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Part I: Technological Innovation: Promise and Pitfalls of BECCS

Fuss, S., J. G. Canadell, G. P. Peters, M. Tavoni, R. M. Andrew, P. Ciais, R. B. Jackson, C. D. Jones, F. Kraxner, N. Nakicenovic, C. Le Quere, M. R. Raupach, A. Sharifi, P. Smith and Y. Yamagata (2014). "Betting on negative emissions." Nature Clim. Change 4(10): 850-853.

A new paper by Fuss and colleagues explores the implication of greenhouse gas emission scenarios used in climate projections that rely heavily on bioenergy with carbon capture and storage (BECCS). This process removes carbon dioxide from the atmosphere (negative emissions) while producing energy from biological sources.

Negative carbon dioxide emissions are achieved in BECCS in two parts. First as a tree or energy crop grows, it takes in carbon dioxide from the atmosphere in the process of photosynthesis – about 50% of dry biomass is carbon. And second, if the biomass is burned in a power plant for example, the heat can be used to produce steam that drives a turbine producing electricity. In the process of combustion the carbon would again be released to the atmosphere as CO2 unless captured from the flue gas. During BECCS, the CO2 is captured, and once captured it can be compressed and pumped underground into a geologic formation where it can be stored. This sequence then yields useful energy while removing carbon dioxide from the atmosphere.

Emissions scenarios that rely heavily on this approach may achieve a global average temperature in the range of 0.9 – 2.3 deg C by 2100, relative to pre-industrial temperatures, thereby providing a chance of achieving the goal of staying below warming of 2 deg C (see Figure 1). However, this approach requires massive alteration of land-use, competing with food production and biodiversity requirements. Moreover, it is a new technology with many unanswered questions that need further research, development and demonstration.

The scale of deployment for BECCS considered in the very low greenhouse gas emission scenario Representative Concentration Pathway (RCP 2.6) displaces conventional fossil-based energy on the order of 100 exajoules (EJ) or more per year by 2050. The figure from the Fuss report shows carbon dioxide emissions since 1980 climbing from about 20 billion tonnes of CO2

per year to about 36 billion tonnes in 2013. The colored lines departing from the observation (black line) in the figure show possible emissions out to 2100. For climate models to project future change in temperature, social scientists need to provide climate modelers possible future emissions to feed into the climate models. These RCPs range from low emission scenarios, such as RCP 2.6, to very high scenarios, such as RCP 8.5. Each Representative Concentration Pathway takes into consideration factors such as population, economic growth, land-use, and energy technologies yielding different possible futures and the consequent concentration of carbon dioxide in the atmosphere driving climate change.

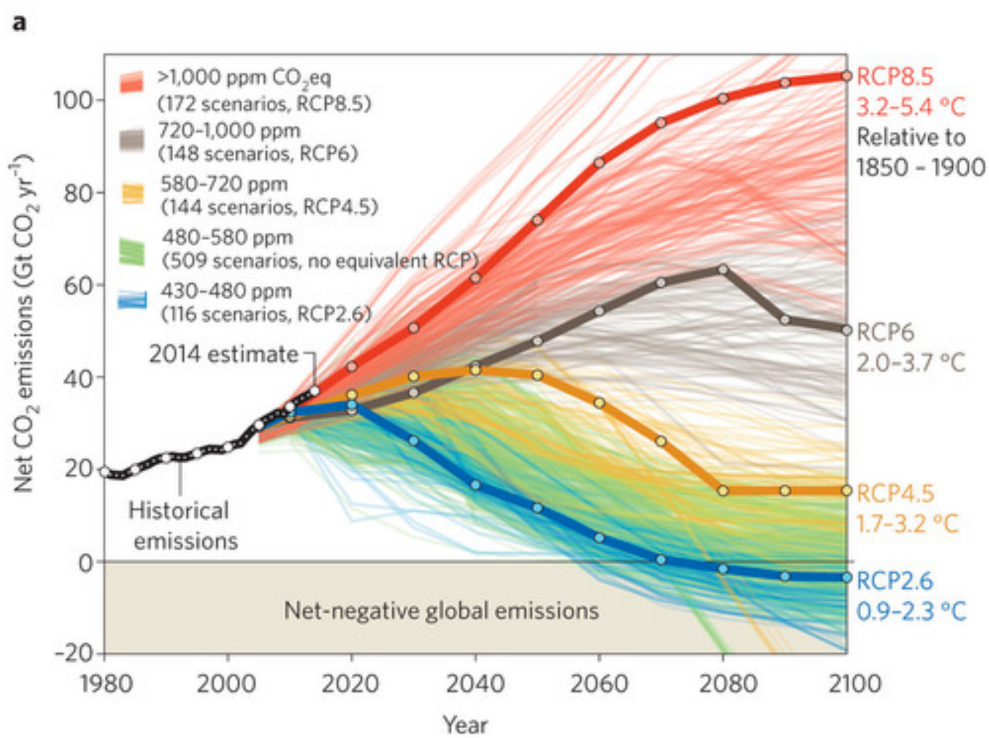

Figure from Fuss showing historical emissions in black, four Representative Concentration Pathways (RCPs) in bold line and the scenarios that group with each of the RCPs in pale colors.

The primary concern in the Fuss paper is that there are too many unknowns with BECCS to rely so heavily on it as the key low emission pathway being modeled. Other major considerations include: where to store the captured CO2 in a safe and reliable manner, the water and fertilizer requirements of managed biomass at scale, unknowns regarding cost, the effect on the global carbon cycle, and competition for investment in other non-carbon emitting strategies, such as renewables. The authors go on to state the need for a regulatory framework as a key component — not only the need for climate policies, but also for the long-term management and verification of captured and stored carbon dioxide. The implication made is that climate stabilization scenarios that place too much dependence on BECCS may create a "dangerous distraction" from other viable options.

Part II: Advances in Observations: Tracking Methane Emissions from Space

Schneising, O., J. P. Burrows, R. R. Dickerson, M. Buchwitz, M. Reuter and H. Bovensmann (2014). "Remote sensing of fugitive methane emissions from oil and gas production in North American tight geologic formations." Earth's Future: 2014EF000265.

The fracking boom underway in the United States changes the landscape of fossil fuel reserves. While natural gas combustion produces less carbon dioxide than coal on an energy basis (about 56% less), from a climate perspective, for natural gas to best coal, fugitive emissions of methane resulting from its extraction must be contained at less than 3.2 percent leakage (Alvarez et al 2012) for there to be a climate benefit in fuel switching. Existing estimates of fugitive emissions lack sufficient data to understand the scope of the problem. Schneising et al present a methodology for estimating fugitive emissions from space that can complement existing approaches. They use as case studies three production regions in the United States: the Bakken, Eagle Ford, and Marcellus formations. For the Eagle Ford and Bakken areas, their method yields high-leakage rates of between 9 to 10 percent, indicating that existing methodologies may understate actual fugitive emissions, particularly in rapidly developing extraction regions.

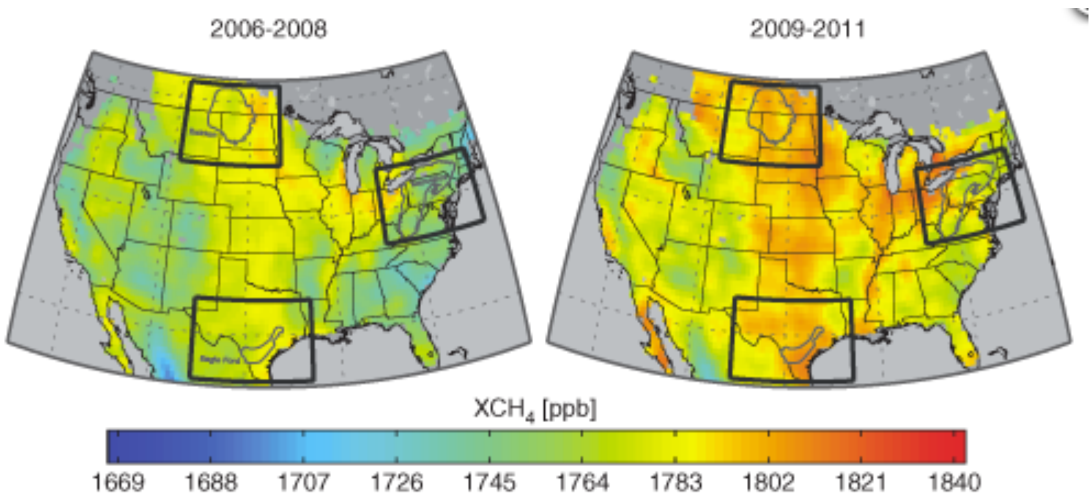

Figure from Schneising showing the Eagle Ford, Bakken, and Marcellus areas discussed in the paper showing the change in parts per billion between the two periods.

The authors point out that the leakage rates reported in other studies are defined as total emissions divided by total production, whereas the method they use creates a derived leakage rate by the ratio of emissions increase between two time periods divided by the production growth in the same two periods. This method assumes industrial practices are the same between the time periods and are best suited to regions where drilling is active versus mature fields.

They conclude with a review of new instruments scheduled to launch in the coming years that will deliver higher spatial resolution and potentially be able to resolve at the point source scale. Space based observations combined with aircraft and field measurements will help constrain the uncertainty in fugitive emissions over the lifecycle of oil and gas basin development.

Part III: Policy Perspective: Loss and Damage from Climate Change

James, Rachel, Friederike Otto, Hannah Parker, Emily Boyd, Rosalind Cornforth, Daniel Mitchell, and Myles Allen. 2014. "Characterizing Loss and Damage from Climate Change." Nature Climate Change 4 (11) (October 29): 938–939. doi:10.1038/nclimate2411. http://www.nature.com/doifinder/10.1038/nclimate2411.

White House Science Advisor John Holdren famously broke down possible societal responses to climate change into three wedges: (1) mitigation (reducing greenhouse gas emissions), (2) adaptation (preparing for and responding to changes in climate), and (3) suffering. In concept, this framing suggests that suffering from the impacts of climate change increase in proportion to the inadequacy of adaptation and mitigation. Given the shortcomings in both mitigation and adaptation efforts to date, more attention—in both climate policy and research—is focusing on the losses and damages (i.e. suffering) that are already occurring or will occur due to climate change. As a result, perennial questions in climate research are gaining newfound attention, such as: what specifically counts as a loss or damage from climate change and how do we know?

A commentary in *Nature Climate Change* by James and colleagues takes note of current policy and research initiatives concerning loss and damage and suggests this as an area where collaboration between science and policy is crucial.

Which flood was caused by climate change? Two events are pictured: flooding in York, England in 2000 (left) and flooding in Pakistan in 2010 (right). In the York example, a study that involved the combination of climate and hydrology models was able to demonstrate that 20th century greenhouse gas emissions significantly increased the probability of flood risk in the study area (Pall et al. 2011). However, in the Pakistan case, a combined lack of modeling capability and observations data prevented clear attribution to greenhouse gas increases (Christidis et al. 2013 ctd. in James et al. 2014).

At the international policy level, the United Nations Framework Convention on Climate Change has formed a mechanism to address climate change losses and damages under the Warsaw International Mechanism (WIM), initiated in 2013. Focusing first on non-economic losses, the

WIM raises fundamental questions about how to define what counts as a loss from climate change, as separate from impacts of other natural or social hazards. While discussions currently are focused on less controversial topics like impacts to cultural heritage and loss of life, the eventual ramifications of such discussions may extend to economic dimensions of costs of damages and responsible parties.

The scientific community has for many years conducted research into the cause of weather and climate events and to what extent greenhouse gas emissions from human activities are at play. Significant progress has been made in linking long-term global trends, such as average temperature or sea level rise, and capability is emerging to make similar connections at smaller regional and shorter temporal scales. The approaches taken in this work are probabilistic rather than absolute, suggesting how elevated greenhouse gas levels increase the *chance* for climate impacts rather than unequivocal connections. Still, limitations to existing models and gaps in historical observations in some places are an obstacle to further progress.