PACIFIC CLIMATE IMPACTS CONSORTIUM

PCIC SCIENCE BRIEF: ON THE PROMISE OF BIOMASS AND BIOSPHERE-CLIMATE INTERACTIONS

Two articles recently published in the peer-review literature seek to answer two related questions: What role could utilizing vegetation burning for energy, with methods to capture the carbon dioxide emitted, have in aggressive short-term climate mitigation in western North America? And, how might North American vegetation and its interactions with the climate change in the future?

Addressing the first question in *Nature Climate Change*, Sanchez et al. (2015) find that western North America could attain a carbon-negative power system by 2050 through strong deployment of renewable energy sources, including Bio-Energy with Carbon Capture and Storage (BECCS), and fossil fuel reductions. Their results indicate that reductions of up to 145% from 1990s emissions are possible. They also find that the primary value of BECCS is not electricity production, but carbon sequestration, and note that BECCS can also be used to reduce emissions in the transportation and industrial sectors.

Publishing in the *Journal of Geophysical Research: Atmospheres*, Garnaud and Sushama (2015) examine the second question. In order to do this they downscale output from a global climate model using a regional climate model that can simulate vegetation dynamics. They find that the projected future increases to growing season length result in greater vegetation productivity and biomass, though this plateaus at the end of of the 21st century. Their projections also indicate an increase in the water-use efficiency of plants, but decreased plant productivity in the southeastern US over the 2071-2100 period. In addition, they find that accounting for vegetation feedbacks leads to increased warming in summer at higher latitudes and a reduction in summer warming at lower latitudes.

Though the International Energy Agency (IEA) has recently announced their finding that 2014 carbon dioxide emissions were the same as 2013[1] emissions, on the timescale of decades, atmospheric greenhouse gas concentrations continue to increase, following a trajectory that falls within the upper range of the Intergovernmental Panel on Climate Change's emissions scenarios. Because of the projected impacts associated with high carbon dioxide emissions[2], interest continues to grow in both low-carbon energy pathways and the details of the response of Earth's climate to projected emissions. These issues intersect each other in many ways. Our choice of energy pathway will affect our emissions, and hence, our future climate. Our choice of energy pathway may also be partly dependent on the response of the Earth's climate system to carbon emissions, both in terms of determining the costs and benefits of different forms of power generation and in terms of constraints placed on energy choices in light of future climate change. For example, offshore oil platforms could be vulnerable to increases in extreme weather events, the potential for bioenergy production could be reduced if it is harder to grow vegetation in the future, and if water temperatures and availability are altered, this may affect the efficiency of certain types of power generation, including nuclear, fossil fuel and hydroelectric.

Sanchez and colleagues examine one question about energy pathways in detail: what role could sustainable biomass, in the form of Bioenergy with Carbon Capture and Storage[3] (BECCS), play in low-carbon energy pathways for western North America? In order to do this, they use an electricity supply planning model to simulate different energy pathways for the western United States and western

1. The announcement from the IEA comes before the release of their Special Report on Energy and Climate that will be released in June. IEA, 2015: *Global energy-related emissions of carbon dioxide stalled in 2014*. <http://www.iea.org/newsroomandevents/news/2015/march/global-energy-related-emissions-of-carbon-dioxide-stalled-in-2014.html>.
2. For an overview of these projected impacts, see IPCC, 2014: Summary for policymakers. In: *Climate Change 2014: Impacts,Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1-32.

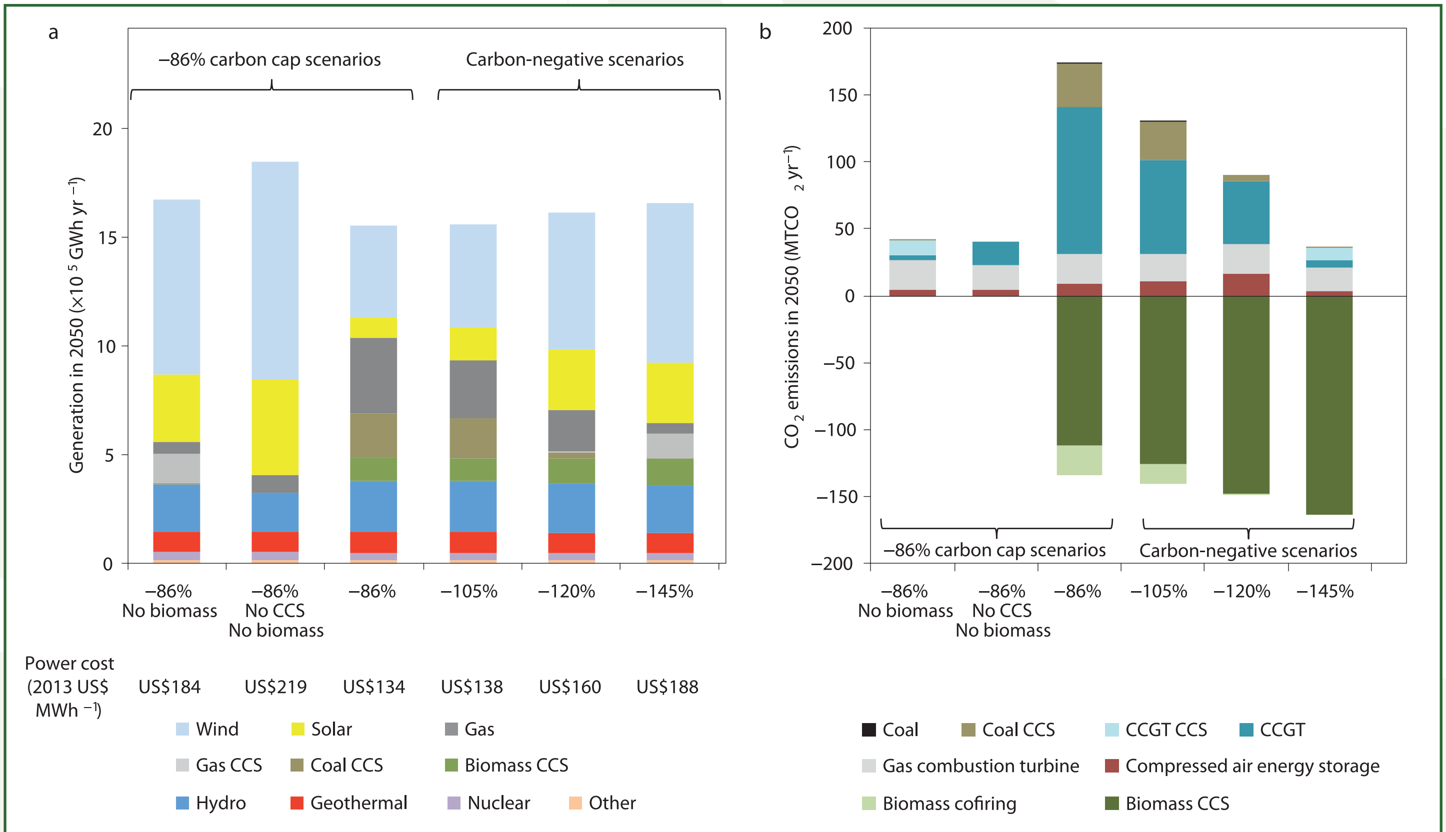


Figure 1: Generations, power cost and carbon emissions in 2050, from Sanchez et al. (2014).
Plots of a) the energy generation under each scenario for 2050, by energy source, with associated power costs in 2013 US dollar equivalents and b) carbon dioxide emissions in each scenario for 2050, by emissions source. The total power generation is not constant between models because only emissions reductions were stipulated.

Canada, including Alberta. After determining the amount of available fuel for bioenergy in the form of recoverable biomass for burning, they set three emissions reductions goals for 2050 with respect to the emissions level of 1990: 105%, 120% and 145%. These are chosen to better understand and explore the deployment of BECCS in situations that require both carbon-neutral and carbon negative emissions from power generation. They also examine three similar scenarios with an emissions reduction goal of 86%: one that uses BECCS and two that do not assume the use of bioenergy. The latter two are further divided into one that assumes the use of Carbon Capture and Storage (CCS) and one that does not.

The authors find that, for the 86% reduction scenario without bioenergy, renewables including wind, solar, hydro and geothermal make up 86% of the total energy production, with gas (with and without CCS) making up most of the rest, to compensate for intermittency (Figure 1, Panel a). Without CCS, the amount of energy produced by renewables must be higher (94%). If bioenergy and CCS are allowed, fossil-fuels can play a larger role, with a fuel mix that has some coal with CCS and gas without CCS. However, as the emissions reductions become ever more stringent, coal with CCS and gas without CCS are squeezed out of the energy supply, with coal entirely absent to meet the 145% emissions reduction goal.

In the 145% reduction scenario, through the utilization of BECCS, overall power generation is carbon-negative by 2050. The price of power is also similar in the 145% reduction scenario, which uses BECCS, and the 86% reduction scenario, which does not utilize biomass. The authors note that electricity prices only increase by 6% when BECCS is

3. Biomass with Carbon Capture and Storage uses vegetation, such as pulpwood, switch grass, orchard and vineyard waste and residues from forests, mills and agriculture as a source of fuel. This fuel is burned, while capturing the resulting carbon dioxide emissions using capture techniques, such as forcing the resulting gas through a liquid solution that contains amines. These amines undergo a chemical reaction with the carbon dioxide, forming carbamates in the solution, which can later be heated to release carbon dioxide gas. This gas is then transported and sequestered, with current candidates for large-scale sequestration being geological formations, where the gas is trapped by some combination of impermeable rock, minerals that it "binds" with and salt water that it dissolves in. For context and an overview of BECCS and climate change mitigation, see Creutzig et al., 2014.

used only for carbon sequestration, compared to when it is used for both sequestration and electricity. This suggests that the primary benefit of BECCS is in sequestering carbon in biomass. As Panel b of Figure 1 indicates, BECCS is the primary source of negative emissions. Though the authors discuss the price of electricity, they do not provide a regional projection of the effects of BECCS on GDP[4].

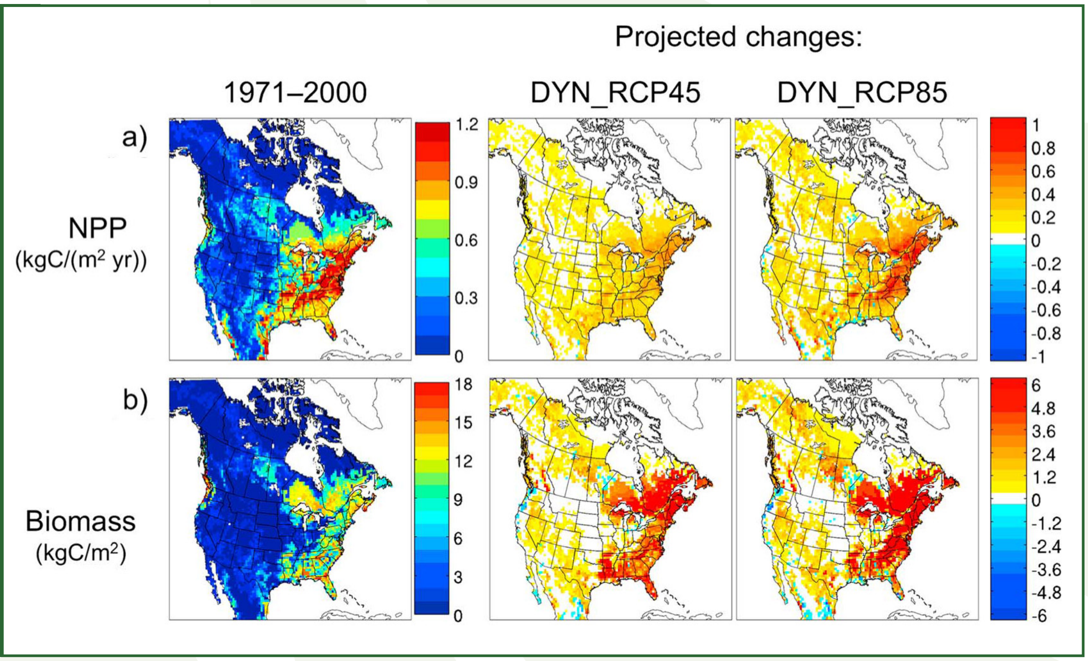
It is worth noting that Sanchez et al. hold the amount of nuclear power that is used constant. Recent research by Hong, Bradshaw and Brook (2015) suggests that optimal cost and land-use effectiveness is achieved though increased use of nuclear along with a mix of renewables, though Working Group III notes, in their contribution to the IPCC's Fifth Assessment Report, that while nuclear energy is "a mature low-GHG emission source of baseload power," that "a variety of risks exist" (IPCC, 2014). These risks range from waste disposal and weapon proliferation to mining and operational hazards. The IEA has reduced their nuclear power projections[5] in their scenarios that keep warming since the pre-industrial era to under 2° C by 2100. Their new projection places nuclear power production at 930 gigawatts, down from 1200 gigawatts, due to a mix of factors including increased costs of production, the Fukushima Daiichi incident, and the increases in the price performance of both solar and onshore wind power. However, given the advantages of nuclear in land use and biodiversity, maturity, economics and the increased safety of third generation reactors, their revised projections still call for more than a doubling from current global nuclear power capacity by 2050.

It is also worth noting that, while CCS shows promise and is widely included in climate stabilization scenarios with aggressive emissions reductions, it has associated risks. These include the potential to induce seismic events (Bruckner et al., 2014) and leaks of carbon dioxide from the underground geological formations in which it is stored once it has been drawn out of the air (Bruckner et al., 2014; Fogarty, 2010). Such leaks could reduce the effectiveness of CCS in mitigating climate change (Creutzig et al., 2014) and cause local suffocation (Fogarty, 2010), concerns about which have already led to public opposition to sequestration projects and the cancelation of one in the town of Barendrecht in the Netherlands. The potential for such leaks, however, is very small and a number of monitoring and active management systems for CCS storage exist (Bruckner et al., 2014). It also has potential environmental impacts. These include the ecosystem impacts from converting land to fuel stock for bioenergy, groundwater contamination and those impacts associated with continued fossil fuel use, such as reduced air quality[6], as well as potential climate impacts (Creutzig et al., 2014). In addition, it is a relatively young set of technologies with associated uncertainties having to do with land use competition (and related food security issues) and the costs of technology. It also requires massive scaling up to meet the goals of some climate stabilization scenarios (Fuss et al., 2014). To give a sense of scale, Fuss et al. note that the scenarios used in the IPCC's Fifth Assessment Report that keep surface temperature warming under 2° C by 2100 call for BECCS to drawn down between two and ten billion tonnes of carbon dioxide per year, whereas the ocean and terrestrial biosphere draw down roughly nine and ten billion tonnes per year, respectively.

The discussion of biomass as a component of future low-carbon energy pathways naturally leads to questions about both the projected conditions for future biomass growth and projected future climate in light of interactions between climate and the biosphere. We want to know not only if and how vegetation biomass energy can help us to meet our low-carbon energy goals, but also what growing conditions may be like for vegetation in the future and how these conditions will further influence climate.

4. For a broad overview of different energy options, including BECCS, as they are used in integrated assessment involving economics, see Bruckner et al., 2014. For a further discussion of BECCS costs under different constraints, see Kriegler et al. 2013, Fuss et al., 2013 and Azar et al., 2013.
5. See the International Energy Agency's (2015) *Technology Roadmap: Nuclear Energy*.
6. Proposed CCS technologies are anticipated to reduce sulphur dioxide, particulate matter and air pollutant emissions from coal plants in general. However, the European Environment Agency (2011) notes that nitrogen oxide emissions may be reduced or unaffected if no additional measures to capture them are implemented. Ammonia emissions are expected to increase, due to the breaking down of the solvents used for CCS, and these can form fine particulate matter that may reduce air quality, especially during cold weather (Heo et al., 2015).
7. For more information on the Canadian Regional Climate Model, see Laprise et al., 2013.
8. Phenology refers to the timing of life-cycle events of plants and animals, such as flowers blooming, butterflies undergoing metamorphosis and birds migrating. In the context of vegetation modelling using CTEM, which is the terrestrial ecosystem model which is used in CRCM5, it refers to the four leaf states of plants: maximal leaf growth (in spring), normal leaf growth, leaf fall and crop harvest (in fall) and a dormant state with no leaves (winter). These are modelled in CTEM for three different types of deciduous trees, two types of evergreens, two types of crops and two types of grass. For more information, see: Arora, V.K. and G.J. Boer, 2005: A parameterization of leaf phenology for the terrestrial ecosystem component of climate models, *Global Change Biology*, **11**, 1, 39-59.
9. For more about CanESM2, see Arora, V. K., J. F. Scinocca, G. J. Boer, J. R. Christian, K. L. Denman, G. M. Flato, V. V. Kharin, W. G. Lee, and W. J. Merryfield, 2011: Carbon emission limits required to satisfy future representative concentration pathways of greenhouse gases, *Geophysical Research Letters*, **38**, L05805, doi:10.1029/2010GL046270.

Figure 2: Projected Changes in Vegetation, edited, from Garnaud and Sushama (2015).
Average values for a) Net Primary Productivity[11] (NPP) and Biomass b) for the 1971-2000 period from the RCP4.5 simulations are on left and projected changes to these along RCP4.5 and RCP8.5 for the 2071-2100 period are on the right.



To investigate these questions Garnaud and Sushama (2015) use the Canadian Regional Climate Model[7] (CRCM5) with dynamic vegetation, including phenology[8] dynamics, to downscale output from the Canadian Earth System Model[9] (CanESM2). They use two emissions scenarios[10], one that leads to approximately a doubling of the preindustrial concentration of carbon dioxide in the atmosphere by 2100 (RCP4.5) and one that is more emissions intensive, leading approximately to a quadrupling (RCP8.5).

The authors find that projected increases in temperature lead to earlier leaf onset throughout the century under both emissions scenarios in all but the southernmost regions of North America, with the emissions intensive scenario having earlier leaf onset. For the 2071-2100 period, leaf onset occurs 27 days earlier than in the 1971-2000 period for RCP 8.5 compared to 21 days earlier for RCP 4.5. It is worth noting that research has already detected a change in growing season length that is at least partially attributable to anthropogenic emissions[12]. Largely as a result of earlier leaf onset, both scenarios also show longer growing seasons. Along with increased CO_2 fertilization, this results in greater vegetation productivity and biomass, especially in higher latitudes and in the east (Figure 2), though this effect plateaus at the end of the 21st century. (Note that this is not a continuation of the current trend toward reforestation in the East, because the vegetation model used was not set up to account for changing forest area.) Projected vegetation productivity decreases in some areas of the southeastern US over the 2071-2100 period, which the authors attribute to increased heat and water stress. Garnaud and Sushama also find an increase in the water-use efficiency of plants.

The authors find that accounting for vegetation feedbacks increases warming in summer at higher latitudes while reducing summer warming at lower latitudes, because the increased amount of vegetation affects the hydrological cycle, by changing the amount of solar energy used to evaporate water. A similar pattern is seen during the spring, with vegetation causing changes in the amount of solar radiation absorbed in the higher latitudes and changes to hydrological feedbacks in lower latitude regions. The authors' projections also show that annual average precipitation decreases over time in the southern states and along the coasts in the emissions-intensive scenario.

Garnaud and Sushama note two important limitations of their study: plant types were not allowed to move and compete with each other, and land use change such as changes in forest and crop areas were not taken into account. These are important because changes in the amount and type of vegetation in a region can affect, among other things, the

10. The Intergovernmental Panel on Climate Change use four new trajectories of atmospheric greenhouse gas concentration, known as Representative Concentration Pathways (RCP) for its Fifth Assessment Report. The four trajectories are denoted by the radiative forcings that would result from each concentration in 2100, e.g. RCP 4.5 would result in a warming effect of 4.5 Watts per square meter in 2100, as compared to the preindustrial period (taken to be the year 1750). For more information on the RCPs, see: van Vuuren et al., 2011.
11. Net Primary Productivity (NPP) is the difference between the amount of carbon dioxide that plants draw down during photosynthesis and how much carbon dioxide that is released during plant respiration and decomposition.
12. For more on this, see Christidis et al., 2007. For more recent observations of increased growing season length in high-latitude regions, see Zeng et al., 2011.

local hydrological cycle and the amount of solar radiation that is absorbed in an area.

Taken together with the results of Sanchez et al., these findings may suggest that BECCS, could become a more attractive option over time in North America, especially in the eastern US and Canada, as biofuel becomes more available due to increases in growing season length and increases in available biomass. These findings also fit with a general picture of projected increases to growing season length and agricultural productivity in higher latitude regions.

In British Columbia, interest in bioenergy has been growing, for example, as indicated by the BC Bioenergy Strategy, which states that, "[b]ioenergy is absolutely critical to achieving B.C.'s climate goals and economic objectives." More recently, the BC Bio Economy Report also discusses the potential for bioenergy in BC and some current developments. The results from the research by Sanchez et al. and Garnaud and Sushama presented here support the position that bioenergy could play a role in efforts to reduce the province's greenhouse gas emissions. They also indicate that projected trends in vegetation production may provide some further support for such efforts, at least until late in this century.

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