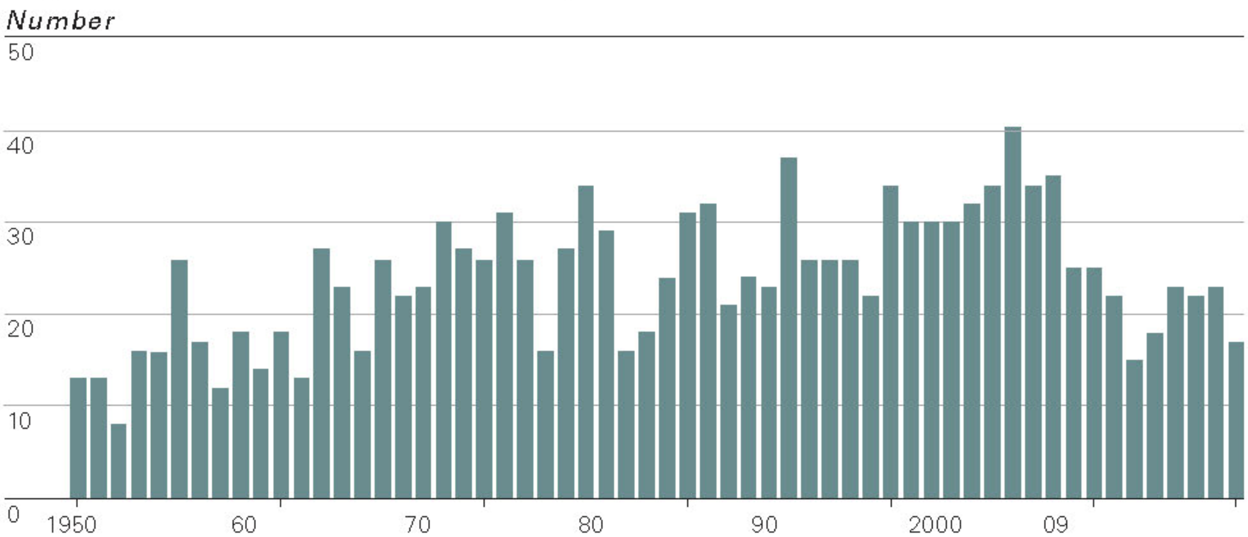
Major Discoveries of Non-Ferrous Metal Deposits 1950-2009



Source: Minex Consulting March 2010. http://www.minexconsulting.com/publications/Global%20Discovery%20Trends%201950-2009%20PDAC%20March%202010.pdf

Note: Presentation Schodde, Richard (2010) "Global discovery trends 1950-2009: What, where and who found them", MinEx Consulting, Toronto, 7 March 2010.

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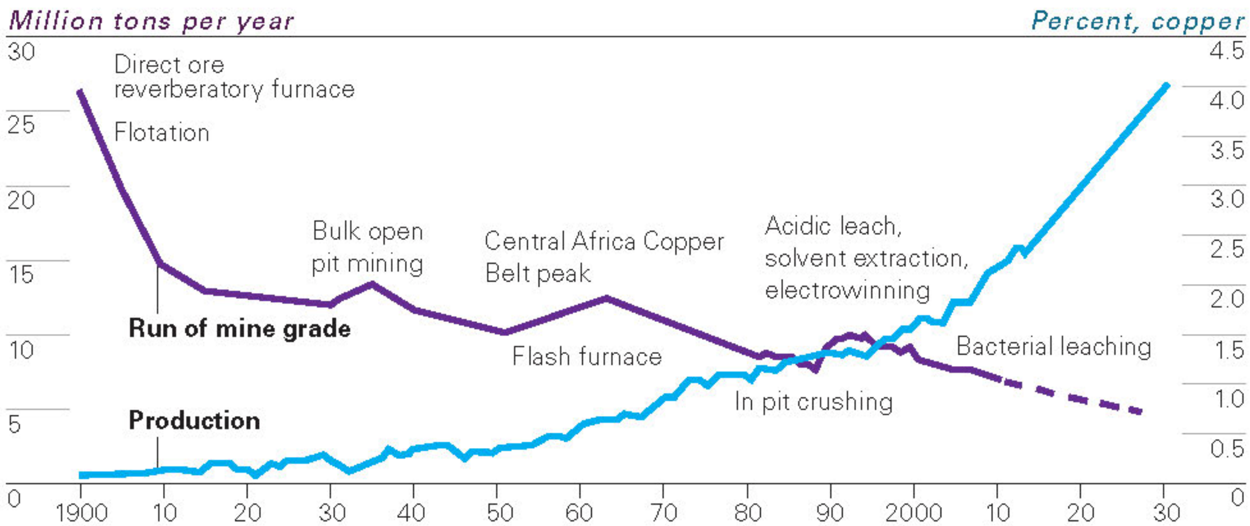
Evidence on the future costs of mineral production is inconclusive. Optimists point to the fact that evolving technology has enabled profitable mining of lower ore grades (see below). Pessimists respond that there is no guarantee that past successes in coping with lower grades will be repeated, especially if pressures from ore grades are compounded by rising energy costs, water scarcity, and the need to reduce carbon emissions.

Technical Progress, Copper Production and Ore Grades 1900–2030



Source: Presentation, Mackenzie, Andrew, 2011 "Mineral Deposits and their Global Strategic Supply" BHP Billiton. London, 14 December 2011.slide 25. Based on data from the US Geological Survey (1900-83) and Brook Hunt (1984 onwards).

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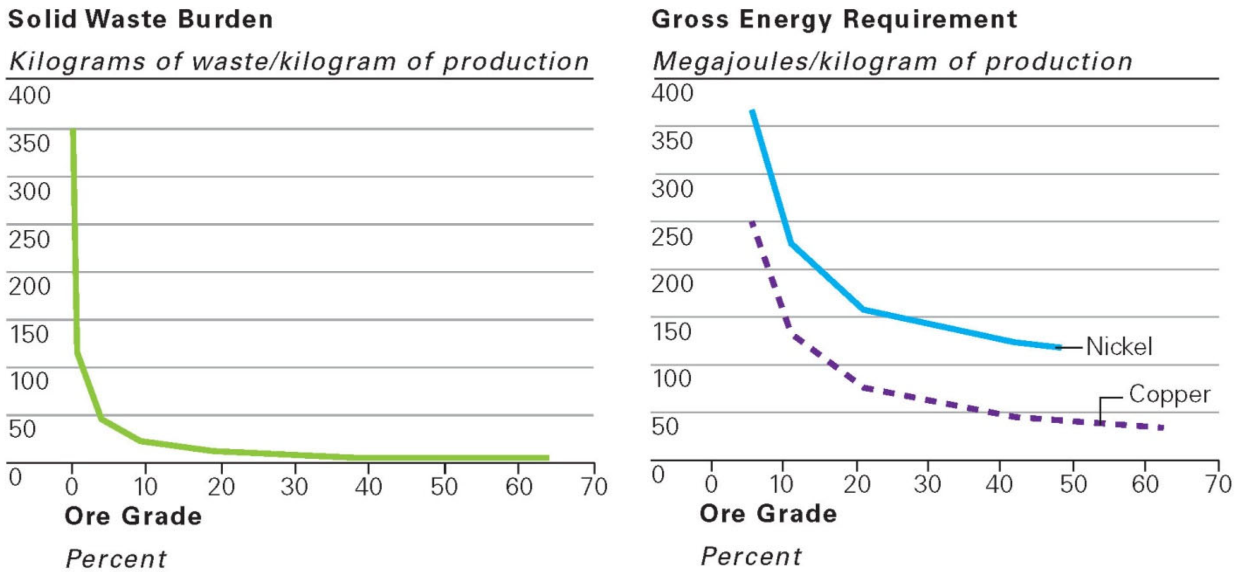
Ore grade declines affect individual metals to different extents. Ore grades in iron and bauxite mining are likely to remain relatively stable over the coming years. Zinc, lead, and particularly copper and nickel mining will be affected by ore grade declines, as will precious metals such as gold and Platinum Group Metals (PGMs). Geophysical constraints are therefore likely to be more important for the future production of these metals. Falling ore grades may lead, for example, to an exponential increase in the amount of energy and water needed to extract metals (see figures on page 40).

Waste Burden and Energy Use Per Kilogram of Metal Mined at Various Ore Grades



Source: Norgate, T.E., Jahanshahi, S., Rankin, W.J., 2006 "Assessing the environmental impact of metal production processes" Journal of Cleaner Production Volume 15, Issue 8-9, p. 838-848, p: 845.

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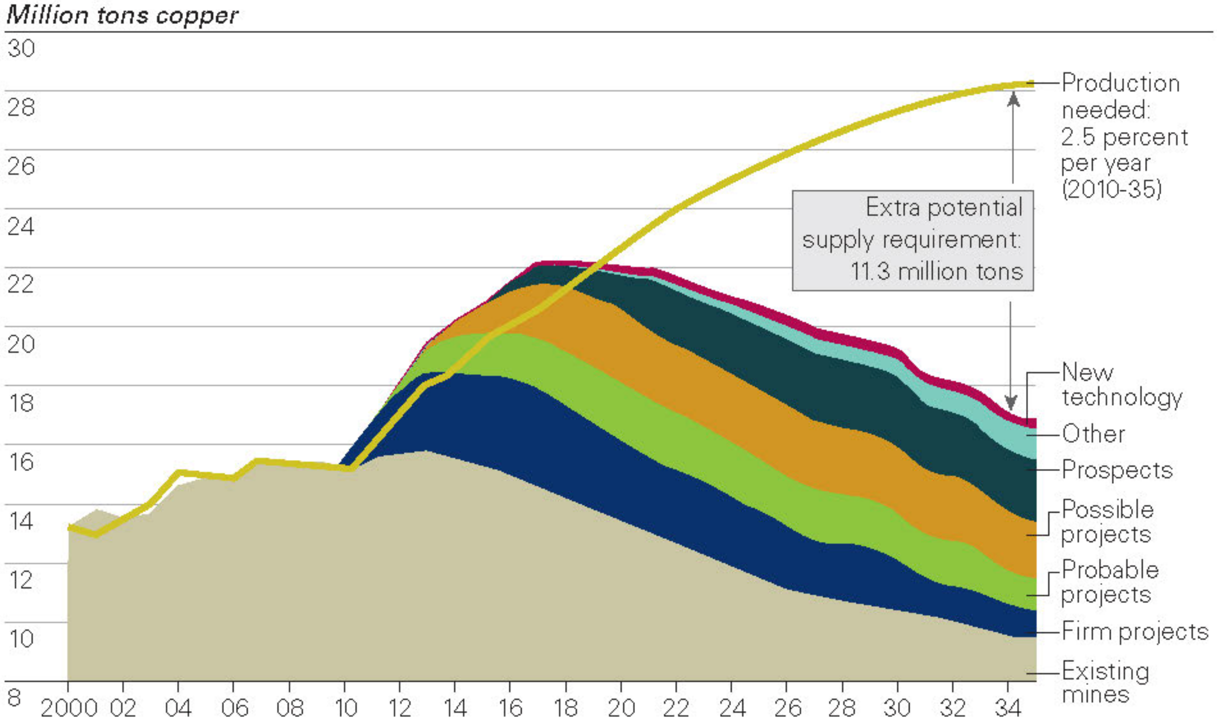
Although geophysical constraints may pose challenges in the medium and long term, 'above-ground' factors are more important in determining the availability of metals by 2030. These include the ability to secure financing for large-scale infrastructure development in politically unstable countries, shortages of skilled labor, potential for labor unrest, and the operational and commercial challenges and risks related to climate change. The quality and stability of investment and ownership frameworks in mineral-rich developing countries are therefore key factors in determining future supply growth.

Uncertainties over future supply are compounded by the fact that long-term supply forecasts often suffer from what mineral economists have described as 'mountain syndrome.' Supply is modeled using bottom-up projections of the output of existing mines and new mines under construction. Projections of future supply from these mines declines once their production has peaked. Because assumptions are not made about the next wave of investments, supply projections are often mountain-shaped. A gap between supply and demand in long term forecasts therefore does not necessarily indicate actual future shortages, but the size of the gap is a reasonable indication of the challenges that global supply will have to face in order to meet supply expectations (see figure page 41).

2010 Projection of the Global Copper Supply-Demand Balance Toward 2035

World Mine Production, 2000-35



Source: Presentation, Allan Trench, "The China Influence–Commodity Markets to 2012 and Beyond," Australian Resources Chinese Investment Conference, Adelaide, July 2010.

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Specialty Metals

Supply concerns over specialty metals and rare earths in particular have come into sharp focus in recent years, especially in advanced economies. Supply bottlenecks and concerns over monopolistic market structures have led to national security concerns, because specialty metals are essential to high-tech applications including emerging energy technologies and weapons systems. Concerns over specialty metals should be considered separately from bulk metals because of the very different nature of demand drivers and supply constraints. Declining ore grades and exhausted deposits are, for example, less relevant for specialty metals because they have mostly not been mined extensively in the past. Specialty metals are however not necessarily scarcer than bulk metals. Although such as tellurium and rhenium are geologically rare for example, many others, including rare earth elements, are not (see Annex D for an explanation of rare earth elements). The markets for specialty metals are typically small because their broader industrial applications have only recently been developed. The quantities of specialty metals consumed worldwide are typically three or four orders of magnitude smaller than those for non-ferrous bulk

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(…continued) **Specialty Metals**

metals like copper and zinc. In most cases, these metals are by-products of other mining and refining activities. Where they are mined directly, most of world supply tends to come from a handful of mines worldwide, as is the case for rare earths.

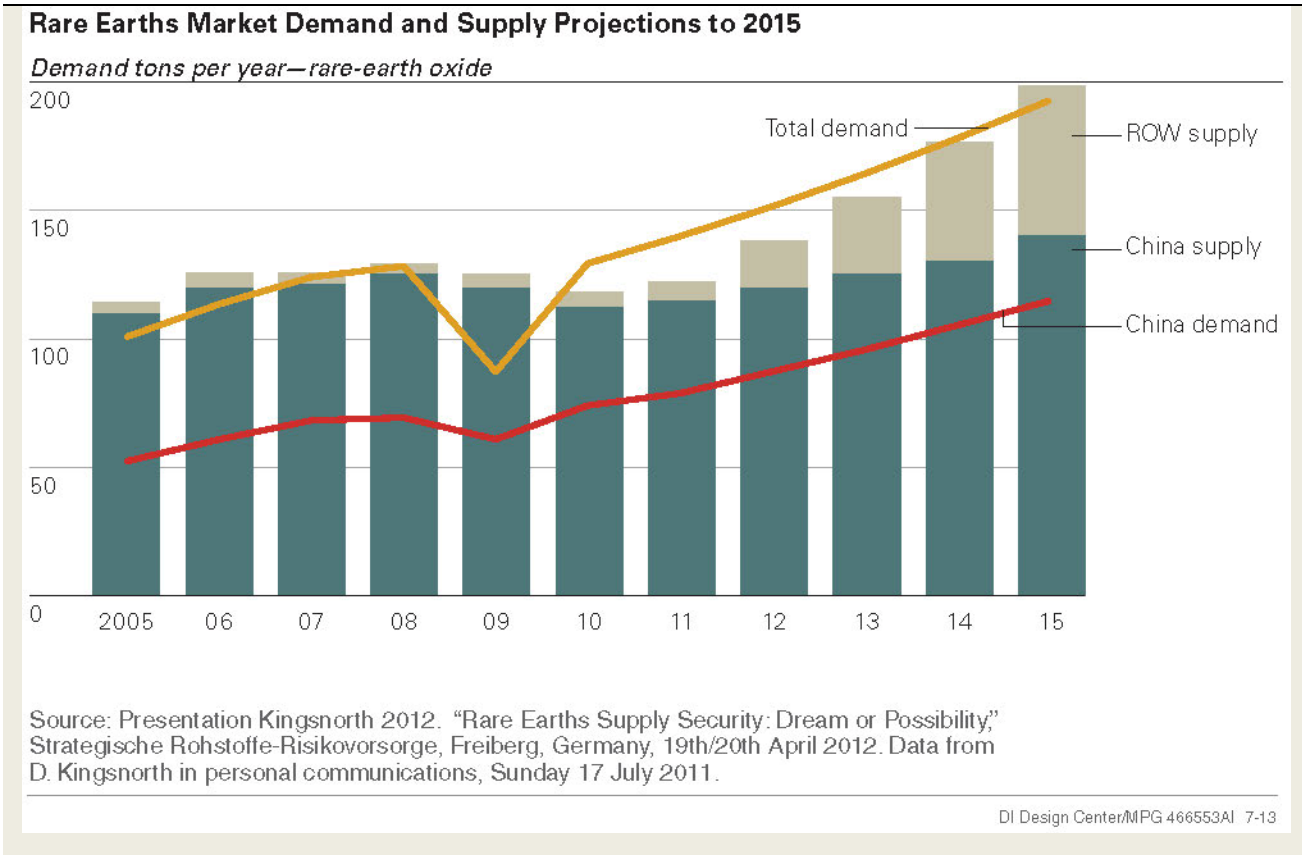
Small markets and the need for technically challenging refining and processing capabilities tend to concentrate market power for specialty metals in the hands of a few companies worldwide. As result, the sourcing of specialty metals is typically much more concentrated in terms of countries than bulk metal sourcing. Over 90 percent of global niobium supply is, for example, controlled by Brazil, with over 80 percent coming from a single mine owned by one company.

The central challenge to specialty metals supply is the extremely inelastic nature of supply in the short to medium term. When the few available suppliers reach full capacity, large market deficits can develop within a short timeframe, especially when new technical applications come on stream. This can lead to panic buying, physical shortages, and sharp price spikes of several hundred percent within twelve months. Such episodes are often exacerbated by speculation in opaque specialty metals markets as more transparent exchange-based trading does not currently exist for these metals. Government interventions such as the creation or release of stockpiles or export restrictions can also have a large impact on the availability of specialty metals. In addition to the recent price spikes for several rare earths, spikes for indium, gallium, or tantalum are also illustrative of these dynamics. Similar supply crises are highly likely in the future as new high-tech applications generate new demand booms. These spikes are typically followed by extended gluts with capacity expansion and research and development (R&D) contributing to demand destruction through improved resource efficiency and substitution.

In the rare earths case, the recent price spike in response to rapidly expanding use in magnet technologies and Chinese export restrictions has begun to ease as high prices have led to significant demand destruction. Mines in California and Australia were scheduled to go into production in 2012 and experts expect light rare earths such as cerium and lanthanum to be in excess supply for a considerable time to come (see figure on page 43). The Mountain Pass (California) and Mount Weld (Western Australia) mines will begin to produce in 2012, but will only add small amounts to heavy rare earths supply, so finding additional sources of supply remains essential. In contrast to other light rare earths, neodymium supply remains under pressure from strong growth in magnet applications and heavy rare earths will remain in deficit if additional non-Chinese mining operations do not come online. Recent exploration has led to promising new projects around the world (including for example projects in Canada, Vietnam, Sweden, and South Africa). Given falling rare earths prices, however, it is unclear whether these projects will secure financing to come into production before 2020.

The long-term prospects for rare earths are even more difficult to assess because their demand is driven mainly by emerging technologies such as electric vehicles and wind-turbines, for which rates of deployment and use of rare earths are difficult to forecast.

This paper does not represent US Government views.



For metals, copper faces some of the most serious supply side challenges: By 2020, the gap between projected demand and mines that are currently producing or are being currently constructed could amount to 30 percent and may increase to over 50 percent by 2030, even using fairly conservative demand growth rates. Even if possible projects and projects that are currently being explored are fully realized, industry sources still forecast a small supply gap in 2020 and a 40 percent supply gap in 2030. By the 2030s substitution and increased recycling may, however, alleviate the supply gap (see Metals Recycling text box next page).

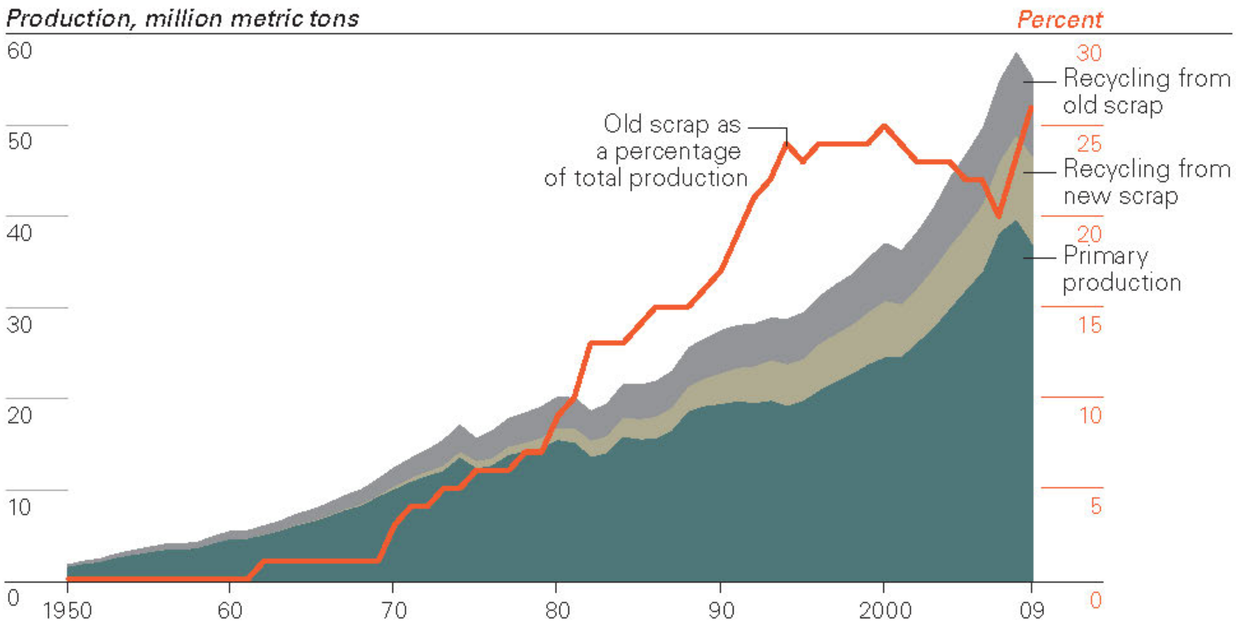
Aside from copper, meeting further demand growth in other metals will also require sustained large-scale investment and policy support in mineral rich economies. Abundant reserves and the oligopolistic structure of sea-borne iron-ore markets are likely to ensure that the future supply expansion is likely to be managed broadly in step with demand growth, even if price volatility and short-term supply disruptions are likely to persist. Industry projections show that the largest three iron ore suppliers (Vale, Rio Tinto, BHP Billiton) are likely to retain a market share of 65 percent of the seaborne market until at least 2025 and will continue to control over 80 percent of the relevant port and rail capacity.

For zinc, the projected supply gap from currently producing mines and mines under construction in 2020 is roughly a quarter of demand. If all mining projects currently being evaluated would come into production, the zinc market would reach a state of surplus by 2020. For nickel currently producing mines and recycling are likely to satisfy demand until at least 2020, and even by 2025 forecasts show only a small supply gap. For aluminum, rising energy costs are the key threat to future supply, as production is extremely energy intensive and already account for a large share of production costs.

Metals Recycling

Recycling is likely to play an increasingly important role, but the development of the recycling industry over the past decades has been disappointing when compared to the conventional extraction of new ore. This may be explained by a lack of focus of the industry on non-conventional supply, but also that governments have not provided adequate policy guidance to enable profitable recycling operations, including recycling friendly product design, the improvement of collection infrastructures, and better separation technologies. Towards 2030 and 2040, recycling may become an important source of supply for metals with rapidly declining ore grades such as copper.

Aluminum Production and Recycling, 1950-2009



Source: Estimates of primary and recycling production provided by the International Aluminum Institute in personal communications.
Note: Note: Recycling manufacturers define old scrap as discarded aluminum, such as aluminum lawn chairs, aluminum foil, pie tins or decorative aluminum items. New scrap materials are the little extras produced at aluminum plants that can be remelted and made into other aluminum products. These include clippings, borings and leftover skeletons from aluminum sheets that are cut to create cans.

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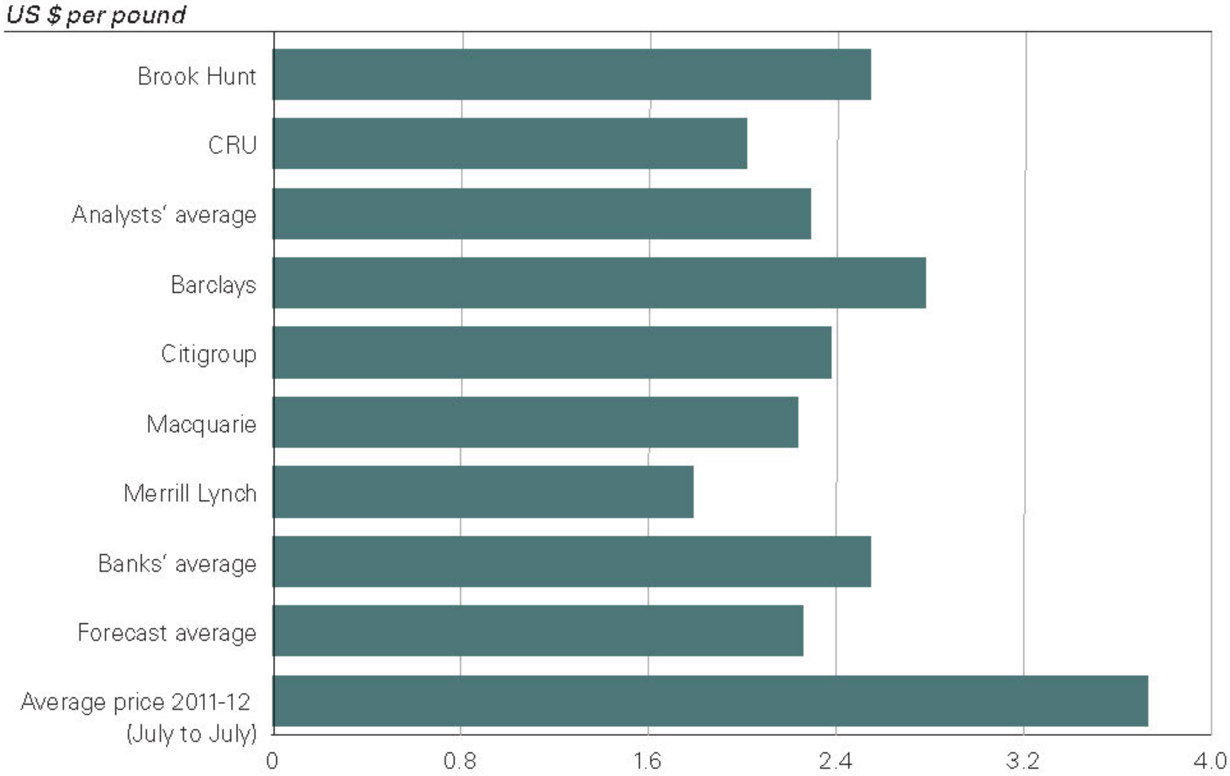
Investment, ownership, and taxation regimes as well as environmental legislation will be a crucial determinant of production costs and investment decisions by mining companies. The policies of large emerging economies and Australia, which currently dominate global mining, will therefore play a key role in determining the speed and costs of supply expansion over the next decade.

Increasingly, supply expansion will depend on relatively small developing countries, which account for a growing share of greenfield projects—projects that lack constraints from prior work. Such countries include Peru and Mongolia, as well as Sub-Saharan African states such as Guinea or the Democratic Republic of the Congo (DRC). Due to constraints on domestically available expertise and financing, these countries will have to rely on foreign investments both from major emerging economies and Western mining multinationals. This may lead to increasing frictions between Western mining multinationals and growing mining companies from major emerging economies such as China, Brazil, or India. China's controversial involvement in the extractive sectors of African countries foreshadows such tensions, although both its current influence over the African mining sector, which remains dominated by Western mining multi-national companies (MNCs), and Africa's importance to Chinese metal supply are often exaggerated.

Prices are subject to significant volatility, but with increased production costs long-term declines are unlikely to occur. Given expectations of continued high demand growth and the significant uncertainties surrounding supply, further price hikes and supply bottlenecks for individual metals are certainly possible. Generally, there are few detailed long-term metal price forecasts and most are not available in the public domain. Additionally, large uncertainties persist with regard to actual price levels, which are reflected in wide ranges between optimistic and pessimistic forecasts. The figure below shows, for example, a variety of estimates from industry analysts and banks for long-term copper prices.

Copper Price Forecasts Published in 2010 From Various Commercial Sources

US $ per pound



Source: Presentation. Diego Hernandez (2010) International mining industry overview: updates and future perspectives. 14th American School of Mines Investing in Latin America conference. 22 September 2010. www.pwc.com.br/pt_BR/br/eventos-pwc/school-of-mines/english/assets/plenary/09h15-intern-industry-overview-diego-hernand.pdf

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Key Minerals Uncertainties to 2020, 2030s, and 2040s			
Timeframe	**2011-2020**	**2021-2030**	**2031-2040**
Demand	*Economic growth* • For major metals: growth rate of China and acceleration of other emerging economies in metal use. *Technology* • For specialty metals: pace of global deployment of green technologies, particularly in advanced economies.	*Economic growth* • Speed of economic development of India and other emerging economies and the metal intensities of their growth-paths. *Consumption patterns* • Reductions in advanced economies' metal demand through re-use and resource efficiency improvements.	*Economic growth* • Development trajectories of developing countries, especially in Africa. *Technological development* • Material profile of the green economy.
Supply	*Geotechnical constraints* • For major metals: whether brownfield expansion in major producer countries can continue. *Political stability* • For major metals: speed of major greenfield projects in resource frontier states (e.g., Mongolia, Afghanistan, DRC, Guinea, Arctic) coming into production. • For specialty metals: availability of sufficient long-term financing to sustain capacity expansion.	*Political stability* • The reliability of resource frontier states (adequate investment, infrastructure, political stability, expertise). *Technology* • Ability of improvements in exploration, mining and processing technology to overcome geophysical constraints (e.g., ore grades, water constraints). *Policy* • Improvements in scrap recycling rates.	*Policy* • The extent to which re-cycling will supplant conventional metal extraction.

Many experts expect metal prices to remain structurally high as production and capital costs for projects have shifted upward over the past decade (see figures on page 47).

Price Volatility

Growing price volatility, as opposed to just higher price levels, has emerged as a key concern for natural resources. According to McKinsey, after relatively low price volatility in the 1990s annual price volatility is higher today than at any time in the last century, with the exception of the 1970s (see figure on page 48). Volatility is a key concern for both consumers and producers in commodity markets.

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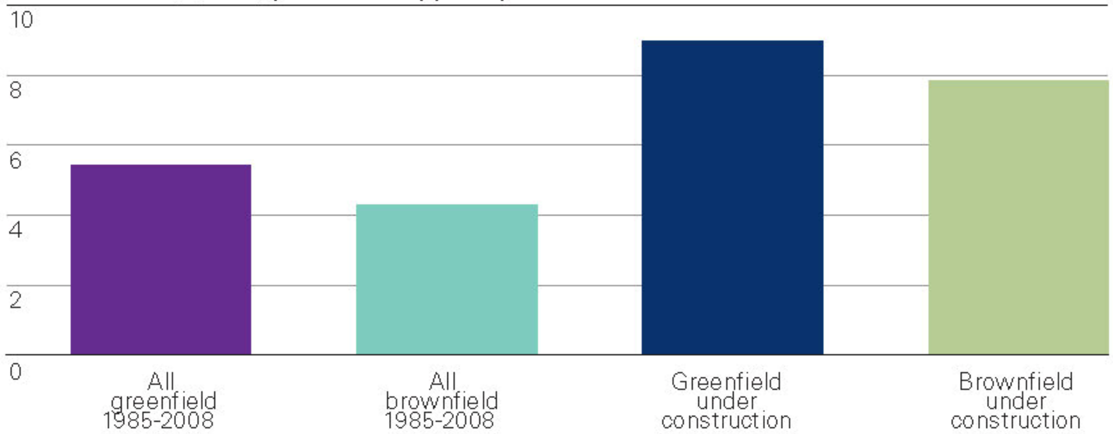
Capital Costs for Next-Generation Copper Projects Are Nearly Double of Mines in Production

Thousand US $ (2008) per ton of copper equivalent



Source: Presentation. Xstrata (2011) Transformation through organic growth and operational excellence. Investor presentation by S. de Kruijff (COO Xstrata copper North Queensland) during analyst visit Ernst Henry mining. April 2011. Slide 18.
www.pwc.com.br/pt_BR/br/eventos-pwc/school-of-mines/english/assets/plenary/09h15-intern-industry-overview-diego-hernand.pdf

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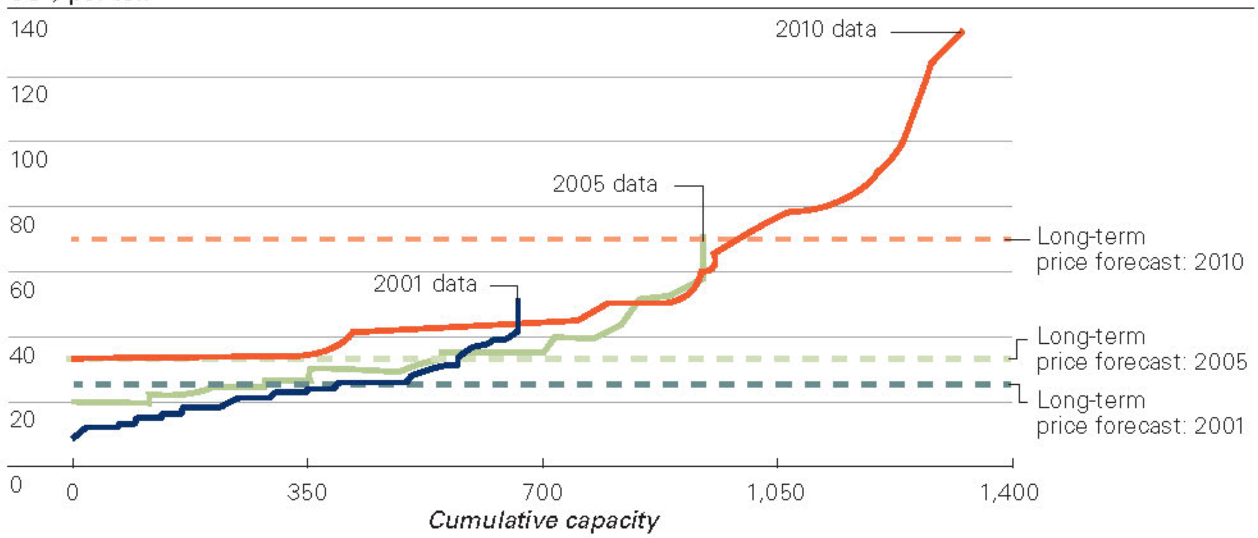
Iron Ore Cost Curves Have Shifted Up During the Past Decade

US $ per ton



Source: Presentation, Trench, Allan, 2010 "The China Influence – Commodity Markets to 2012 and Beyond" Australian Resources Chinese Investment Conference, Adelaide, July 2010.
https://docs.google.com/viewer?a=v&q=cache:0SNOhimXWDEJ:apolloglobal.com.au/site/DefaultSite/filesystem/documents/ARCI/Thursday/1320-1500/1420%2520CRU.pdf+The+China+Influence+Commodity+Markets+to+2012+and+Beyond&hl=en&gl=uk&pid=bl&srcid=ADGEESgvte8P-UUaGc3-ICLRYIE8dV-__z1IKkPfGnLEdqMw3QWS1raymlrcrvjRF4DhxG3ILs4OCUBqXpZmovsb9GXc2XrwjNHD2x6_uCy2aCP1MrGz3ErtgTiUVKAil5TqBWC55-24&sig=AHIEtbTUrgU2VxzvOzYvJwNNIvzEVetXVQ

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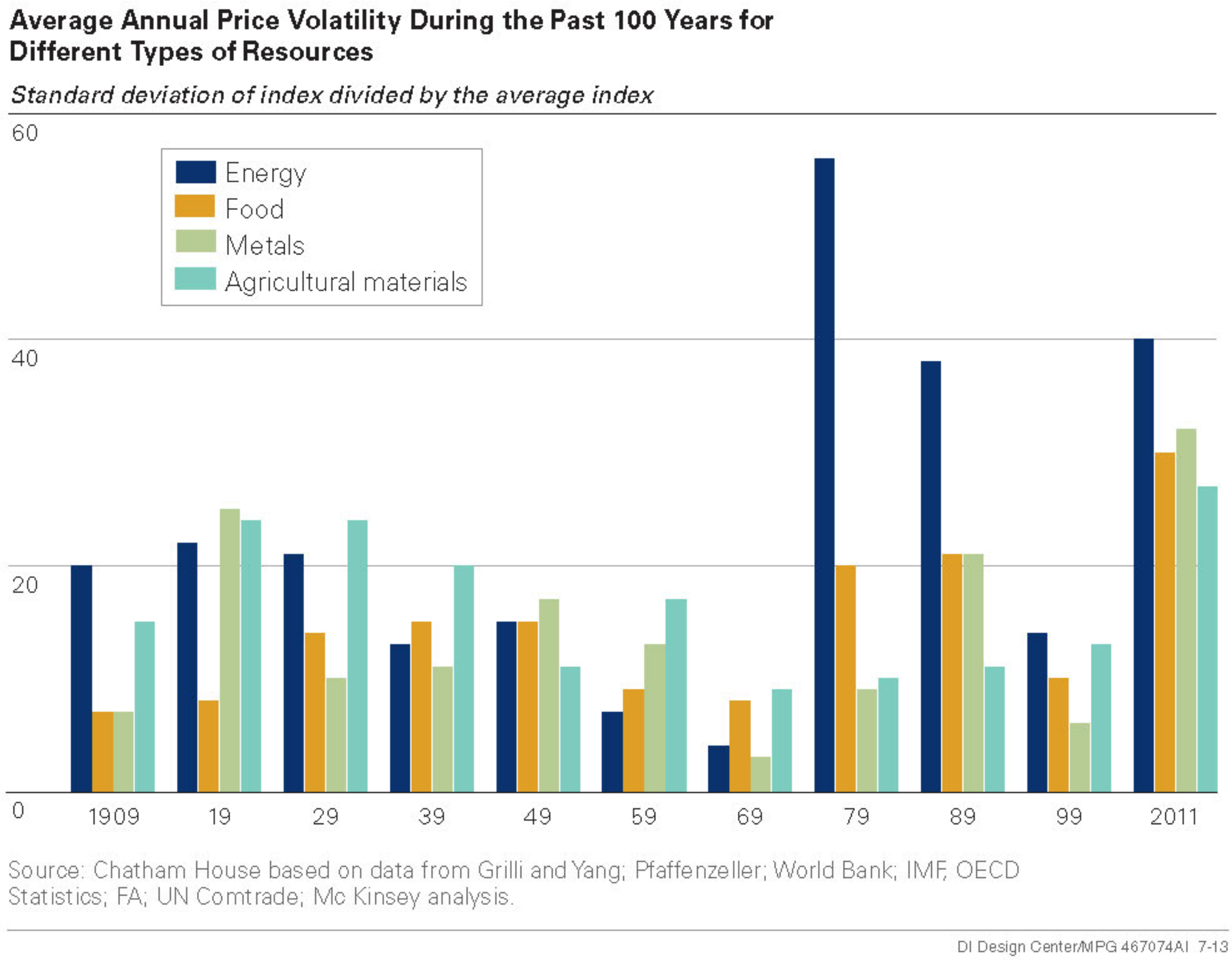


For producers, price volatility translates directly to volatility of revenues from resource production. Especially for resource-dependent economies relying on one or two commodities for the bulk of their income, price volatility can result in large fluctuations in income, fueling economic and political instability. Price volatility also poses significant short-term threats to the livelihoods of poor populations reliant on resource production (such as smallholder farmers or artisanal miners) with limited means to hedge against such fluctuations. Crucially price volatility leads to increased risk margins that will deter adequate investment, therefore translating into future resource constraints. This is not only a problem for vulnerable producers, but also for the extractive industries where large-scale and long-term investments require careful planning of cash flows and future revenue.

Manufacturers and retailers are similarly vulnerable to short-term price volatility that can lead to sudden jumps in import bills, cut significantly into profit margins, and lead to tensions over long-term supply contracts. Finally, end-users can be affected by price volatility, especially of food and energy. Short-term price spikes, rather than long-term increases in prices to which consumers and producers can more easily adjust, can be catalysts for social unrest.

An important function of derivative markets is price discovery—for example, by indicating expectations of future scarcity, derivative prices might signal to farmers to increase production. In the oil sector, controversy continues regarding the role of speculation in pushing up prices and increasing volatility. The

IEA continues to argue that market fundamentals—factors affecting the supply/demand balance—are primary drivers behind commodity prices changes. Although it does not rule out a role for commodities traders in price setting, it suggests that oil has seen similar volatility to other resources in recent years (see text box on Sources of Vulnerability). For oil, it is helpful to distinguish between wet markets and paper markets. The wet barrel market is where producers sell and refiners buy physical oil, and the paper barrel market is where promises written on paper are made.

As most commodity markets are expected to remain tight for the foreseeable future, high price volatility for natural resources is likely to remain high on the policy agenda creating frictions between producers and consumers and creating pressure for heavy handed interventions in derivative and commodity markets. Past attempts to control price volatility in international markets however show that while they cater to popular discontent, effective market interventions are extremely difficult to design and can backfire significantly.

Sources of Vulnerability

The sources of volatility and adequate policy responses remain hotly debated. Tight fundamentals and low stocks certainly contribute to volatility. But the literature discusses a range of additional possible drivers, including export restrictions or financial speculation. The extent to which financial speculation via commodity derivatives has contributed to recent price volatility for food and other commodities such as oil and many metals remains highly controversial, with credible and highly qualified experts lining up on both sides of the debate. The question is whether resource price volatility is excessive, due to a disconnection between financial markets and physical production.

The players in the paper market are conventionally divided into commercial and non-commercial players. The commercials are traders who operate in the wet barrel market and are interested ultimately in real wet barrels. The non-commercials are often referred to as ‘speculators.’ However, these distinctions could be misleading. For example, many of the major oil companies that would be classified as commercial operators also behave as non-commercials would behave.

Speculators move in and out of the market on a short-term basis and thrive on price volatility. Much of the money going into paper barrel markets recently has been investments by institutional investors pursuing portfolio diversification strategies just as they have in the case of food.

The links between wet and paper barrel markets are complex. The paper market provides the signals that create the context in which prices in the wet barrel market are negotiated. It does not set the price *per se* but indicates a starting point for discussion of the numbers in the contract. Perceptions in the paper market about surpluses or shortages in the wet barrel market inform behavior that determines the paper barrel price: perceptions of shortage, current or impending, will push the price up, and vice versa, as the money managers move cash into and out of the paper markets in anticipation of price changes.

- Since the 2008/9 price spikes in food and energy, there has been particular media and academic interest in this issue, not least because of the perceived role of derivatives market in the accompanying financial crisis. As the United Nations Conference on Trade and Development (UNCTAD) notes, ‘the increasing presence of financial investors in commodity markets has,

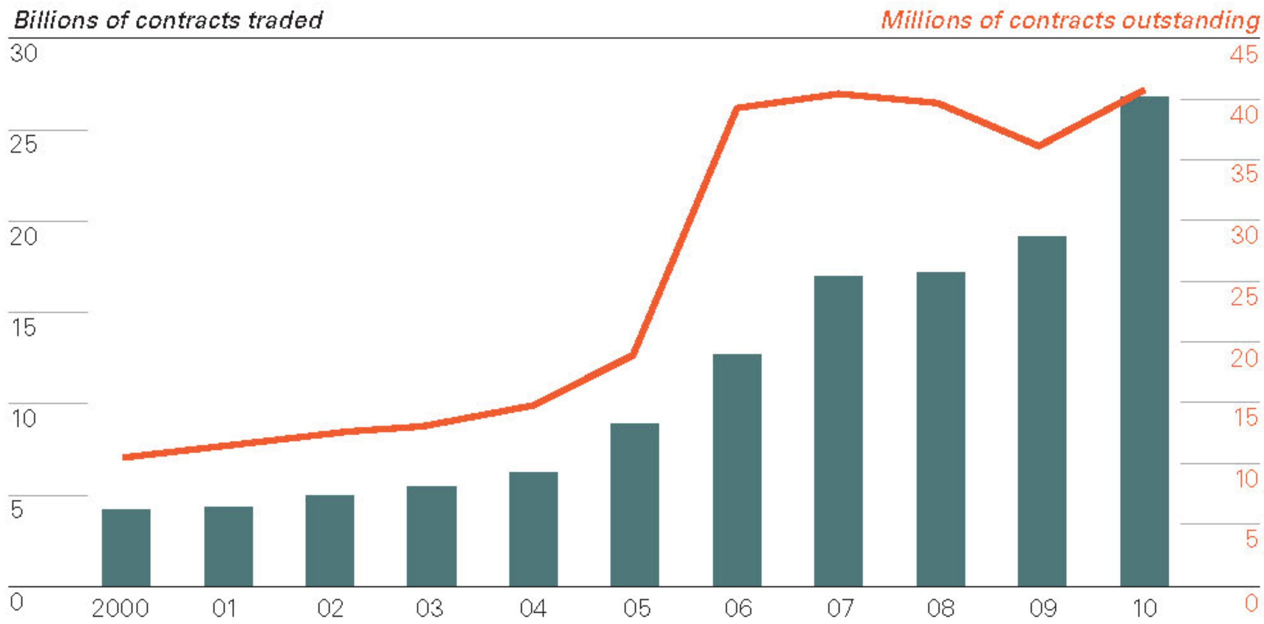
(Continued on next page…)

(…continued) **Sources of Vulnerability**

however, raised concerns that financial investors are creating increased volatility and price movements unrelated to market fundamentals.' As shown in the figure below, the sharp rise in commodity trading over the last ten years has coincided with the period of increased prices and price volatility.

The extent to which futures prices are signaling to participants in physical commodity markets to hoard on the expectation of real price rises, and in so doing are exerting upward pressure on real prices, is not settled. In the case of food, skeptics argue that the run-down in stock levels prior to recent price spikes indicates that no such behavior is occurring. Their opponents argue that stock data are too unreliable to demonstrate this relationship; rather, it is not a question of whether stocks are going up, but whether they are going down less rapidly than they would in the absence of speculation.

The Evolution in Commodity Trading on World Exchanges, 2000-10



Source: United Nations Conference on Trade and Development (2011), "Recent Developments in Key Commodity Markets: Trends and Challenges" (Geneva: United Nations Publications), Figure 5, p. 11.

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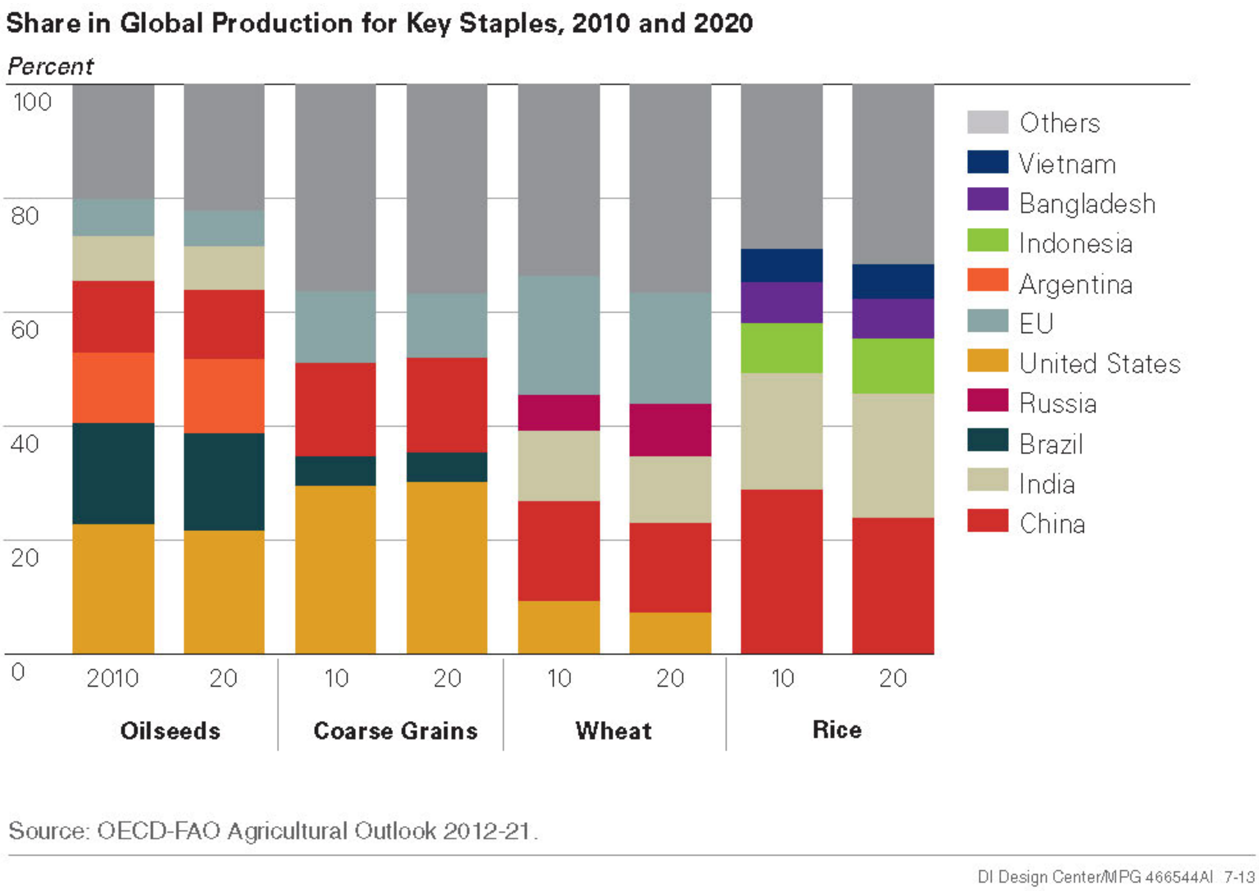
Uncertainty over the possible adverse impact of paper markets raises the question of whether precautionary regulatory measures should be taken, given that derivatives offer an important hedging function for producers. Nonetheless, there is a range of possible strategies for governments that do not reduce price volatility as such but help actors to deal with its consequences, from sovereign funds that absorb windfall profits on the upswing for producer countries, to targeted social protection and safety net programs for the most vulnerable populations.

Future Access to and Availability of Natural Resources

Looking to the future, the resources landscape—whether in terms of production, consumption, or trade—continues to face a wide range of critical uncertainties with the anticipation of expanding demand. Some of the new market dynamics—from the emergence of new players, shifting market balance—as well as major uncertainties could constrain future production, destabilize the global trading system, or generate political instabilities in key producing or import-dependent states.

New Market Dynamics

China accounts for nearly two thirds (63 percent) of the increase in global demand for soybeans over the last ten years, as well as 20 percent of the additional demand for maize and palm oil. China also accounts for nearly 50 percent of additional petroleum and a staggering 83 percent of coal consumption. India accounts for around 10 percent of growth in palm oil, wheat, oil, and coal.

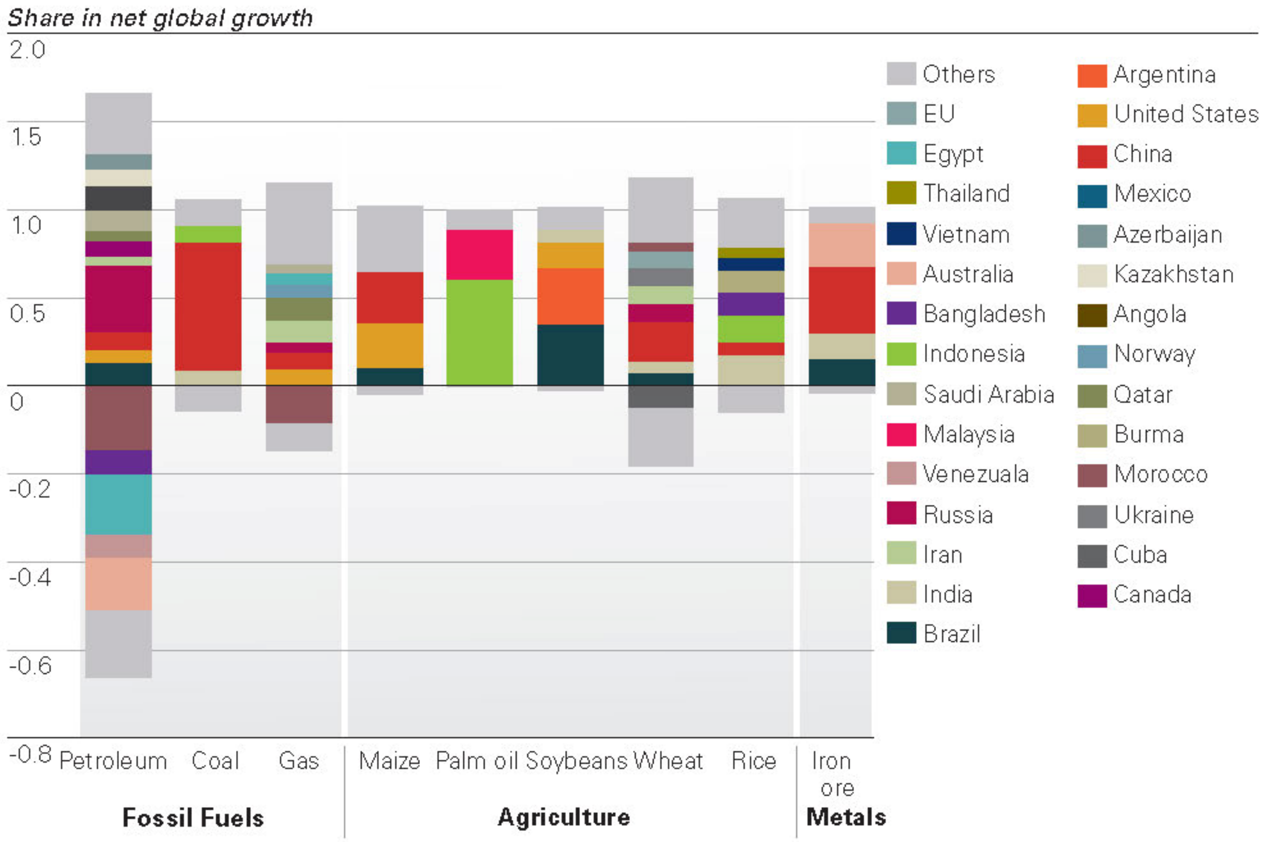


There is little doubt that China will continue to have a major impact on resource consumption and production over the next ten years, but when its resource consumption peaks—and for several key categories this is likely to occur in the 2020s—it is much less clear whether India and other emerging economies will fully take up the slack. This could be the difference between a return to lower resource prices due to excess production capacity, or a further tightening of global demand and supply.

Many other countries are driving global growth in one or two categories. The United States accounts for nearly 50 percent of additional maize consumption, while Argentina and Brazil together account for 25 percent of growth in soybean consumption. Only a relatively small set of countries, in most cases larger industrialized countries like the United States, Japan, or the European Union, have reduced their consumption over the same period and by relatively small amounts.

The emerging economies have also dominated global growth in resource production in the past decade. The emerging economies have dominated the global production expansion, with the role of the United States in agricultural products being the only major exception (see figure below). Poorer developing countries, with the exception of Angola for oil, have played a marginal role in production growth.

Share of Global Production Growth 2000-10 for Major Commodities



Source: Chatham House calculations based on various sources. Data for coal, gas, and petroleum come from International Energy Statistics of the US Energy Information Administration (EIA). Data for agricultural commodities are taken from FAOSTAT. Iron ore production data has been taken from the appendix to the USGS mineral commodity summaries..

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Major commodities consumer countries often encourage domestic production. Economically inefficient use of those resources can occur where this results in a strong domestic producer lobby in favor of policies such as production subsidies, price support, or other trade-related measures. Examples include the US biofuel mandate, Japanese rice production, industrialized country agriculture more broadly, Saudi Arabia and Iran for petroleum and gas, and China for coal and steel.

A combination of natural resource endowment, the domestic pressures brought by rising consumption, and current exploitation rates lie behind the patterns of production increase over the past decade. The countries shown in the figure on page 52 contributed at least 5 percent of net global growth in the past ten years for each commodity shown. Many of the countries grouped under ‘other,’ however, could be important to watch over the next few years to 2020 and beyond.

New winners and losers are reshaping emerging market dynamics. The table on page 54 provides a list of producers and consumers that are currently relatively small players in the respective resource market, but may emerge as important players in the medium to long term. Each of these countries has already contributed significantly to global supply or demand growth over the past decade (at least 1 percent of the last ten years’ additions). They have also been growing fast, with at least 7 percent increases in production or consumption per year.

Most of these potential future players are sitting at the threshold to higher income groups, medium sized in population, and belong to the booming second generation of emerging market economies. Key countries that stand out include Vietnam in five categories and Iran in seven. Some OECD countries and the BRICS appear in some categories (such as gas) if they have played a small role in the past and either consumption or production is expanding very rapidly.

Changing market structures for key commodities will erode the power of OECD countries as rule-setters in the global economy, especially in energy. Global markets for key commodities, as discussed in earlier sections, have undergone tremendous transformation in the past decade. In all the commodities analyzed, the markets are and will remain tight and rigid, not least due to a range of supply uncertainties in terms of geological reserves, and land availability.

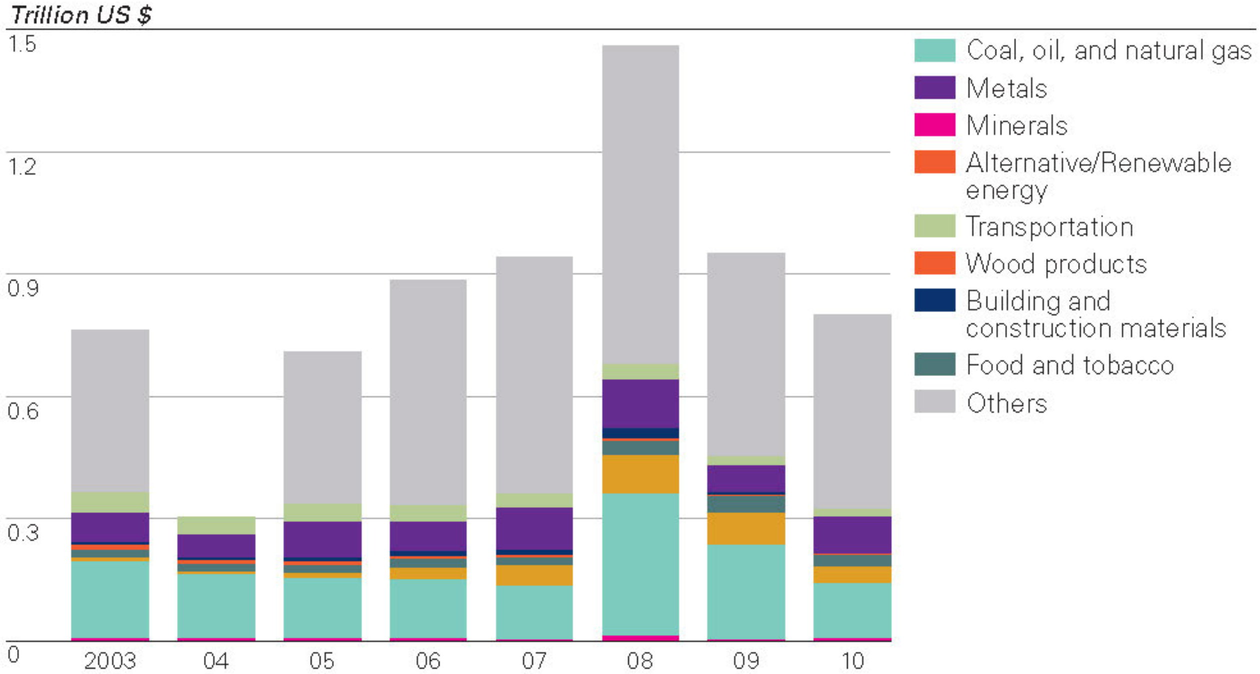
It is now widely understood that very large demand growth from emerging economies has redrawn the landscape for resources, from minerals, energy, food, to water. The combined effect of this resources demand growth together with shifting wealth to emerging economies is yet to be thoroughly analyzed and translated into policy planning.

The geography of oil imports and exports is adjusting to rapid growth in the emerging economies. By 2020, Asia-Pacific oil imports are likely to exceed and outgrow the surpluses available from the Middle East. The Middle East and other regions using pipeline supplies from Russia and Central Asia and sea transport from West Africa and probably Brazil will meet the Asia-Pacific deficits. Meanwhile, Russia, not the Middle East, will become the default supplier of Europe’s oil deficits.

State-backed Asian resource investment strategies are changing the business environment for competitors in extractive industries and other infrastructure investments in developing countries (see the figure on page 55). As oil consumption declines in the Atlantic region, so will the power of the OECD countries to be rule setters in the international oil market (see the figure on page 55). Beyond the next decade, Saudi Arabia may also lose its ability to control the global spare capacity in oil as its own domestic energy demand surges. Therefore, the traditional consumer and producer blocs will be less able to influence oil prices over the medium to long term and that will increase volatility.

Watchlist of Potential Large Future Producer and Consumer Countries		
	Emerging Producers	**Emerging Consumers**
Maize	Indonesia, Ukraine	Indonesia, Nigeria, Philippines, Iran, Vietnam
Wheat	Iran, Brazil	Pakistan, Egypt
Rice	Myanmar, Cambodia	Vietnam, Thailand, Philippines
Soybeans	Paraguay, Ukraine, Uruguay	Russia, Paraguay, Iran, Ukraine, Egypt, Syria
Aluminum	India, Brazil, UAE, Bahrain, Iceland, Mozambique	
Iron / Steel	Ukraine, South Africa, Iran, Guinea	Brazil, Turkey, Iran, Thailand, Vietnam
Copper	Zambia, DRC, Brazil, Iran, Laos, Mongolia	
Crude oil	Brazil, Angola, East Africa	India, Iran, Saudi Arabia, Russia, Brazil
Gas	China, Saudi Arabia, Egypt, East Africa	China, India, Saudi Arabia, UAE, Mexico, Egypt, Thailand, South Korea
Coal	Indonesia, Mongolia, Colombia, Vietnam, Mozambique	Kazakhstan, Indonesia, Vietnam, Turkey

A Significant Share of Global FDI Flows Into Resources and Resource-Related Industries



Source: UNCTADSTAT, based on information from the Financial Times Ltd, fDi Markets (www.fDimarkets.com).
Note: Data refer to estimated amounts of capital investment.

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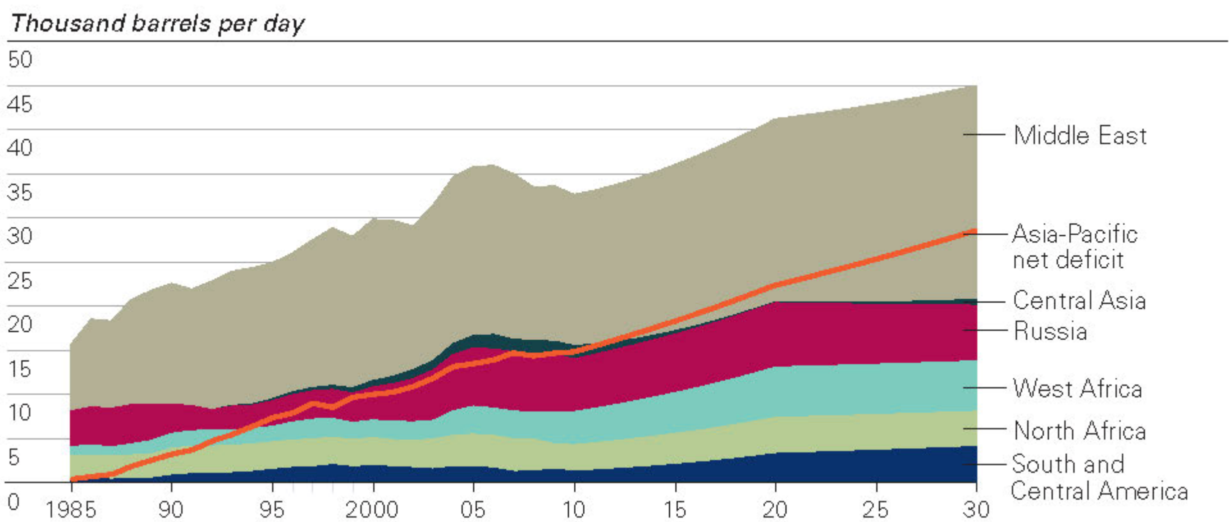
Global Oil Balances, 1985-2030



Source: Mitchell, J.V. (2010) "More for Asia: Rebalancing World Oil and Gas" (London: Chatham House).

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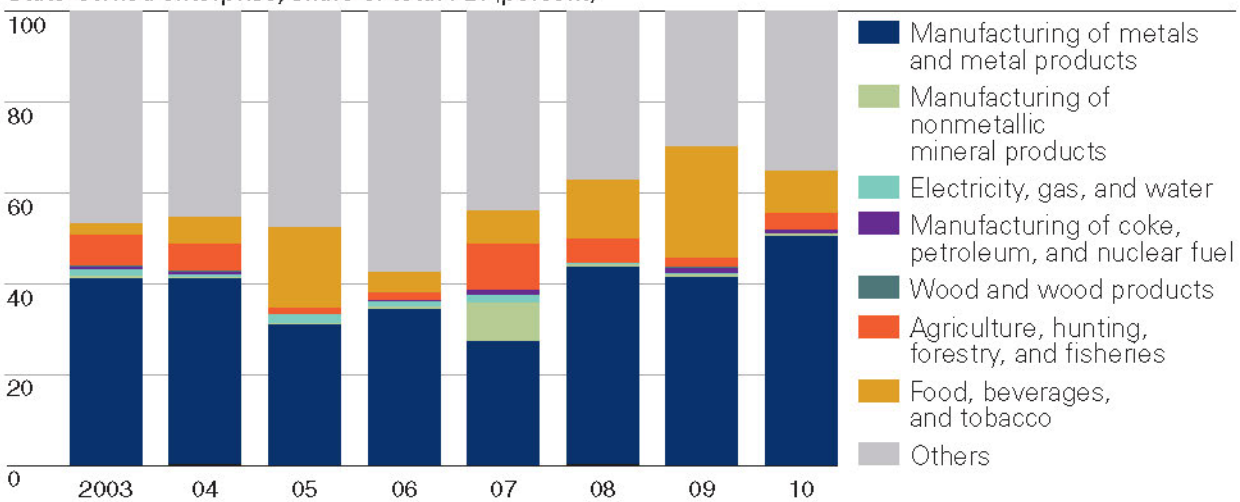
Foreign Direct Investments (FDI) by state-owned enterprises (SOE)—largely based in emerging markets—have focused increasingly on mining, quarrying, and petroleum. Overall, commodities are now responsible for about two thirds of SOE FDI. Today, Asian countries already prioritize long-term bilateral resource supply deals for oil, gas, and coal, sealed with political and economic support. And the search for water is already one of the driving forces between the recent wave of deals by some of the major emerging economies and Arab Gulf states to secure land for agricultural production overseas.

Over Half of FDI by SOEs Goes to Natural Resources and Closely Related Sectors

State-owned enterprise, share of total FDI (percent)



Source: UNCTADSTAT.
Note: The data include major SOE investors. FDI projects include both cross-border M&As and greenfield FDI projects. Industry/sector refers to that of the target/project, thus no count of relevant SO-TNCs is given.

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China has already replaced OECD countries as the largest import market for most metals, including iron ore, aluminum, and copper. Chinese policies will continue to influence global demand, supply and prices, and China is likely to use its status as a dominant customer where it sees its interests threatened. Disputes with Brazilian Vale over the control of iron ore shipping, or the pressure on Rio Tinto and other suppliers to abandon the decades old benchmark pricing system in favor of spot markets are examples of where China is already exercising this power. By 2030, India also may seek to exert itself in global resource markets as its imports rise.

Although state-owned or state-led companies are playing bigger roles in metals markets, the continued importance of Western-backed multinationals should not be understated. Industry consolidation, driven by ever larger economies of scale, has led to a few companies controlling an increasingly large share of global metals markets. The three largest companies controlled 15 percent of global non-fuel mineral markets in 2008, up from 10 percent in 1990. The share of the ten largest companies increased from 20 to 35 percent over the same timeframe.

The ability to dominate food markets is less clear-cut, as OECD countries are static consumers and heavy subsidizers of agriculture. Although the average temperature and precipitation changes from climate change are unlikely to have significant impacts on production in the near term, the occurrence of more extreme weather events—floods and droughts—will increase the volatility within food markets. In the medium term, climate change may benefit temperate regions in Europe and North America while harming tropical and sub-tropical farming. This coupled with agricultural subsidies, greater public and private spending on agricultural R&D, as well as greater resources for climate adaptation, suggests that OECD agricultural production is likely to remain strong to 2040, although new producing regions in South America and Eastern Europe will continue to develop.

Agricultural trade remains heavily distorted, in particular by the protectionist policies of many OECD countries including the United States, the European Union, and Japan. Although some progress in decoupling subsidies from production has been made in recent years, farm support remains controversial at the international level, where a stalled WTO process offers little hope of progress. Attempts to address the issue at the G20 have also failed, where industrialized country agricultural subsidies hampered attempts to deal with export controls, contributing to a situation where emerging economies refused to address export controls without progress on subsidies. In general, the continued subsidization of agricultural sectors by OECD countries limits their ability to advance an agenda designed to reduce food price volatility. Such an agenda would address the following key gaps in the global governance of food security, all recognized by the G20:

- The need for reform of biofuel policies, perhaps through the introduction of flexible mandates or safety valve mechanisms that would curtail demand during price spikes;
- A lack of rules for dealing with (and preventing) export controls;
- The persistence of trade distorting agricultural subsidies in many OECD countries that dis-incentivize developing country agriculture and lead to inefficient global production; and
- The failure to generate technology-related public goods including sufficient R&D for developing country agriculture.

Environmental Factors… a Source of Change

Climate change has been described as a 'threat multiplier,' exacerbating existing vulnerability in weak states. The problems associated with the rapidly increasing consumption of resources are exacerbated and multiplied by the effects of climate change: availability of water, food, and other raw materials is reduced, the risk of conflict over rapidly vanishing resources increases, and communities made vulnerable by their lack of resources face mounting environmental hazards. In its Global Environment Outlook 5, UNEP concludes that these complex, non-linear changes in global environmental systems are already having serious impacts on human wellbeing. Academic research reports that three of nine critical and interlinked thresholds of global environmental stability have already been overstepped.

Over the past few years, the security implications of climate change have increasingly been explored. These include reports and analysis by research institutions and nongovernmental organizations, governmental, and intergovernmental organizations. The CNA corporation in 2007 published a report that outlined the role of climate change as "a threat multiplier for instability in some of the most volatile regions of the world." In 2008, the US National Intelligence Council completed a classified assessment that explored how climate change could threaten US security in the next 20 years by causing political instability, mass movements of refugees, terrorism, or conflicts over water and other resources in specific countries.

An assessment completed in 2007 by the Australian Defense Force concluded that climate change and rising sea levels posed one of the biggest threats to security in the Pacific; these impacts might also spark a global conflict over energy reserves under melting Arctic ice.

The past five years have seen a steady uptake of climate threats in national security assessments. In the United States, for example, the 2010 Quadrennial Defense Review suggests that climate change may accelerate instability and conflict, and will change its operating environment. Similar exercises were undertaken in Spain, Italy, Sweden and the United Kingdom by agencies associated with defense ministries.

Projected Climate Impacts on Different Regions

The impacts of climate change and the resulting consequences vary across regions and latitudes, increasing the complexity of both the practical and the political problems involved in preparing for them. For example, an increase of 2 degrees Celsius could make parts of the Northern Hemisphere more agriculturally viable, while in South Asia and Latin America this increase would mean a significant deterioration of food production. Based on the findings of the IPCC (2007), the section below summarizes the likely impacts of climate change in different regions.

Africa. By 2020, between 75 and 250 million people are projected to be exposed to increased water stress due to climate change. In some countries, yields from rain-fed agriculture could be reduced by up to 50 percent by 2020, and agricultural production in many African countries is projected to be severely compromised. This would further adversely affect food security and exacerbate malnutrition. Towards the end of the 21st century, projected sea level rise will affect low-lying coastal areas with large populations. The cost of adaptation could amount to at least 5-10 percent of Gross Domestic Product (GDP). An increase of 5-8 percent of arid and semi-arid land in Africa is projected by 2020 under a range of climate scenarios.

***Asia*.** Climate change is projected to compound the pressures on natural resources and the environment associated with rapid urbanization, industrialization, and economic development. By the 2050s, freshwater availability in Central, South, East, and Southeast Asia, particularly in large river basins, is projected to decrease. Coastal areas, especially heavily populated mega delta regions in South, East and Southeast Asia, will be at greatest risk due to increased flooding from the sea and, in some mega deltas, flooding from rivers. Endemic morbidity and mortality due to diarrheal disease primarily associated with floods and droughts are expected to rise in East, South, and Southeast Asia due to projected changes in the hydrological cycle.

Australia and New Zealand. By 2020, significant loss of biodiversity is projected to occur in some ecologically rich sites, including the Great Barrier Reef and Queensland Wet Tropics. Water security problems and a decline in agriculture and forestry are projected for southern and eastern Australia, as well as eastern New Zealand, by 2030. However, initial benefits are projected in some regions of New Zealand. By 2050, ongoing coastal development and population growth in some areas of Australia and New Zealand is projected to exacerbate risks from sea level rise and the severity and frequency of storms and coastal flooding.

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(…continued) **Projected Climate Impacts on Different Regions**

Europe. Climate change is expected to magnify regional differences in Europe's natural resources and assets. Negative impacts will include increased risk of inland flash floods, more frequent coastal flooding, and increased erosion (due to amplified storm intensity/frequency and sea level rise). Mountainous areas will face glacier retreat, reduced snow cover and winter tourism, and extensive species losses (in some areas up to 60 percent by 2080 under high-emissions scenarios). In southern Europe, climate change is projected to worsen conditions (high temperatures and drought) in a region already vulnerable to climate variability, and to reduce water availability, hydropower potential, summer tourism, and crop productivity. Climate change is also projected to increase health risks due to heat waves and the frequency of wildfires.

Latin America. By mid-century, higher temperature and associated decreases in soil water are projected to lead to gradual replacement of tropical forest by savanna in eastern Amazonia, and semi-arid vegetation will tend to be replaced by arid-land vegetation. There is also a risk of significant biodiversity loss through species extinction in many areas of tropical Latin America, and productivity of some important crops is projected to decrease and livestock productivity to decline, with adverse consequences for food security. In temperate zones, soybean yields are projected to grow. Overall, the number of people at risk of hunger is projected to increase. Changes in precipitation patterns and the disappearance of glaciers are projected to affect significantly water availability for human consumption, agriculture, and energy generation.

North America. Warming in western mountains is projected to cause decreased snow pack, more winter flooding and reduced summer flows, exacerbating competition for over-allocated water resources. In the early decades of the century, moderate climate change is projected to increase aggregate yields of rain-fed agriculture by 5-20 percent, but with important variations across regions. Major challenges are projected for crops that are near the warm end of their suitable range or which depend on highly utilized water resources. Cities currently experiencing heat waves are expected to be challenged further by an increased number, intensity, and duration of heat waves during the course of the century, with potential for adverse health impacts. Coastal communities and habitats will be increasingly stressed by climate change impacts interacting with development and pollution.

Polar Regions. The main projected biophysical effects are reductions in thickness and extent of glaciers, ice sheets, and sea ice, as well as changes in natural ecosystems with detrimental effects on many organisms including migratory birds, mammals, and higher predators. For human communities, impacts are projected to be mixed, particularly those resulting from changing snow and ice conditions. Detrimental impacts would include those on infrastructure and traditional indigenous ways of life. In both polar regions, specific ecosystems and habitats are projected to be vulnerable, as climatic barriers to species invasions are lowered.

Small islands. Sea level rise is expected to exacerbate inundation, storm surge, erosion, and other coastal hazards, thus threatening vital infrastructure, settlements and facilities that support the livelihood of island communities. Deterioration in coastal conditions, through erosion of beaches and coral bleaching, for example, is expected to affect local resources. By mid-century, climate change is

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(…continued) **Projected Climate Impacts on Different Regions**

expected to reduce water resources in many small islands, for example in the Caribbean and Pacific, to the point where they become insufficient to meet demand during low-rainfall periods. With higher temperatures, increased invasion by non-native species is expected to occur, particularly on mid- and high-latitude islands.

Source: E3G (2011) based on IPCC report

At the global level, a number of trends are perceived as potential accelerants of future conflict:

- **Food or water scarcities**: The World Bank estimates that by 2025 climate change will result in 1.4 billion people across 36 countries facing crop or water scarcities (600 million people in 21 countries are currently affected by resource scarcities). The effects of climate change in North Africa are likely to further degrade existing water and food scarcities, unstable economies, deteriorating urban infrastructure, and sociopolitical systems, and lead to increased economic migration pressures.

- **Large-scale migration:** By 2030, dramatic changes in patterns of human settlement are predicted by many. Antonio Guterres, the UN High Commissioner for Refugees, has warned that climate change could uproot populations by provoking conflicts over increasingly scarce resources. By 2050, 200 million people may be permanently displaced climate migrants, a ten-fold increase over the current total documented refugee and internally displaced populations.

- **Glacial melting and water disputes:** The impacts of Himalayan melting will be felt across a number of countries, including India, Pakistan, Afghanistan, Burma/Myanmar, Bangladesh, Nepal, Bhutan, and China. This is likely to undermine the already fragile water sharing arrangements among these states.

- **Extreme weather and floods:** Increasing sea levels and recurring floods or droughts could lead to a large-scale displacement of populations from small island states like the Maldives and Tuvalu and flood prone nations such as Bangladesh.

Increasing environmental disruptions and natural resource stresses will impact migration patterns over the next 50 years. In addition to population growth, instability in the availability of, and access to, natural resources and the rapid transmission of price increases can be a direct—though multi-dimensional—driver for large-scale and inter and intrastate migration. Over the last 50 years, international migration levels have steadily increased and current estimates imply a further growth to 252 million by 2030, and 283 million by 2060.

Evidence suggests that looking forward over the next 50 years, although migration will mostly be concentrated within international borders, it is likely that almost as many people who will be moving out of areas with increased environmental risks and natural resource constraints, will be moving into them.

Different regional landscapes will continue to pose distinctive challenges to their local populations as the impacts of climate change and environmental degradation perpetuate themselves in rising temperatures, fluctuating rainfall, and land degradation. Within dry land regions, which make up almost half of the global land area, there are already an estimated two billion people experiencing the negative impacts of ecosystem disruption, at least half of whom are considered to depend directly on natural resources. Although large areas of these predominantly inhospitable regions are currently used for agriculture production, income diversification is considered unlikely, placing much of the population at an increasing disadvantage.

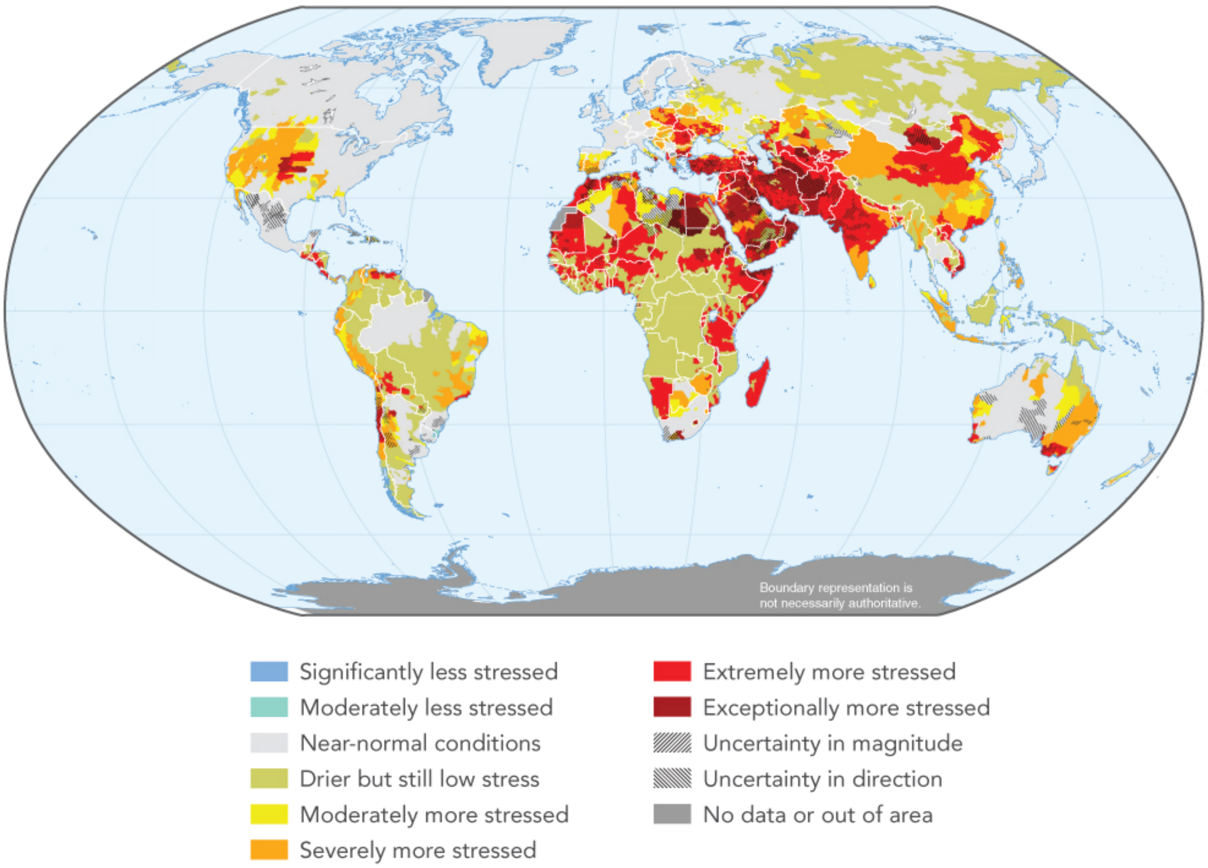
There will remain many who are unable, due to lack of financial resources and transferable labor skills, to move from areas where there is an acute squeeze on natural resource access and availability. This often involuntary entrapment within already vulnerable regions can and will continue to contribute to social tensions and conflict as populations compete for valuable natural resources during environmental shocks such as drought and flooding.

Social-economic and political conditions, policy interventions, and human adaptation to dealing with environmental events all have the ability to change the characteristics of migration behavior. However, what is certain is that resource pressures will continue to affect and influence migration patterns globally over the 2020, 2030, and 2040 time horizons.

Water scarcity will grow as a significant crosscutting constraint on future resource production. ***According to UNEP, water demand is now above sustainable supply levels in many parts of the world, often acting as a constraint on development, degrading the environment, and encouraging growth in desalination. Countries already facing serious water stress include those of the Middle East, South Asia, and East Asia. Overlaying regions of land scarcity reveals China and India to be facing some of the most acute aggregate stress across both resources.***

Water scarcity is likely to worsen significantly by 2025 (see map on page 62). About 80 percent of the world's population live in areas with high levels of threat to water security. In 2000, half a billion people lived in countries chronically short of water. By 2050, three quarters of the global population could face freshwater shortages. While global water withdrawals have tripled in the last 50 years, the reliable supply of water has stayed relatively constant during the same period. According to the Water Resources Group's 2030 scenarios (published in 2009) current levels of demand for water at the global level already exceed sustainable supply, unsustainable water withdrawals from non-renewable aquifers being coupled with unreliable availability in many places. Water demand could be as much as 40 percent greater than supply by 2030 (see figure on page 63). The supply gap varies by geography. It is most severe in developing countries and countries in transition. It is easy to overlook the connections between different resource uses. Some of those regions most at risk of water shortages are also globally important agricultural centers: including northwest India, northeast China, northeast Pakistan, California's Central Valley, and the midwestern United States.

Projected Change in Water Stress to 2030



Source: World Resources Institute and ISciences, LLC.

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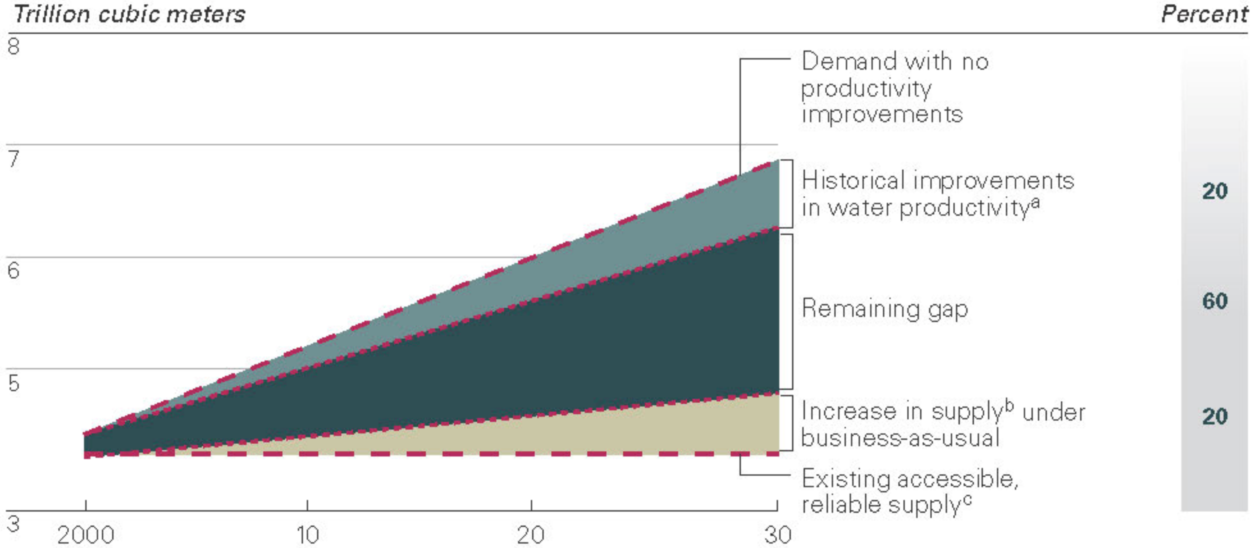
Although energy production is forecast to grow by approximately 40 percent over the next two decades, water consumption by the energy sector is set to more than double over the same period. The effects of water stress will be felt most directly in the hydropower sector but also in nuclear and thermal power stations reliant on water coolant systems and in a wide range of manufacturing industries. Water availability will be a critical determinant for decisions on where to invest and where to produce. According to FAO localized environmental degradation (aquifer depletion, declines in soil quality, and reductions in biodiversity) interacts with climate change to present a major challenge to food production and to other competing uses of water on every major continent.

Projected Global Demand for Water



[a] Based on historical agricultural yield growth rates from 1990-2004 from FAOSTAT, agricultural and industrial efficiency improvements from IFPRI.
[b] Total increased capture of raw water through infrastructure buildout, excluding unsustainable extraction.
[c] Supply shown at 90-percent reliability and includes infrastructure investments scheduled and funded through 2010. Current 90-percent-reliable supply does not meet average demand.
Source: 2030 Water Resources Group–Global Water Supply and Demand model; IFPRI; FAOSTAT.
http://www.mckinsey.com/App_Media/Reports/Water/Charting_Our_Water_Future_Exec%20Summary_001.pdf

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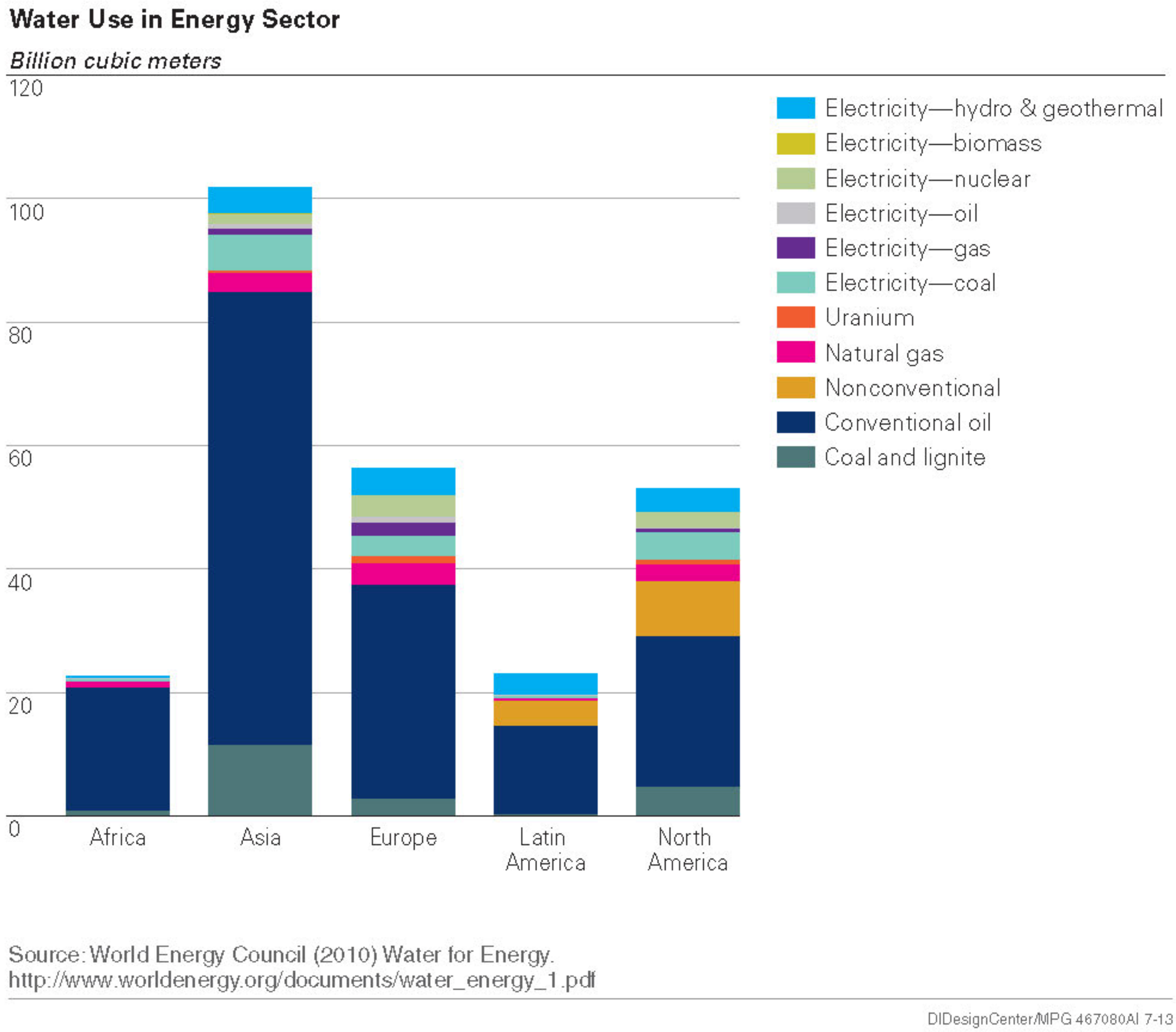
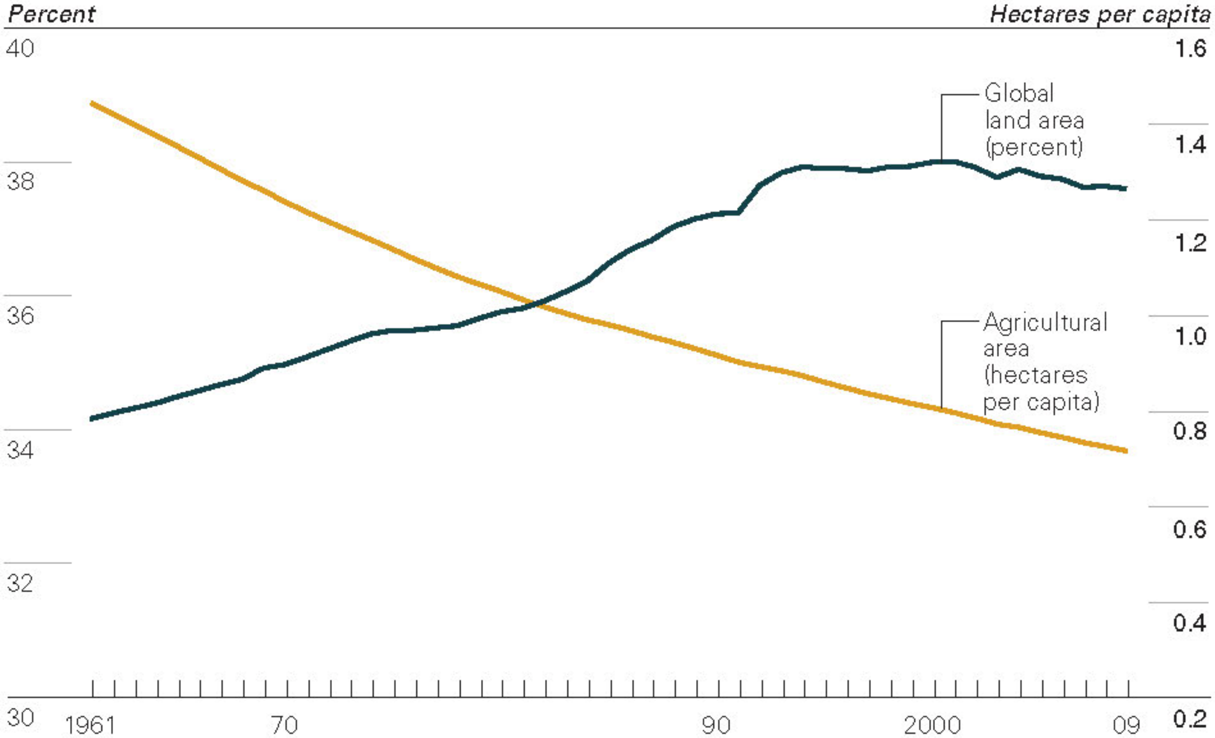
The energy sector is also a significant user of water, with the World Energy Council suggesting that use in 2005 was in the order of 1.6 trillion m^3. The majority of this, over 80 percent, is used in the production of traditional biomass, with 257 billion m^3 associated with commercial energy and electricity production. This compares to the total freshwater withdrawal of water of around 3862 km^3 (3.8 trillion m^3) as assessed by Aquastat. Aquastat further suggests that 723 km^3 of water are used globally (around 35 percent of total water use) in industrial processes such as mining, transport, processing or transforming of energy. The figure on page 64 shows the regional breakdown of the water consumption in the commercial energy sector.



Land for food production is coming under increasing pressure from competing uses, with good cropland being lost to urbanization and industrial development, or being put to alternative uses such as biofuel production and reforestation (see the figure on page 65). Losses of high-quality cropland are expected to continue due to the higher returns available from non-agricultural uses. In response, agriculture is gradually shifting onto more marginal lands, with poorer soils and less developed infrastructure, and a particular focus on Sub-Saharan Africa where the largest reserves of arable land remain.

The question of how much arable land remains continues to challenge researchers and policymakers. Estimates depend upon assumptions of future land uses and value-based judgments about acceptable levels of land-use change emissions, biodiversity loss, and community displacement for example. A recent report by the UK Government on the future of farming concluded that we should "work on the assumption that there is little new land for agriculture."

Declining Share of Land Devoted to Agriculture, 1961-2009



Source: Oxfam (2011) "Growing a Better Future: Food Justice in a Resource Constrained World." Available at: http://www.oxfam.org/sites/www.oxfam.org/files/growing-a-better-future-010611-en.pdf (p.17). Calculated from FAO, http://faostat.fao.org/site/377/default.aspx

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The displacement of agriculture to more marginal and climate-vulnerable regions presents obvious challenges. As well as having lower productive potentials, these areas have weak infrastructure and are generally more susceptible to production shortfalls, particularly as climate change gathers pace and more extreme climatic events become more common. Desertification, expected to accelerate in many arid regions as a result of climate change, is already claiming agricultural land at an estimated 12 million hectares a year—enough to grow 20 million tons of grain. **By 2050, up to 50 percent of agricultural land in Latin America—one of the world's two key production and export centers—may be subject to desertification.**

Just as land is coming under increasing pressure from municipal and industrial uses, so too is water. Almost a third of global croplands are located in areas of 'medium high' to 'extremely high' water stress. Globally, agriculture accounts for about 70 percent of fresh water use and as much as 90 percent in many developing countries. These shares of agriculture water use are not sustainable if industrialization and urbanization are to proceed. Looking to the medium term, agriculture is the sector likely to suffer most, with consequences for food security. UNESCO estimated that, under current conditions, water demand for agriculture would rise by 70-90 percent by 2050 in order to feed the projected world population at that date.

Future food security is under threat from climate change. Climate change poses a major threat to future food security. A recent study estimated that global temperature rises are already exerting a significant drag on cereal yields: between 1980 and 2008, it found global production of maize and wheat to be 3.8 percent and 5.5 percent lower respectively as a result of warming. But serious impacts of climate change on food security are not expected until the middle of the century. In particular, these impacts will be felt most keenly in the developing world, especially in Sub-Saharan Africa, where much remaining arable land is situated and where agriculture expansion is possible.

Urgent investment in infrastructure, irrigation, and climate adaptation is needed if Africa is to avoid severe declines in yields. Conversely, a productive and resilient agricultural sector in Africa would offer important benefits: it would enhance regional food security and reduce poverty, minimizing vulnerability to shocks and concomitant instability and crisis; moreover, by closing the yield gap with developed countries, global food security would be enhanced through greater and more diversified production. Without adaptation, climate change is also expected to reduce yields in current key exporting regions—particularly Latin America, Australia, and Southeast Asia.

In any plausible scenario, the United States will remain a key agricultural producer and exporter. It is already an efficient producer, it is a leading agricultural technology center, and it has the resources to adapt to climate change which will affect many other regions more severely. Climate change, land availability, and the potential to increase yields also points towards an increasingly important role for Eastern Europe. However high yield variability and the recently demonstrated readiness of governments to resort to unilateral export controls raises concerns about the reliability of this source for importers.

Growing Risks to Commodity Supply Chains

With interdependence, the geographic spread of impacts from any national or local crisis—whether from an earthquake, a hurricane, a pandemic, or a terrorist attack—can go beyond national borders. The globalization of production and the optimization of supply chains have created systemic efficiencies in the global economy. But they have also increased both the potential scope and speed of contagion should a disruption to the system occur. Further, disruption of optimized supply chains will have second- or third-order impacts which are hard or impossible to predict.

In an increasingly connected global economy and society, more people are (and will continue to be) affected by shocks, irrespective of whether or not 'high-impact events' are actually becoming more frequent. As the IPCC report noted, economic losses from weather and climate-related events over the last few decades resulted in direct damages to assets, and cost impacts are unequally distributed. Between 1970 and 2008, 95 percent of the deaths from extreme events took place in developing countries. Economically, middle-income countries with expanding asset bases are the most exposed. They have suffered about 1 percent of GDP annually as a result of these events between 2001 and 2006.

Unpredictable and uncontrollable events can pose risks that stretch beyond the normal range of economic variables. In an increasingly globalized world, a disruption in one sector can swiftly cascade to other parts of the economy and society. Even relatively 'small' events can generate significant overall effects across regions and around the world. These may be low- or high-probability events of short or long duration and all of these characteristics can alter the nature of the results. Notably, even when initial effects are low, if change is persistent rather than short-lived, the impact is likely to build up. The effects tend to be uneven, rising and falling as new sectors, or countries, are caught up in the chain reaction.

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Weather-related events affect the production and distribution of commodities, with probable increases in the frequency of heat and precipitation events. Weather-related extremes pose a threat to production sites for many commodities. Food production can be seriously affected by heavy rain, drought, and wild-fire events; major mines can flood; and hurricanes can damage oil rigs. In terms of transport, heavy storms in particular can disrupt air traffic, shipping, and roads, especially if infrastructure is severely damaged.

More Extreme Weather Events

Empirical evidence alone—without reference to climate models—indicates that a general warming trend is affecting weather and ecosystems with increasing impacts on humans. Recent weather has been characterized by an increase in the frequency of extreme weather events—floods, droughts, tornadoes, glacial lake outbreaks, extreme coastal high-water levels, heat waves, and cold spells—and this will continue during the next 20 years.

According to the recent IPCC Special Report on Extreme Events (SREX), climate and socioeconomic trends will reinforce extreme weather, making it more frequent and intense. Although the number of tropical and extratropical cyclones probably will not increase, the average maximum wind speed for tropical cyclones will increase. Meanwhile, population growth and economic development will widen the exposure of people and property. The key unknown is whether improved disaster risk management measures will be adopted to effectively cope with these changing conditions by 2030.

Food security has been aggravated partly because during the last two decades the world's land masses are experiencing weather conditions outside of expected norms. Observed temperature increases (though enhanced in the Arctic) are not solely a high-latitude phenomenon. Recent scientific work shows that temperature anomalies during growing seasons and droughts have lessened agricultural productivity. Degraded agriculture productivity, when coupled with more protectionist national policies tightening global supply, undercuts food security, especially in impoverished regions.

Flows in the Nile, Tigris-Euphrates, Niger, Amazon, and Mekong river basins have been diminished by droughts that have been persistent over the past decade. These trends are consistent with the expected effects of increased greenhouse gas (GHG) concentrations in the atmosphere, but due to the limited observational record (60 years) and a lack of understanding of decadal variability, one cannot discount the possibility that observed trends are due to other natural causes of weather variability.

Dramatic and unforeseen changes are occurring at a faster rate than expected in regions with frozen water. Current estimates suggest that Arctic summer sea ice will vanish in the period 2030-2050. Changes are occurring in the major ice shelves (Greenland and Antarctica) that were unforeseen even five years ago. Future rates of change are currently unpredictable because observed changes have outpaced the development of ice-prediction models. Scientists now estimate sea-level rise (SLR) of one meter or greater by the end of the century, most of which is expected to occur toward the end of the century. Sea-level rise could increase with rapid melt of either the Greenland Ice Sheet or the West Antarctica Ice Shelf. In the next 20 years, barring collapse of the ice shelves, the SLR trend will be modest and consistent with the recent record, about 3.3±0.4mm/year (that is, an additional ~2.5 inches global average sea-level rise). However, even this change, when coupled with potential storm surges

(Continued on next page…)

(…continued) **More Extreme Weather Events**

from more intense storms and subsidence of delta lands, will have a significant adverse impact on coastal regions and Pacific small-island states.

Improved understanding of the changes in the stratosphere reveal that the ozone layer over the Northern Hemisphere is diminishing, leading to the possibility of greater ultraviolet (UV) radiation over Northern Hemisphere countries. Based on a better understanding of climate sensitivity and emissions, the present emissions pathway will lead to approximately 2°C warming by mid-century and approximately 3° to 6°C by the end of the century, depending on economic performance, technological advances, and energy policy. By 2030, the emissions trajectory will be cast, determining this century's climate outcome.

Ninety-five percent of deaths due to weather events have taken place in developing countries. Economically, middle income countries with expanding asset bases are the most exposed: about 1 percent of their GDP has been lost due to weather related events between 2001 and 2006.

Implications for the United States

Changing market structures, the emergence of new resource players, and environmental constraints from water, land, and climate change will drive the prices and trajectories of resources production, consumption, and trade in the coming three decades. Results from these changes will also pose national security risks to the United States in the coming three decades.

Future Resource Scarcities and Challenges

At the aggregate level, there are significant scarcity challenges for a number of key natural resources with potential impacts on US security (see table page 69). **While these impacts may not directly affect the United States, they may adversely impact US economic partners, military allies, or regions important to US national security.** Price volatility will likely continue with tight and rigid markets for many commodities (see table page 71).

Food. **Markets for agricultural commodities will remain tight through to 2020 and probably to 2030. By 2040 demand growth should slow, and new technologies and investments may have begun to deliver returns.** Consumption and production substitutability of crops means that prices of commodities will generally rise together. **However, among cereals, maize is likely to demonstrate the strongest international price rises, of the likely order of 20 percent by 2020, 80 percent by 2030 and 100 percent by 2040 (against recent long-run prices). Rising demand for biofuels and animal feed exerts particular pressures on maize prices and extreme weather will cause episodic deficits in production. From 2030, climate change will exert a significant drag on maize yields.** The impacts from extreme weather events may be felt much sooner. Similar drivers will underpin oilseed growth, but more available cropland for expansion in South America will help restrain prices.

Market tightness and the reliance on maize as a biofuel feedstock means that prices will be volatile. This will affect feed prices, and then meat prices. It will also transmit volatility to other cereals through substitution effects. There is also the risk of transmitting price volatility to white maize, the staple food of Mexico, via the intermediating effect of feed markets, if livestock producers switch from yellow to white maize in response to high prices for the former.

Wheat is likely to exhibit high price volatility through to 2040. Growing demand as developing country consumers switch from rice will strain productivity growth, which has been slowing rapidly and where technology has so far delivered relatively little. Significant production occurs in water-stressed and climate-vulnerable regions in Asia (China, India, Pakistan, and Australia) indicating that markets will remain tight, and vulnerable to harvest shocks. A near-term supply disruption could result when Ug99 stem rust arrives in South Asia, something that is quite likely to happen within the next few years. Production is growing in Eastern Europe, but output is variable and governments have already demonstrated a readiness to impose export controls.

Outlook on Resource Scarcities			
	By 2020	**By 2030**	**By 2040**
Food	• Markets for major agricultural commodities remain tight • Biofuel and feed use drives scarcity in maize and oilseeds • The arrival of Ug99 stem rust in South Asia disrupts supply of wheat further	• Impacts of climate change and environmental constraints begin to exert a significant drag on cereal and oilseed yields	• Climate change, water scarcity, and land scarcity constrain production • New technologies boost productivity while demand growth slows
Energy	• Markets for oil remain tight and scarcities in both gas and coal arise • Short-term, localized scarcities will afflict coal, oil, gas, and water affecting Eastern Europe, India, Africa, South Asia, and parts of China and the Middle East • Constrained gas supplies to certain regions	• Constrained oil supplies occur • High demand from Asian power plants, mine closures, and increased dependence on coal imports cause intermittent scarcities	• New stresses on energy resource production and transportation occur from changing climates and weather patterns
Minerals	• Copper faces serious supply challenges, as production from existing mines declines and replacements remain modest • Markets for light rare earths remain in surplus while heavy rare earths remain in deficit • New greenfield production will occur primarily in poorer developing countries	• The supply gap for copper may continue to persist • Potential for temporary supply shortages for specialty metals • New emerging producers are likely to emerge as a major source of metal supply growth	• Nickel may face tighter supply constraints but new refining technologies could open up new reserves • Metal supply will rely less on virgin materials

Energy. **Markets for oil will likely remain tight overall, with potentially extreme volatility to 2020. In the absence of ambitious policies on efficiency and deployment of new technology or significant production for unconventional sources, severe shortages of oil between 2025 and 2030 will very likely prompt emergency measures to reduce demand.** In some markets, given the necessary infrastructure and finance, electric vehicles may be cost-competitive with the internal combustion engine shortly after 2020, but they will have a limited impact on global fuel demand before 2030.

In natural gas markets, a confluence of factors could constrain supplies to certain regions by 2020, including lack of investment in global LNG due to the expectation of North American shale gas development; failure of Russian Arctic gas projects and pipelines to materialize; rising domestic demand in the Middle East; and a failure of unconventional gas to compensate for the above, given investment and regulatory obstacles. Although there are abundant coal resources, a combination of massive demand from planned Asian power plants, coal mine closures, and increased dependence on imports could cause intermittent scarcities through shipping and transportation bottlenecks. This is likely to worsen as the effects of coal mining and coal cleaning compete with water resources by 2030. By 2020, the prospect of cost-competitive renewable energy could become a destabilizing factor for fossil fuel-based investments in countries with sufficient renewable resources.

Prices for oil will likely remain above $100 average to 2020, with potential to go much higher as a result of a crisis or supply disruptions. The prolonged impact could send prices down by 2030 as consumers respond, and prices could fall further by 2040 as substitute technologies take hold.

Minerals. **Depending on how rapidly China's metal demand growth slows over the next ten years, metals markets may experience less tight market conditions compared to the past decade. Prices may ease from their record levels, but are likely to remain at elevated levels due to upward shifts in producer cost curves.** This medium-term easing is contingent on a number of large greenfield projects coming into production over the next decade, despite significant technical, economic, and political challenges. **Especially for copper, the combination of continued ore grade declines and reliance on greenfield projects in countries such as Mongolia, the DRC, and Afghanistan could keep markets under pressure. Continued high prices and volatility may also encourage lasting substitution, especially between copper and cheaper aluminum. Although light rare earths[4] are likely to continue to be in surplus over most of the next decade, heavy rare earth supplies will remain tight until at least the middle of the current decade, relaxing only after a second generation of non-Chinese rare earths producers emerges.**

Beyond 2020, pressures on metal markets are going to be determined mainly by the growth of other emerging economies and the ability of industry to keep replacing depleting mines and responding to growing demand. This may either be through technological breakthroughs that allow for the processing of lower quality resources at acceptable cost; by building large scale mining industries in countries that currently still lack finance, expertise, infrastructure and political stability; or by developing recycling and remanufacturing industries much more extensively. **Given the large investments needed either way, high prices are likely to persist for a considerable time to come.**

[4] See Annex D for full description of light and heavy rare earth elements.

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Price Levels and Volatility			
	By 2020	**By 2030**	**By 2040**
Food	• Substitutability of most crops causes commodity prices to rise together • Maize experiences dramatic long-run price increase of 20 percent. • Volatility remains high for all cereals	• Long-run price rises for maize will continue up to 80 percent • Greater available cropland for expansion in South America will help restrain oilseed prices • Volatility reduces as new technologies emerge and governments take action to reduce export controls	• By 2040, the long-run price of maize will have increased by 100 percent • Volatility re-emerges as climate change and environmental constraints bite
Energy	• Oil prices remain above $100 with further increases possible as a result of a supply crunch • Rising domestic demand brings fiscal challenges to fast growing energy importers such as Indonesia, India, and importing producers such as Nigeria and Iran	• A prolonged supply crunch increases oil prices to record levels • Rising domestic demand in producer countries affects fiscal balances (Algeria, Saudi Arabia, Iraq, and Indonesia) • Technology and efficiency policy interventions in oil import-dependent states accelerate development of alternative technologies • By the end of the decade prices fall as consumers switch to alternatives	• Oil prices potentially fall further as substitute technologies take hold
Minerals	• Markets for metals are likely to remain tight and rigid, especially for copper and heavy rare earths	• Increased substitution towards aluminum may ease copper markets • Supply challenges for specialty metals will produce large short-term price spikes	• Prices may gradually ease as demand growth slows and greater use is made of substitutes and recycling

Effects of Commodity Price Fluctuations

As recent events have shown, the rapid transmission of price increases to poorer consumers can lead to political unrest and instability, and potentially to large-scale migration. Price increases also undermine the macro-economic position of importing countries, affecting their stability but also their regional influence. On the other hand, a price collapse can undermine the stability of countries and regions dependent on resource exports for a large share of their export income (see the table on page 74).

Resource-rich countries with weak governance and poor financial resilience can also be caught in the classic 'resource curse'—a mixture of souring exchange rates which dampen non-resource growth; increased opportunity and incentive for corruption, and the challenge of making efficient and effective investments with the new-found revenue. Without good financial management and instruments, they can also be particularly exposed to a price fall. Such countries are often considered to be at greater risk of internal conflict as a consequence of corruption and unequal allocation of funds to sections of the population, although this is difficult to prove.

Food. **Short-term, localized scarcities will affect wheat, due to weather-related or disease-related shocks in key producer regions. India and Pakistan are vulnerable to domestic production shocks, while the countries of the Middle East and North Africa are particularly vulnerable to price-related shocks. Governments will continue to resort to export controls through to at least 2030, exacerbating volatility further and transmitting political instability from nation to nation. In the longer run (beyond 2030), increasing frequency and severity of weather-related shocks will result in regional production shortfalls generally.**

Energy. **Short-term, localized scarcities will likely afflict the following commodities in the 2020s: coal, oil, gas, and water, affecting Eastern Europe (gas), parts of South Asia and Africa (oil products, coal and gas), parts of China (gas) and the Middle East (gas), South Asia and Sub-Saharan Africa (water for hydropower). Oil producers who lack adequate refining capacity and infrastructure could also suffer fuel shortages as ongoing crises in Iraq, Nigeria, and Yemen demonstrate. Parts of South and Southeast Asia—India and Pakistan in particular—will continue facing severe power shortages linked to gas and oil fuel supply constraints, affecting industry and social stability. Water for hydropower will also be constrained intermittently, both through changes to climate and increased competition for supplies, potentially affecting countries in Asia, Latin America, and Sub-Saharan Africa where dependence on hydropower is high. The lack of energy infrastructure will hinder development in Sub-Saharan Africa and parts of South Asia.**

Weak governance in emerging producer countries (Nigeria, Sudan, Yemen, Iraq, Venezuela) suggests higher risk of social instability leading to political instability.

Metals. **Short-term price hikes are problematic for manufacturers, but are socially and politically less pertinent than energy or food prices. Sudden price slumps will be challenging to manage for countries with a large share of production, such as Chile and Peru for copper or Australia and Brazil for iron ore. Weak governance in emerging producer countries could result in political instability and potential conflicts in response to price volatility, including in Mongolia, Peru, the DRC, Guinea, or Afghanistan.**

This paper does not represent US Government views.

Vulnerabilities in Producer States			
	By 2020	**By 2030**	**By 2040**
Food	• Government and market interventions continue to result in price volatility via export controls	• Markets remain tight, and vulnerable to harvest shocks in climate and water-stressed producing regions such as Asia and Australia	• Climate shocks become more extreme and frequent driving crop specific scarcities and food price volatility
Energy	• Strategic investments in resource production create new tensions between China and host governments in Central Asia and Africa • Weak governance in emerging producer countries (Nigeria, Sudan, Yemen, Southern Iraq, and Venezuela) create conflict situations • Oil producers lacking adequate refining capacity and infrastructure (e.g., Iraq, Nigeria, and Yemen) will suffer fuel shortages	• Increased temperatures and water stress shut down nuclear power production in Europe, US, and China • Oil and gas transit by pipelines and railroads built on permafrost in Russia and Canada are compromised • Domestic oil and gas consumption constrain export in several countries, (e.g., Iraq, Saudi Arabia, Indonesia, and Nigeria) • Public pressures to end energy production due to environmental impacts increase, (e.g., coal mining in Australia, tar sands in Canada)	• Decreased global demand for oil leads to crises for oil exporters with undiversified economies • Infrastructure in energy exporting countries is affected by severe weather events, particularly offshore oil production and coastal oil refining facilities
Minerals	• Disruptions in Andean states, Brazil, or Australia could translate into disruptions of seaborne iron ore or copper supplies • China will aim to expand control of supplies abroad	• Indian investors play a growing role in the export market • Tensions may arise between large metal importers and smaller developing countries (Mongolia, Afghanistan) and other emerging economies (Indonesia, Brazil, Peru)	• Declining reserves lead to economic destabilization in export-reliant producer countries such as Guinea, Chile, and South Africa

Commodity price shocks could destabilize producing regions. Commodity price fluctuations can create significant macro-economic shocks in producer countries, especially where commodities and exports account for a large share of GDP. The African Development Bank (AfDB) identifies a number of African exporters as vulnerable to commodity price fluctuations because the share of resources in exports is greater than 20 percent.

Resource Price Exposure of Exporting Countries in Africa		
	Commodity sub-categories	**Countries with a share of exports from commodity superior to 20 percent (2009 data)**
Agricultural	Grains and oilseeds—corn, wheat, soybeans, soymeal, soyoil, oat, and rice Soft commodities—sugar, cocoa, coffee, and cotton	Benin, Burundi, Burkina Faso, Cameroon, Cote d'Ivoire, Ethiopia, Ghana, Mali, Rwanda, Sao Tome and Principe, Swaziland, Togo, Uganda
Energy	Crude Oil Ethanol Natural Gas Coal	Equatorial Guinea, Angola, Nigeria, Chad, Libya, Democratic Republic of Congo, Sudan, Algeria, Gabon, Cameroon, Egypt, Somalia
Minerals and metals	Precious: gold, silver, platinum, palladium Base: Copper Ferrous: Steel Other: Uranium	Zambia, Burkina Faso, Namibia, Mali, Democratic Republic of Congo

Source: AfDB (2011)

Producer countries will be particularly exposed to commodity price fluctuations when their economies, particularly dependent on exports and commodities, account for a significant share of exports. Seventy-nine producer countries are exposed to commodity price fluctuations based on openness of their economy and with commodities making up at least 20 percent of their GDP and at least half of their exports. Thirty-three of these countries, fifteen of which are in Africa, are identified as highly exposed to resource price volatility, with more than 70 percent of exports consisting of resources and exports being at least 30 percent of GDP. For most of these countries it is a mixture of metals, minerals, and fuels that leads to the very high share of commodities in exports. There are however a few countries where agricultural products contribute significantly to exports, including for example Paraguay, Belize, Cote d'Ivoire, and Ecuador, as well as a number of smaller island states.

Commodity price shocks will afflict a wide range of consuming countries with weak governance regimes or high income inequality (India, China, Pakistan, Afghanistan, Indonesia, Ukraine, and countries in sub-Saharan Africa including Kenya and Somalia). Many consumer countries around the world are increasingly vulnerable to food and energy price spikes or supply disruptions, with potential US security implications. For example, analysts have linked high wheat prices in 2011 with social unrest in North Africa and subsequently the Middle East. This region remains particularly vulnerable to high wheat prices, and wheat is expected to remain volatile for the foreseeable future. Closer to home, Mexico is vulnerable to price rises in white maize which may spill over from yellow maize markets, where price is driven by US biofuel policy and oil prices. This could happen if livestock producers switch from yellow maize to white maize in response to higher prices for the former. The 2007 Mexico civil disobedience over maize prices demonstrated the potential for social unrest that could result from these dynamics. This potential is likely to increase with rapid urbanization increasing the scope for urban protest.

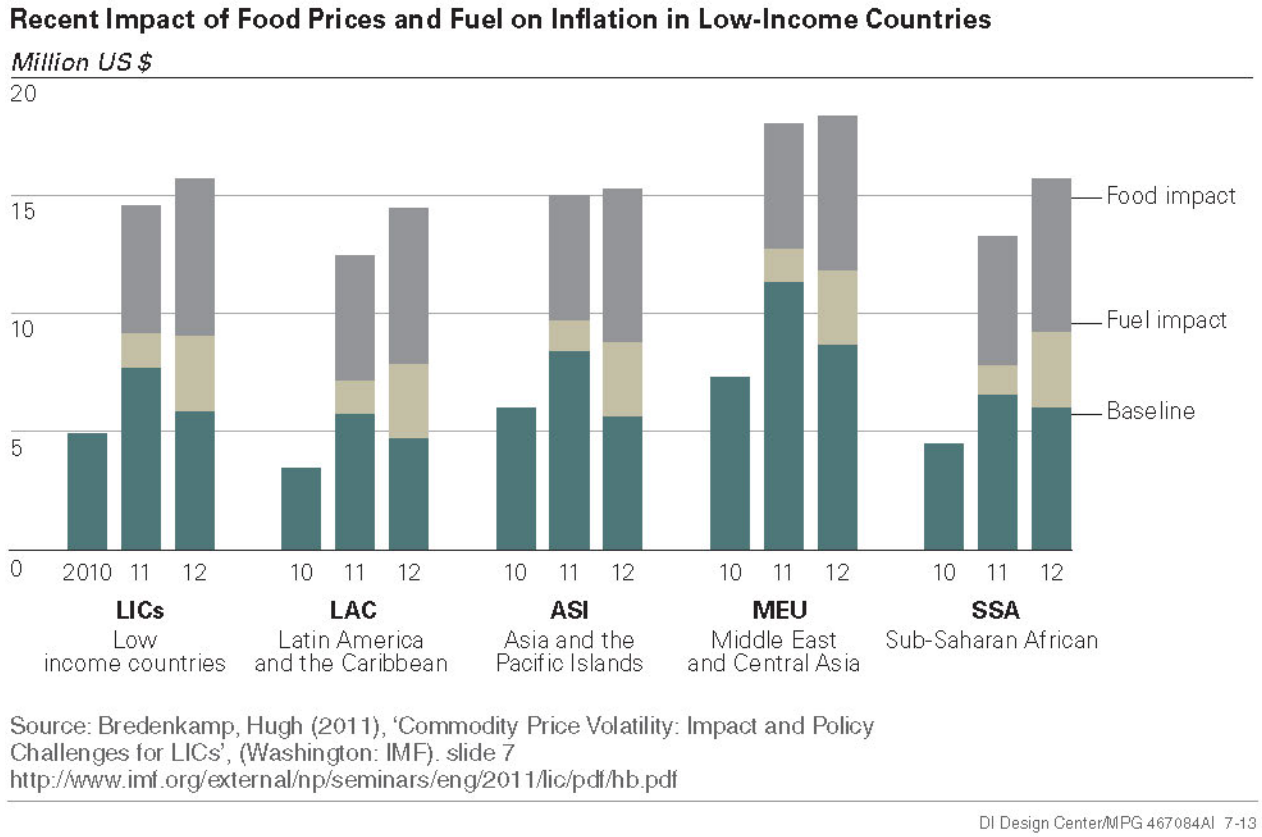
High prices will particularly afflict importing states with weak governance regimes or high income inequality. In developing countries where the energy price is set by the market, a further substantial increase in oil prices could quickly lead to social disruptions. Countries with artificially low consumer prices will face longer-term structural problems that will eventually prove unsustainable, especially those with weaker balance sheets. The alternate of rapid subsidy reductions is fraught with political risk.

Potential Impacts of High and Volatile Prices on Instability in Consumer States			
	By 2020	**By 2030**	**By 2040**
Food	• Middle East and North Africa remain vulnerable to volatility in international wheat prices	• Chinese and Indian policies to ensure self-sufficiency in grain will come under increasing strain and start to be unwound	• Climate change, under-development and population growth will result in regional food crises (of availability and access) in Sub-Saharan Africa
Energy	• South and Southeast Asia, India and Pakistan will face severe power shortages due to supply constraints, affecting industry and social stability • High prices will afflict importing states with weak governance regimes	• Price spikes and scarcity caused by bottlenecks will cause unrest in developed importing countries and weaken economies of developing importers • Political fragmentation or long term political instability in US, China, or India could reduce economic growth and demand for fossil fuels	• Infrastructure failures in developed and developing countries if supply networks are not adapted to new climate conditions
Minerals	• Tight supplies of major metals may slow infrastructure buildup in emerging economies	• Consuming countries with large high-tech manufacturing sectors continue to be affected by temporary shortages of specialty metals	• Temporary shortages of specialty metals could continue

The political and social consequences of a resource price shock are most acute where the transmission mechanism is rapid and resilience is low—staple foods and oil are the obvious examples. As the World Bank has noted, these are the two commodities that pose the greatest threat to economic recovery in poor countries following the 2008 financial crisis. Price increases immediately affect poorer households, which spend a high proportion of their income on these commodities and tend to have fewer choices. Food and fuel together make up about 50 percent of consumer expenditure in low-income countries.

The figure on page 76 shows the impact of recent price rises on domestic inflation in developing countries. A sharp increase in oil prices also hits the transportation sector, affecting the movement of goods and, in turn, economic activity. The transmission of prices in other commodities, such as other minerals, metals and natural gas, is less direct; for example, the price effect is often felt first by industry and the power sector. Mineral and metal commodities therefore tend to be a lower priority for governments.

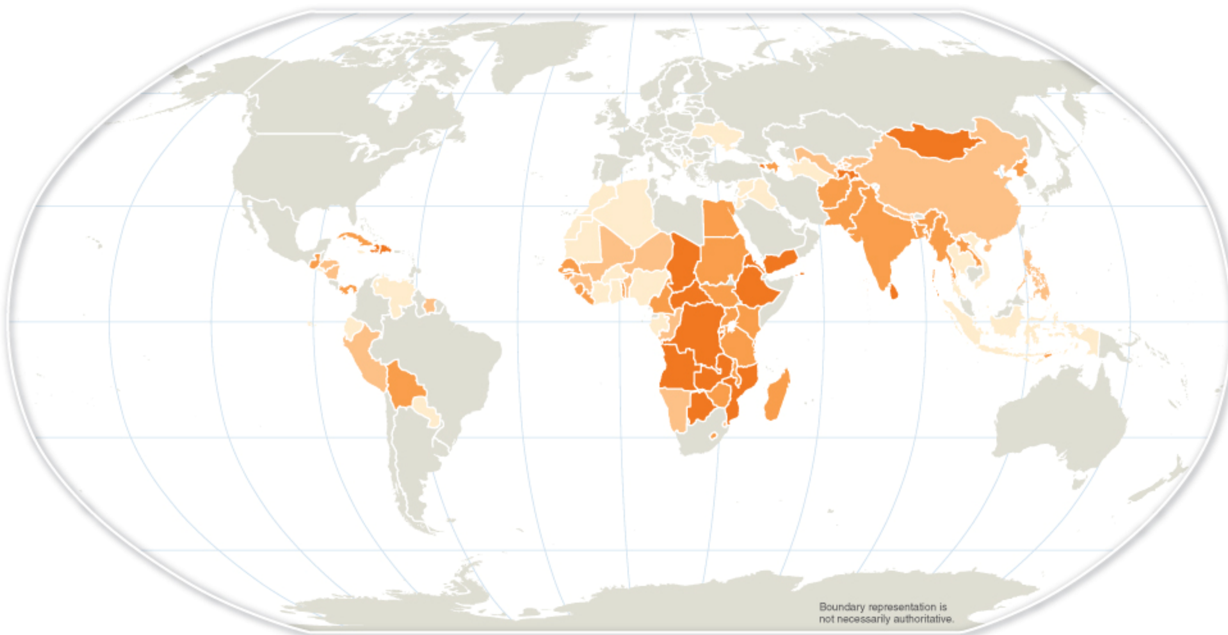
Most academic research on natural resources and political disruption has focused on food, presumably because of the remarkable link to political instability (see text box: International Food Prices and Political Instability, page 79). There have also been attempts to assess vulnerability to oil price rises or commodity price fluctuations as well as the impact of price and other uncertainties on investment. A few studies also try account for broader macro-economic stability and the ability to pay for imports by looking at current and fiscal account balances.



The Food and Agriculture Organization (FAO) identifies countries as vulnerable to food price increases if they are 'low-income food deficit countries' (LIFDC), i.e., they are classified as low-income countries and have been net food importers over the past three years. Academic research has identified a broader selection of countries based on cereal import dependency, the share of cereal imports in total imports, and the level of income.

The map on page 77 provides an overview of countries vulnerable to food price spikes. It combines undernourishment data with data on the degree of food import dependence provided by the FAO and data on the average share of income spent on food from the World Bank. The use of undernourishment data (as opposed to income level) reflects the fact that food security is not only a simple function of income, but also depends on a diverse set of factors such as income inequality, the strength of social protection frameworks, or the vulnerability of marginalized groups in society. The resulting indicator identifies a number of vulnerable countries not captured in other, income-based lists, either because of their higher level of income (such as Angola or China) or relatively low import dependence (such as Zambia, Bolivia, Burma, or Guatemala).

Countries Vulnerable to Food Price Spikes



Food Vulnerability Index

- Medium
- Medium-high
- High
- Very high

Source: Chatham House based on data on undernourishment and the degree of import dependence are taken from FAOSTAT. Data on the share of income spend on food is taken from the World Bank.

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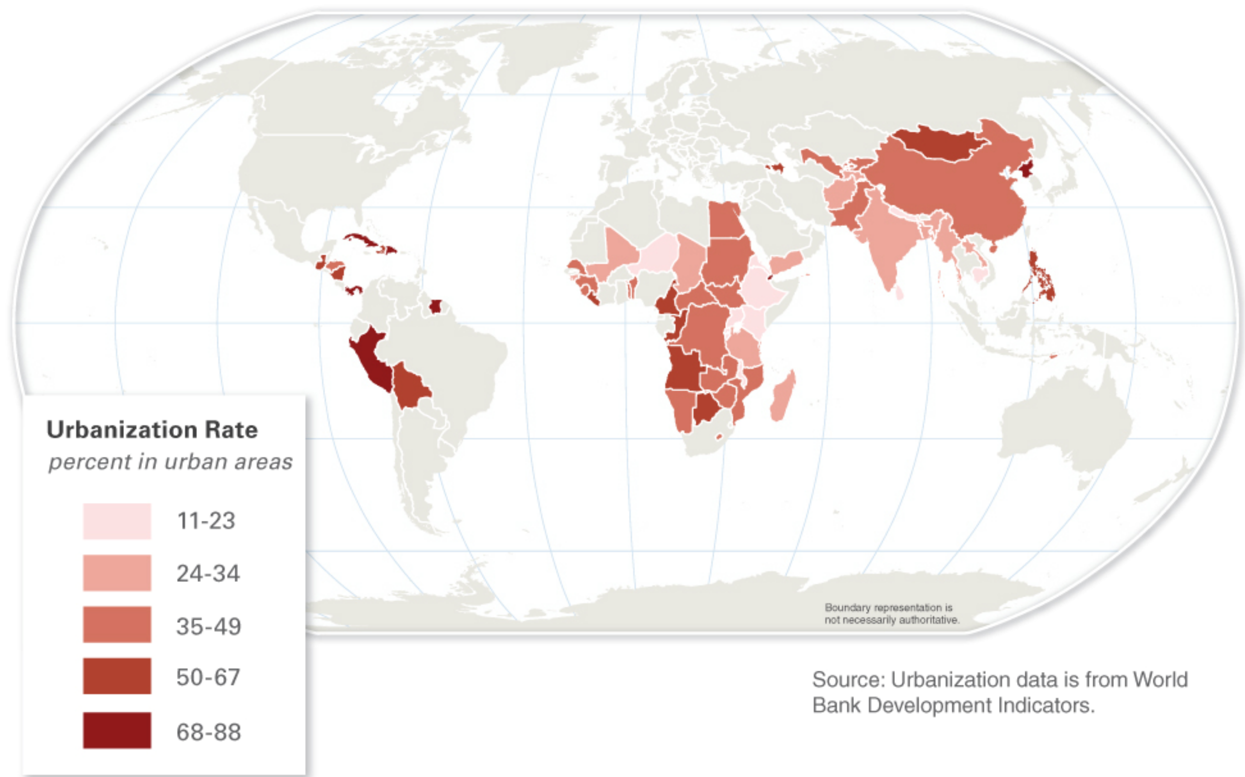
The level of urbanization of food importing countries is another key driver of vulnerability to food price spikes, but is rarely included in these metrics. Urban populations tend to be net food buyers, which means that food price rises disproportionately affect the urban poor. They also mobilize more rapidly and effectively than rural populations, precipitating political instability. The map on page 78 shows urbanization rates for those countries of medium-high food price vulnerability or above.

High food and fuel prices led to reported incidents of unrest in cities in 2009 across a diverse range of countries, according to the World Bank: Haiti, Mexico, Peru, Egypt, Morocco, Afghanistan, Yemen, Bangladesh, Burkina Faso, Cameroon, Senegal, Mauritania, Mozambique, Guinea, and Indonesia. Of these, Mexico, Peru, and Morocco are not on the FAO LIFDC list, and Mexico is missing from the list developed here. Two further aspects that are hard to represent in such indicators are food and energy distribution within the country, and the relationship between perceptions of scarcity and price fluctuations.

Share of Population in Urban Areas in Countries Highly Vulnerable to Food Price Spikes



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Market Manipulation a Likely Response

Food. **Agricultural markets are among the most politicized in the world.** Significant government interventions can be broadly categorized as follows:

- Protection of domestic agriculture, typically pursued by industrialized economies, and where interventions include farm subsidies, import tariffs and have recently extended to indirect support via biofuel policies.

- National self-sufficiency strategies, typically pursued by developing countries such as India and China where experience of famine continues to shape policymaking and stable food prices are key to social stability; interventions include maintenance of national reserves, targeting of acreage, and market interventions to set domestic prices.

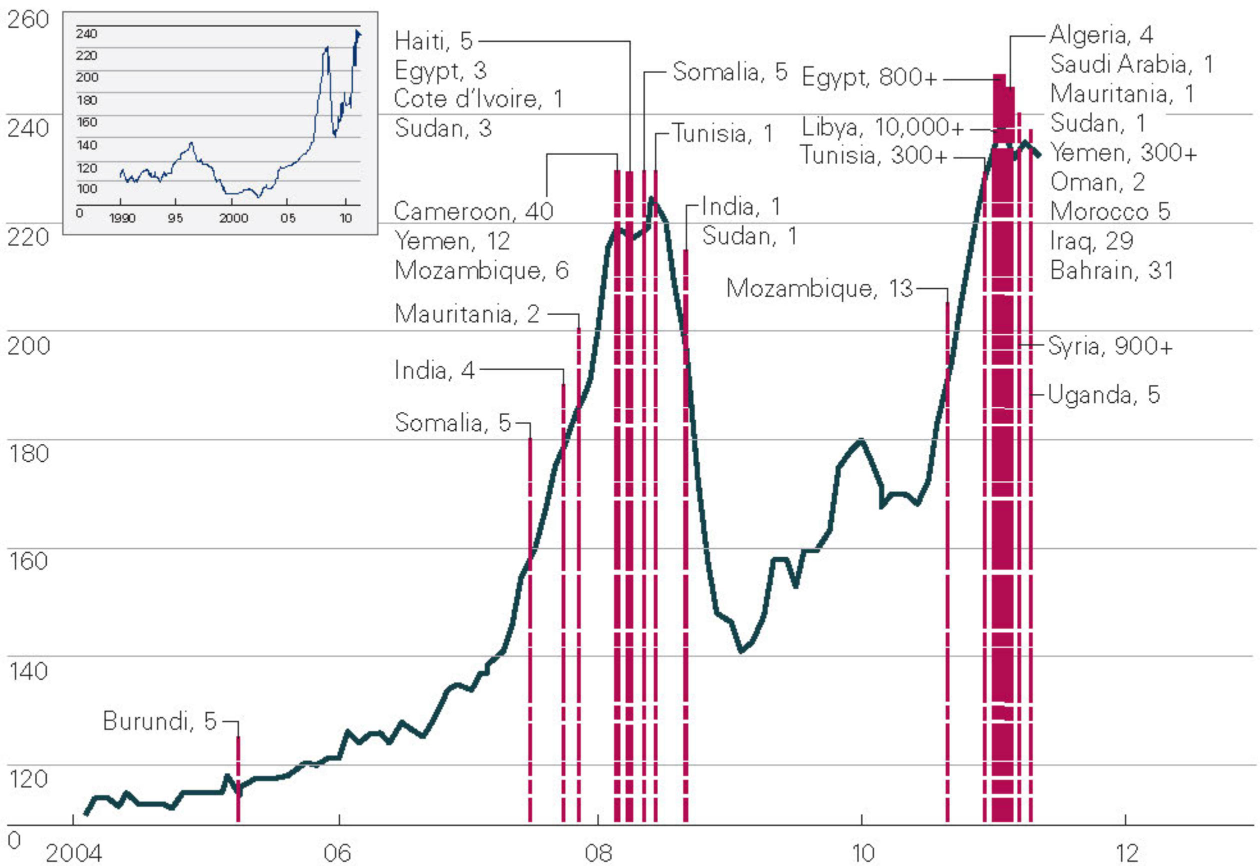
Export restrictions, typically applied in response to rising domestic prices by developing countries with food insecure or restive populations, interventions include taxes, quotas, licenses, and bans. These policies are often applied in response to temporary price rises; however, in countries such as Argentina they are essentially permanent and a structural element of government revenue.

International Food Prices and Political Instability

In recent decades, food availability and price volatility were not considered an existential threat. But the 2007/8 crisis saw protests in 61 countries with riots in 23 and one change of government. Three years later, high food prices once more contributed to civil unrest and political instability throughout the Arab World.

Civil Unrest and Food Prices, 2004-11

Time dependence of FAO Food Price Index from January 2004 to May 2011. Red dashed vertical lines correspond to beginning dates of "food riots" and protests associated with the major recent unrest in North Africa and the Middle East. The overall death toll is reported following location of the civil unrest. Inset shows FAO Food Price Index from 1990 to 2011.



Source: Lagi, M. et al (2011), "The Food Crises and Political Instability in North Africa and the Middle East," (Cambridge MA: New England Complex Systems Institute).

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(Continued on next page…)

(…continued) **International Food Prices and Political Instability**

Research has demonstrated a clear link between food price volatility and political instability, particularly within poor countries where populations spend substantial parts of their incomes on basic food items and institutions are weaker. Governments are feeling increasingly vulnerable. Successive price spikes have thrown into sharp relief their exposure to the vagaries of international markets and the domestic politics of producer countries that may choose to impose export controls without warning. This new sense of political vulnerability coupled to the speed at which price rises transmit from international to domestic markets sharpens political risks, and creates incentives for governments to act in the short term and narrow self-interest—for example, by imposing export controls—with deleterious effects on one another and their agricultural sectors.

In all cases, government interventions are driven by domestic politics in response to farm lobbies, conceptions of national security, or restive urban populations. Intervention is a constant. A key question to consider over the outlook period is the potential for *significant changes* in intervention policies.

For industrialized countries, farm support mechanisms will continue to be challenged as concerns over fiscal balances persist through to 2020. High forecast prices for wheat and maize and pressure on industrialized countries from large developing country agricultural producers will help continue a shift from trade-distorting interventions towards decoupling of production and support. In sum, direct developed country support for wheat and maize production is likely to decline through to 2040. However, this will likely be offset through the use of biofuel policies that artificially create demand in particular for maize, but also wheat (and oilseeds in the European Union), propping up farm prices and effecting transfers to farm lobbies. Governments are stepping back from fiscal support for biofuels in the United States and the European Union; however, entrenched sectoral interests suggest the use of mandates will continue to at least 2020. Another serious international price spike would shine the spotlight back onto biofuel mandates, probably at the G20, where discussions would likely focus on the use of safety valves and flexible mandates.

The grain self-sufficiency strategies of China and India also present uncertainties with systemic implications, as environmental constraints and rising demand increasingly challenge the sustainability of these policies.

Export restrictions are very often applied to crops of particular relevance to national food consumers. Recent experience indicates that rice and wheat are particularly vulnerable to this form of intervention (see table on page 81). Global governance currently provides no framework for preventing or removing export restrictions, and attempts to discuss the issue at the G-20 have been unsuccessful. Intractable politics suggest that no effective international framework for dealing with export controls is likely until beyond 2020. By then, prolonged price volatility will have raised the issue up the international agenda and further progress on developed country subsidies may have opened up political space. For the specific case of rice, which was severely affected by export controls during the 2008 price crisis, the likelihood of future restrictions has been reduced by a shared understanding among Asian countries of the problems caused during this period, and discussions at the regional level to improve transparency on stock levels and avoid further controls. Wheat, however, remains a challenge given its volatile price outlook, susceptibility to regional harvest shocks, and production in countries that readily resort to implementing export controls such as Russia, India, Pakistan, and Ukraine.

This paper does not represent US Government views.

Trade Restrictions on Food Introduced Since 2008 Price Crisis		
Country	**Product**	**Restrictive Policy Instrument Used**
Argentina	Wheat, maize, soybean, sunflower seeds	Tax (ad valorem), Tax, (variable), Quota, Ban
China	Rice, wheat, maize, flour	Tax (ad valorem), Quota/License
India	Basmati rice	Minimum Export Price (MEP), Tax (specific), State Trading Enterprise (STE)
	Ordinary rice	Ban, MEP, STE
	Wheat	Ban, quota, STE
Egypt	Rice	Tax (specific), Quota, Ban
Pakistan	Rice (ordinary and basmati)	MEP
	Wheat	Tax (ad valorem), Quota, Ban
Russia	Wheat, maize, barley, flour	Tax (ad valorem), Ban
	Rapeseed	Tax (ad valorem)
Ukraine	Wheat, maize, barley	Quota
Vietnam	Rice	MEP, Quota, Ban, Tax (variable), STE
Other 20 countries	35 products affected, mostly cereals, but also sugar, beans, oils	Ban in 32 cases, 1 MEP, 1 Tax (ad valorem) and 1 STE

Source: Sharma, Ramesh (2011)

Energy. Strategic investments by state-owned enterprises from emerging economies in key resources production may create new and destabilizing tensions between the investment and the host governments in some countries by 2020.

On a day-to-day basis, key factors of ‘interference’ in the price of oil to 2020 are likely to continue to be the rising budgetary needs in oil-exporting countries, largely defended by OPEC, commodities traders response to geopolitical events that threaten to affect oil flows, and domestic policies to maintain below-market costs for fuel and therefore reduce demand response to price. In the event of supply crises, the IEA will continue to release its strategic petroleum reserves (SPR). Both this and the restocking of the SPR effectively interfere with the market price. Political sanctions such as those recently affecting Iran and Sudan’s oil exports will periodically take volumes of oil ‘off the market’, thus causing short-term price rises.

By 2020, China will be able to use its SPR for up to 90 days in the event of a crisis. Other non-OECD importers will also develop SPRs (India proposes to more than triple its current reserve by 2020) and it is possible these will be used on a more frequent basis to bolster economies and calm political tensions. More general price trends will continue to be affected not only by the growth of Asia but also by perceptions of future scarcity in the paper barrel market. If international agreement is reached on carbon emissions quotas, this will raise prices at some point in the energy supply chain and ultimately drive down demand over the medium term.

Between 2030 and 2040, more stringent energy policies in major consuming countries to cut demand and change appliance use will likely affect price. Less predictable use of SPRs in India and China may also create further price volatility.

To 2020, commodities hedging will likely drive up coal prices due to future demand growth from Asia. Policy decisions in China and India regarding domestic mining and the investment conditions for coal-fired power generation will also influence coal prices. Their increasing state and private interests in foreign coal mining and long-term contracts for coal may significantly affect the global market.

This paper does not represent US Government views.

As gas can be a substitute fuel, coal will continue to be affected by gas market liberalization and gas contracts. In North America, unconventional gas production will depress the demand for local coal and may result in exports of coal to other regions, most likely Asia. Beyond 2020, much depends on whether China has grown as a net coal importer or whether it has developed its northern coal resources. Policies to increase gas, renewables, and nuclear in the national energy mixes of some countries may put downward pressure on coal. Carbon markets and emissions reduction policies that require clean coal technology are likely to increase the cost of coal and so reduce demand growth. In contrast, the successful development of CCS technologies may increase the use of coal.

Minerals. **Over the 2020 time frame, Chinese investors are likely to be under the greatest pressure to expand their domestic supplies abroad, but towards 2030 Indian investors are also likely to play a growing role. Tensions may not only arise in smaller developing countries such as Mongolia, Afghanistan, or African countries such as Zambia, Guinea, or the DRC, but also with other emerging economies such as Indonesia, Brazil, Peru, and developed countries with large mining sectors such as Australia or Canada.**

China's role as by far the largest customer and key producer in international metals markets is set to increase further over the next decade and will only slowly be eroded over the 2020 to 2030 and 2030 to 2040 timeframe. This gives China considerable leverage over prices, production volumes, and the flow of investments in international metals markets. Nonetheless, China's role as both a large consumer and producer will somewhat constrain market interventions. Lower prices for iron ore, for example, would help Chinese steel producers, but China's large, high-cost iron ore mining industry would be hurt considerably by structurally lower prices. China's reliance on imports and domestic production will similarly make it difficult to establish differential pricing regimes for its domestic market such as the one it currently operates for rare earths.

For rare earths, China will continue to yield overwhelming influence on supply and pricing over much of the current decade. Diversifying global supply and the fact that China is likely to become a net importer of rare earths towards 2020 will, however, erode this market dominance.

Given the diversified nature of global supply and imports, any one consumer acting unilaterally will only have a limited impact on global market dynamics, with the exception of India whose influence may grow towards 2030 and particularly 2040.

However, the policies of a small set of key producers and exporters other than China will be able to influence market dynamics considerably. These include Australia and Brazil for sea-borne iron ore and bauxite; Chile and Peru for copper; Australia and Peru for zinc; Russia, Indonesia, and the Philippines for nickel. Rising domestic consumption may compel some of the emerging markets to impose export restrictions: for example, Indonesia is scheduled to apply controls on nickel in 2014 to protect domestic processing.

Although the relative influence of these players may change over the time frame considered (e.g., Peru's importance in copper markets increasing while Chile's declines towards 2020 and 2030), the global distribution is unlikely to shift fast enough for significant new players to emerge.

Continuing consolidation of the global metals industry is likely to make global metals markets increasingly oligopolistic towards 2020. Large players in individual metal markets, which mostly consist of Western-backed, diversified multi-national corporations, will increasingly be able to influence supply, investment, and pricing of major metal commodities.

The influence of state-owned and state-led companies in individual metal markets—for example, Vale (Brazil), Chinalco (China), Codelco (Chile), and Norilsk Nickel (Russia)—is also set to increase, especially in financing mining projects in politically unstable regimes or regimes hostile to Western interests.

There is considerable scope for conflict between large Western-backed mining companies with large emerging consumer countries over pricing, producer countries over ownership and investments, and further rivalries both between multinationals and SOEs and among SOEs. These are likely to intensify as the industry consolidates further towards 2020, and may trigger serious efforts towards breaking the power of oligopolies, e.g., by China or regulators in OECD countries. These may lead to significant diplomatic tensions among emerging economies, OECD countries, and major producer countries.

In the Short Term… Increased Risk of Trade Disruptions

Governments are not well equipped to manage the effects of a prolonged disruption to critical trade and transport networks. The vulnerabilities of the just-in-time business model are likely to be exposed by any disruption lasting more than a few days.

Disruption to a major transport hub can render meaningless the apparent resilience of having multiple suppliers. The production of a complex product that requires thousands of parts can be halted by an absence of a single component. According to the World Bank, global industrial production declined 1.1 percent in April 2011 in the wake of the Tohoku earthquake and tsunami in Japan, reflecting supply-chain disruptions.

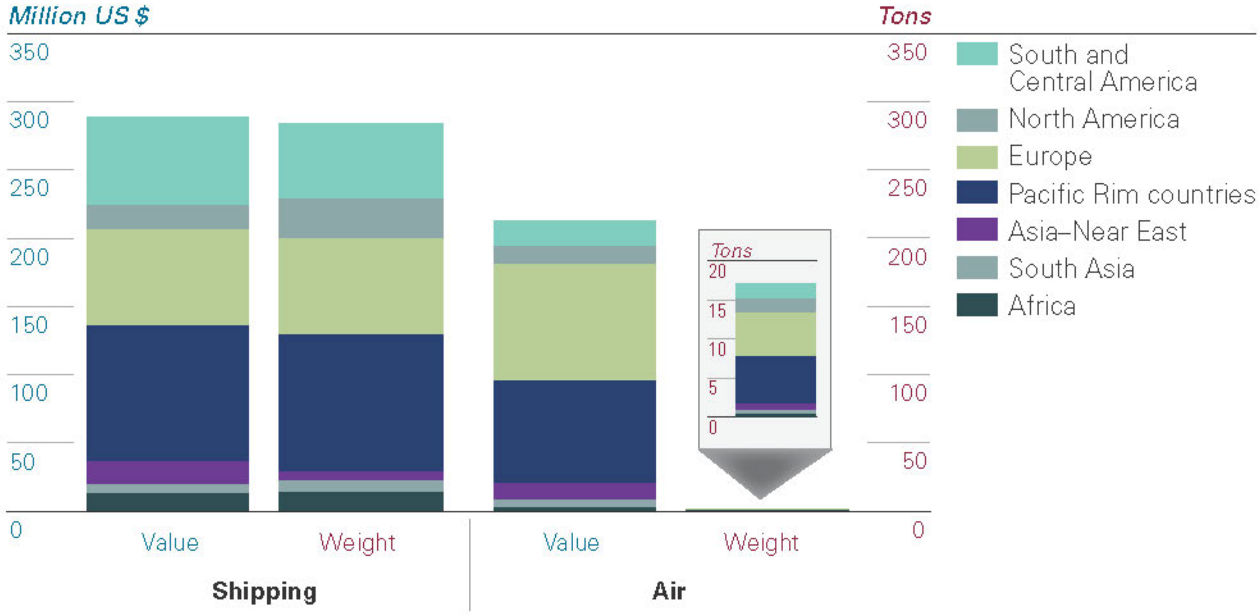
With 90 percent of world trade carried by sea, merchant ships are a vital mode of transportation. Twenty major ports have the highest number of ship visits and connections with other ports. The global energy transport system is particularly vulnerable to disruption at key maritime choke points such as the Straits of Malacca and Singapore, Bab Al-Mandab, the Suez Canal, the Turkish Straits, and the Straits of Hormuz. As for other commodities, the impact of a disruption on energy supply, prices, and markets depends on its extent and duration. When there is a risk of disruption, perceptions and the interaction of physical oil and gas markets with paper trading markets play a major role in determining price level and volatility.

Most Integrated and Busy Ports	
1. Panama Canal **2. Suez Canal** **3. Shanghai** **4. Singapore** **5. Antwerp** **6. Piraeus** **7. Terneuzen** **8. Plaquemines** **9. Houston** **10. Ijmuiden**	**11. Santos** **12. Tianjin** **13. New York & New Jersey** **14. Europoort** **15. Hamburg** **16. Le Havre** **17. St. Petersburg** **18. Bremerhaven** **19. Las Palmas** **20. Barcelona**

Air transport is also critical to the functioning of the global economy, but is probably even more vulnerable to disruption. This was highlighted by the 2003 SARS outbreak, since international aviation served as the key mechanism for wider dispersion, and countries responded by introducing border restrictions. This resulted in a sizeable impact on Asian economies from SARS even in countries with no actual cases—for example, due to disruption to tourism. Estimates after the event suggested that SARS caused an average loss in regional GDP for East Asia of about 0.6–0.7 percent for 2003.

High-value, low-weight products such as electronic components, fine chemicals, and medical vaccines tend to be airfreighted. In economic terms, this matters most to countries that produce high-value products for high-tech manufacturing. For example, the United States exported about 150 times more by sea than by air by weight in the first half of 2012, but in value terms shipping was only about a third larger (see figure below).

Exports From the US by Air and by Sea, Value vs. Weight January-June 2012



Source: US Census-U.S. Exports-Domestic and Foreign Merchandise: Country of Destination and Method of Transportation.

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Vulnerability of Energy Infrastructure

Political and physical threats to resource supply will persist in the medium term. On energy, for example, there remains the potential for political and economic cut-offs such as the Ukraine/Russia gas crisis that came to a head in January 2009 and resulted in 18 European countries reporting major falls or cut-offs in their gas supply. Other disruptions may result from low water-storage capacity, insufficient cooling water, and adverse weather conditions such as occurred in the winter of 2010 in the United Kingdom, where over 100 businesses had their gas supply cut off. In the Gulf, gas shortages in recent years have been compounded by underpricing and heavy demand from the petrochemicals industry. Without changes in the tariff system, this is likely to continue.

These threats to energy supply together with environmental change—whether extreme weather events, water shortages, changing sea levels, and melting glaciers—will continue to pose serious threats to critical infrastructure as well as global production and delivery systems. Based on density, regions with the most vulnerable energy infrastructure include the East coast of North America, Europe, Northern Asia (mostly former Soviet Union), Southeast Asia, Japan, and the Middle East—many of which are key producers of fossil fuel for the global market. These vulnerabilities highlight the imperative of climate- and energy-resilient investments, and developments that will prepare the world for the 'once in a century' energy transformation.

There are, for example, obvious "choke points" for oil, the most important being the Straits of Hormuz, which gives access to oil markets in Asia and the Atlantic Basin for Gulf crude oil exports. However, there are other less obvious ones. For example, for the most part, consumers want oil products rather than crude oil, which means that crude oil must be processed and refined and therefore the infrastructure associated with this process can also be regarded as a "choke point." The best example is the Abqaiq facility in Saudi Arabia that processes between five to six million barrels per day (mbd) of crude. Another example would be the huge loading terminals at Ras Tanura in Saudi Arabia, through which the bulk of Saudi exports pass, or the Straits of Hormuz. Refineries can also present problems although the global availability of refinery capacity reduces the risk. Another example of less obvious "choke points" relates to the fact that "sanctions" from whatever source can effectively create their own restrictions on supply. Finally, in recent times, the activity of Somali pirates over a very wide area of ocean also presents a threat to oil supplies.

"Choke points" for gas are more difficult to define. Gas can be transported either by pipeline or as LNG. LNG seaborne trade is obviously subject to the same sort of potential routing problems associated with crude oil. But relationships are not always obvious. If the Suez Canal were to close, that would pose a greater threat to European gas supplies than to oil supplies. The Straits of Hormuz, which Iran could theoretically close as a political gesture, sees the passage of some 28 percent of global LNG exports.

However, pipelines, because of their fixed locations and inflexibility, represent serious potential "choke points" although the impact tends to be regional rather than global. Twice in the last five years, Russian pipelines into Europe via Ukraine experienced major disruptions leading to serious shortages in southeastern Europe. The following table provides estimates of some of the key choke points and the volumes of oil and gas involved in 2010.

(Continued on next page…)

(…continued) **Vulnerability of Energy Infrastructure**

Potential oil and gas choke points		
Choke point	**Estimates of crude oil Transiting mn b/d**	**Estimates of LNG Transiting bcf/d**
Straits of Hormuz	15.5—17.5	3.5
Straits of Malacca	13.6 – 15	N/A
Bab al Mandab	3.2—3.5	3.5—4.0
Suez Canal	3.5—4.5	3.5—4.0
Bosporus	2.4—2.9	0
Panama Canal	0.8	N/A

Source: Emmerson and Stevens, 2012

Annex A

Summary Tables

This report identifies the most important natural resource trends for US national security over a 2020, 2030, and 2040 time horizon. The scope of the analysis covers water, fuel, food, and metals. The trends—which include patterns of demand, supply, availability, price levels, and price volatility—are set in the context of emerging ecological flashpoints including climate changes, evolving demographic patterns, and environmental degradation.

The report considers how local and global availability of natural resources will impact US security interests in the near term (to 2020) and long term (specifically 2030 and 2040). It identifies potential natural resource stresses (in terms of aggregate availability, absolute prices, or rapid price changes) and analyzes their likely impact on the United States and states/regions of interest to the United States. The report also explores how these stresses will interact with one another and other pre-existing conditions, including poverty, social tensions, environmental degradation, ineffectual leadership, and weak political institutions. Summary tables provide an overview of key resource-related threats and their potential impact on the United States and other major economies.

This section presents key insights from the report as a series of summary tables. The first table considers generic resource-related threats and the severity of the risk, with reference to the underlying pressures responsible for the threat and potential trigger events.

Potential Trigger Events, Timeframe, and Underlying Pressures			
Generic threats	**Trigger event(s) - timeframe**	**Underlying pressures**	**Risk**
High and volatile international food prices	Natural disasters or water shortages in producer countries (2020, 2030, 2040) Export restrictions by producer states (2020) Oil price spikes (ongoing 2020, 2030)	Rise in consumption in emerging economies from: water shortages, climate volatility, oil price volatility, population growth	High
High and volatile international fossil fuel prices	Conflicts or social disruptions in oil or gas-producing regions (2020, 2030, 2040) Terrorist attacks on critical gas infrastructure (ongoing: 2020, 2030, 2040) Water shortages in producer countries. (2020, 2030, 2040) Critical infrastructure damage from extreme weather events (ongoing with increasing frequency 2030, 2040) Groundwater contamination with shale gas extraction (2020) Large scale accident in nuclear power station leading to rapid fuel switch	Weak governance of resource producers Climate volatility Rise in consumption in emerging economies Water shortages Declining production from conventional resources and existing producers	High

(Continued on next page…)

(…continued) **Potential Trigger Events, Timeframe, and Underlying Pressures**			
Generic Threats	**Trigger Event(s) - Timeframe**	**Underlying Pressures**	**Risk**
Disrupted Physical Access to Critical Resources	Disruptions to Sea Lanes of Communications (SLOC) (2030, 2040) Export restrictions (2020) Natural disasters/ extreme weather (2030, 2040)	Climate volatility Weak governance of resource producers Tight supply conditions	Medium
Water Shortages	Droughts (ongoing: 2020, 2030, 2040) Extreme weather events ongoing (2030, 2040) Groundwater contamination with shale gas extraction	Water shortages in specific states Unsustainable consumption	Medium

The next table summarizes the potential impact of "social risks" on major economies posed by resource security-related concerns. Social risk is understood here as the risk of significant *local* social disruption (protests, riots, or targeted destruction of property). High *local* social risk can, in the presence of other factors—income inequality (or poverty), environmental degradation, ineffectual leadership, weak political institutions—lead to challenges to the nation-state and potentially state failure.

Severity of Social Risks to 2030				
	Food Security	**Energy Security**	**Water Availability**	**Mineral Resources Security**
United States	Low	Low	Medium	Low
European Union	Low	Low	Low	Low
China	Medium	Medium	High	Low
Brazil	Medium	Medium	Low	Low
Russia	Medium	Low	Low	Low
India	Medium	Medium	High	Medium
Japan	Low	Low	Low	Low

This table considers, from the perspective of the US, the outlook on specific resource-related threats.

Outlook of Resource-Related Risks (of occurrence) to the United States				
Generic Threats	**Direct Impacts on the US**	**Trigger Event(s) – timeframe**	**Underlying Pressures**	**Risk**
High and Volatile International Food Prices	Higher domestic prices for food in the US	Natural disasters or water shortages in producer countries (2020, 2030, 2040) Export restrictions by producer states (2020) Oil price spikes (2020, 2030)	Rise in consumption in emerging economies Water shortages Climate volatility Oil price volatility Population growth	High
High and Volatile International Energy Prices	High gasoline prices in the US	Conflicts or social disruptions in oil-producing regions (2020, 2030) Terrorist attacks on critical oil infrastructure (2020) Water shortages in producer countries (2020, 2030, 2040) Critical infrastructure damage from extreme weather events (2030, 2040) Groundwater contamination with shale gas extraction (2020)	Weak governance of resource producers Climate volatility Rise in consumption in emerging economies Water shortages	Medium
Disrupted Physical Access to Critical Fuels and/or Minerals	Disruptions to US industrial production and/or exports of manufactured goods, reducing US productivity	Disruptions to Sea Lanes of Communications (SLOC) (2030, 2040) Export restrictions (2020) Natural disasters/ extreme weather (2030, 2040)	Climate volatility Weak governance of resource producers Tight supply conditions	High

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This paper does not represent US Government views.

(…continued) **Outlook of Resource-Related Risks (of occurrence) to the United States**				
Generic Threats	**Direct Impacts on the US**	**Trigger Event(s) - Timeframe**	**Underlying Pressures**	**Risk**
Disrupted Physical Access to Critical Fuels in Theatres of War	Disruptions to energy supply in war zones, reducing military capability	Disruptions to Sea Lanes of Communications (SLOC) (2030, 2040) Extreme weather (2040) Export restrictions (2020, 2030, 2040)	Slow technological development in the energy sector Climate volatility Tight supply conditions	Medium
Diplomatic or Military Entanglement in Producer Regions	Reduced US access to key resources Increased military spending	Internal conflicts in producer countries; or conflict between producer countries and others (2020, 2030, 2040)	Weak governance of resource producers Persistent inequality	Medium to high
Diplomatic or Military Entanglement in Producer Regions	Influx of refugees	Conflicts in the water-scarce producer regions	Weak governance of resource producers Persistent inequality Unsustainable water use Climate volatility	Low to medium
Water Shortages	Lowered agricultural productivity in the US Reduction of US competitiveness in exports market Forced openings of US market (especially for corn in the Midwest)	Droughts in the US (2020, 2030, 2040) Extreme weather events (2030, 2040) Groundwater contamination with shale gas extraction (2020)	Water shortages in specific states Unsustainable consumption	Low to medium

This final summary table considers risks to other countries of interest to the United States.

Threats to States of Interest to the United States					
Generic Threats	**States of Interest**	**Type of Threat**	**Trigger Event(s)—Timeframe**	**Underlying Pressures**	**Risk of Occurrence**
High and Volatile International Food Prices	Import-dependent countries with poor, urbanized populations: Mexico, Pakistan, Azerbaijan, Syria, Iraq, Egypt, Democratic Republic of the Congo, Philippines, and North Korea. Producing countries that may impose export restrictions in response to high prices: Argentina, Brazil, Russia, Ukraine, Thailand, Indonesia	Riots and political instability Regime collapse High inflation Further destabilization of global food markets Panic buying by consumer countries	Natural disasters or water shortages in producer countries (2020, 2030, 2040) Export restrictions by producer states (2020) Oil price spikes (2020, 2030)	Rise in consumption in emerging economies Water shortages Climate volatility Oil price volatility Population growth	High
High and Volatile International Energy Prices	Developing countries with high import-dependence: Eastern European countries, Caribbean Islands, Chile, India, Turkey	Riots and political instability Regime collapse Deteriorating public finances as subsidies expand High inflation and economic crises	Conflicts or social disruptions in energy producing regions (2030, 2040) Terrorist attacks on critical energy infrastructure (2020, 2030, 2040) Water shortages in producer countries (2020, 2030, 2040) Critical infrastructure damage from extreme weather events (2030, 2040)	Weak governance of resource producers Climate volatility Rise in consumption in emerging economies Water shortages	High

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(…continued) **Threats to States of Interest to the United States**					
Generic Threats	**States of Interest**	**Type of Threat**	**Trigger Event(s)—Timeframe**	**Underlying Pressures**	**Risk of Occurrence**
Disruptions of Physical Access to Critical Metals or Minerals	High-tech manufacturing sectors in import-dependent countries: Germany and other European manufacturers, Japan, South Korea, Taiwan	Disruption of supply chains and loss of income Diplomatic tensions with producer states Panic buying and creation of stockpiles exacerbating disruptions	Disruptions to Sea Lanes of Communications (SLOC) (2030, 2040) Export restrictions (2020) Natural disasters/ extreme weather (2030, 2040)	Climate volatility Weak governance of resource producers Tight supply conditions	Low
General Commodity Price Volatility	Developing countries that rely on exports for a large share of GDP: Iraq, Democratic Republic of the Congo, Uganda, Algeria, Guinea	Spending increases when prices are high lead to fiscal pressure when prices fall Increasing reliance on foreign aid Political instability	Economic crises (2020, 2030, 2040) Political instability in major consuming countries (2020, 2030) Extreme weather events (2040)	Weak governance of resource producers Climate volatility	Medium
Water Shortages	Water-stressed regions and countries with high inequality and/or weak governance: Middle East, North Africa, Caucasus, and Central Asia; Mongolia, Pakistan, India, Afghanistan, and South Sudan	Famines and increased migratory pressures that can result in country or regional destabilization Increasing dependence on foreign aid Increased diplomatic conflict over trans-boundary water resources	Droughts in the US (2020, 2030, 2040) Extreme weather events (2030, 2040) Groundwater contamination with shale gas extraction (2020)	Water shortages in specific states Unsustainable consumption	High

This paper does not represent US Government views.

Annex B

About this Report

This report identifies the most important natural resource trends for US national security over a 2020, 2030, and 2040 time horizon. The scope of the analysis covers water, fuel, food, and metals and minerals, including rare earth elements. The trends—which include patterns of demand, supply, availability, and price (level and volatility)—are set in the context of emerging ecological flashpoints including climate changes, evolving demographic patterns, and environmental degradation.

The analysis considers how expected changes in the availability of, or access to, natural resources could impact on US national security. Three interconnected factors determine the national security implications of resource scarcity (or perceived resource scarcity): the geo-physical (actual scarcity, and location of the scarcity/need); geo-economic (economic strength/tools available to secure those resources); and geo-political (degree to which national governments are involved in policy related to managing/securing resources). Key questions for this report include:

How will local and global aggregate (supply versus demand) availability of natural resources (individually or in combination with each other) impact US security interests in the near-term (out to 2020) and long-term (specifically 2030, and 2040)? Key dimensions of this question include:

1. How will aggregate availability of natural resources impact global commodity markets? Which markets are likely to experience the greatest price rises, and greatest price volatility in 2020, 2030, and 2040? What markets will be most vulnerable to market speculation?

2. What will be the natural resource stresses (aggregate availability, absolute price, or rapid price changes) in 2020, 2030, and 2040? How will these stresses impact states/regions of interest to the United States? This will address both severity and likelihood of the impacts of individual natural resource stresses to develop, and how they will interact with each other and other pre-existing conditions—poverty, social tensions, environmental degradation, ineffectual leadership, and weak political institutions.

- How will human use patterns driven by demographics, economic development, technology, and environmental degradation further increase or reduce national resource stresses in states?

- What is the potential for existing institutions (state, non-state, and multi-state), market systems, and treaties to address expected natural resource challenges; and what are the resulting implications for US national security?

- How will anticipated changes in natural resource stresses force inter- and intra-state migrations, cause economic hardship, or result in increased social tensions or state instability within selected states/regions?

- What new sources of supply (or technology) would change the anticipated natural resource stresses (i.e., shale, gas, algae biofuels, etc.)? What would be the ramifications to US security interests?

3. What individual natural resources are most critical to US security interests in 2020, 2030, and 2040? What combinations of natural resources are most critical to US security interests in 2020, 2030, and 2040? What countries/regions important to US security interests will be most affected by natural resource stresses? What countries/regions will have the most benefit from natural resource stresses?

The major assumption underpinning this analysis is that mounting prosperity in both the developed and the developing world will continue to drive increased consumer demand for key resources. At the same time, constraints in energy, water, and other critical natural resources and infrastructure, together with socio-economic shifts, will bring new and hard-to-manage instabilities. There will be an increasing risk of discontinuous and systemic shocks to 2040 as a consequence of these factors.

This report provides answers to the listed questions above in the following manner:

- Identifies general drivers that have shaped the overall production and consumption trajectories of different resources, as well as pricing trends.

- Analyzes sectoral dynamics and trends for food, energy, and mineral producers and consumers from now to 2040.

- Assesses the changing conditions for the availability and access to key resources. These include shifting power balance and market structures; emergence of new actors, including winners and losers; environmental factors including land degradation and water scarcity, extreme weather events, and natural disasters; and governance conditions in key producer and consumer states undergoing most transitions.

- Calls attention to direct and indirect threats to US security interests.

This paper does not represent US Government views.

Annex C

Key Modeling Uncertainties

Key Modeling Uncertainties				
	Structural Uncertainties in long-Term Projections	**Potential Discontinuities**	**Information Gaps / Level of Scientific Understanding**	**Key policy-Related Uncertainties**
Population Growth	A key input into models and projections	Rapid migration events, pandemics	UN projects between 8.1 to 9.7 billion people in 2040—a substantial range	1 child policy in China; availability of birth-control; education of women; infant mortality improvements
Economic Growth	Compound effects mean small adjustments in economic growth assumptions have large consequences for resource projections	Rapid slow-down in China Collapse of the Eurozone	Simplistic assumptions about energy/resource intensity based on historical experience Short-term economic outlook is highly volatile	Assumption is that governments will pursue high-growth policies
Resource Prices	Modeling is highly sensitive to energy and resource price levels—leads to very different choices, e.g., for power generation.	Impact of extreme price spike in short term unclear Was there a role played by energy prices in 2008 financial crisis?	Disconnect between physical and paper markets and other volatility questions Unclear what the macro-economic impact is of long-term, high-resource prices	Price shocks and political consequences can lead to radical policy changes (e.g., Japan after 1973 oil shock) Pricing in of externalities, e.g., carbon
Resource Availability	Physical and economic availability of reserves Incremental improvements in yield (crops / recovery, (minerals processing) Environmental viability of some minerals / fuels Extent of recycling in key commodities	Unconventional fuels and low-grade minerals become economically viable, e.g., fracking, tar sands Substitution - within crops, metals (e.g., alternatives to REEs) or between categories, e.g., metals to plastics	Reserve data probabilistic and limited	Access to resources in terms of investment and exports Subsidies for resource extraction Other trade measures—quotas, tariffs, etc.

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(…continued) **Key Modeling Uncertainties**				
	Structural Uncertainties in Long-Term Projections	**Potential Discontinuities**	**Information Gaps / Level of Scientific Understanding**	**Key Policy-Related Uncertainties**
		Breakthrough technologies to retrieve materials from waste Enhanced monitoring equipment finds large scale new reserves		
Environmental Changes / Impacts	Level of climate change by 2040; degradation of land and water	Weather-related shocks (water scarcity/drought) Tipping points: climate-related; ecosystem instability; fish stock collapse Risks associated with new technologies, e.g., geo-engineering, nanotech, GMOs	Impossible to accurately predict extreme events. Unclear what constitute 'safe environmental thresholds' or maximum sustainable yields Complexity of climate modeling and downscaling Modeling interactions between resources, e.g., climate—water—food—economy	Level of action on climate change in key economies Quality of resource governance
Resource Intensity of the Economy	Rate of innovation in key technologies i.e. cost curves Deployment of best available technology adoption in emerging economies Infrastructure and urban planning decisions	Successful demonstration of resource-efficient industrialization leads to rapid switch in industrial policy Break-even point of game-changing technologies notably solar PV and electric vehicles Impact of smart systems / technologies Breakthrough in substitutability, e.g., steel, oil with an alternative	Resource implications of unforeseen technologies or applications, e.g., rare earth metals only recently a concern due to electronics; additive manufacturing approaches	Resource efficiency measures in China and other emerging economies Investment in innovation

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Annex D
Natural Resources Considered in This Report

Type	Subtype
Fresh Water Resources	n/a
Principal Food Products Including	Major cereals and coarse grains (wheat, rice, maize)
	Oilseeds (soybeans and palm oil)
	Meat (pork, poultry, beef)
	Sugars (sugar cane)
Key Fossil Fuels and Renewable Energy Resources	Oil
	Gas
	Coal
	Nuclear
	Hydro
	Renewables (biomass, solar PV, wind)
Key Metals	Iron
	Aluminum
	Copper
	Nickel
	Specialty metals (rare earths)

Rare Earth Elements

As defined by International Union of Pure and Applied Chemistry, **rare earth elements** ("REEs") or **rare earth metals** are a set of seventeen chemical elements in the periodic table, specifically the fifteen lanthanides plus scandium and yttrium. Scandium and yttrium are considered rare earth elements since they tend to occur in the same ore deposits as the lanthanides and exhibit similar chemical properties.

Despite their name, rare earth elements (with the exception of the radioactive promethium) are relatively plentiful in the Earth's crust, with cerium being the 25th most abundant element at 68 parts per million (similar to copper). However, because of their geochemical properties, rare earth elements are typically dispersed and not often found concentrated as rare earth minerals in economically exploitable ore deposits. It was the very scarcity of these minerals (previously called "earths") that led to the term "rare earth." The first such mineral discovered was gadolinite, a compound of cerium, yttrium, iron, silicon, and other elements. This mineral was extracted from a mine in the village of Ytterby in Sweden; several of the rare earth elements bear names derived from this location. See the table next page for a list of selected rare earth elements and their common applications.

Selected Rare Earth Elements and their Applications		
Name (Symbol)	**Category**	**Selected Applications**
Thulium (Tm)	Neither	Portable X-ray machines, metal-halide lamps, lasers
Cerium (Ce)	Light	Chemical oxidizing agent, polishing powder, yellow colors in glass and ceramics, catalyst for self-cleaning ovens, fluid catalytic cracking catalyst for oil refineries, ferrocerium flints for lighters
Europium (Eu)	Light	Red and blue phosphors, lasers, mercury-vapor lamps, fluorescent lamps, NMR relaxation agent
Gadolinium (Gd)	Light	Rare-earth magnets, high refractive index glass or garnets, lasers, X-ray tubes, computer memories, neutron capture, MRI contrast agent, NMR relaxation agent, additive to steel
Lanthanum (La)	Light	High refractive index glass, flint, hydrogen storage, battery-electrodes, camera lenses, fluid catalytic cracking catalyst for oil refineries
Neodymium (Nd)	Light	Rare-earth magnets, lasers, violet colors in glass and ceramics, didymium glass, ceramic capacitors
Praseodymium (Pr)	Light	Rare-earth magnets, lasers, core material for carbon arc lighting, colorant in glasses and enamels, additive in didymium glass used in welding goggles, ferrocerium firesteel (flint) products
Promethium (Pm)	Light	Nuclear batteries
Samarium (Sm)	Light	Rare-earth magnets, lasers, neutron capture, masers
Dysprosium(Dy)	Heavy	Rare-earth magnets, lasers, magnetostrictive alloys
Erbium (Er)	Heavy	Lasers, vanadium steel, fiber-optic technology
Holmium (Ho)	Heavy	Lasers, wavelength calibration standards for optical spectrophotometer, magnets
Lutetium (Lu)	Heavy	Positron emission tomography - PET scan detectors, high refractive index glass, lutetium tantalate hosts for phosphors
Terbium (Tb)	Heavy	Green phosphors, lasers, fluorescent lamps, magnetostrictive alloys
Ytterbium (Yb)	Heavy	Infrared lasers, chemical reducing agent, decoy flares, stainless steel, stress gauges, nuclear medicine
Yttrium (Y)	Heavy	Yttrium aluminum garnet (YAG) laser, yttrium vanadate (YVO_4) as host for europium in TV red phosphor, YBCO high-temperature superconductors, Yttria-stabilized zirconia (YSZ), yttrium iron garnet (YIG) microwave filters, energy-efficient light bulbs, spark plugs, gas mantles, additive to steel

Scandium has at times also been classified as a rare earth element.

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