Energy Resource Depletion and Carbon Emissions Global Projections to 2050

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1 Introduction

In consideration of global warming issues, it is generally assumed that long-term depletion of global fossil fuel resources will come too late to have any bearing on policies designed to mitigate carbon dioxide emissions. It is argued here that this assumption is incorrect. It does not account for the geographical distribution of fossil fuel deposits, local depletion in particular countries, and the bearing this will have on global fuel transportation and distribution. Consideration of these factors indicates that depletion should have a bearing on choice of appropriate carbon pollution mitigation policies.

While it is straightforward to perform “years of supply” calculations for producers based on the ratio of reserves to current production, it is more difficult to calculate how these estimates will change, given the reallocation of global production in response to depletion in major producer countries. To accomplish this task it is necessary to have some idea how trade flows may respond to demand and supply requirements. This paper presents some initial results of a 79-country model designed to facilitate such a computation. The results show projections, given particular assumptions, of economic growth, fossil fuel production, trade and consumption to the year 2050, specifically taking account of fuel reserves and depletion.

Production of industrial carbon dioxide emissions is directly linked to fossil fuel consumption, so that a model that projects fuel consumption can readily be used to project CO_2 emissions. This has also been done here, to illustrate the implications of the assumptions. However it is not the purpose here to investigate policies required for effective CO_2 mitigation. That task is left to a later stage.

The magnitude of the mitigation task cannot be overstated. In order to stabilise the climate, greenhouse gas emissions need to be reduced, in the near term, by an amount equivalent to the entire global emissions from coal consumption. It is reasonable to state that, given the policy proposals so far under consideration, it seems highly unlikely that this result will be achieved. Rather, it seems that without supply limitations, emissions will go on increasing well into the current century. However, supply limitations may well intervene. Hence it is productive to consider the geographical distribution of resources and what implications may be drawn in terms of policy formulation.

The approach here will be first to outline the model assumptions, and then to proceed to assess the projections for each fossil fuel in turn: coal, oil and natural gas. We will then turn to an overall evaluation of the implications.

2 Model assumptions

The results for this study have been produced using a new global model. The model has been constructed using a combination of schematised growth rate equations providing national income components, national income identities, a commodity-based trade flow matrix, and a stock adjustment model providing resource production and consumption. In the growth equations, the parameters are all elasticities. Export supply, subject to resource availability constraints, is determined from import demands via the trade flow matrix.

A particular feature of the model is that it is able to incorporate any given set of data and short-term forecasts, and incorporate these into policy simulations and long-term projections[1]. It does this using error term correction.

An advantage of this type of model is that it is highly parameterised, and all parameters have a readily accessible economic interpretation. It is planned that the model will be user- accessible, so that results will be readily recomputable under alternative assumptions.

Several key assumptions have been made, which together provide the key determinants of the aggregate results. These are not forecasts, but merely assumptions used to formulate a scenario for the evaluation of global fuel use and CO_2 emissions.

The first assumption is that national incomes have been set to conform with a specific long- term growth path. In this, average historical growth rates are replicated in the short term, but in the long term are convergent to a steady state growth of one percent in 2050. This is less than half the long-term average, but reflects the possibility that economic circumstances, given resource constraints and environmental issues, may be more difficult in future.

The second set of assumptions is that fuel prices, set exogenously, will rise in the long term, relative to other commodity prices. This is more the case for coal, which reflects an assessment that the future supply situation, as will be outlined, may be as tight as, or tighter than, for oil or gas. The annual increments assumed are: coal 4%; oil 2%; and gas 1%. These assumptions may also be regarded as reflecting carbon mitigation schemes.

The third major assumption set regards the energy intensity of each fuel with respect to national income. It is assumed that coal consumption, across all users, decreases by 2% annually with respect to GDP growth, while oil and gas consumption decrease by 1%. These assumptions reflect the fact that being the most polluting fuel, and where alternatives in electricity generation are more available, coal use will decline more than other fuels.

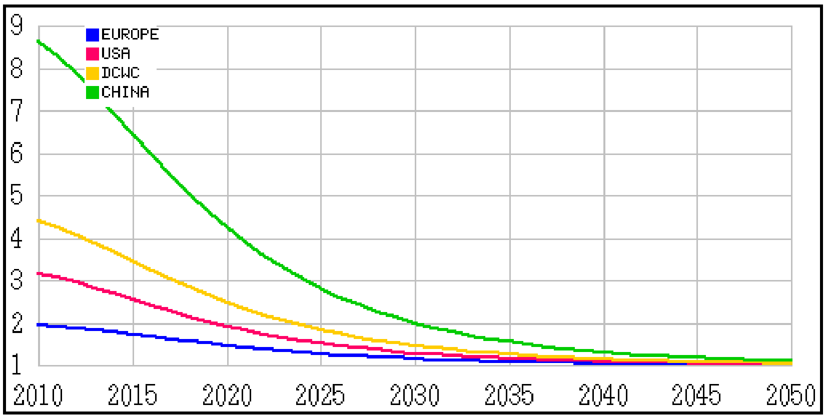

Figure 1. Real growth rate convergence assumption

Note: DCWC is developing countries without China.

It may be thought that these assumptions, particularly the low growth assumption, provide a relatively pro-mitigation carbon emission scenario. However it must be understood that the model, as currently construed, provides little scope for alternative energy substitution. This will be incorporated, in subsequent development, by increasing the rate of energy intensity reduction over

[1] The model arose from an idea to utilise the forecast data provided on the UN Project Link website.

time, as relative fuel prices are deemed to make alternative energy production more viable. However the purpose here is to focus on the effects of resource depletion, rather than viable emissions reduction scenarios.

It is known that the input assumptions are unrealistic simplifications. The point is to examine the implications of them, to see what alternative assumptions may be required in order to produce more realistic and desirable projections.

3 Results of projections

Based on the assumptions provided, the model provides solutions for all economic variables for 79 countries. Generally both imports and exports increase as a share of national incomes. The results presented here focus on fossil fuel production, trade and reserves.

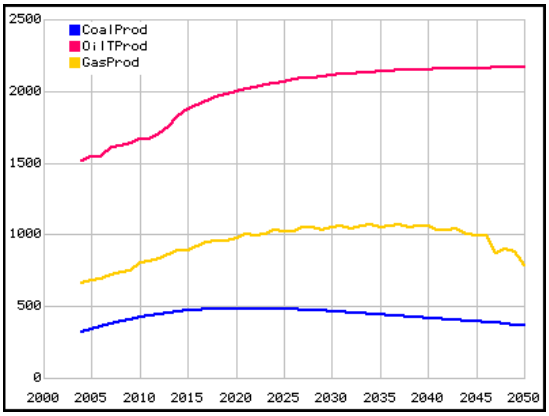

Figure 2. Fuel production (2005 $ bn)

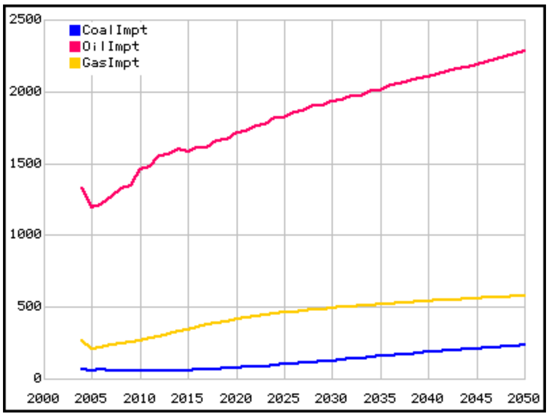

Figure 3. Fuel imports (2005 $ bn)[2]

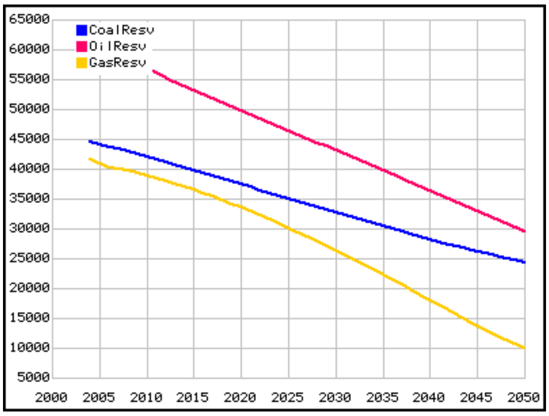

Figure 4. Fuel reserves (2005 $ bn)

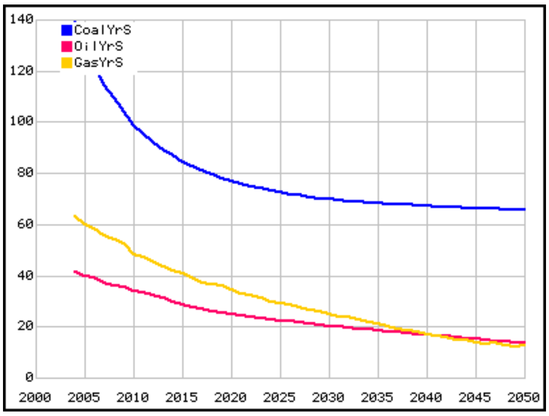

Figure 5. Years of supply (R/P)

The results shown in Figure 2 indicate that oil production is sustained, but demand for coal declines somewhat, after 2020. Gas production is affected by supply constraints. Figure 3 shows an increasing proportion of production is traded. Figure 4 indicates that substantial proportions of total reserves are depleted over the period. The assumption that production generally declines in proportion to remaining reserves means that the years of remaining reserves, as calculated by the reserves to production ratio, tends to stabilise, as shown in Figure 5. These trends in global reserves tend to mask important details in individual country reserve depletion, and the effect this has on demand and trading patterns.

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[2] Total world imports equals total world exports, apart from valuation changes, freight charges etc.

4 Coal

Coal is commonly considered to be the most abundant fossil fuel. However there are several uncertainties that warrant the revaluation of this assumption. While new discoveries of oil and gas may roughly keep pace with annual production, this is not the case with coal, where reserve estimates have often been revised downward. A considerable degree of the uncertainty arises from the distinction between reserve estimates and ultimately recoverable reserves. While there is no necessary reason that a resource production profile over time should follow a Hubbert-type bell-shaped curve, reserve estimates based on the assumption have often been more historically accurate[3].

A detailed study involving mine site data in 132 countries, by Mohr and Evans, has found that peak global coal production may occur in 2026, and that the "notion that coal is widely abundant therefore appears unjustified".[4] A further study by the European Commission's Joint Research Centre further highlights the uncertainties.[5] Most future supplies are expected to have to come from deeper deposits, from underground rather than open cut mines, from more remote locations, involving higher cost and lower quality coal. The European Commission report highlights the concentration in suppliers and suggests that "Australia is gradually becoming the ultimate global supplier of coal" (p.5).

Table 1. Coal reserves in 2005 (billion tonnes)

	Reserves	Cum %	Years of supply
United States	200.7	29.3	195
Russia	124.6	47.5	428
China	98.8	61.2	65
Australia	64.7	71.3	172
India	55.2	79.4	129
South Africa	48.0	86.4	195
Ukraine	28.3	90.5	469
Total	685.6	100.0	107

Source: US EIA. Black coal equivalent. China reserves increased by 50%

Data sources vary considerably regarding estimates of coal reserves. The estimates used here are those published by the US Department of Energy's Energy Information Administration. In view of the fact that recent statements in China refer to newfound reserves in Xinzhiang Province, the estimates of China's reserves have been increased by 50% for the simulation.

Notable about the reserves, given in Table 1, is that just seven countries hold over 90% of the world's reserves. While the reserves equate to 107 years of world supply, which is much higher than for oil and gas, this perhaps masks the true supply situation. Four of the top five countries in coal reserves are not currently great exporters, and are in fact increasingly turning to imports for

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3 The Hubbert curve is named after M. King Hubbert, who suggested in 1956 that resource production over time would follow a bell-shaped curve.

4 Mohr, S.H and G.M. Evans, "Forecasting coal production until 2100", *Fuel*, Vol 88, 2009, p.2066

5 Kavalov, B, and S. D. Peteves, *The Future of Coal*, Directorate General – Joint Research Centre, European Commission, February 2007. See http://ie.jrc.ec.europa.eu/downloads/file.php?id=75.

supply. China, in particular, does not have a large quantity of reserves in per capita terms, and is by far the world's biggest consumer of coal. Hence China, of all the consumers, faces the greatest future supply difficulties.

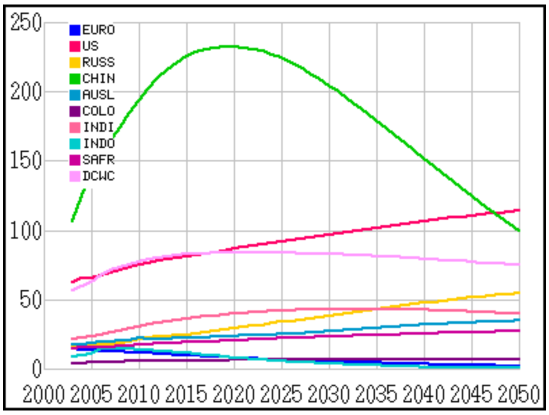


Figure 6. Coal production (2005 $ bn)

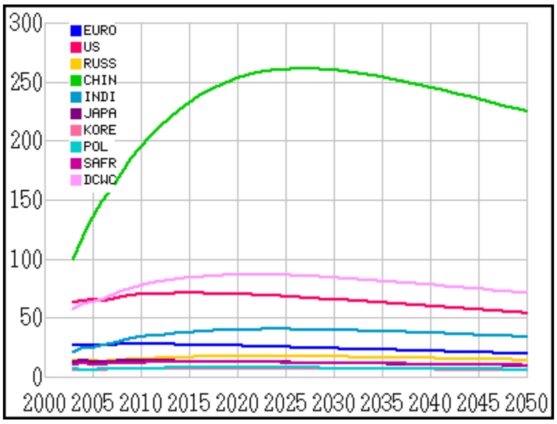


Figure 7. Coal consumption (2005 $ bn)

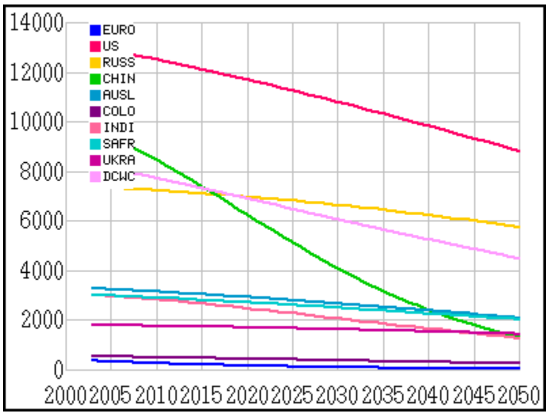


Figure 8. Coal reserves (2005 $ bn)

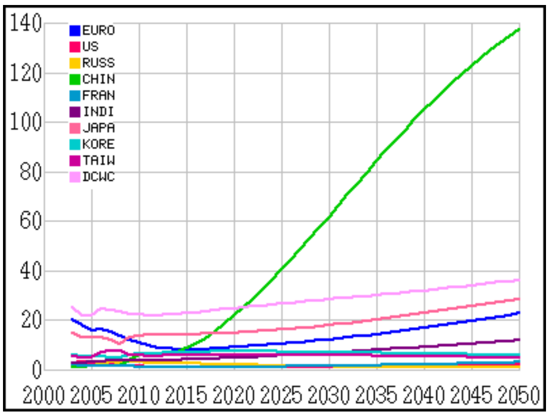


Figure 9. Coal Imports (2005 $ bn)

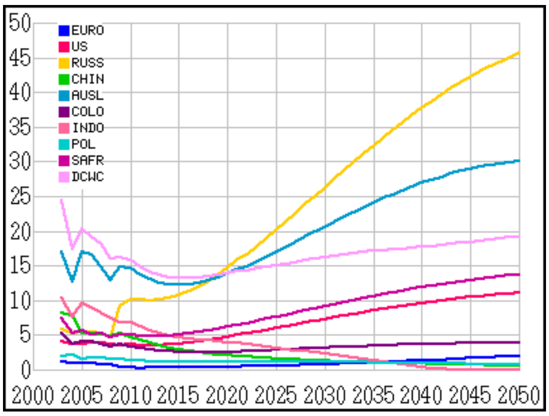


Figure 10. Coal exports (2005 $ bn)

The projections for coal, shown in Figures 6-10, show the supply difficulties that China may face. In the model, production is linked to GDP growth but with a reserve depletion factor, calculated as the ratio of current reserves to 2006 reserves. This simplifying assumption provides a production profile that at least has the desirable property that production ceases when there are no reserves left. The result is a bell-shaped curve in which Chinese coal production peaks in 2018. The result of increasing China's reserves by 50% was only to extend this peak by 3 years from 2015. Mohr and Evans's "best guess" of the peak year for China is 2010. Given China's vast coal consumption, this supply gap opens up a huge import demand, as shown in Figure 9. The extent of the problem can be gauged from the fact that currently, Australia's total coal exports, by far the biggest of any exporter, still only represent 5% of China's consumption. Figure 10 shows the model's response in expanding both Russian and Australian exports to meet China's import demand. In reality however, the supply logistics would be highly problematical.

The impact on coal prices of such a supply crisis could be considerable, and would not be without some risk of international diplomatic tensions. A high international coal price would, in addition, have relevance for global warming issues, in advance of rising oil prices, as a result of petroleum resource depletion. Thus the potential for such a situation to develop deserves the attention of policy makers, and foreshadows the need for consideration of an international agreement on resource pricing and the international distribution of revenues arising from resource rents, in this case, in association with global warming mitigation policies.

4 Oil

Consideration of future oil supplies and the notion of "peak oil" are far more familiar than similar concepts in relation to coal. The situation is similar in that, while global supplies seem secure, at least for several decades, local depletion in major consuming countries will present increasing difficulties in supply logistics.

Table 2. Oil reserves in 2005 (billion barrels)

	Reserves	Cum %	Years of supply
Saudi Arabia	262.3	21.8	76
Iran	134.6	33.0	90
Other West Asian Exporters[6]	131.2	43.9	54
Iran	120.0	53.8	176
Canada	102.4	62.3	119
Kuwait	100.8	70.7	110
Russia	67.2	76.3	21
Venezuela	66.4	81.8	72
Total	1204	100	39

Source: US EIA. Average of World Oil and Oil & Gas Journal estimates

As the reserve estimates in Table 2 indicate, while not as concentrated as in the case of coal, more than 80% of oil reserves are held in just a dozen or so countries. Current consumption equates to 39 years of global supply, much tighter than the apparent situation for coal. The projections shown in Figures 11-15 allow for a 1% annual increase in reserves, prior to the deduction for production, to account for new reserves coming on line.

[6] Principally United Arab Emirates, Kazakhstan, and Qatar

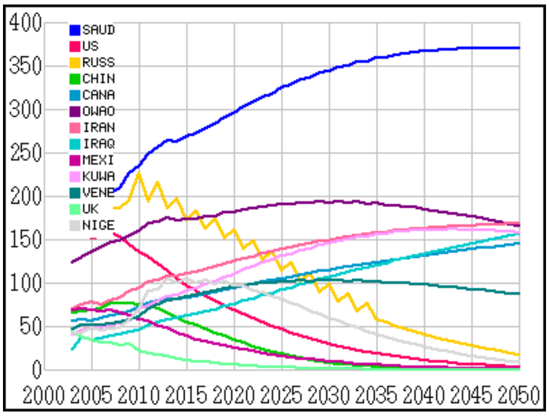


Figure 11. Oil production (2005 $ bn)

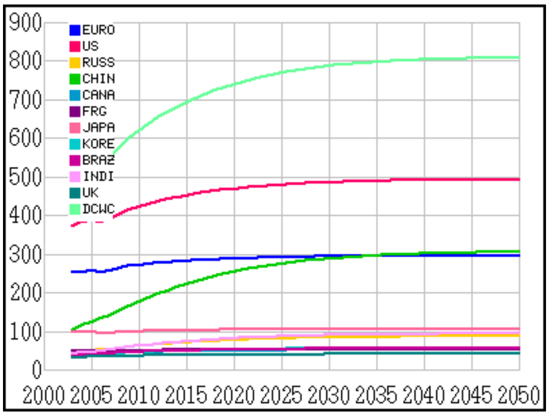


Figure 12. Oil consumption (2005 $ bn)

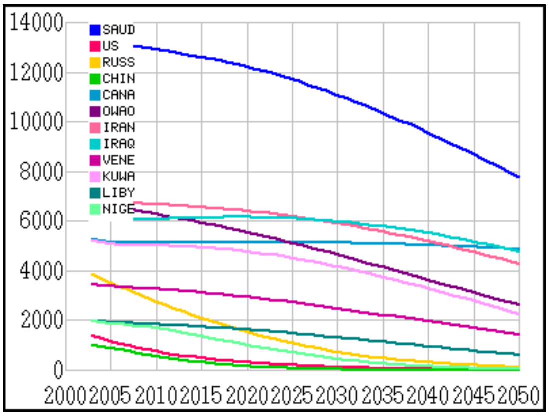


Figure 13. Oil reserves (2005 $ bn)

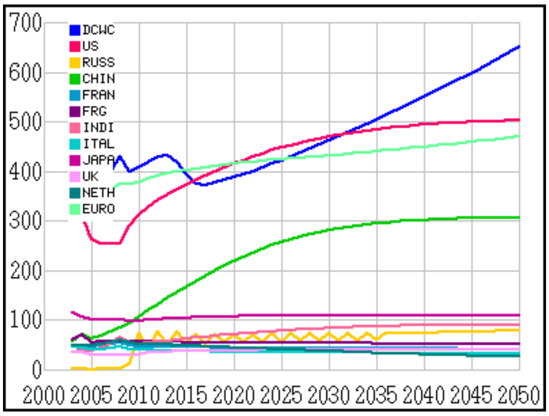


Figure 14. Oil imports (2005 $ bn)

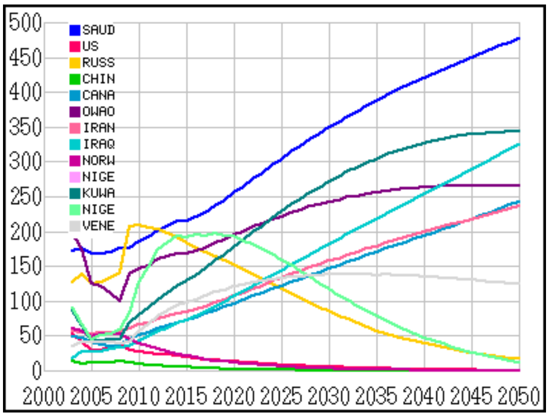


Figure 15. Oil exports (2005 $ bn)

The figures indicate that while reserves decline generally, the fact that US and Chinese reserves are substantially exhausted, leads to rising import demands in these countries, putting pressure on other suppliers. The decline in Russian production and exports of oil further exacerbates the supply situation. The gap is filled by rising production and exports in traditional suppliers like Saudi Arabia, Iraq and Kuwait. The problem again is that as the number of countries with viable reserves decreases, supply capabilities, infrastructure and logistical difficulties may make the satisfying of import requirements problematical. The potential exists for considerable economic disruption.

5 Natural gas

The future supply situation for natural gas also appears highly fraught with difficulty. As shown in Table 3, the distribution of resources is highly concentrated. Just three countries, Russia, Qatar and Iran, hold over 50% of the reserves, and about a dozen countries hold almost 80%. The major reserve countries appear to have many years of supply, however this is deceptive, as production increases due to depletion in other countries can quickly reduce the apparent time horizon.

Table 3. Natural gas reserves in 2005 (trillion cubic feet)

	Reserves	Cum %	Years of supply
Russia	1684.4	27.6	75
Other West Asian Exporters[7]	1241.2	48.4	218
Iran	974.0	64.5	274
Saudi Arabia	246.3	68.6	99
United States	211.1	72.0	13
Nigeria	183.2	75.1	53
Algeria	161.5	77.7	125
Venezuela	151.7	80.2	151
Total	6048.9	100.0	58

As with oil, the projections shown in Figures 16-20 allow for a 1% annual increase in reserves, to account for new reserves coming on line. The production and exports profiles show how disruptive regional exhaustion can be to global supply patterns.

As with the production, consumption and trade graphs for coal and oil, the projections for natural gas should not be interpreted as a specific projection for each country, but rather as a general characteristic of a world struggling to cope with supply constraints. Changes in the sequence of country depletion will shift production to remaining reserves at different times.

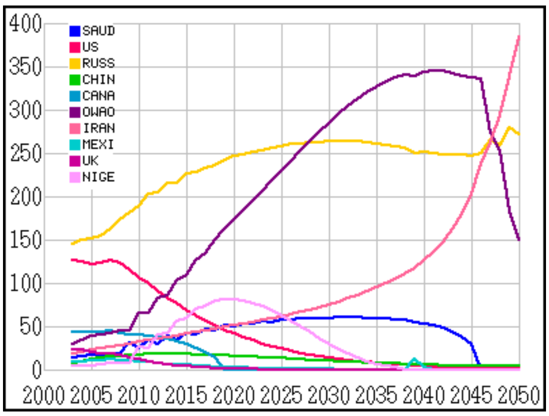


Figure 16. Gas production (2005 $ bn)

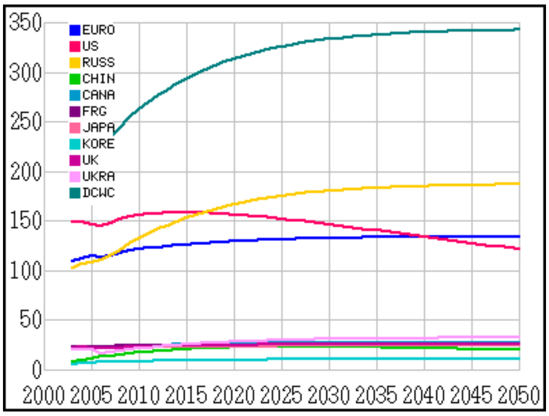


Figure 17. Gas consumption (2005 $ bn)

[7] The principal gas exporters in this group are Qatar, United Arab Emirates and Kazakhstan.

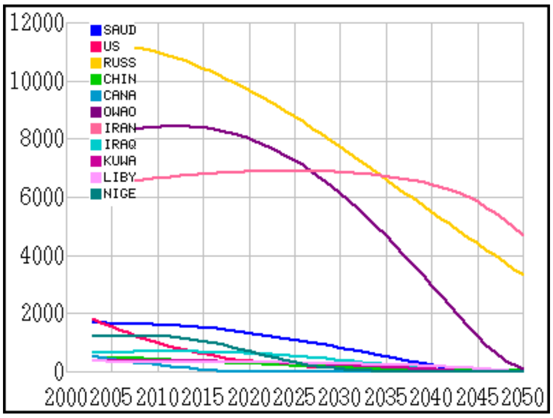


Figure 18. Gas reserves (2005 $ bn)

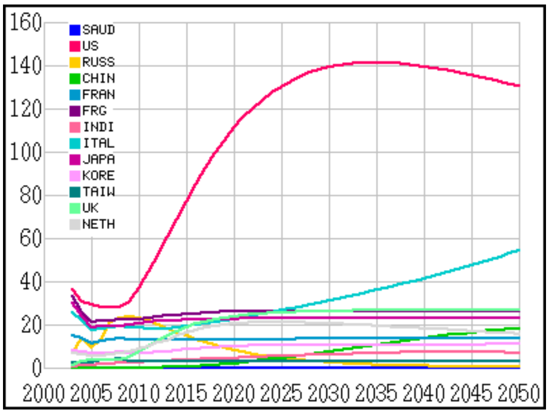


Figure 19. Gas imports (2005 $ bn)

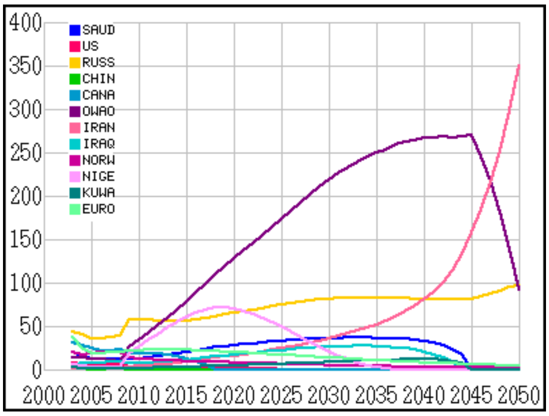


Figure 20. Gas exports (2005 $ bn)

The figures highlight the geographical disparities in global supply that may occur. Given the global concentration in reserves, but with more evenly spread consumption patterns, the model indicates that all but two of the major suppliers, Russia and Iran, may become effectively depleted. The US, being a major consumer, then becomes a major importer.

These results may be highly dependent on the model assumptions and data set selections. The model assumes that suppliers can mobilise to satisfy demand requirements. No doubt many alternative scenarios may be contemplated. However it is inevitable that severe supply issues will eventuate in the decades ahead.

6 Carbon dioxide emissions

Given the projected supply scenarios for coal, oil and gas, there is ample reason to plan large-scale investments in alternative energy supplies. If this is insufficient however, then consideration of the carbon dioxide emissions that are implied by the fossil fuel projections are further evidence of the necessity.

Carbon dioxide emissions can be readily calibrated against each fuel type, on the assumption that all carbon dioxide resulting from combustion is emitted. Given the limited scope for capture and storage, and the scale of the infrastructure that would be required, this is a realistic assumption.

National CO_2 emissions are usually associated with the country in which fuel combustion occurs. However in this study it has also been possible to associate emissions with the country of original fuel source. The purpose of tracing origins is that this may shed some light on alternative mitigation policies that may be relevant. Figures 21-28 show emissions for each fuel type and for total emissions by country.

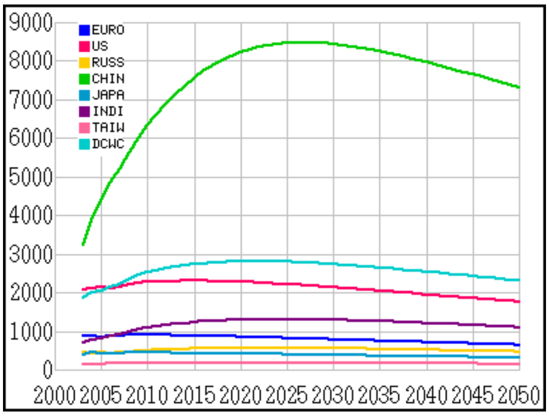


Figure 21. CO_2 emissions from coal use
By country of coal consumption (m tonnes)

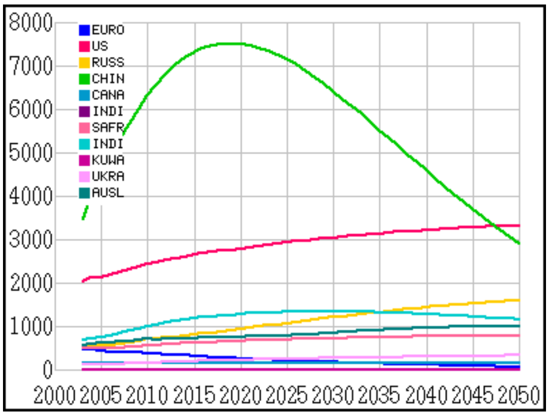


Figure 22. CO_2 emissions from coal supply
By country of coal origin (m tonnes)

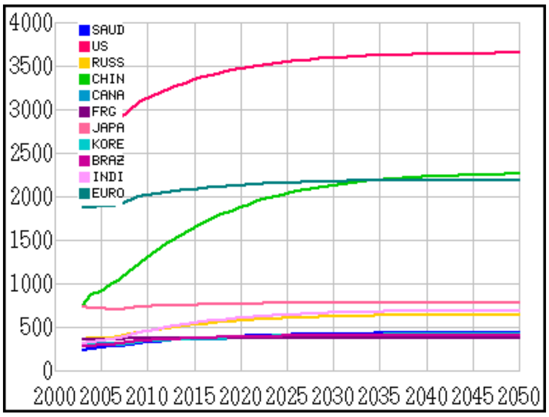


Figure 23. CO_2 emissions from oil use
By country of oil consumption (m tonnes)

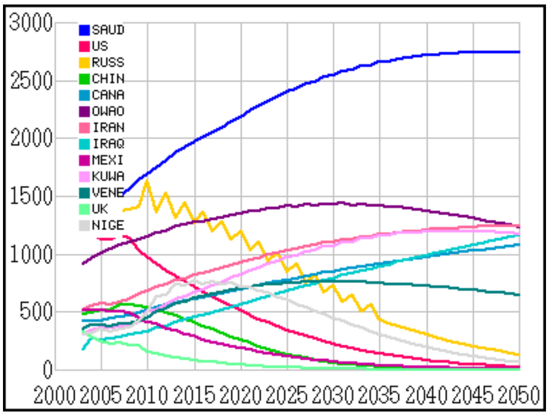


Figure 24. CO_2 emissions from oil supply
By country of oil origin (m tonnes)

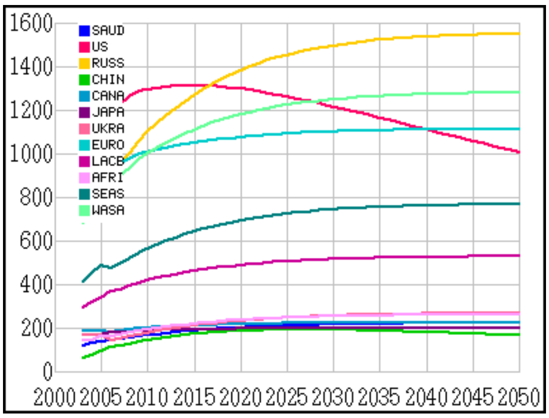


Figure 25. CO_2 emissions from gas use
By country of gas consumption (m tonnes)

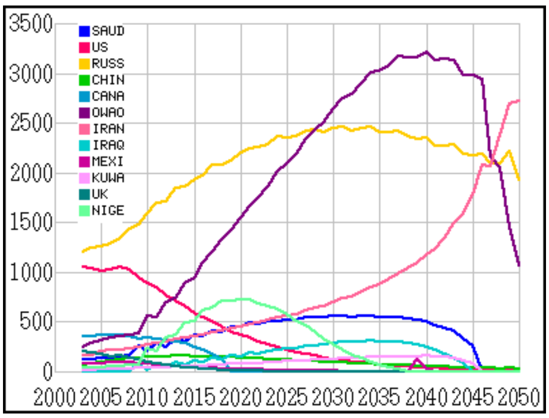
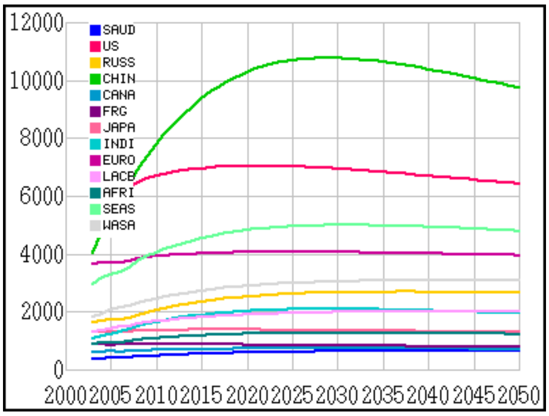


Figure 26. CO_2 emissions from gas supply
By country of gas origin (m tonnes)



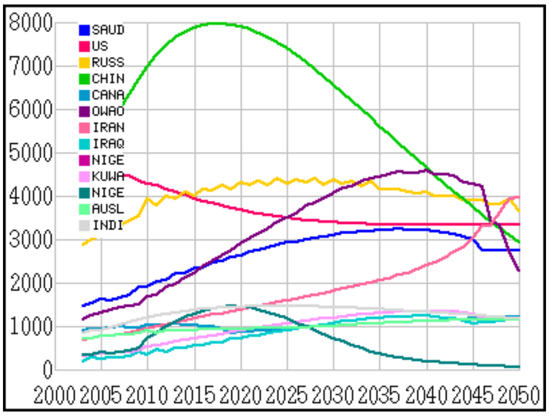
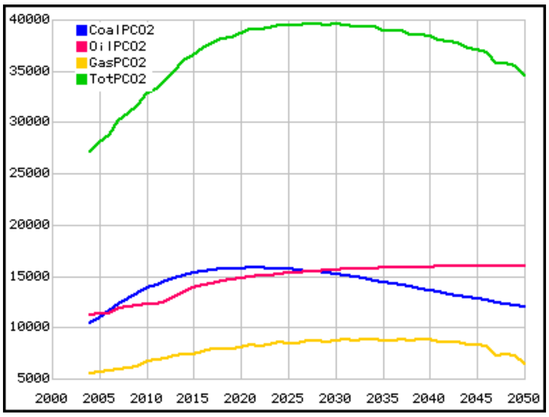


Figure 27. Total fossil fuel CO_2 emissions By country of fuel consumption (m tonnes)

Figure 28. Total fossil fuel CO_2 emissions By country of fuel origin (m tonnes)

The fact that the graphs show that emissions by country of consumption are far less volatile than by country of fuel origin is merely a product of the model's assumption that suppliers will adjust to demand requirements. In practice this is probably quite unrealistic, as suppliers may be quite unable to increase production as required, and it is more likely that consumption supplies will be disrupted. The purpose of showing both graphs is to illustrate that demand and supply are two sides of the same issue, and that whereas current mitigation policies are directed towards demand side management, policies directed to the supply side are equally possible, and may indeed be more feasible.



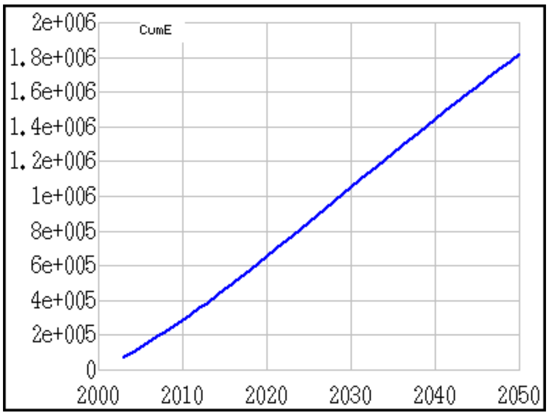
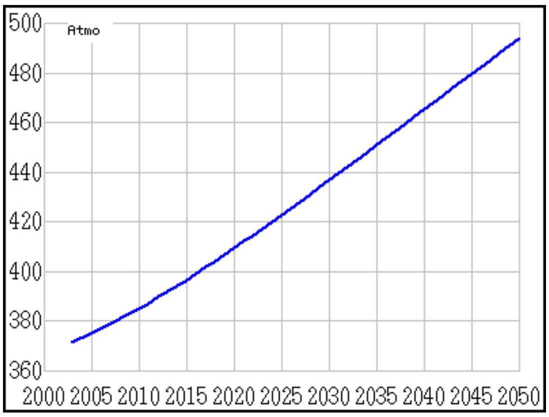


Figure 29. Global CO_2 emissions by fuel

Figure 30. Cumulative CO_2 emissions



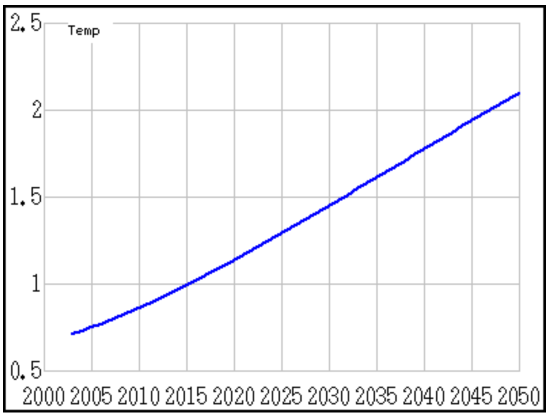


Figure 31. Atmospheric CO_2 ppm

Figure 32. Global temperature rise
Deviation from 1951-80 average - degrees C

The final set of figures presented show the linkages between the economic variables and the environmental measures commonly referred to in the context of climate change. Figure 29 shows global emissions by fuel type[8]. In the context of climate change, the time at which emissions peak is not as relevant as the quantity of emissions that occur. Figure 30 shows the cumulative emissions from 2000 that are implied by the emissions profile. It has been said that the environment has a "budget" of 1 trillion tonnes of CO_2 emissions until the year 2050. Figure 30 indicates that in this scenario, the budget is exceeded before 2030.

Atmospheric carbon dioxide concentrations increase because of the planet's limited ability to absorb emissions. The graph of CO_2 concentrations in parts per million shown in Figure 31 is based on an assumption of an atmospheric retention factor of approximately 45% over the period. A suggested benchmark for the transition to unacceptably dangerous climate change is 460 ppm. As shown in the figure, this benchmark is passed in 2037.

The relationship between CO_2 concentration and temperature rise is based here on a simple point estimate[9]. These results are not intended to be definitive, but are provided as an illustration of the linkages that can be readily computed. However by this calculation, the temperature exceeds that which is considered safe, a 2 degree rise in 2045, by which time sufficient emissions have accumulated for temperature to continue rising for some time after that.

It may be thought that the model assumptions used here incorporate certain greenhouse gas abatement assumptions, and that the environmental outlook is therefore bleak. It should be understood that the results here are not intended to provide a realistic scenario for the climate, and there are several reasons why the model as currently configured, even with these assumptions, will probably overstate future emissions.

Firstly, the model incorporates only a very limited ability to substitute alternative energy for fossil fuel consumption. There is no mechanism in the model in this scenario whereby the increasing relative price of fossil fuels will generate a transition to alternatives. The assumption of a GDP growth convergence to 1%, together with 1-2% reduction in the GDP intensity of emissions, means that emissions will necessarily tend merely to stabilise at a high level. In practice, increasing relative prices and supply shortages will mean that the GDP intensity reduction will accelerate over the projected period. This can be examined in further scenarios.

Secondly, although the model, apart from certain mitigation assumptions, contemplates "business as usual" in the fuel trade sector, the supply constraints that appear imminent make this highly unlikely. Although the model can highlight factors constraining future supplies, exactly how they may be resolved is a matter for speculation. The purpose here is to point to possible problems and suggest policy options that might be relevant.

Conclusion

The projections here show that impending supply constraints will make fuel consumption patterns that resemble "business as usual" quite untenable. The effects on prices of non-renewable fuel depletion will become increasingly apparent in the next five years, and a new long-term price regime will probably be well established within ten years. In this situation, the only constraint on the upward pressure on prices will be the provision of alternative energy. The current focus on carbon mitigation, without consideration of the effects of scarcity on prices, may well be a misplaced effort.

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8 Aggregating over consumer countries or producer countries produces the same graph.

9 See Perkins, John L., "A simple econometrician's guide to global warming", The Skeptic, Vol 28, No.4: Summer 2008.

In the current study, resource prices were set exogenously, so that the specific price increases that may arise as a result of depletion are not provided. However it is clear that they must rise to the level that drives investment in alternative energy. While alternative modelling assumptions need to be investigated, it is unlikely that any other assumptions or data revisions will change this conclusion. The inevitable may be delayed, but not avoided. What should the policy response be?

In the annals of economics we may find certain tenets that may seem relevant to the issues at hand, such Pigou's suggestion of a tax to remedy the effects of market failure caused by negative externalities[10] and Hoteling's Rule for an optimal tax on exhaustible resources[11]. These proposals address the issue of incorporating an external shadow price into the market price, and of optimising the time path of consumption of an exhaustible resource. A resource rent tax also addresses the distributional problem of monopoly rents accruing to the holders of increasingly scarce resources.

These past wisdoms, which may be applicable locally, have been discarded in an international setting because it appears there is no authority with any jurisdiction to impose an international tax, nor any precedent for any such financial instrument. However we do see the international community increasingly turning to international agreements in response to international crises: financial, economic and environmental.

It is therefore pertinent to imagine, in an ideal world, what an appropriate solution might be, that may simultaneously address the range of issues that resource depletion and global warming pose. A related issue is that of the global financial imbalances that may increasingly tend to develop as a result of high resource prices and disparities in the terms of trade between resource exporters and importers. Already we do see a tendency for resource prices to diverge widely from production costs, and for monopoly profits to accrue in sovereign wealth funds.

Resource prices do not currently reflect the environmental costs, and this has given rise to schemes and proposals to limit carbon emissions. In future, resources prices may be sufficiently high so as to reflect these costs. Concern will then turn to the issue of financial imbalances and the monopoly profits that accrue to resource holders.

What is required is a solution that utilises these trends in a way that can be seen as being in the long-term interests of both resource producers and consumers. Contrary to other proposals, it may be preferable to seek to impose a resource tax at the point of production, rather than consumption, so that the effects inevitably impinge on the global chain of supply and distribution. Also contrary to end-user based taxes and trading schemes, there may be more incentives for suppliers to provide this service, as the competitive disadvantages are more easily minimised through cooperation.

This is particularly the case as resource supplies are concentrated in a limited number of countries. In relation to Australia's emerging role as the primary international supplier of coal, several proposals have already been made in this regard[12]. In view of the impending problems, it may be seen by consumers that the payment of a proportion of resource revenues into a global fund, to be used for the purpose of greenhouse gas mitigation, is an appropriate use of the market power that resource suppliers will increasingly possess. For producers, investing in the future of the planet will be the soundest investment they will ever make.

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[10] See Arthur Pigou's *Wealth and Welfare*, published in 1912.

[11] H. Hotelling, "The Economics of Exhaustible Resources", *Journal of Political Economy*, Vol. 39:137-175, 1931

[12] See Perkins, John L, "Global warming: The case for a coal tax", NIEIR Conference Paper, July 2007, and "Carbon Pollution Reduction Scheme - NIEIR Submission", Department of Climate Change, 10 September 2008.