Fossil fuels and climate change: alternative projections to 2050

Key questions in the climate change debate are to what extent fossil fuel depletion will reduce emissions, and what country-by-country emissions reductions are required in order to avoid climate catastrophe. Answers to these questions are explored here with reference to a multi-country world trade economic model.

These answers are investigated using alternative assumptions on resource availability, and alternative assumptions of GDP fuel intensity reductions in model projections to 2050.[1] What is presented here is a summary of the simulation end points for selected variables. For a full description and data please refer to the references below and to the model itself.

To properly interpret the results, the following aspects of the model's operation are relevant:

- Resource consumption is currently entirely demand-driven in the model: production and exports will rise to meet domestic and import demand requirements.
- When exporter countries are constrained by depletion, demand is allocated to other exporters in proportion to remaining reserves.
- Prices are largely exogenous and the effects of market constraints are reflected in the GDP intensity factors.

In practice, these assumptions are unrealistic, and the logistics of supply, amongst other factors, will certainly impose constraints on consumption. The results therefore represent the "best case" in terms of satisfying consumption requirements.

Reserve increment effects

Estimates of recoverable reserves of coal, oil and natural gas vary between data sources, and all may differ from what may eventually prove to be recoverable. Exact data on the extent of reserves may be regarded as trade secrets or state secrets. Reserves may be deliberately understated in order to inflate prices or overstated to avoid panicking markets.

Historically, coal reserves have tended to be overestimated, when the reserves in underground mines prove too dangerous to recover. Currently many open cut mines are on the way to depletion and remaining reserves are of lower quality, in remoter regions and deeper underground. The data used here are based on US EIA estimates, except that China's coal reserves have been increased by 50% from those figures. An option in the model software provides this facility.

An assessment of the effects of changes in reserve estimates provides an indication of how important reserve depletion will be in affecting emissions and global warming. A mechanism used in the model allows for an annual increment of existing reserves in order to accommodate new discoveries. (To prevent a runaway effect, this increment is constrained to be less than annual production, by country). The effects of assuming a 1% annual increment in coal reserves is shown in Table 1.

The results analysing reserve increments assume a minimal amount of emissions abatement (GDP fuel intensity reduction). For these projections, the GHG/GDP intensity reduction factors are set at 1%, for coal, oil and gas. This means that they are high fuel use, high emissions scenarios. Hence in this case, the effect or reserve increments will be more pronounced.

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[1] To obtain detailed results for any of the projections described here, download and install the MELTrade model, open the Resource Equations page, click on the relevant parameters, enter new values, run the model, and then generate the output results.

Coal Reserve increment factor (%)	Coal reserves remaining in 2050 (% of 2003)					No. of coal producers remaining	No. of coal producers depleted
	Australia	China	USA	Russia	World		
0.0	48.54	0.00	56.56	65.64	40.08	16	9
1.0	72.22	0.38	82.94	80.25	57.95	17	8

Table 1: Effect of an annual increment in coal reserves.
Source: MELTrade model.

On these estimates, China's coal will be depleted well before 2050. World coal reserves would fall to 40.08% of 2003 levels in 2050, and nine current producers would be depleted. If a 1% annual increment in reserves is assumed, in all producers, to account for discoveries and revisions, then China narrowly avoids depletion and 57.95% of reserves remain 2050. It is unlikely that new discoveries will substantially increase known world reserves of coal.

Saudi Arabia has the largest reserves of oil, however there is some speculation that these reserves are in fact greatly overstated. The estimates of Canada's oil reserves are the mid-point between the Oil and Gas journal and World Oil estimates. The effect of an increment in oil reserves (same in all countries) is shown in Table 2.

Oil Reserve increment factor (%)	Oil reserves remaining in 2050 (% of 2003)					No. of oil producers remaining	No. of oil producers depleted
	Saudi Arabia	Canada	Iran	Iraq	World		
0.0	28.22	48.67	32.57	50.46	23.77	6	25
1.0	48.58	82.39	56.09	75.13	40.74	10	21

Table 2: Effect of an annual increment in oil reserves.
Source: MELTrade model.

The results show that by 2050, without any increment, only 23.77% of world oil reserves will remain (relative to 2003 levels). Of the current oil producer countries, 25 will be depleted and only 6 will remain. If an annual increment of 1% is assumed, then 40.74% of world reserves will remain. Saudi Arabia shows the largest percentage reduction in reserves due to production being allocated in proportion to reserves.

Based on the reserves estimates used, natural gas is the fossil fuel that will in future be in the shortest supply. Without at least a 1% increment assumption, exporters are depleted and unable to meet demand by 2050. The effect of an increase from 1% to 2% is shown in Table 3.

Gas Reserve increment factor (%)	Gas reserves remaining in 2050 (% of 2003)				No. of gas producers remaining	No. of gas producers depleted
	Russia	Other West Asia	Iran	World		
1.0	0.00	32.24	21.94	12.57	7	27
2.0	0.94	57.33	48.50	25.98	13	21

Table 3: Effect of an annual increment in gas reserves.
Source: MELTrade model.

The results show that by 2050, with a 1% increment, only 12.57% of world gas reserves will remain (relative to 2003 levels). Of the current natural gas producer countries, 27 will be depleted and only 7 will remain. If an annual increment of 2% is assumed, then 25.98% of world reserves will remain in 2050. As Russia starts with the largest reserves, it is therefore allocated more production in the early stages, and then becomes depleted in this scenario.

GDP intensity reduction effects: coal

Whatever policy mechanism is used, or whatever constraints on GHG emissions are imposed by resource depletion, the effects will be apparent in a reduction of emissions relative to GDP. The results here demonstrate what will be required in this regard in order to begin to stabilise the earth’s climate.

The model allows for a GHG abatement factor to be specified for coal, oil and gas, for each country. This factor represents an annual percent reduction in fuel intensity, that is, in the emissions from that fuel type per unit of GDP.

Because these reductions are relative to GDP, countries with high GDP growth rates can still have high emissions growth. GDP growth rates are assumed to converge to 2% by 2050, less a reduction due to global temperature increase.

The effects of a range of values for this annual intensity reduction, from 1% to 4%, for coal, for all countries, are shown in Table 4. In these scenarios for coal, the intensity reduction factors for oil and gas are set to 4% and 2% respectively, so that for the climate, this represents the best case scenario.

Coal/GDP intensity reduction factor (%)	Total CO_2 emissions in 2050 relative to 2003					Temp. increase (deg C) 2050	Est. max. temp. increase	Year of max. temp.
	China	USA	Europe	SE Asia	World			
1.0	3.90	0.89	0.73	1.56	1.48	1.96	2.11	2066
2.0	2.67	0.72	0.62	1.20	1.14	1.74	1.74	2058
3.0	1.85	0.61	0.55	0.96	0.91	1.57	1.58	2055
4.0	1.31	0.54	0.50	0.80	0.76	1.44	1.45	2053

Table 4: Effect of coal intensity reduction on emissions.
Source: MELTrade model.

The results show that with only a 1% intensity reduction, Chinese emissions from coal are 3.9 times higher in 2050 than in 2003. This contributes to world emissions being almost 50% higher (factor 1.48), despite reductions in the developed world (Europe 27% lower, factor 0.73). In this scenario, global temperatures increase by 1.96^{o}C, and are rising, in 2050. Only when the annual intensity reduction factor is 4% for all countries, are global temperatures stabilised, albeit after an increase of 1.44 ^{o}C.

The greater the coal intensity reduction, the less coal is consumed and the more remains at the end of the period. The effects on coal reserves of the different coal consumption scenarios are shown in Table 5.

Coal GDP intensity reduction factor(%)	Coal reserves remaining in 2050 (% of 2003)					No. of coal producers remaining	No. of coal producers depleted
	Australia	China	USA	Russia	World		
1.0	48.02	0.00	56.10	65.24	39.70	16	9
2.0	54.93	0.00	62.16	70.24	45.12	16	9
3.0	64.94	8.90	69.38	77.90	53.47	21	4
4.0	73.73	17.27	76.21	84.28	61.07	23	2

Table 5: Effect of coal intensity reduction on reserves.
Source: MELTrade model.

With only a 1% intensity reduction, 39.70% of reserves remain in 2050, when there are 16 producers and 9 are depleted (a producer is counted if providing more than 0.1% of global production). With a 4% reduction, 61.07% of reserves remain, and 23 countries remain in production. In the first two scenarios however, China's reserves of coal are depleted and China's vast consumption requirements are provided by coal mainly from Australia and Russia. This accounts for the much larger reserve depletion in these countries in these scenarios. While the model provides this solution for China, the logistics of it being achieved in the real world would appear highly problematic.

Note in these scenarios, the reserve increment factors are: coal 0%, oil 1%, gas 2%. Other intensity factors are: oil 4%, gas 2%.

GDP intensity reduction effects: oil

As for coal, the effects of different oil/GDP intensity factors on emissions and reserves are calculated. Table 6 shows the results for emission intensity reduction factors of 1-4%. These results are calculated with coal intensity reduction set at 4% and gas at 2%.

Oil / GDP intensity reduction factor (%)	Total CO_2 emissions in 2050 relative 2003					Temp. increase (deg. C) 2050	Est. max. temp. increase	Year of max. temp.
	China	USA	Europe	SE Asia	World			
1.0	1.81	1.03	0.95	1.48	1.28	1.82	1.91	2063
2.0	1.57	0.80	0.74	1.15	1.03	1.66	1.68	2057
3.0	1.41	0.64	0.59	0.94	0.87	1.53	1.54	2055
4.0	1.31	0.54	0.50	0.80	0.76	1.44	1.45	2053

Table 6: Effect of oil intensity reduction on emissions.
Source: MELTrade model.

The effect on CO_2 emissions of the reduction of oil consumption is not as pronounced as for coal, since oil contributes less to total emissions than coal. World emissions are reduced from 28% above 2003 level to 24% below (0.76 factor). The increase in global temperatures is reduced by 0.38 degrees (1.82-1.44).

Oil / GDP intensity reduction factor (%)	Oil reserves remaining in 2050 (% of 2003)					No. of oil producers remaining	No. of oil producers depleted
	Saudi Arabia	Canada	Iran	Iraq	World		
1.0	47.79	81.63	55.28	74.44	40.13	10	21
2.0	48.27	83.89	56.32	77.76	41.78	10	21
3.0	48.49	84.97	56.91	79.96	42.89	11	20
4.0	52.90	89.13	61.40	83.79	46.53	11	20

Table 7: Effect of oil intensity reduction on oil reserves.
Source: MELTrade model.

The effect of reduced oil consumption on reserves is shown in Table 7. With an intensity reduction factor of 1%, 40.13% of oil reserves remain in 2050. If the reduction is 4%, then 46.53% remain. Note that these estimates depend substantially on the reserve increment factor assumed. The reserve increment factors used are: coal 0%, oil 1%, gas 2%. Other intensity factors: coal 4%, gas 2%.

GDP intensity reduction effects: natural gas

The effect of intensity reduction increments for natural gas are shown in Table 8. These are calculated with the intensity reductions for coal and oil both set at 4%.

Gas / GDP intensity reduction factor (%)	Total CO_2 emissions in 2050 relative to 2003					Temp. increase (deg. C) 2050	Est. max. temp. increase	Year of max. temp.
	China	USA	Europe	SE Asia	World			
1.0	1.33	0.64	0.61	0.90	0.89	1.52	1.54	2056
2.0	1.31	0.54	0.50	0.80	0.76	1.44	1.45	2053
3.0	1.29	0.47	0.42	0.73	0.67	1.38	1.38	2052
4.0	1.28	0.43	0.37	0.68	0.62	1.33	1.33	2051

Table 8: Effect of oil intensity reduction on emissions.
Source: MELTrade model.

The effects on total emissions of the reduction in gas consumption is rather marginal, compared with coal and oil, since gas has a lower contribution to total emissions than both coal and oil. The effect on reserves of the changes is substantial however, as shown in Table 9, since gas is in relatively shorter supply. With the 1% assumption, only 24.02% of reserves remain in 2050 and 21 countries have ceased production, including Russia. With the 4% assumption however, 81.76% of reserves remain.

Gas / GDP intensity reduction factor(%)	Gas reserves remaining in 2050 (% of 2003)				No. of gas producers remaining	No. of gas producers depleted
	Russia	Other West Asia	Iran	World		
1.0	0.00	54.46	44.66	24.02	13	21
2.0	28.24	78.75	75.30	47.93	19	15
3.0	57.24	90.45	87.20	65.84	21	13
4.0	83.03	98.78	95.28	81.76	26	8

Table 9: Effect of oil intensity reduction on gas reserves.

Source: MELTrade model.

Note that in these scenarios, the reserve increment factors are: coal 0%, 1%, gas 2%. Other intensity factors are: coal 4%, oil 4%.

Conclusion

The results here are not definitive but are indicative of the relationship between future contingencies. Further work is no doubt required. The results are all based on specific assumptions, mathematical relationships and data sets. Whatever inadequacies these may entail, a wide range of alternative assumptions parameters and data adjustments can easily be provided using the user-operable MELTrade model.

As is already known, the world faces serious problems in the decades ahead. The results here attempt to quantify the relationships that affect the complex interactions between resource depletion, emissions mitigation and climate change.

What is clear is that without major structural change in global energy provision, by 2050, the world will be generally so short of fossil fuels that continued reliance upon them will be impossible. Therefore climate projections that assume emissions continuing through to 2100 seem quite implausible.

Quite stringent assumptions regarding fossil fuel intensity reductions are required in order to preserve fuel and mitigate climate change. Reductions of fossil fuel use of 4% per annum in relation to GDP seem beyond the scope of any known climate policy. Yet without a smooth transition these changes will ultimately be forced brutally upon us anyway.

The fact that fuel depletion will eventually mitigate climate does not reduce the urgency of the need for a global carbon price. This price is needed now, in order to guarantee that the necessary investment in alternative energy can get underway.

At best, it seems that global temperature will rise by about 1.5 degrees, or three times the current increase. With the consequences we already observe, it seems this rise will be severely destructive to human civilisation.

It is assumed in the model that the system of world trade will deal with issues of local resource depletion in major consumer countries. In reality this is unlikely to proceed smoothly and there is a strong possibility of resource inequities leading to international tensions and conflict.

Resource shortages will mean higher prices and these will likely force reduction in fuel intensity. The results here demonstrate the degree to which this will be necessary. Higher resource prices will mean lower real incomes for consumer countries and higher incomes for producer countries. These imbalances will be another source of potential international tension and conflict.

Resource wealth derived from international trade in non-renewable resources must not be squandered by national governments, due to greed, corruption and incompetence, but should be used globally to deal with both climate and resource issues, mitigation, and investment in alternative energy to reduce the international income inequities that will arise.

A global management system is required. National economic policies that deal with externalities and exhaustible resources are known but insufficient. An authority with global jurisdiction must be instigated to deal with these issues. What is required is nothing less than a new global ethic, free of the many ideological constraints that beset many current policies.

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