XIV WORLD FORESTRY CONGRESS, Durban, South Africa, 7-11 September 2015

Driving clean energy and green economy with the help of forest-based bioenergy with CCS (BECCS) - A case study on Indonesia

Florian Kraxner[1], Sabine Fuss[2,1], Sylvain Leduc[1], Ping Yowargana[1,3], Georg Kindermann[1], Stephan Pietsch[1], Jens Hetland[4]

[1]Ecosystems Services and Management Program (ESM), International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria
[2]Working Group on Resources and International Trade, Mercator Research Institute on Global Commons and Climate Change (MCC), Berlin, Germany
[3]President's Delivery Unit for Development Monitoring and Oversight (UKP-PPP), Jakarta, Indonesia
[4]Dep. of Gas Technology, SINTEF Energi AS, Trondheim, Norway

Abstract

Indonesia, on the one hand, is a tropical country with large biomass productivity and increasing oil and gas sector activities. On the other hand, it is the 3rd largest GHG emitter globally and some 90% of its emissions are generated from massive land-use change, i.e. tropical deforestation. At the same time, Indonesia has developed very ambitious climate targets aiming at 26% GHG emission reduction without foreign aid and even 41% with foreign aid by 2020. In addition, these targets need to be balance with an envisaged GDP growth by 7% and projected 5 times higher energy consumption in 2050 compared to 2010. The BECCS technology (i.e. the combination of forest based bioenergy with carbon capture and storage) is seen as a promising tool to bridge between the various future challenges Indonesia is facing and at the same time to deliver large quantities of negative emissions needed by the end of this century.
The objective of the presented BECCS case study is to analyse the in situ BECCS capacity for green-field bioenergy plants in Indonesia under different scenario assumptions. We examined the technical potential of bioenergy production from sustainably grown regional forest biomass. First results from the assessment indicate that the potentials vary substantially over the different scenario assumptions. It is demonstrated that sustainable production of biomass feedstock, energy demand and supply as well as competing industries and existing transport infrastructure are important input parameters in order to achieve an optimal BECCS solution for national and regional applications. The scenario on clean energy access for all with special emphasis on remote area and small islands in Indonesia turned out to be especially interesting from a socio-economic, emission savings and innovation perspective.

Keywords: forest bioenergy; BECCS; CCS; negative emissions; clean energy; green economy; Indonesia; mitigation;

Introduction, scope and main objectives

General introduction to negative emissions and BECCS

In 2013, the Earth's CO2 level peaked at 400 ppm, which is the highest level in our history since the Pliocene. It thus appears that we are indeed steering toward an overshoot by which current climate change mitigation scenarios are characterized (GEA, 2012, IPCC AR4 and AR5), before stabilizing at concentration levels allowing us to restrict global warming to 2°C above preindustrial levels.
One core ingredient in the mitigation mix necessary to achieve these safe concentration levels are negative emissions (NEs, cf. Fuss et al., 2013), shown in Figure 1.

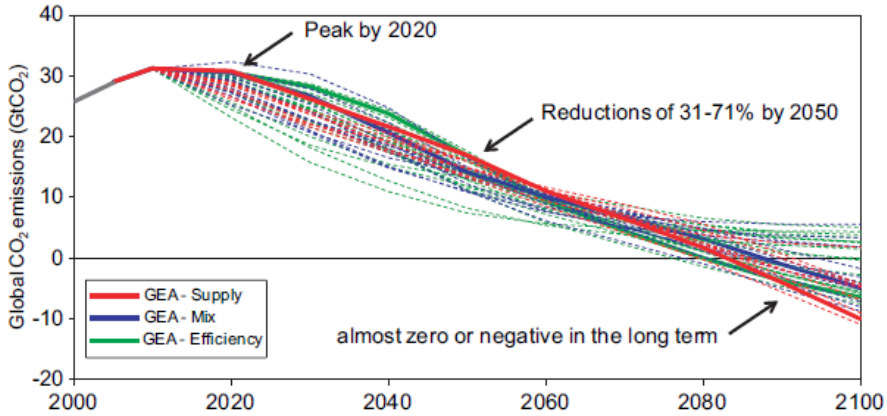

Fig. 1: Negative emissions demanded by GEA scenarios starting around 2080. Source: Global Energy Assessment (GEA), Chapter 17, Fig. 17.37 (2012).

NEs are mostly based on carbon-neutral bioenergy (due to the same amount being sequestered by feedstock growth as being emitted when combusting biomass for energy generation, cf. Obersteiner et al. (2001), Kraxner et al. (2003), or Uddin and Barreto (2007)) combined with carbon capture and storage (BECCS), which in addition captures CO2 during the energy production phase. This mechanism is illustrated in Figure 2.

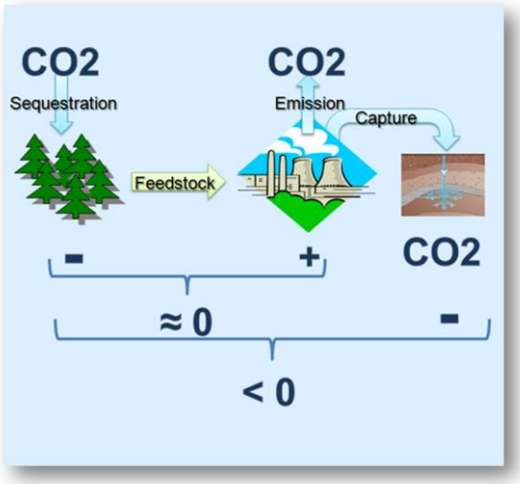

Fig. 2: Illustration of the BECCS concept. Source: Fuss et al. (2014)

Measuring aggregate BECCS potentials at global scale poses dangerous pitfalls in terms of not taking into account the local specificities that could support but also inhibit the adoption and diffusion of BECCS. It is therefore important to study the implementation possibilities at sub-national level, not only taking into account the geographically explicit bioenergy, but also the transport, injection and storage potentials.

The provided information in this article reveals that bioenergy production, its feedstock, and respective potentials need to be seen as the crucial components of BECCS. Moreover, the sustainability of the potential—from forest, agriculture, or other origin—is a very sensitive issue that needs special attention, especially when considering the huge global demand for bioenergy/BECCS projected [see e.g., Kraxner et al. (2013), or Kato and Yamagata (2014)]. It is furthermore demonstrated that only spatially explicit potential assessments, carried out with high accuracy and resolution, will be able to point to the realizable BECCS potential of a certain region, country, or smaller locations. The importance of

geographically explicit case studies and pilots is shown with the help of Figure 3, which reveals the global accumulation of biomass for possible bioenergy production in energy units.

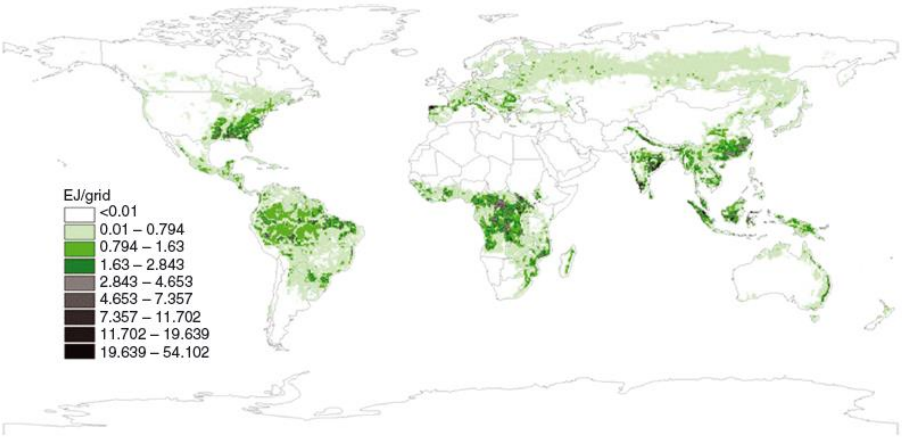

Fig. 3 Cumulative biomass production (EJ/grid) for bioenergy between 2000 and 2100 at the energy price supplied by IIASA's MESSAGE model based on the revised IPCC (2007) SRES A2r scenario (country investment risk excluded). Source: Reproduced from Rokityanskiy et al., 2007.

It is shown that the highest biomass accumulations have been identified mostly in the tropical belt of the southern hemisphere of the globe where—based on the favorable climate conditions—the productivity is very high. Such an assessment of potentials would point to a possible concentration of BECCS activities in these highly productive areas. However, it is especially the tropical belt of our southern hemisphere that is essential for our land-based mitigation through carbon sequestration and at the same time highly vulnerable to, for example, deforestation and loss of biodiversity.

Despite the importance of spatially explicit case studies, present literature reviews reveal that apart from a few engineering manuscripts presented at energy conferences such as the World Renewable Energy Congress (WREC) in 2011 (Kraxner et al. 2011a), or at special BECCS conferences and workshops, for example, the Bio-CCS workshop series held in 2010 at the University of Orleans, France (Kraxner et al. 2010), and in 2011 at Cardiff University in United Kingdom (Kraxner et al. 2011b), or at the IEA-IIASA BECCS Experts Workshop described in the introduction of this chapter, there is—to our knowledge—only very little literature available that features geographically explicit BECCS applications at high levels of resolution, especially for non-European countries. An exception forms, for example, the techno-economic approach for optimal design of bioenergy and BECCS plants developed by IIASA and first published by Kraxner et al. (2012a).

Specific Information on Indonesia

In order to add to the scientific insight, this article is putting emphasis on a country study on Indonesia. It is the world's largest archipelago state and has the fourth largest population with about 240 million people. Current annual GDP growth is between 5% and 6% and it is a leading coal and LNG exporter (Best et al. 2011). Indonesia faces huge energy challenges if it is to meet the government's "pro-poor, pro-jobs, pro-growth, and pro-environment" development vision, while making good its vow to reduce national emissions by 26% below the business-as-usual level by 2020, with a further reduction of up to 41% if adequate international support is provided.

Indonesia is also the third-highest emitter of greenhouse gases (GHGs) in the world, after the USA and China, with most emissions coming from land uses and land-use changes, particularly deforestation. And BECCS could be the answer to the tropical country's energy problems, not only lowering the current account deficit caused by fuel import, but enhancing domestic energy security and alleviating poverty especially in rural areas.

In 2008 oil was the dominant energy source with approximately 48% share of the energy mix, followed by coal with about 30% and natural gas with about 19%. Primary Energy Consumption was approximately 0.62 TOE/Capita in 2008 and it is growing at about 5% per year (Best et al. 2011). Given

the rate of growth and likelihood of increasing emissions in a business as usual approach with continued reliance on fossil fuels, and increased industrialization, the role of CCS is critical. The IEA CCS Roadmap highlighted the significance that CCS – also in combination with bioenergy - will play in achieving an atmospheric CO2 stabilization on 450ppm.
Given the large feedstock potential of a tropical country, but showing at the same time strong needs for considering environmental constraints, the main objective of this article is to analyse the in situ BECCS capacity for green-field bioenergy plants in Indonesia under different scenario assumptions. In the assessment, we concentrated on the technical potential of bioenergy production from sustainably grown regional forest biomass.

Methodology/approach

As explained also by Kraxner et al. (2012a), there are various types of CCS systems, such as underground geological storage, ocean storage, mineral carbonation, or for industrial use (e.g., enhanced oil recovery, EOR). For the case studies in this section, CCS with post combustion capture technology for underground storage in geological formations in direct in situ storage has been used. The latter means, carbon storage (CS) in the immediate vicinity of the combustion units [CHP (coupled heat and power) plants], such that e.g. transport costs can be minimized. Furthermore, it has been assumed that all (80%) CO2 emissions generated by a BECCS unit (in this case a CHP plant coupled with in situ CCS) are to be captured and stored. In a first step, IIASA's biophysical Global Forestry Model G4M (Kindermann et al., 2008) is used to estimate the local biomass availability. In a second step, the biomass results from the forestry model are used as input data to IIASA's engineering model BeWhere (Leduc et al., 2009) for optimized scaling and locating of integrated renewable energy systems, that is, CHP plants. The geographically explicit locations and capacities for forest-based bioenergy plants thus obtained are subsequently overlaid with a map of geological suitability for CS. From this, a theoretical potential for in situ BECCS is derived.

The Global Forest Model (G4M)

IIASA's Global Forest Model (G4M, www.iiasa.ac.at/g4m) has been used for the case studies to calculate the forest growing stock and the sustainable biomass extraction rate. G4M, as described by Kindermann et al. (2008), was developed to predict wood increment and stocking biomass in forests. As an input parameter, it uses yield power, which is derived from the net primary productivity (NPP) for a specific region. The model can be used to provide information on how much biomass can be harvested under a certain rotation time as well as how much biomass is stocking in the forest. G4M also supplies information on harvesting losses such as needles, leaves, and branches that typically remain in forests under sustainable management. Other economic parameters such as harvesting costs—depending on tree size and slope—can also be calculated using G4M.

BeWhere model

BeWhere (www.iiasa.ac.at/bewhere), a spatially explicit, techno-economic model for renewable energy systems optimization (including full supply chain representation), was used for the in situ BECCS assessment in the presented case studies (Leduc et al., 2009). In the case of BECCS (bioenergy), the model, developed at IIASA, considers industries that compete, for example, for wood resources. On the supply side, forest wood harvests (input by G4M), sawmill co-products (SCP), and wood imports serve as biomass resources for possible green-field or existing bioenergy plants. On the demand side, the demand for wood by competing industries such as pulp and paper mills, existing bioenergy plants, as well as private households can be considered. Transportation of wood from biomass supply to demand spots by truck, train, or boat is considered. BeWhere consequently selects optimal locations for greenfield bioenergy plants by minimizing the costs of biomass supply, biomass transport, and energy distribution. The full costs and emissions at the optimal locations are calculated such that the technical BECCS potentials for the individual case study areas can be identified. The supply–demand optimization routines of the BeWhere model are also used to consider transportation costs (truck, train, and ship), the existing road and railway networks for the case study areas, as well as different travel speeds.

Results

Since this article is concentrating on bioenergy from regional forest biomass only, in a first step, the potential wood production from the managed forests of Indonesia have been calculated with the help of the Global Forestry Model (G4M) as explained above. Figure 4 indicates the geographical distribution and intensity of the annual wood production and harvesting potential.

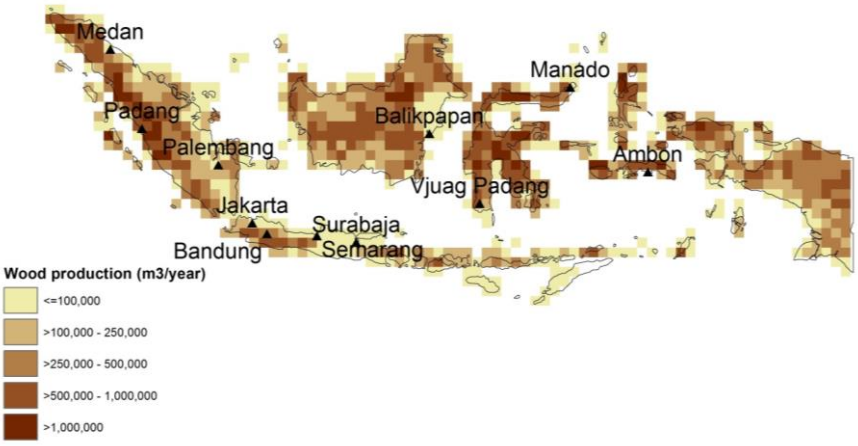

Fig. 4: Managed forest in Indonesia. Location and intensity of the annual sustainable harvesting potential based on G4M calculations. Source: own compilation (2013)

For sustainability reasons, it is assumed that only 20% of the current forest increment will be used for bioenergy production.

In addition to the assumption that only wood from managed forests is used, it is assumed that the existing demand (such as wood for pulp and paper production, timber production etc.) needs to be met first. For instance, the wood demand for pulp is 40 million m^3 per year. A second sustainability constraint is the exclusion of natural parks and protected areas from harvesting. Table 1 indicates the harvesting potential (in million cubic meters) in managed forests versus the one in unmanaged forests including the energy content (in Peta Joules).

Table 1: Harvesting potential and energy content in managed forests vs. unmanaged forests. Source: own compilation (2013)

	PJ	Mm^3
Managed	8,537	923
Unmanaged	4,594	497

For further calculations to optimize the optimal bioenergy plant (CHP) location and dimension by IIASA's BeWhere model, it is assumed that heat can be supplied within a radius of 40 km only. Heat can be supplied to cities (> 50,000 inhabitants) with larger infrastructure for cooling purposes (e.g. for hospitals, hotels, industries, offices, etc.). The maximum electricity supply radius is limited to 100 km. The heat and power demand is oriented towards the national consumption. Furthermore, it is assumed that on-island feedstock transport mostly is carried out by truck whereas the trade between the individual islands happens by boat. The biomass feedstock can be shipped between all islands. The present fossil fuel prices are considered as a benchmark for economic feasibility.

Figure 5 represents the first geographically explicit BECCS map for Indonesia, indicating the potential location and capacities of bioenergy plants distributed over the archipelago. All plants are CHP plants and it is assumed the only 20% of the current forest increment is used as a bioenergy feedstock. The shaded area indicates possible CCS suitability. All bioenergy plants located on CCS suitable underground are considered as "in-situ" BECCS plants and can be accounted for Indonesia's BECCS potential.

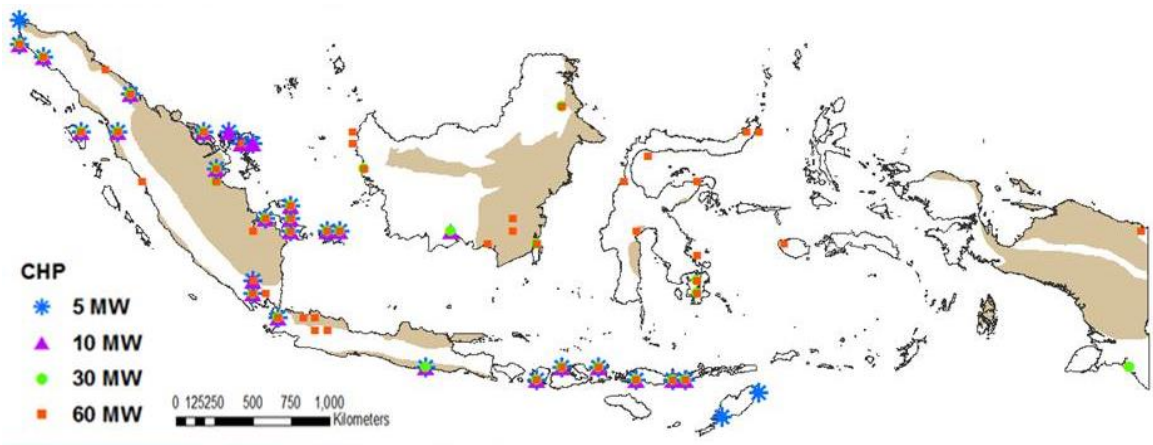

Fig. 5: BECCS map for Indonesia, indicating locations of bioenergy plants, their capacities as well as in-situ status. CCS suitable area shaded in light brown. Source: own compilation (2013)

About half of the optimal bioenergy plant locations are not directly place on suitable carbon storage underground. However, Table 2 indicates that the capacity of all "in-situ" BECCS plants amount to 1,185 MW and would theoretically be able to capture (@ 80% efficiency) some 2.5 million tons CO_2 per year. Multiplying each ton of captured and stored carbon with a modest carbon price of 5 US$ per ton, the annual benefit would reach 12.5 million US$.

Table 2: First BECCS potential for Indonesia. Source: own compilation (2013)

# plants with suitable storage access	Captured CO2 at 80% capture efficiency	Carbon benefit @ 5 US$/ton
1,185 MW	2.5 Mt CO2/yr	12.5 mill. US$

Discussion

Results of the first BECCS map and BECCS potential for Indonesia indicate that – in the specific case of in-situ BECCS plants – the achievable amount of CO_2 that can be directly captured and stored is not very large and would correspond to only a rather small fraction of Indonesia's emission reduction target. However, it needs to be considered that much larger amounts of CO2 could be captured and stored, if the larger plants (in-situ and off-situ) could e.g. be bundled to reach economic viability (economy of scale). Furthermore, different kinds of feedstock could be taken into consideration (e.g. forest-based feedstock combined with agricultural waste or waste from oil palm plantations etc.). In addition, other technologies such as an increased demand for cooling could be considered for the future. An important component of emission reduction would be of course also the maximization of other land-based mitigation options and demand-side reduction of energy consumption.

The topic of BECCS and sustainable bioenergy production is also a matter of capacity building that needs to go hand in hand with relevant policy support (e.g. reduction of fossil fuel subsidies, sustainable forest management certification, etc.).
Despite a low level of public awareness of CCS in Indonesia compared to a developed country, over the past few years, oil and gas industry practitioners have developed a good and growing understanding of CCS. Through programs such as the Indonesia CCS Working Group that is comprised of Ministry of Mineral Resources, Ministry of Environment, PT PLN, World Energy Council, Shell and British Embassy, who have been actively disseminating CCS information with joint workshop and publications. In the future, more work will also need to be undertaken to engage stakeholders and build public awareness especially with local communities – as has started by IIASA's Tropical Futures Initiative (TFI).

Conclusions/outlook

In this article we could show the importance of negative emission and – moreover – the importance of detailed national and regional studies in order to derive the real potential for BECCS. We could show for Indonesia, that under simple assumptions, bioenergy combined with CCS is feasible without harming the environment – by restricting the feedstock to a minor share of the annual increment of managed forests. In this manuscript, we could furthermore show that optimal scaling and siting for forest-based bioenergy plants in combination with BECCS is possible, while considering ecological factors such as sustainable forest management, economic factors such as optimization by supply, demand, and means of transport, as well as social factors such as capacity building with respect to BECCS and support of bottom-up future policy design (see inter alia Lemoine et al., 2012). Detailed and spatially explicit case studies, as shown in this article are turning out to be inevitable for determining the adapted to each case study is a good start for further comparative assessments necessary to be carried out in the near term. Critical factors such as the availability of sustainably produced biomass, sufficient demand for individual energy types (e.g., heat and electricity), economies of scale (which might get into conflict with sustainability), geological suitability for CS, and consequently supportive and science informed policies have to be considered.

Acknowledgements

The authors thank the cooperation and support from the partner research institutions, mainly the International Research Institute for Applied System Analysis (IIASA) and the Mercator Research Institute on Global Commons and Climate Change (MCC). The work has been co-financed by IIASA's Tropical Futures Initiative (TFI). Finally, the author's would like to thank the International Research NGO Global Alpine Synergies (GAS, www.global-syn.org), Austria, for its dedicated support.

The views expressed in this information product are those of the author(s) and do not necessarily reflect the views or policies of FAO.

References

Best D, Mulyana R, Jacobs B, Iskandar UP, Beck B. 2011. Status of CCS Development in Indonesia. *Energy Procedia*, 4, 6152-6156.

Fuss, S., Canadell, J.G., Peters, G.P., et al. 2014. Betting on negative emissions. *Nature Climate Change*, 850–853, doi:10.1038/nclimate2392.

Fuss, S., Reuter, W.H., Szolgayova, J., and Obersteiner, M. 2013. Optimal mitigation strategies with negative emission technologies and carbon sinks under uncertainty. *Climatic Change*, **118** (11), 73–87.

GEA Global Energy Assessment. 2012.—Toward a Sustainable Future, *Cambridge University Press, Cambridge.*

IEA International Energy Agency. 2009. *Carbon Capture and Storage Technology Roadmap*. Available at: www.iea.org [accessed 30.04.15]

IPCC. 2007. Intergovernmental Panel on Climate Change (2007) Climate Change 2007: Mitigation of Climate Change. *Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (eds. B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, and L.A. Meyer), Cambridge University Press, Cambridge.

IPCC, Intergovernmental Panel on Climate Change. 2014. Summary for policymakers. In: Edenhofer, O., Pichs-Madruga, R., Sokona, Y., et al. (eds.), Climate Change 2014: Mitigation of Climate Change. *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge.

Kato, E. and Yamagata, Y. 2014. BECCS capability of dedicated bioenergy crops under a future land-use scenario targeting net negative carbon emissions. *Earth's Future*, 421–439, doi:10.1002/2014EF000249.

Kindermann, G., Obersteiner, M., Sohngen, B., et al. 2008. Global cost estimates of reducing carbon emissions through avoided deforestation. *PNAS*, 105 (30), 10302–10307.

Kraxner, F., Aoki, K., Leduc, S., et al. 2011a. BECCS in South Korea—An Analysis of Negative Emissions Potential for Bioenergy as a Mitigation Tool. *Proceedings of the World Renewable Energy Congress (WREC)*, 8–13 May, Linköping, Sweden; Linköping University Electronic Press, Link¨opings universitet; ISBN: 978-91-7393-070-3, pp. 676–683.

Kraxner, F., Aoki, K., Leduc, S., et al. 2011b. BECCS in Japan—The Potential of Negative Emissions from Bioenergy. *Paper presented at the 2nd Biomass & Carbon Capture and Storage (Bio-CCS) Worksho*p, 25–26 October, Cardiff University, Wales, UK, http://www.cu-gtrc.co.uk/categories.html?cid=55 [accessed 30.04.15]

Kraxner, F., Aoki, K., Leduc, S., et al. 2012a. BECCS in South Korea—analyzing the negative emissions potential of bioenergy as a mitigation tool. *Renewable Energy*, 61, 102–108.

Kraxner, F., Kindermann, G., Leduc, S., et al. 2010. Bioenergy Use for Negative Emissions—Potentials for Carbon Capture and Storage (BECCS) from a Global Forest Model Combined with Optimized Siting and Scaling of Bioenergy Plants in Europe. *Paper presented at the First International Workshop on Biomass and Carbon Capture and Storage*, October 2010, University of Orléans, France, http://www.univ-orleans.fr/leo/bccs/index.php [accessed 30.04.15]

Kraxner, F., Nilsson, S., and Obersteiner, M. 2003. Negative emissions from BioEnergy use, carbon capture and sequestration (BECS)—the case of biomass production by sustainable forest management from semi-natural temperate forests. *Biomass and Bioenergy*, 24, 285–296.

Kraxner, F., Nordstrom, E.-M., Havlik, P., et al. 2013. Global bioenergy scenarios—future forest development, land-use implications, and trade-offs. *Biomass and Bioenergy*, 57, 86–96.

Leduc, S., Schmid, E., Obersteiner, M., and Riahi, K. 2009. Methanol production by gasification using a geographically explicit model. *Biomass and Bioenergy*, 33 (5), 745–751.

Lemoine, D.M., Fuss, S., Szolgayova, J., et al. 2012. The influence of negative emission technologies and technology policies on the optimal climate mitigation portfolio. *Climatic Change*, 113 (2), 141–162.

Obersteiner, M., Azar, C., Kauppi, P., et al. 2001. Managing climate risk. *Science*, 294 (5543), 786–787.

Rokityanskiy, D., Benitez, P.C., Kraxner, F., et al. 2007. Geographically explicit global modeling of land-use change, carbon sequestration, and biomass supply. *Technological Forecasting & Social Change* (Special Issue: Greenhouse Gases—Integrated Assessment), 74 (7), 1057–1082.

Uddin, S.N. and Barreto, L. 2007. Biomass-fired cogeneration systems with CO2 capture and storage. *Renewable Energy*, 32, 1006–1019.