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The implications of fossil fuel supply constraints on climate change projections: A supply-side analysis

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ABSTRACT

Climate projections are based on emission scenarios. The emission scenarios used by the IPCC and by mainstream climate scientists are largely derived from the predicted *demand* for fossil fuels, and in our view take insufficient consideration of the constrained emissions that are likely due to the depletion of these fuels. This paper, by contrast, takes a supply-side view of CO_2 emission, and generates two supply-driven emission scenarios based on a comprehensive investigation of likely long-term pathways of fossil fuel production drawn from peer-reviewed literature published since 2000. The potential rapid increases in the supply of the non-conventional fossil fuels are also investigated. Climate projections calculated in this paper indicate that the future atmospheric CO_2 concentration will not exceed 610 ppm in this century; and that the increase in global surface temperature will be lower than 2.6 °C compared to pre-industrial level even if there is a significant increase in the production of non-conventional fossil fuels. Our results indicate therefore that the IPCC's climate projections overestimate the upper-bound of climate change. Furthermore, this paper shows that different production pathways of fossil fuels use, and different climate models, are the two main reasons for the significant differences in current literature on the topic.

1. Introduction and research background

Climate change has been seen as perhaps the biggest environmental threat to the future development of human society (Alley et al., 2003), and anthropogenic greenhouse gas (GHG) emissions, especially CO_2 emissions mainly due to the usage of fossil fuels, have been considered as the dominant cause of the observed change in the global climate to-date (IPCC, 2007, 2013). The results of climate projections are crucial for international climate negotiations. Therefore, as the basic input and a major uncertainty in climate projections (Garrett, 2011; Stott & Kettleborough, 2002), anthropogenic emissions should be given substantial research attention (Webster et al., 2002).

Until recently, emissions scenarios from the Special Report on Emissions Scenarios (SRES) of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2000) are most commonly used by the IPCC itself, and by much other scientific literature in order to analyze relevant impacts on natural, social, and economic systems, and to recommend policies or measures to cope

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with climate change effects (Arnell et al., 2004, 2013; IPCC, 2001, 2007; Stott & Kettleborough, 2002). However, the anthropogenic future emissions resulting from energy usage in these scenarios were all largely derived from a demand-side analysis (Brecha, 2008; Höök & Tang, 2013; Vernon, Thompson, & Cornell, 2011; York, 2012). In that analysis fossil fuel resources were assumed to be abundant, especially if non-conventional fossil fuel resources were included (Rogner, 1997). Moreover, it was assumed that these resources could be extracted at the required flow rate to meet demand due to the improving technical and economic conditions. Thus the future usage of fossil fuels largely only depended on demand, which in turn was set by the assumed future levels of socio-economic development. This 'demand-driven' approach to setting emission scenarios has been supported by most economists, and as mentioned, was adopted by IPCC in developing the emissions scenarios contained in SRES.

In 2009, a set of new emission scenarios (the representative concentration pathways or RCPs) were developed and released, and used in the Fifth Assessment Report (AR5) of Climate Change by the IPCC (Moss et al., 2010; Rogelj, Meinshausen, & Knutti, 2012). However, these new emission scenarios are still fundamentally demand-driven, and are based on similar socio-economic models as those used to develop the SRES scenarios (Ward et al., 2012). Therefore, both SRES and RCPs include some extremely high emissions scenarios, such as A1FI in SRES, and RCP8.5 in the RCPs. Furthermore, all of the scenarios in SRES and RCPs are considered equally plausible, since no probabilities or likelihoods are given to these (Höök & Tang, 2013; IPCC, 2000; Moss et al., 2010).

In this paper we look at the issue of CO_2 emissions from the supply side, and hence from the need to recognize that fossil fuels, the main energy sources and dominant contributor to current and future anthropogenic CO_2 emissions, are finite. This is mainly reflected in two aspects: one is in geology, which means the total volumes existing in the earth are finite (i.e., the *total resources*); the other is in technology and economics, which means the recoverable volumes from the total volumes, are also limited (i.e., the *recoverable resources*). Generally, the volumes of total resources are much larger than the volumes of recoverable resources. However, compared to the total resources, the recoverable resources are the more important for future production, since the production rate of any fossil fuel is influenced not only by geological factors, but also by technical and economic factors. In the IPCC's SRES and RCPs, the total resources are chosen as the base for analyzing future supply (IPCC, 2000). Moreover, even if the *recoverable* resources are large this does not automatically permit their production to be large. This is because empirical evidence shows that the production of fossil resources in most regions reaches a peak even when up to more than a half of the recoverable resources still remain (Brandt, 2007). As a result, the production curves of fossil fuels should generally be modeled as rising to a peak and then decreasing.

An early peak study of fossil fuel production was that by Hubbert (1949). Since then much scientific literature has been written analyzing the possible peaks in exploitation of global or regional fossil fuels and their possible impacts on the development of the economy and human society (see, for example, Nel & Cooper, 2009; Nel & van Zyl, 2010). Today the concept of peak fossil fuel production is generally widely accepted (Bentley & Bentley, 2015; de Almeida & Silva, 2011; Zhao, Feng, & Hall, 2009), and an increasing number of scientific and commercial forecasts have shown that the world will experience a near-term production peak (or at least, plateau) of *conventional* fossil fuel production, and especially of the production of convention oil and conventional gas (Campbell & Laherrere, 1998; Heinberg & Fridley, 2010; Kerr, 2011; Murray & King, 2012). Moreover, the International Energy Agency (IEA), one of the world's main energy forecasting organizations, has been steadily reducing its forecast global production levels for conventional fossil hydrocarbons (i.e., oil & gas) in its annual flagship reports, the *World Energy Outlooks* (WEOs) (Miller, 2011). The IEA first mentioned the issue of peak oil in its WEO 1998, and later in all WEOs published since 2008; and also indicated that the global production of conventional crude oil (less natural gas liquids, NGLs) had possibly peaked in 2006 (IEA, 2008).

The peak in fossil fuel production has been seen as an extremely important issue for humankind (Krumdieck, Page, & Dantas, 2010), and as mentioned above the coming of peak fossil fuels may have significant influence on climate change due to the close relationship between usage of fossil fuels and the anthropogenic CO_2 emissions (Friedrichs, 2011; Newbery, 2011). Hence, in our view, supply-side analysis is needed to examine the likely upper-bound usage of fossil fuels, and hence related emissions, even though we recognize that technological progress can mitigate such constraints to some extent (Meadows, Randers, & Meadows, 2004).

A number of studies have already paid attention to possible supply-driven emission scenarios, and hence their impacts on climate projections. These include Brecha (2008), Chiari and Zecca (2011), Doose (2004), Grubb (2001), Höök and Tang (2013), Kharecha and Hansen (2008), Nel and Cooper (2009), Tans (2009), Ward, Werner, Nel, and Beecham (2011), and Ward, Mohr, Myers, and Nel (2012). However, many of these studies use their own, and often rather simple, analyses of future fossil fuel production; and moreover the production in some of these analyses covers only *conventional* fossil fuels, and not all fossil fuels, thus giving insufficient consideration of the likely increasing production of the non-conventional fossil fuels (Brecha, 2008; Chiari & Zecca, 2011; Kharecha & Hansen, 2008; Nel & Cooper, 2009). As a result, such studies are likely to give a less than convincing conclusion (Kharecha & Hansen, 2008). Furthermore, the significant differences among these current supply-side studies call for a comprehensive analysis of the reasons for these differences. Note also that such supply-side analyses, and their related emission scenarios, are still largely excluded by many economists and climate scientists in climate change analyses (Ward et al., 2012).

The aim of this paper, therefore, is to present a comprehensive analysis in order to understand the impacts of supply constraints of all fossil fuels (oil, gas and coal, and both conventional and non-conventional) on future climate change.