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BECCS in South Korea—Analyzing the negative emissions potential of bioenergy as a mitigation tool

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The objective of this study is to analyze the in situ BECCS capacity for green-field bioenergy plants in South Korea. The technical assessment is used to support a policy discussion on the suitability of BECCS as a mitigation tool. We examined the technical potential of bioenergy production from domestic forest biomass. In a first step, the biophysical global forestry model (G4M) was applied to estimate biomass availability. In a second step, the results from G4M were used as input data to the engineering model BeWhere, which optimizes scaling and location of combined heat and power plants (CHP). The geographically explicit locations and capacities obtained for forest-based bioenergy plants were then overlaid with a geological suitability map for carbon storage. From this, a theoretical potential for in situ BECCS was derived. Results indicate that, given the abundant forest cover in South Korea, there is substantial potential for bioenergy production, which could contribute not only to substituting emissions from fossil fuels but also to meeting the targets of the country's commitments under any climate change mitigation agreement. However, there seems to be only limited potential for direct in situ carbon storage in South Korea.

1. Introduction

The use of bioenergy in combination with carbon capture and storage (BECCS) could make a substantial contribution to achieving low atmospheric CO_2 concentration levels. As a result, there is an active debate on the potential of BECCS in the scientific community. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) considers BECCS as "a potential rapid-response prevention strategy for abrupt climate change" and thus as one of the options for achieving compliance with the targets agreed under the Kyoto Protocol [1]. Also the International Energy Agency (IEA) advocates the special advantages of BECCS in their recent policy strategy report [2] and various economic assessments state that by the inclusion of negative emission technologies in the energy portfolios substantive cost reductions in climate stabilization strategies could be achieved [e.g., [3]]. During the last decade various authors [4–6] have demonstrated that terrestrial ecosystems can offer a permanent carbon sink if biomass is used to produce energy and the carbon from biomass conversion facilities is captured and permanently stored in geological formations. However, compared with conventional fossil fuel systems plus carbon capture and storage, very little information can be found in the scientific literature on the technical aspects of BECCS or its potential applications. Moreover, apart from engineering papers presented at energy conferences such as the World Renewable Energy Congress (WREC) in 2011 [e.g., [7]], or at special BECCS conferences and workshops, for example the Bio-CCS workshop series held in 2010 at the University of Orleans, France [8], and in 2011 at Cardiff University in UK [9], or at the IEA-IIASA BECCS Experts Workshop held in 2011 in Laxenburg, Austria [10], there is no literature available to our knowledge that features geographically explicit BECCS applications, especially for non-European countries. With respect to literature on renewable energy in Korea, the biomass-based bioenergy sector is mostly not included in recent studies [e.g., [11]] or it plays a minor role in the assessments [e.g., [12]]. The fact that the focus in the relevant Korean

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literature is not put on bioenergy might be due to a) a still low share of biomass in total energy production, and b) the recent attention to nuclear power after the Fukushima incident in nearby-Japan.

South Korea is an interesting study area for BECCS, as the country's forestry sector has only recently regained ecological and economic importance. Although the land base of South Korea is small, as much as 64% of the country is forested. As a result of the highly efficient and rapid national reforestation program of the 1970s in South Korea, the majority of forests have now reached age classes of 30 and 40 years, which means they need "intensive care" in terms of thinning and pruning or other sustainable forest management (SFM) activities such as harvesting and replanting. Silvicultural and forest management activities like these can generate a significant amount of raw material which can be used, for example, to produce wood chips and wood pellets.

South Korea is trying to build up its bioenergy sector for various reasons. Inter alia, bioenergy should contribute to improve energy security by increasing the energy portfolio and simultaneously drive the green economy [12], while on the other hand the energy sector should help reducing CO_2 emissions. The introduction of "sustainable forest management" (SFM) is seen as the linking key between both paths and also as a crucial driving force. The government has introduced ambitious policies and plans for bioenergy production, for example, the "Low Carbon—Green Growth" initiative which is part of the National Energy Plan [13]. However, a lack of forestry infrastructure, such as adequate forest roads for important management activities like harvesting or replanting, makes biomass and related energy production too costly to undertake [14]. Among others, the renewable energy sector is also facing strong competition from the fossil and nuclear energy sectors – in 2009 the share of fossil electricity from Korea's total electricity generation was 65%, the nuclear electricity's share 29% and the fossil heat share of Korea's total heat production was 90% [15]. To develop and support improved and better-targeted policies in the area of energy, climate, and environment, while supporting related co-benefits such as rural development and activation/reactivation of sustainable forest management, policymakers in Korea must improve their ability to quantify the country's sustainable bioenergy potential. This would involve identifying economically and biophysically optimized locations for new bioenergy plants and also adding value to this information by selecting locations with in situ potential for combining bioenergy with CCS technology.

The aim of the technical part of our manuscript is threefold. First, it helps to identify, in a geographically explicit manner, the biomass available from forests for bioenergy production under sustainable management conditions in South Korea. Second, it indicates the optimal size and location of green-field, forest biomass-based bioenergy CHP (combined heat and power) technology plants. Third, it identifies the potential number and capacity of in situ BECCS units in South Korea.

2. Method

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). In this study, we considered CCS with post-combustion capture technology for underground storage in geological formations in direct "in situ" storage, namely, storage in the immediate vicinity of the combustion units (CHP plants) such that transport costs and other obstacles are minimized. For this case study, we also assumed that all CO_2 emissions generated by a BECCS unit (in this case a CHP plant coupled with in situ CCS) will be captured and stored. We further undertook an assessment to examine the technical potential of bioenergy production from domestic forest biomass. This was used as the basis for a policy discussion on the suitability of BECCS as a mitigation tool in South Korea. In a first step, we applied the biophysical global forestry model G4M [16] to estimate biomass availability. In a second step, we used the biomass results from the forestry model as input data to the engineering model BeWhere [17] for optimized scaling and locating of CHP plants. The locations and capacities for forest-based bioenergy plants thus obtained were subsequently overlaid with a map of geological suitability for carbon storage in a third step. From this, a theoretical potential for "in situ" BECCS was derived.

2.1. The global forest model (G4M)

IIASA's global forest model (G4M) was used to calculate the forest growing stock and the sustainable biomass extraction rate. G4M, as described by [16], was developed to predict wood increment and stocking biomass in forests. As an input parameter it uses yield level, which is derived from the net primary productivity (NPP) for a specific region. This NPP can be supplied by existing NPP maps [e.g., [18]] or, for higher accuracy, estimated using driver information of soil, temperature, and precipitation. The model can be used like common yield tables to estimate the increment for a specific rotation time. It can also be used to estimate the increment-related optimal rotation time and 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 and residues like needles, leaves, and branches which 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.

2.2. The BeWhere model

The BeWhere model, a spatially explicit optimization model depicting the supply chain of bioenergy industries, was used for the in situ BECCS assessment [17]. The model, developed at IIASA, considers industries that compete for wood resources. On the supply side, forest wood harvests, sawmill co-products (SCP), and wood imports serve as biomass resources for possible new bioenergy plants. On the demand side, the demand for wood of pulp and paper mills, existing bioenergy plants, and private households was considered. The model assumes that the existing wood demand has to be filled, and allows new plants to be built only if there is a surplus of wood available. The transportation of wood from biomass supply to demand spots by truck, train, or boat is considered. The model selects optimal locations for green-field bioenergy plants by minimizing the costs of biomass supply, biomass transport, and energy distribution. The full costs and emissions at the optimal locations were calculated such that we were able to indicate the technical BECCS potential for South Korea. G4M estimated and provided spatial distribution of forestry yields, the harvesting costs (as a function of tree size depending on site quality and rotation time), and the slope steepness.

3. Results

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