CALCULATIONS

Associated explanation and calculations for "Who should sell the last of the fossil fuels: Stranded assets, equity and climate change" blog

APRIL 2016

The calculations below were done to support a blog posted on Oxfam's Policy and Practice website. They describe how, so long as developing countries have exclusive rights to develop their fossil fuel reserves, all those reserves could be fully exploited and we would still stand a 50% chance of keeping global temperatures below 1.5^{o}C. The intention behind the calculations is not to make a simple case for giving developing countries exclusive rights to extract and sell their fossil fuels, but rather to point to the scale of the equity question involved in stranding fossil fuel assets. You can find the full blog here.

Thanks to Steve Pye, at University College, London, for his review and comments on these calculations.

The first calculation is to determine *how much carbon we can burn*. We start with the idea that we want to keep global temperatures below 1.5^{o}C. Before we do so it is worth noting that modelling sensitivity to a 1.5^{o}C increase in temperature has received much less attention than modelling for a 2^{o}C rise. As such uncertainty around a 1.5^{o}C rise is greater than it is for 2^{o}C. With this caveat in mind, the available models indicate that in order to stand a 50% chance of keeping global temperature rise below 1.5^{o}C we need to limit our total carbon emissions to 525 gigatones of carbon dioxide ($GtCO_2$) between 2013 and 2050.

Next we need to *calculate the total reserves* in the developing world in order to see how much of this we could burn while still staying within the 525 gigaton budget. In order to do that we turn to the BP Statistical Review of World Energy, which gives us the total global reserves of oil, gas and coal, by country, estimated for the end of 2014. If we take the UNDP measure of developing countries (comprising countries of 'medium human development' and 'low human development') as all those with HDI scores of less than 0.7 we can work out the total reserves in the developing world.

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Table 1. Developing world reserves compared to global reserves at the end of 2014.

	Oil (billion barrels)	Gas (trillion cubic ft)	Coal (Anthracite and bitimous) (million tons)	Coal (subbitimous and lignite) (million tons)
Global reserves	1,700.06	6,606.51	403,199.00	488,332.00
Reserves in the developing world	240.36	1,330.58	89,537.00	39,508.00

Note: when using the BP statistical review, 'Other Africa', 'Other Latin America' and 'Other Asia' are classed as developing countries, while 'Other middle east' is classed as developed.

Now we have to work out *how much carbon dioxide is contained in these reserves* of oil, gas and coal. To do this we first look to the EPA's emission factors. Emission factors tell us how much carbon is emitted when you burn different quantities of different fuels. The IPCC has more specific emission factors for the specific types of fossil fuels in each country. Using the EPA factors is less accurate, but is thought to be a justifiable shortcut for a blog like this.

Notably, the EPA give emission factors for gas and four different types of coal. A problem here is that the four different types of coal are combined in the BP statistical data – as in Table 1. To account for this we take the *average emission factors across different types of coal*. Again this is a shortcut, but it is thought to be acceptable for a blog like this one.

Oil presents a particular problem for emission factors because we don't really burn oil for energy. Instead we refine oil in to a number of products (gasoline, jet fuel, diesel etc.) and burn those. Troublingly each of those has a different emission factor. Thankfully someone else has already looked at this problem for us. They solve it by looking at how an average barrel of oil is treated in US refineries, and what products it is refined into. They then calculate the carbon emissions for each of the fuel types to get a single emission factor for a barrel of oil. For our purposes we will do the same and treat every barrel of oil as if it were an average barrel of oil in a US refinery – another shortcut, but an acceptable one.

Table 2. Emission factors for different fuels

Fuel	Oil (kg. CO2 per barrel of oil)	Gas (kg.CO2/scf)	Coal (Anthracite and bitimous) (kg.CO2/metric ton)	Coal (subbitimous and lignite) (kg.CO2/metric ton)
Emission factor	317	0.05444	2715.5431	1689.2916

Once we have the emission factors and the reserves, we can work out the total carbon dioxide that would be released by burning all of the reserves – we just have to multiply the reserves by the emission factors (paying attention the units). We can then add up all the potential emissions from all the developing countries in the world. We come to a total of: 458.51 $GtCO_2$, as the amount of carbon dioxide that would be produced if we burnt all of the known reserves in the developing world (at the end of 2014).

Table 3. Total CO2 contained in the world's reserves

	Oil	Gas	Coal (Anthracite and bitimous)	Coal (subbitimous and lignite)	Total
World total (GtCO2)	538.92	359.66	1,092.01	826.17	2,816.76*
Developing countries total (GtCO2)	76.19	72.44	243.14	66.74	458.51

*The IEA puts the total carbon dioxide in global reserves at 2860 $GtCO_2$ in 2013 (pp. 259). McGlade and Elkins (2015)[1] estimate that it is 'nearly 2900 $GtCO_2$' (pp. 188). Both figures serve as a useful validation of my calculations.

Importantly, 458.51 $GtCO_2$ is less that the 525 $GtCO_2$ that we had left in our carbon budget and that we need to stay below in order to give ourselves a 50% chance of keeping temperatures below 1.5^oC. However, because that budget was from the beginning of 2013 we have to adjust it for the last two years of CO_2 emissions (in order to take us to the end of 2014 which is date the country reserves were measured). Since we know that we emit CO_2 at around 35$GtCO_2$ per year, we have to subtract 70$GtCO_2$ (35$GtCO_2$ for 2 years) from 525$GtCO_2$. This gives us 455$GtCO_2$, which is just under (but remarkably close to) the total for reserves in developing countries: 458.51$GtCO_2$.

So now we know that we could exploit virtually all the reserves in developing countries and still stand a 50% chance of limiting the rise in global average temperature rise to 1.5^oC. But a question remains: How much are these resources worth? And how much of a development opportunity would be foregone if they all had to be stranded?

Before doing this calculation it should be acknowledged that it is something of a fool's errand (i.e. a big shortcut). As we have seen recently the price of different fuels are liable to change rapidly, and certainly if we were to limit all production to only that which was taking place in the developing world, demand would drive prices up drastically. At the same time, as we transition away from fossil fuels towards renewables, demand for fossil fuels will drop and so will their price. For the sake of illustration however let us just assume that average prices remain as they are currently, between now and 2050.

Assuming an oil price of $50 a barrel, and taking average prices for gas and coal from 2013, we get a total value for fossil fuel reserves in developing countries of $21.951 trillion. Over the 35 years between 2015 and 2050. That translates into around $627.172 billion per year.

[1] McGlade, Christophe. and Elkins, Paul. 2015. The geographical distribution of fossil fuels unused when limiting global warming to 2^oC, Nature, 517: 187-202.

Table 4. Assumed fossil fuel prices

oil price ($/barrel)	gas price ($/thousand cubic feet)	Coal (Anthracite and bitimous) ($/ton)	Coal (subbitimous and lignite) ($/ton)
50.00	6.95	74.22	17.41

What these calculations suggest therefore is that we could burn all the fossil fuel reserves in developing countries, and still stand a 50% chance of remaining below 1.5^{o}C of warming. At the same time, this process would generate substantial revenues for developing countries that could be spent on human development. This of course would require that we 1) prioritize only developing countries for resource extraction and 2) stop investing in any further exploration for new resources and stop translating resources into reserves.

Finally, some quick reflections on these calculations:

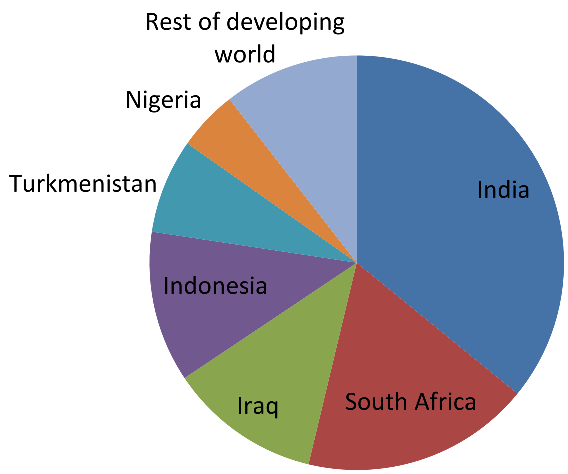
A first thing to note is that this figure of $21 trillion is the total value of the reserves. This is not what the rents from the reserves would be worth (i.e. this is not what the country containing the reserves could receive in revenue). In order to calculate that figure you would first have to estimate the costs of extraction of different fuel types, in different locations, and subtract it from the total value. In addition you would have to subtract some sort of return on capital, to get a sense of how much countries would be paying the companies (or what they would be paying on the capital costs of national fossil fuel companies) who extract the fossil fuels. As such the rents would be worth less than the $21 trillion.

Secondly this calculation does not include China (which has an HDI score of 0.727). This is important because China has significant coal reserves, which mean that China alone would contribute 269.7GtCO_2 to the atmosphere if all of its fossil fuel reserves were exploited. This would clearly take the world above 1.5^{o}C - although it would still give us an 80% chance of staying below a 2^{o}C rise in temperature (which requires keeping global CO_2 emissions below 900 GtCO_2).

Third, the Carbon contained in reserves of fossil fuels in the developing world are heavily concentrated in only five countries: India, South Africa, Iraq, Indonesia, Turkmenistan and Nigeria (see figure 1 below). This shows the heavy dominance of coal in India and South Africa, and raises the question of whether the world would be better off limiting extraction to fuels with lower carbon intensities such as oil and gas, and then compensating countries for stranding their reserves of coal.

Finally, and relatedly, if the world were to drop its use of coal for electricity generation as suggested above, these revenues could be made significantly larger. Coal is a very carbon intensive fuel, yet it yields relatively small revenues as it is mainly used for domestic electricity production. If the carbon budget currently going to coal was used for oil or gas this could either allow more countries with low levels of human development to exploit their reserves and generate greater revenues, or allow this existing set of countries to develop more of their oil and gas resources into reserves for subsequent exploitation.

Figure 1: Proportional location of C contained in fossil fuel reserves in the developing world



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