Available online at www.sciencedirect.com
ScienceDirect
Energy Procedia 61 (2014) 2791 – 2796
Energy Procedia

The 6th International Conference on Applied Energy – ICAE2014

Energy resilient solutions for Japan - a BECCS case study

Florian Kraxner[a,]*, Sylvain Leduc[a], Sabine Fuss[b,a], Kentaro Aoki[c,a], Georg Kindermann[a,d], Yoshiki Yamagata[e,a]

[a] *International Institute for Applied Systems Analysis (IIASA), Schlossplatz 1, A-2361 Laxenburg, Austria*
[b]*Mercator Research Institute on Global Commons and Climate Change (MCC), Torgauer Str. 12 – 15, 10829 Berlin, Germany*
[c]*United Nations Industrial Development Organisation (UNIDO), P.O. Box 300, A-1400 Vienna, Austria*
[d]*Federal Research and Training Centre for Forests (BFW), Seckendorff-Gudent-Weg 8, A-1131 Vienna, Austria*
[e]*National Institute for Environmental Studies (NIES), Onogawa 16-2 Tsukuba Ibaraki 305-8506, Japan*

Abstract

The objective of this study is to analyze Japan's BECCS potential. A technical assessment is used to support a policy discussion on the suitability of this mitigation tool for Japan. IIASA's BeWhere Model is used to examine the technical potential of bioenergy including optimal locations and capacities of biomass plants. The plant locations are overlaid with a geological suitability map for carbon storage. Results indicate that there is a substantial potential for bioenergy production which could contribute to substituting emissions from fossil fuels. By further developing the renewable energy pathway, Japan could substantially add to a more resilient and domestic resources-based energy sector. There is limited potential for direct negative emissions from bioenergy, but some of the coastal regions appear suitable for carbon storage. A higher potential could be achieved through off-shore carbon storage and enhanced cross-border collaboration.

Peer-review under responsibility of the Organizing Committee of ICAE2014

Keywords: BECCS; Energy Resilience; Forest Bioenergy; Carbon Capture and Storage; Biomass Modeling; Energy Policy;

1. Introduction and Background

Bioenergy in combination with carbon capture and storage (BECCS) could remove CO_2 from the atmosphere in order to contribute substantially to achieving low levels of concentration [1-3]. However, compared to fossil CCS (Carbon Capture and Storage), very little information can be found in scientific literature so far for both the technical and potential application of BECCS. Moreover, apart from engineering papers presented at e.g. special BECCS conferences such as [4, 5] on Europe, there is -

* Corresponding author. Tel.: +43-2236-807-233; fax: +43-2236-807-599.
E-mail address: kraxner@iiasa.ac.at.

Peer-review under responsibility of the Organizing Committee of ICAE2014
doi:10.1016/j.egypro.2014.12.316

according to our knowledge - to date no literature available that features geographic explicit BECCS applications for Japan.

The crisis after the Fukushima power plant incident has prompted a national review of energy policy in Japan and turned the public's view to the renewable energy again. However, in terms of overall renewable energy utilization, Japan is lagging far behind the rest of the developed countries. Renewable sources currently account for only 1 percent of Japan's energy supply. To increase the share of renewable energy use in Japan, continuous and effective policy support is needed, especially a well-designed energy policy which is also economically viable. Furthermore, special incentives are needed in order to accelerate the development of the bioenergy sector in Japan. One of these incentives has been identified in BECCS.

The aim of the technical part of our manuscript was threefold. 1) to help identifying - in a geographically explicit manner - the available biomass potential from forest for bioenergy production under sustainable management conditions in Japan [6]; 2) to indicate the optimal size and location of green-field forest biomass-based bioenergy CHP (Coupled Heat and Power technology) plants; 3) to identify the amount and capacity of potential in-situ BECCS units in Japan.

2. Method

There are various systems for CCS, such as underground geological storage, ocean storage, mineral carbonation, or industrial use. In this study, we considered the CCS System (with post combustion capture technology) for the underground geological storage into a suitable geological formation in the on-shore earth's subsurface. Additionally, we were especially aiming at direct "in-situ" storage. The storage happens in direct vicinity to the combustion units (CHP plants) in order to minimize transport costs and complications. Further we assumed that the total amount of CO2 - emissions generated at a BECCS unit will be captured and stored in-situ. A technical assessment was used to support a policy discussion on the suitability of this mitigation tool. We first examined the technical potential of bioenergy production from domestic forest biomass. For this exercise, in a first step, the biophysical Global Forestry Model G4M [7] was applied in order to estimate the biomass availability. In a second step, the biomass results from the forestry model were used as input data for the engineering model BeWhere [8] for optimized scaling and locating of CHP plants. The obtained geographically explicit locations and capacities for forest-based bioenergy plants were consequently overlaid with a geological suitability map for carbon storage. From this, a theoretical potential for "in-situ" BECCS was derived.

3. Results

There were 3 complementary main sets of results derived from this study and indicated at country level: 1) the sustainably available biomass potential for harvest together with the national heat demand as a main prerequisite for the installation of green-field CHP plants; 2) the geological suitability for CS (Carbon Storage); and 3) the identified locations for BECCS units together with their individual bioenergy production capacity as well as their CCS capacity.

About 41% of forest area in Japan is plantation forest. In this study we focused on the biomass as energy feedstock from coniferous plantations only. The resulting sustainable amount of annual biomass extraction ranges 8-10 m^3/ha-year for Japanese cedar, 5-6.6 m^3/ha-year for Japanese Cypress and 3-4.6 m^3/ha-year for Japanese Larch. We assume about 1.33 million m^3 (665,000 tdm/year) of stem biomass are utilized for heat and electricity production every year. This amount is about 0.05% of the total growing stock of coniferous plantations (2,335 million m^3) in 2007 [9, 10].

Although the suitable geological formations for geological CS available in Japan seem to be limited (the lands are mostly covered by volcanic terrain or craters), there are wide off-shore prospective areas in

this region (e.g. East Sea). We identified especially basins as potential in-situ on-shore locations suitable for CO2 geological storage in Japan and South Korea based on the studies by [11] and [12, 5].

To identify the optimal locations for green-field bioenergy plants, two different sizes of CHP plants are considered (10 and 50 MW). We assumed that diversification with respect to plant size would on the one hand result in a better distribution of plants within the country, which increases usually also the co-benefits of bioenergy plants. On the other hand we expected to identify more bioenergy plants suitable for in-situ CS. Within each scenario (plant capacity) the aim was to meet the target for the maximum sustainable biomass extraction (about 665,000 tdm/year).

For this study we defined in-situ CS suitability such that the bioenergy plant needs to be located within a 0.5 degree grid cell (about 55 x 55 km) of the suitable geologic province in order to directly inject CO2 underneath a plant or at any place up to a maximum of 25 km radius distance (e.g. with the help of a short pipeline).

Based on these assumptions, Fig. 1 shows the optimized location in a geographically explicit manner by plant size.

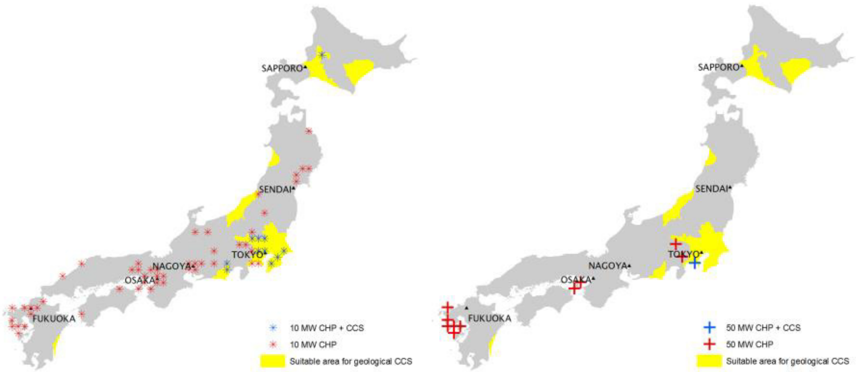

Fig. 1. 2 different scenarios (left:10 MW, right: 50 MW) for optimized green-field biomass plant locations in Japan. Geographically explicit locations without BECCS shown in red color. In-situ BECCS unit locations indicated in blue color on light yellow background (geologically suitable formation for CS).

Table 1 indicates the optimized amount of green field bioenergy plants for Japan, listed by plants with and without in-situ CS suitability, divided into the different plant capacity categories.

Table 1. Energy produced sustainably, emissions substituted, CCS Capacity by CHP plant with/without BECCS

Plant size/capacity	10 MW **NO** CCS	50 MW **NO** CCS	10 MW CCS	50 MW CCS
Plant #	50	10	11	1
Biomass used (tdm/year)	554,125	487,957	630,957	552,957
Heat produced (GJ/year)	6,613,750	6,613,750	8,068,775	7,275,125
El. produced (GJ/year)	4,208,750	4,208,750	5,134,675	4,629,625
Subst. emissions (tCO_2/year)	1,214,525	1,214,525	13,203,450	11,904,750
CCS Capacity (tCO2/year)	***0***	***0***	***1,481,721***	***1,335,978***

We could identify a maximum of 77 green-field bioenergy plants, of which there are 66 under the 10 MW-scenario, indicating 10 plants on geologically suitable ground in order to meet the criteria for BECCS units. Under the 50 MW scenario, 11 bioenergy plants were optimally distributed over the country, among which only 1 plant qualified as BECCS plant. In the best case (10 MW scenario), the "BECCS-effect" (emissions accounted as negative) could reach a potential capacity of some 1.5 million tons of CO2 to be directly stored permanently belowground per year and to be accounted as negative emissions.

4. Discussion and Conclusion

This BECCS exercise offers several new insights to the bioenergy sector in Japan and provides crucial information for policy support and energy resilience design. First of all, it is important to note that even under conservative assumptions (e.g. sustainable biomass extraction, allowing only for the use of 0.05% of the total growing stock of coniferous plantations) - Japan could double the energy produced biomass and waste. These results indicate a substantial potential of bioenergy growth in Japan – especially given the present policies and targets of the National Energy Plan to e.g. increase the bioenergy share in total energy production and decrease the total GHG emissions by 25% in 2020 and 80% in 2050 (target as of 2010). However, this study also indicates, that a much higher share of the actual growing stock might need to be used for bioenergy production in order to achieve larger effects on the energy portfolio and energy security of such a highly industrialized country.

From the 2 different scenarios (plant capacities), the 10 MW scenario turned out to offer the best country-wide coverage with its 61 green-field bioenergy facilities, which consequently could provide direct and indirect co-benefits such as driving the green economy, i.e. providing job opportunities both at the facility and in the biomass production. Another major benefit of growth in the bioenergy sector would be the resulting investments in forest and forest management primarily by small-scale forest owners, e.g. in forest infrastructure and sustainable forest management certification [13]. These benefits are based on the assumption that forest biomass would see a price increase, which justifies investments into forest infrastructure (to improve forest access) which lowers harvesting costs and increases competitiveness.

Although the suitable geological formations for in-situ CS in Japan are limited to less than 10% of the country area (mainly concentrating on the Kanto Basin), with the help of this study we could show that there is a theoretical potential for 1 (50 MW plants) to 10 (10 MW plants) green-field BECCS plants with in-situ CS. Based on our assumptions, the in-situ BECCS-effect might amount to 1,3 – 1,5 million tons CO2 per year in addition to an amount of 12-13 million tons CO2 per year substituted fossil fuel emissions. These BECCS- and emission reduction effects come in addition to the biomass co-benefits discussed earlier and could be used as a key issue for future policy design and decision makers.

However, the BECCS-effect - and with it a crucial lever for climate, environment and rural development policies - could be substantially increased and strengthened. An important caveat to bear in mind is that with our study we only could point out the theoretical potential without considering the costs of the actual CCS process. If bioenergy plants with higher capacities would be applied, costs could be substantially decreased (scale effect or poly-production). Further, although the suitable formations for geological CCS in Japan are very limited (e.g. earthquake and volcanic activity) there are considerable off-shore prospective areas in this region (e.g. East Sea). Using further capacity for CS (non in-situ), basically all substituted emission from bioenergy production could additionally be stored and accounted as negative. The use of a (trans-national) CO2-pipeline could actually boost the BECCS effect and lower the costs, but further research needs to be done in this field. Also the joint use of off-shore CS together with e.g. South Korea [5] would substantially increase Japan's BECCS capacity, which requires similar research to be extended to South East Asia, potentially using a higher data resolution than 0.25-deg.

We conclude that policy targeted bioenergy-based re-activation of forest management in Japan would evoke a real win-win-situation. First, bioenergy production and BECCS would directly contribute to meet ambitious climate change mitigation targets. Second, the forest ecosystem along with the final consumer of forest products would benefit from sustainable management and its certification [13]. Third, the forest owners - and with them the forest sector industry - would benefit from an increased value of the forest property. And last not least, society would benefit through e.g. an improved protective function (from e.g. flooding, landslides, avalanches etc.) and an increased recreational value of the forest.

For possible future energy policies in Japan it seems to be most suitable to concentrate on bioenergy in a de-central small to medium scale – also from an economic view point and in order to realize most of co- and cross-benefits of bioenergy production. Carbon Capture and Storage (CCS), however, might be optimally clustered and potentially combined with large scale power plants and biomass co-fire technology.

Acknowledgements

The research leading to these results has been facilitated by IIASA’s Ecosystem Services and Management Program (ESM), Japan’s Center for Global Environmental Research (CGER) at the National Institute for Environmental Studies (NIES), and by the Global Carbon Project (GCP) office in Tsukuba, Japan, under its special Urban and Regional Carbon Management (URCM) activities. The work on this study has further been supported by the research NGO Global Alpine Synergies (GAS).

References

[1] Obersteiner M, Azar Ch, Kauppi P, Möllersten K, Moreira J, Nilsson S, Read P, Riahi K, Schlamadinger B, Yamagata Y, Yan J, van Ypersele J-P, Managing climate risk. *Science* 2001, 294(5543):786–787

[2] Kraxner F, Nilsson S, Obersteiner M, 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 2003, 285 – 296

[3] Azar C, Lindgren K, Obersteiner M, Riahi K, van Vuuren D P,·den Elzen K M G J, Möllersten K,·Larson E D, The feasibility of low CO2 concentration targets and the role of bio-energy with carbon capture and storage (BECCS). *Climatic Change* 2010, 100:195–202. DOI 10.1007/s10584-010-9832-7

[4] Kraxner F, Kindermann G, Leduc S, Aoki K, Obersteiner M, 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 & Carbon Capture and Storage October 2010, University of Orléans, France, 2010.

[5] Kraxner F, Aoki K, Leduc S, Kindermann G, Fuss S, Yang J, Yamagata Y, Tak K, Obersteiner M. BECCS in South Korea – Analyzing the negative emissions potential of bioenergy as a mitigation tool. *Renewable Energy 2014*, 61:102-108

[6] Kraxner F, Nordstrom E-M, Havlik P, Gusti M, Mosnier A, Frank S, Valin H, Fritz S, Fuss S, Kindermann G, McCallum I, Khabarov N, Bottcher H, See L, Aoki K, Schmid E, Mathe L, Obersteiner M. Global bioenergy scenarios - Future forest development, land-use implications, and trade-offs. *Biomass and Bioenergy* 2013, 57:86-96

[7] Kindermann G, Obersteiner M, Sohngen B, Sathaye J, Andrasko K, Rametsteiner E, Schlamadinger B, Wunder S, Beach R. Global cost estimates of reducing carbon emissions through avoided deforestation, *PNAS* 2008, 105 (30) 10302-10307;

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

[9] Forest Agency (2007) Prefectural comparison of plantation area after tree species and age class (as of March 2007). Data set. Planning Division, Forest Agency, Ministry of Agriculture, Forestry and Fisheries Japan

[10] Kraxner F, Leduc S, Aoki K, Kinoshita T, Yang J, Yamagata Y. Forest Bioenergy in Japan: An Integrated Engineering and Socio-Economic Approach. Paper presented at the *Renewable Energy 2010 Conference*, 27 June – 2 July 2010, Yokohama, Japan.

[11] Bradshaw J B, Dance T. Mapping geological storage prospectivity of CO2 for the world sedimentary basins and regional source to sink matching, *GHGT-7, September 5–9*, 2004, Vancouver, Canada, v.I, 583-592.

[12] USGS, U.S. Geological Survey World Petroleum Assessment 2000 - Description and Results, DDS-60. United States Geological Survey, 2001.

[13] Kraxner F, Yang J, Yamagata Y, Attitudes towards forest, biomass and certification -- A case study approach to integrate public opinion in Japan. *Bioresource Technology* 2009, 100(17):4058-4061

Biography

Florian Kraxner is Deputy Director of the Ecosystems Services and Management (ESM) Program at the International Institute for Applied Systems Analysis (IIASA). He joined IIASA in 2004 and has also been appointed IIASA's Coordinator of the UK Policy-Science Activity FORESIGHT. Furthermore, he is leading ESM's Research Group on Policy-Science Interface (PSI) where he currently focuses on forest-based bioenergy, other renewable technologies, and bioenergy combined with carbon capture and storage (BECCS).