# 15 China's Energy Demand Growth and the Energy Policy Trilemma

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## Introduction

China's remarkable pace of development and transformation in recent decades has been well documented, analysed and discussed. In less than 25 years, from 1985 to 2008, China's GDP per capita increased more than fourfold. The path between comparable levels of development took half a century in Japan (1916 to 1967), a century in Germany (1856 to 1958) and the United States (1840 to 1940), and 120 years in the United Kingdom (1820 to 1940) (Shell 2013).

Yet, China is only now just reaching world average levels of energy and economic development. And, outside China's coastal provinces and major cities, energy use and economic development are still well below world average levels. This naturally raises the question as to where China's development will take it in the next 20 years, and what the implications are for energy supply, the economies of China, Australia and the world, and the environment both locally and globally.

Over the past decade, the rapid redevelopment and construction of China's cities has put pressure on commodity supply chains, particularly for the metals required in the early phase of industrialisation, urbanisation and modernisation of infrastructure to build the new urban environments. Energy demand tends to develop more gradually and steadily with economic growth. Indeed, energy is a key input and driver of economic growth: the first section of this chapter explores the relationship between energy per capita and GDP per capita through both cross-sectional comparisons between countries and longitudinal trajectories over time within countries. The two decades from 1990 to 2010 saw a strong linear correlation in China between energy per capita and GDP per capita. The first section also discusses the factors that are expected to moderate the correlation in coming decades. China is also looked at beyond national averages: the energy-economy data shows the wide range across provinces—no one province in China is equal to the national average. The emerging demand picture underscores the energy challenge ahead of China as it becomes a society of increasing prosperity.

Section two introduces the Energy Policy Trilemma: the tension between maximising security of supply, minimising cost and minimising environmental impacts including emissions. Resolving the Trilemma is the key challenge for energy policy makers everywhere. This chapter explores the Trilemma through four case studies: the 1970s oil crisis, China's cost revolution in nuclear power that is quietly unfolding today, the US unconventional oil and gas techno-economic revolution, and the challenge for Japan in closing the 30 Gigawatt gap in the power system post-Fukushima.

The third section considers the resource challenge to meet China's growing energy demand. This includes the opportunities and challenges involved in the development and management of China's resources; the increasing role of imports to balance domestic supply in oil, gas, coal and uranium; and the evolution of the fuel mix, taking into account fuel diversity and import dependence.

The final section explores emerging technologies, many of which China is actively developing, that have the potential to open up new energy transformation, conversion and utilisation pathways between hydrocarbons and key sectors of the economy. These include coal to liquids, coal to chemicals, coal gasification, gas to liquids, compressed natural gas and liquefied natural gas for transport, and electric vehicles.

China has recently become the world's largest energy consumer, and yet it is still in the very early stages of its energy–economic and environmental development path.

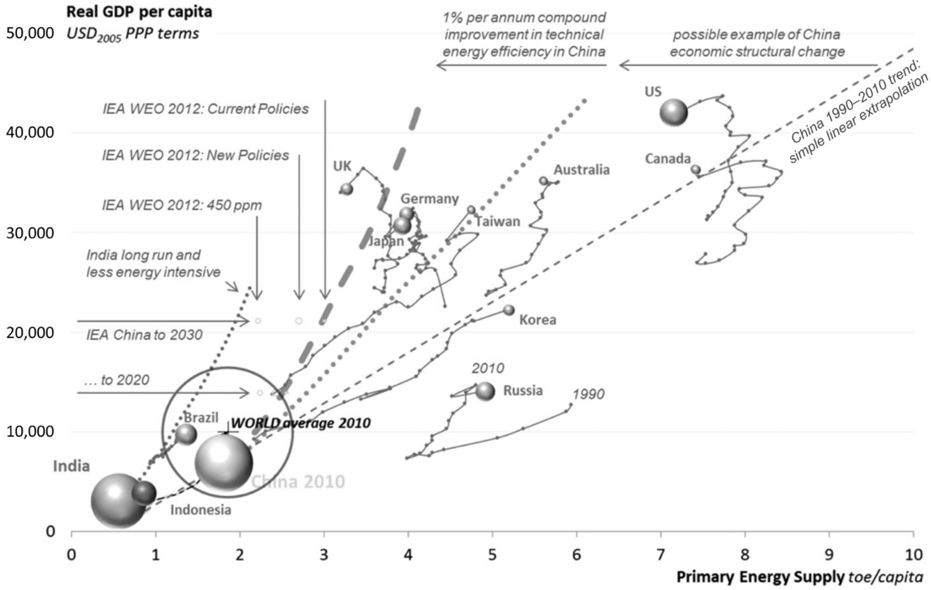
# Energy is a Key Driver of Economic Development and Growth

## China's Development Compared with other Countries

This section presents a straightforward, but not commonly seen way of looking at historical data on demographic, economic and energy development paths. No advanced mathematical or econometric knowledge is required of the reader. The data itself, presented in visual form, is rich and informative, challenging and stimulating for experts, policy-makers and investors alike.

Figure 15.1 charts GDP per capita in constant 2005 US dollars, adjusted for purchasing power parity (PPP) versus per capita primary energy supply (in the common units tonnes of oil equivalent, toe). The bubble sizes represent population.

Figure 15.1 Energy–economy development paths: China, the world and selected economies, 1990–2010




Source: IEA *World Energy Outlook 2012*, IMF online economic database.

Many observations can be made from the data:

- There is a large range between the industrialised economies and the world average.
- There is a range of energy intensities between economies, from the United States and Canada using seven to eight toe per capita; Australia, South Korea and Russia using between five and six; Japan, Germany and Taiwan using between four and five; and, the United Kingdom between three and four. The world average is below two toe per capita. China is at about the world average in terms of energy per capita, while its GDP is well below the world average: China's economy is more energy-intensive than the world average. Brazil's GDP per capita is just below the world average, but it is less energy intensive. India is a long way below the world average in terms of GDP per capita and primary energy, which is a long way below one toe per capita. India's economy is on a less energy intensive trajectory than China's, and has barely begun to develop. Indonesia is ahead of India and on a more energy intensive trajectory.
- The development path of South Korea has been particularly energy intensive.
- In contrast with the steady development of China's economy from 1990 to 2010, the dramatic effect of the collapse of the Soviet Union is visible in the trajectory of Russia.

- The effect of the 2008 global financial crisis on the energy sector and economies of the United States, Canada and the United Kingdom is marked and contrasts with the limited impact on Australia: a testament to Australia's linkage with China.
- In China there has been a strong correlation between energy and GDP: 98 per cent of the growth in per capita energy requirements of the past two decades can be explained by the growth in real PPP-adjusted GDP. The relationship (not shown here) between electricity and the economy is even stronger, explaining over 99 per cent of the growth using GDP per capita as the independent variable. One could equally say that the level of energy supply or consumption almost entirely explains the level of economic activity of the past two decades. Bearing in mind that correlation is not causation, the relationship between energy and the economy is strong.
- The IEA's 'current policies scenario' implies a significant degree of structural change in China's economy combined with about one per cent per annum technical energy efficiency improvement over the next two decades. The 450 ppm scenario allows for only a very small increase in primary energy consumption per capita in China, with sustained growth in GDP per capita.

China has undergone a remarkable story of growth and development in the past three decades, and particularly during the last 10 to 20 years. Hundreds of millions of people have been lifted out of poverty. Modern industrialisation, urbanisation and mobilisation have driven the process of development, and energy in its manifold forms has played an essential role in this process. This is clear in the data for the last 20 years.

International visitors to Beijing and Shanghai today may come away with an impression of prosperity suggesting that China is approaching the mature end of its development curve. Yet the cross-section of international comparisons in Figure 15.1, with a diverse set of major economies at widely varying stages of development shows that China as a whole is only now approaching the global average on the energy–economy development curve.

## Economic Structure and Energy Efficiency

If China was to continue on the linear trajectory of the past 20 years, it would approach North American levels of energy consumption per capita by the time per capita GDP had reached the low 30,000s. This is not expected to happen, however, for several reasons. Firstly, given the size of China's population, the stress that this would place on global energy markets would be expressed in prices that would tend to moderate demand.

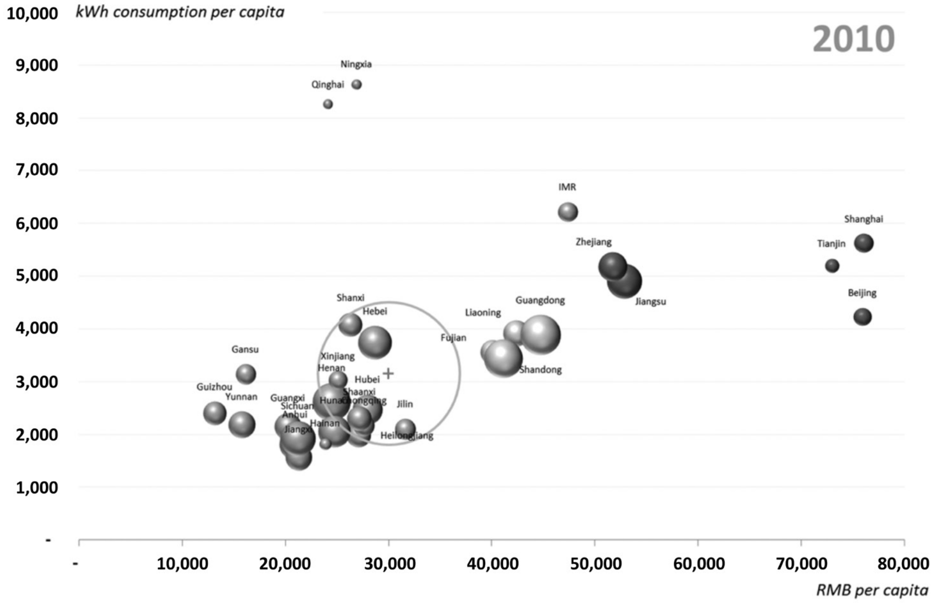
Secondly, the structure of China's economy is expected to begin to evolve away from the energy-intensive, heavy industries towards higher value-adding lighter industries and the services sector and towards increased standards of living for households. This trend will, to some extent, happen naturally, and will also be encouraged by policy-makers. On average, each unit of energy consumed will be expected to generate a greater contribution to GDP. An example of a trajectory showing the effect of economic structural change is shown in Figure 15.1.

Thirdly, the technical efficiency of energy use is expected to increase, driven by improved technology and the many opportunities in a rapidly growing economy with a high proportion of new capital stock to install the latest technology. Increasing incentives for improved efficiency are provided by higher energy prices, and the encouragement of policy-makers. It is difficult to estimate the extent of actual historical technical energy efficiency improvement in an economy, but it is relatively easy to estimate the effects of future technical energy efficiency improvements. The effect of technical energy efficiency improvements of one per cent and two per cent per annum compounding are shown in Figure 15.1. In practice, two per cent is substantial. This is clear when one considers that it is equivalent to saving 20 per cent of energy across all end uses in 10 per cent of the market every year in perpetuity.

## There is no Average Province in China

It is informative to go beyond the cross-section of international comparisons in Figure 15.1 and disaggregate the China data to the provincial level to see the diversity in the rates of development between the major cities and the inland provinces. This shows the degree to which provinces that might be thought economically diverse seem to cluster with respect to electricity and economic development, as well as the broad diversity of development paths across provinces. Figure 15.2 shows electricity per capita versus GDP per capita in RMB terms for each of China's provinces.

Figure 15.2 Electricity–economy and population cross-section of China by provinces




Source: National Bureau of Statistics, China Electricity Council.

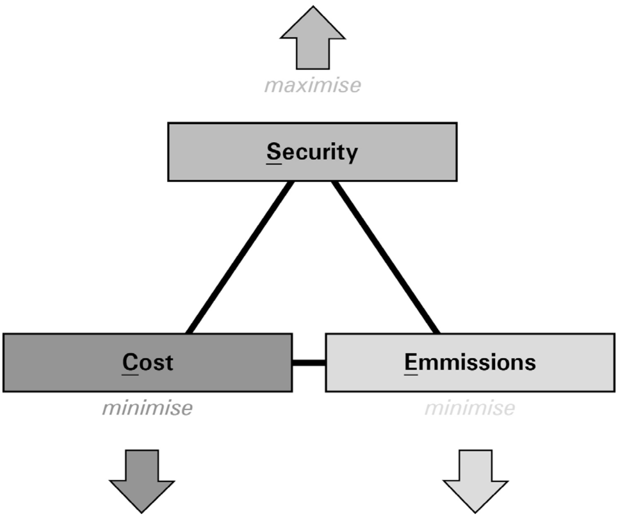
Bubble sizes represent population. The enormous development between 1990 and 2010 is clear in the figure, with the national average increasing from a few thousand RMB and less than 1,000 kWh per capita in 1990 to just over 30,000 RMB and 3,000 kWh per capita in 2010. Even more striking is the wide range of development between the provinces, from the cluster of three key cities Beijing, Tianjin and Shanghai; to Zhejiang and Jiangsu clustered together; then the four coastal provinces of Liaoning, Shandong, Fujian and Guangdong, all with very similar levels of GDP per capita and electricity use per capita. Inner Mongolia, and especially Ningxia and Qinghai are extremely electricity-intensive. The income levels of the inland provinces remain below the national average, as does their electricity consumption, with the exception of the coal-rich provinces, which tend to have higher per capita electricity consumption. Unlike 1990, none of the provinces is representative of the national average marked as '+' at the centre of the circle representing the 2010 China population.

# The Policy-Makers' Challenge

## Resolving the Energy Policy Trilemma

'Policy-makers looking for simultaneous progress towards energy security, economic and environmental objectives are facing increasingly complex—and sometimes contradictory—choices' (International Energy Agency 2012: 24). This may be referred to as the Energy Policy Trilemma (Figure 15.3).

Figure 15.3 The Energy Policy Trilemma




Source: Authors' own schema.

Energy prices, both for liquid fuels, electricity and natural gas, are a political concern in every country: large or small, rich or poor, free market or centrally planned. Every country has an energy policy, and policy makers in all countries are trying to achieve the same three objectives: maximising security of supply, minimising cost, and minimising environmental impacts including emissions. These three objectives are usually in tension—difficult trade-offs are normally required.

Exceptions occur after a major disruptive change. Four case studies illustrate this:

- The 1970s oil crises
- China's quiet revolution in nuclear power
- The US unconventional oil and gas revolution
- Fukushima and Japan's '30 GW problem'

## Case Study 1: The 1970s Oil Crises

The two oil crises of the 1970s—the oil embargo following the 1973 Arab–Israeli war, and the supply disruptions following the 1979 Iranian revolution—brought large step changes in the price of oil, and its price relative to alternative fuels. Policy focus on environmental concerns was in its infancy in the 1970s. Nevertheless, in retrospect, the oil shocks can be seen as having brought the objectives of the Energy Policy Trilemma into alignment. Countries exposed to the price shocks, particularly the United States and the other industrialised economies of the OECD, responded by finding substitutes for oil where possible, particularly in power generation.

## Case Study 2: China's Quiet Cost Revolution in Nuclear Power

One of the ways that OECD countries, such as the United States, France, Germany and Japan, displaced or avoided oil use in the power sector was to build nuclear power plants. In the 1950s it was famously said that nuclear power would be 'too cheap to meter'. For various reasons, particularly in the United States, the economics of nuclear power turned out to be less attractive than expected, largely due to capital cost overruns.

In recent years, China has challenged the contemporary Western conventional wisdom on the economics of nuclear power. Through the partnership between the State Nuclear Power Technology Company (SNPTC) and Toshiba Westinghouse to build the third generation Advanced Passive AP1000 reactor, and subsequently to scale up and develop the design, China is radically reducing the capital cost of building new nuclear reactors, such that nuclear power is now the lowest economic-cost generation option in China. This technological, design, manufacturing, project management and financing cost revolution brings all three elements of the Trilemma into alignment, and explains China's nuclear power policy and stated long-term goal to build 400 GW of nuclear power capacity by 2050, which would be more than the entire global capacity today (China's Medium to Long Term Energy Strategic Plan).

## Case Study 3: The US Unconventional Oil and Gas Revolution

The past five years or so have seen a techno-economic revolution in the United States from the innovative combination of two established oil and gas production technologies. Horizontal directional drilling and hydraulic fracturing have unlocked gas in low permeability shale beds and tight oil in similarly low permeability structures, enabling its commercial production.

Prior to these developments, most observers of the industry expected that the United States would become a major importer of seaborne Liquefied Natural Gas (LNG) to meet its domestic gas demand. Spot natural gas in the United States had seen two sustained price spikes into the mid-teens in terms of dollars per million British thermal units ($/MMBtu) in the 2000s: market conditions that are conducive to attracting LNG imports.

The recent growth in the production of shale gas was so rapid as to lead to temporary overproduction and a price crash to under $2/MMBtu. At the time of writing, prices had recovered to over $4/MMBtu. Widespread industry views suggest US natural gas prices will stabilise around $4 to $6/MMBtu. Reflecting the diametric shift in the supply-demand balance, and the large price differentials between North American and European and Asian gas prices, the nation is now publicly debating the extent to which it should export LNG. The benefits of free markets and free trade are being weighed against energy security and domestic industrial renewal and employment.

As the energy economy seeks a new equilibrium, the unconventional gas revolution has aligned the three Trilemma objectives in the short run. In the long run, the system-wide emission-reduction benefits of gas relative to coal may be offset by the deferral due to low cost gas of new nuclear and renewable energy investments.

## Case Study 4: Fukushima and Japan's '30 GW Problem'

The enormous offshore earthquake and subsequent tsunami that struck the north-east coast of Japan in March 2011 caused a chain of events that resulted in the catastrophic failure of the Fukushima Daiichi nuclear power plant, a second-generation boiling water reactor plant that was first commissioned in 1971. In response, all of the reactors in Japan's nuclear fleet went off-line after their first scheduled maintenance shut down following Fukushima. The 47 GW of capacity in Japan's pre-tsunami nuclear fleet ran at an average load capacity of about 30 GW, thereby leaving a large gap of about 30 per cent in the national power generation supply, which needed to be met initially by gas from LNG imports, and to a lesser extent by increased coal burn.

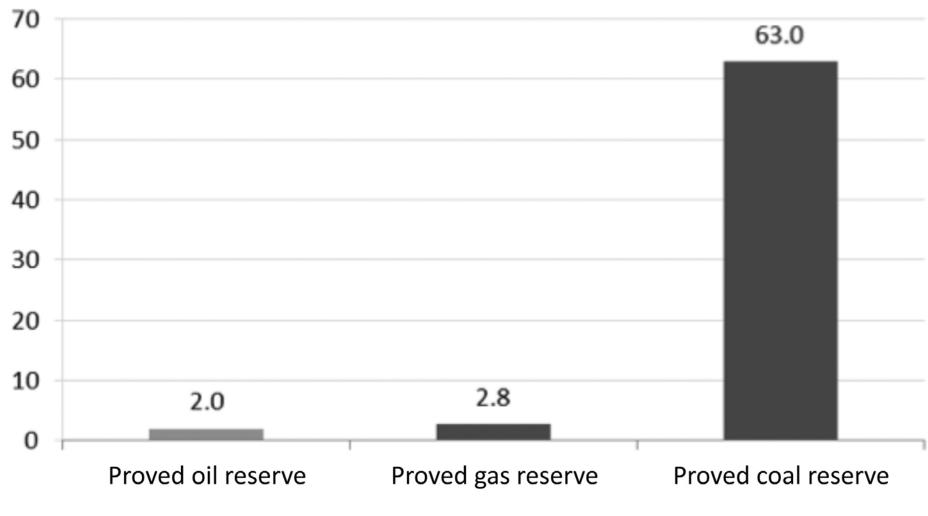
With the previous policy to increase nuclear capacity to 50 per cent of the fuel mix no longer publicly acceptable or practical, and Japan virtually 100 per cent dependent on imports for all its energy needs, the search for a new energy policy confronted a very severe version of the Trilemma. Meeting earlier $CO_2$ emission reduction commitments had become practically impossible without large expansion of nuclear power. Japan's current account swinging to deficit due to increased energy imports, particularly of LNG, highlighted the seriousness of energy cost concerns. At the same time, Japan's traditional energy security concerns were exacerbated by the reduction in the most secure energy source in the mix: Japan maintains probably the longest supply duration uranium stockpiles in the world for its nuclear reactor fleet to provide maximum energy security.

# Resources, Domestic Supply and Imports, and the Fuel Mix

## China's Resources

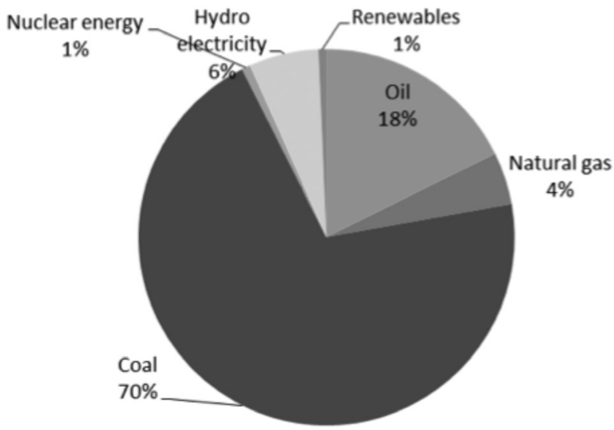
Although China's discoveries of crude oil and natural gas reserves rose in recent years thanks to active and extensive exploration, the reserves are still relatively small compared to its coal resources, which underpin the country's energy security (Figure 15.4). China also has only modest uranium resources—a critical energy source to fuel its massive nuclear power plant expansion plans. According to the OECD-produced 'Red Book', estimates of recoverable resources at 166 100 tU (approximately 432M lbs U3O8) in China is only about a tenth of the level of Australia's known recoverable resources (OECD 2011). Also, China's deposits are mostly small, remotely distributed and have high estimated mining costs. The natural resource endowment has decided the fuel mix structure of China's energy supply, which is coal dominant (Figure 15.5).

Figure 15.4 China's energy resource endowment




Source: BP Statistics, 2011 year-end data, Btoe.

Figure 15.5 China's energy demand by fuel mix

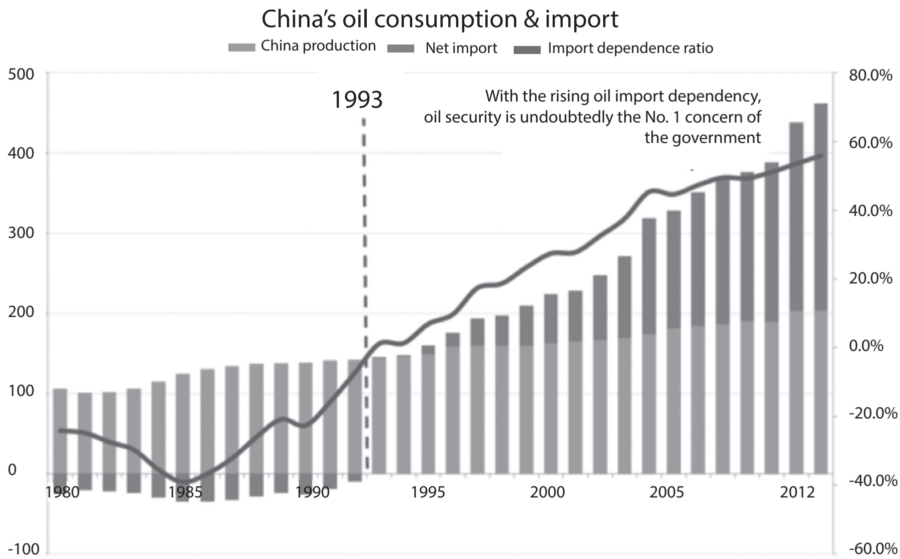



Source: China Customs Statistics, China Customs, Beijing, *2011 year-end data*.

## Domestic Supply and Imports

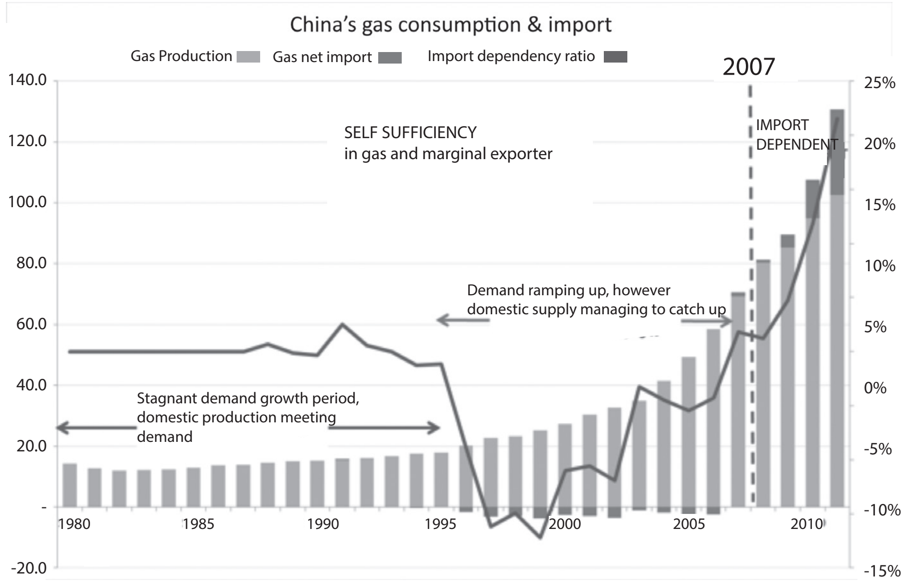
As China's energy requirements have increased, it has made the transition from a producer–consumer, with small net exports, to a major net importer in oil in 1993–1994 (Figure 15.6), in gas in 2006–2007 (Figure 15.7) and in coal in 2008–2009 (Figure 15.8). Oil import dependence is now over 60 per cent and gas import dependence over 20 per cent. Coal imports are still less than ten per cent.

Figure 15.6 China's oil consumption and import (1980–2011, million tonnes)



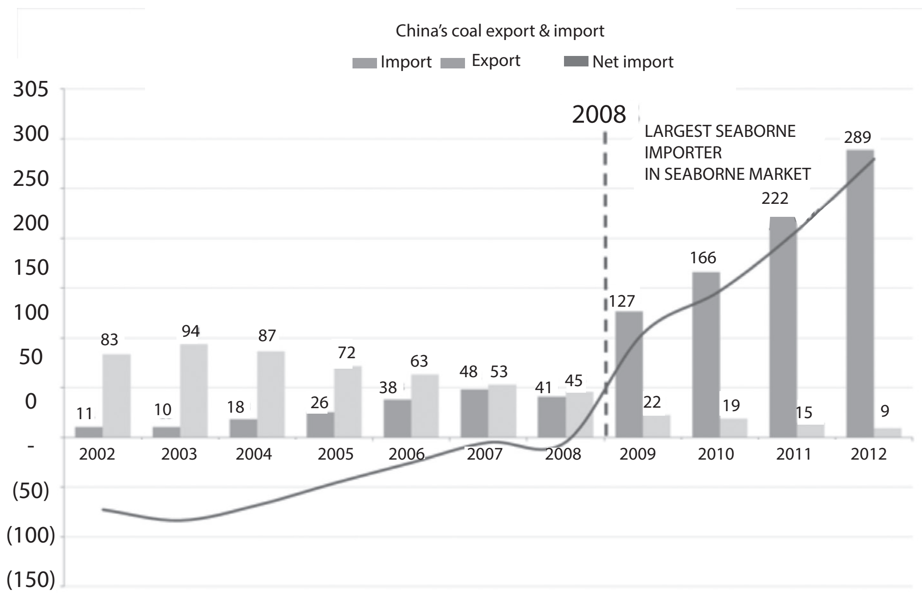

Source: China Customs Statistics, China Customs, Beijing.

Figure 15.7 China's gas consumption and import (1980–2011, billion cubic metres)




Source: China Customs Statistics, China Customs, Beijing.

Figure 15.8 China's coal consumption and import (1980–2011, million tonnes, physical)

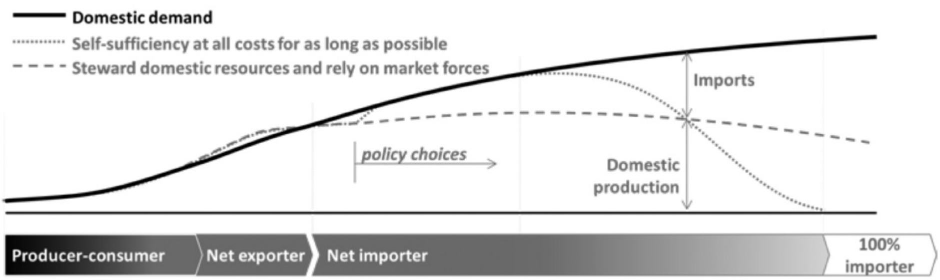



Source: China Customs Statistics, China Customs, Beijing.

China's ability to provide its own needs is limited by the fact that its proven oil and gas reserves are small in relation to its consumption. At current production rates, the reserve to production ratio of oil is only ten years, while gas is 30 years (source: BP statistics, reserve is proven and excludes resource estimates). Consequently, China's reliance on fossil fuel imports has grown significantly in recent years—oil dependency is at 60 per cent and natural gas dependency at 20 per cent and rising.

Figure 15.9 shows a typical evolution of an emerging economy from energy producer–consumer to net energy exporter to net energy importer. Two contrasting policy choices are shown in stylised form: the pursuit of self-sufficiency at all costs for as long as possible, and stewardship of domestic resources relying on market forces to balance imports with domestic supply.

Figure 15.9 Policy choices




Source: Authors' own schema.

The former policy will tend to increase the marginal economic cost of supply and hence prices, while accelerating the depletion of indigenous resources. At its limit, it will bring forward the date of resource depletion and import dependence. The latter policy will tend to minimise marginal costs and hence prices, and optimise the depletion of indigenous resources.

Another policy choice (which would be lower and flatter than the stewardship curve of Figure 15.9) would be to increase imports now to conserve domestic resources for future generations. Such a policy would be expected to increase marginal costs and hence prices, and to push depletion to a later date.

A further policy (which would create a higher and more 'peaked' curve than the self-sufficiency of Figure 15.9) would be to encourage exports. The United States is currently debating whether to allow unrestricted LNG exports now, at the possible cost of higher prices and depletion of shale gas resources faster and sooner. Stewarding domestic resources and relying on market forces may result in net imports balancing supply and demand in some countries and at some times, or in net exports balancing supply and demand in other countries or at other times.

Evidence from current policy settings and the evolution of energy policy in China suggests an approach best described as stewarding domestic resources for the long run by increasingly relying on market forces to find the appropriate balance between domestic supply and imports.

Tax policy can be used to fine-tune such an approach, as has been done in China with, for example, a shift from duties and taxes that encouraged coal exports towards duties and taxes that discourage coal exports.

## Opportunities and Challenges: The 7 Ds Facing the Coal Sector

Despite the fact that coal provides the fundamentals of China's energy security of supply, the over-reliance on this sector and massive production rates at close to 4 billion tonnes per annum has imposed increasingly greater challenges to this sector's future development.

The challenges facing China's coal sector can be summarised in seven D's: *depletion* of the resource base, characterised by increasing mining *depths*; quality *deterioration*; increasing geological *difficulty*; increasing *distances* from mines to markets; and, the imperative to improve safety to reduce mining *deaths*. The challenges of these resource fundamentals are compounded by China's changing *demographics* and socio-economic development, in which the labour pool has begun to shrink, and employment opportunities continue to improve with economic growth.

## Opportunities and Challenges: Unconventional Gas

The shale gas revolution and production boom in the United States has given rise to hopes for China to unlock its unconventional resources and improve energy security in general. According to a consultant's estimate, published by the US Energy Information Administration, China has larger shale gas resources than the United States (Advanced Resources International, Inc. 2011). Estimates by Chinese geologists from the Ministry of Land and Resources estimate China's shale gas resources are around the same scale as the United States.

The benefits of a shale-gas boom in China would be enormous, with the potential benefits and likely environmental costs perhaps even greater than in the United States. So far, however, the sector's success is limited by the challenging geology and the monopolistic structure of China's oil and gas sector.

While over 100,000 horizontal wells have been drilled into shales in the United States and hydraulically fractured or 'fracked', China has only about 80 drill holes to date. The sector is characterised by investors as a high risk proposition, with insufficient infrastructure in place, no third-party access to the pipelines (over 80 per cent of China's pipelines are owned and operated by China National Petroleum Company) and potentially further complicated by local environmental concerns in relation to groundwater and disruption and disturbance of the daily lives of host communities.

Analysts at the optimistic end of the range expect that large-scale, commercial production could happen in the next ten to 20 years. The International Energy Agency predicts China's unconventional gas production could rise from 10 Bcm in 2010 to over 110 Bcm in 2020 and 390 Bcm by 2035 (2012). Under this scenario, total gas production rises from just under 100 Bcm in 2010 to nearly 475 Bcm in 2035, and unconventional gas accounts for 83 per cent of total gas production by the end of the projection period. Unconventional gas production in 2035 is predominately from shale gas (56 per cent). Coal bed methane (38 per cent) and tight gas (six per cent) provide smaller shares. While China would still rely on gas imports, the unconventional gas success would significantly reduce its foreign gas dependency ratio (Table 15.1).

Table 15.1 Two gas development scenarios for China

| | | **Golden Rules Case** | | | **Low Unconventional Case** | | Delta* |
|---|---|---|---|---|---|---|---|
| | **2010** | **2020** | **2035** | | **2020** | **2035** | |
| Production | 97 | 246 | 473 | | 139 | 194 | 279 |
| Unconventional | 12 | 112 | 391 | | 37 | 112 | 279 |
| *Unconventional share of total* | *12%* | *45%* | *83%* | | *27%* | *58%* | *25%* |
| Net imports | 14 | 77 | 119 | | 143 | 262 | –143 |
| *Imports as share of demand* | *12%* | *24%* | *20%* | | *51%* | *57%* | *–37%* |
| **Gas share of the energy mix** | 4% | 8% | 13% | | 7% | 10% | 3% |

*Delta is the difference between the Golden Rules Case and the Low Unconventional Case.

Source: Data and projections: International Energy Agency.

## Diversity and Dependence

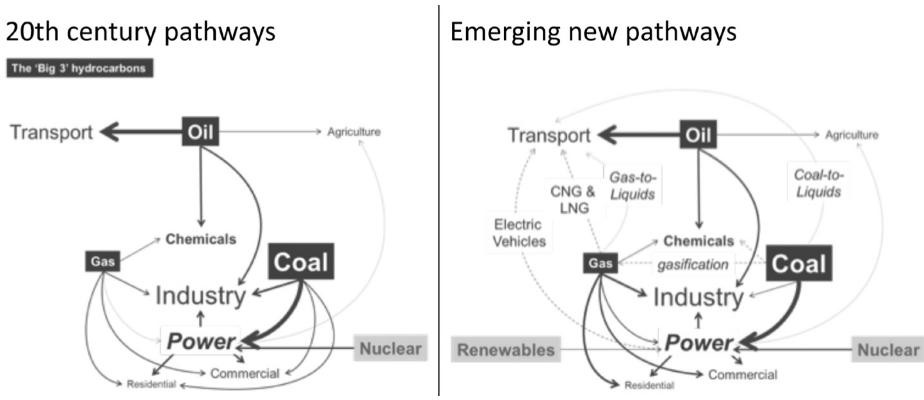
In China, energy security of supply is already equal with or greater than cost as a policy priority. The environment has historically been a lesser concern. This is changing as incomes increase, leading to greater impacts on the environment from increased mobilisation, industrialisation and urbanisation. Reducing the emissions that contribute to local air pollution from oxides of sulphur and nitrogen dioxide and particulate matter is becoming an increasingly important policy priority. This is particularly evident in China's major cities and the more developed coastal provinces, where incomes are highest.

# Pushing the Technology Envelope

## Traditional and Emerging Energy Pathways

The degree of competition between 'the big three' hydrocarbons—oil, gas and coal—varies from country to country. Since the oil crises of the 1970s, however, oil has tended to be priced out of uses such as power generation in most oil-importing countries where new economic alternatives are available. The growth of the gas industry in the second half of the 20th century in Europe and the United States also displaced oil from the industrial sector, leaving oil as the dominant fuel in the transport sector, where it is has the greatest advantages and where it is most challenging to find attractive substitutes. Oil, gas and coal have generally found niches for which their particular characteristics are best suited. The security, cost and logistical advantages of coal are most evident in the power sector. Gas is the premium fuel for the residential, commercial and industrial sectors. The degree of inter-fuel competition varies somewhat from country to country and region to region. The left hand panel of Figure 15.10 illustrates this.

Figure 15.10 Hydrocarbon energy conversion and utilisation pathways




Source: Authors' own schema.

Technology, led by China in particular, is opening up the prospect for emerging new pathways to transform hydrocarbons. As the right hand panel of Figure 15.10 illustrates, this would increase the potential variety of applications for each fuel and hence the extent of possible substitutability. Coal combustion in the residential and commercial sectors is expected to be replaced by gas where possible and, subject to availability and price, gas use will increase in the industrial sector.

## Oil and Gas: Alternatives to Imported Crude Oil—Easing the Pinch Point for Energy Security

The right hand panel of Figure 15.10 shows four emerging new fuel-technology pathways for transport: natural gas vehicles (NGVs) using compressed natural gas (CNG) or liquefied natural gas (LNG); coal-to-liquids (CtL) technologies; gas-to-liquids (GtL) technologies and electric vehicles (EVs).

Gas use in vehicles via CNG and LNG technologies has begun, including for heavy-haul vehicles in China, and is expected to be encouraged by policy settings, and potentially by relative prices, although the oil-to-gas price differential in China is not expected to be as wide as it has been in the United States in recent years.

China is working on CtL technologies and pilot plants. GtL technologies are less likely to be applied in China (compared with the Middle East, for example), as China's oil and gas companies do not have a surplus of gas to monetise. Many CtL technologies, however, use coal gasification as the first step in the process of producing liquid fuels.

Small electric vehicles for urban use, notably scooters, are already common in China and domestic companies such as BYD are manufacturing electric vehicles.

## Coal: Pressures to Reduce Coal Use; Pressures and Opportunities to Increase Coal Use

China is facing a number of internal and external pressures to reduce coal use. These include the economic pressures of rising costs, the social need to further reduce the rate of coal-mining deaths, the need to reduce the impacts of mining on land and communities, and local and international environmental concerns. At the same time the energy required for economic growth brings pressures from the demand side to increase coal use. Profitable opportunities for Chinese companies to develop and mine coal reserves, along with profitable import opportunities also bring supply-side pressure to increase coal use. From the policy level, the importance of reducing pressure on the oil market may increase upward pressure on coal.

Displacing imported oil to increase energy security of supply is a key focus of the emerging new hydrocarbon pathways in China. Alternatives for coal, including increased use of gas in small-scale applications where emissions are difficult to control and monitor, and to enforce regulatory standards, enable coal to be released for transformation to relieve the pressure on oil demand. In addition to CtL, coal can be gasified and the gas used directly. There are over 100 coal-to-chemicals (CtC) projects in various stages of proposal, planning, development and operation in China.

China's nuclear build program, the largest in the world, will complement efforts to relieve the pressure on oil demand. Developing the balance of China's hydro potential, as well as from intermittent renewable energy forms will also contribute to the same goal.

China's efforts to push the technology envelope are best understood within the framework of the Energy Policy Trilemma, and particularly in terms of concerns about oil security of supply. There is a risk of rapid growth in China's oil demand driven by personal and commercial transportation activity rising with incomes and economic growth, which will put enormous stress on the global oil-supply system. This could be expressed in high prices, even in the absence of supply shocks similar to those of the 1970s (for example a conflict-related closure of the Straits of Hormuz).

## Conclusion

China has undergone an enormous economic transformation in the past two decades and is now approaching world average levels of per capita income and energy consumption. Energy is a key driver of economic development, particularly in China's case, where relatively energy-intensive industries have played a key role. Rapid economic transformation has been primarily driven by the coastal provinces and the major cities. Looking beyond national averages into province-level data shows that energy demand and economic development still have a long way to go in China. Structural change in the economy towards a greater weighting of less energy-intensive secondary industries and higher value-added services are expected to moderate the strong linear relationship of the past two decades between energy requirements and GDP. Improvements in technical energy efficiency will further help moderate the rate of energy demand growth.

In absolute terms, China is abundant in energy resources. Relative to the scale of demand arising from the scale of its population and its rapid economic development, however, it will increasingly be fundamentally energy short.

China was historically energy self-sufficient, and even able to export a small proportion of its energy production. Exports of oil stopped in 1993, gas in 2006 and coal in 2008. Security of supply is already the highest policy priority, which is felt most acutely in oil. The trade-offs between the three corners of the Energy Policy Trilemma are steadily becoming more acute in China. As China's energy import dependence deepens from oil to gas, security of supply is expected to increase rather than decrease in importance. The challenges for policy makers will increase as the economic pressures on coal production grow, caused by 'the 7Ds' of resource depletion and demographic change. The increasing imperative to reduce the environmental impacts of energy use on China's local air quality, water resources and soils emphasise the challenge.

China's energy mix is changing, driven by the cost revolution in third generation nuclear reactor technology, the push to increase the role of the gas sector and encouragement of renewable energy technology. In parallel, technology offers the prospect of increased flexibility by transforming coal to oil, chemicals or gas and by new applications for gas and for electricity in the transport sector.

Energy imports, including gas, coal and uranium from stable regional trading partners, such as Australia, have a key role to play in balancing production of China's own resources with its large and rapidly growing energy needs. Continuation of the reforms that have enhanced the scope for price signals to indicate opportunities for energy imports will help to facilitate this process to the mutual benefit of China's people and her regional trade partners.

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