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Geospatial distribution of ecosystem services and biomass energy potential in eastern Japan

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A B S T R A C T

Detailed assessments of the effects of biomass production on ecosystems were carried out in the eastern region of Japan using geographical statistics and statistical methods. Ecosystems that might be used as a source of energy-related biomass already provide a variety of goods and services for humans widely known as ecosystem services. Various indices were mapped to describe the potential supply of biomass energy and the proxy variables for ecosystem services provided in the region. These indices were analyzed using a multivariate statistical technique to identify specific key factors for the use of biomass and ecosystem services. Finally, using zoning software, priority areas of potential supply of biomass energy and ecosystem services were indicated and the conflict between them analyzed. Biomass energy was clearly distinguished into three axes, suggesting that biomass is strongly related to the location and ecosystem, while the distribution of the types of ecosystem services in the studied areas was not separated clearly. The relative priority ranks of bioenergy and ecosystem services were complementarily distributed; however, parts of the studied area had high-ranking areas. The results suggested that a more detailed zoning information is needed for promoting energy-related biomass production considering the high supply of ecosystem services.

1. Introduction

Biomass is a crucial energy resource for creating a sustainable society because of its renewability, low or no carbon emission, and low environmental impact. However, the use of biomass has many disadvantages, as do other renewable resources such as solar and wind power. Transport of the biomass is relatively difficult due to its high moisture content, and its gross heating value is lower than that of other energy resources. Additionally, intensive production of biomass can lead to competition with forest conservation and cultivation for food supply. Harvesting the biomass from forests and agricultural ecosystems has also some effects on these and the neighboring ecosystems, and the growth of biomass requires the use of land for this purpose over relatively long intervals.

Surveys of potential biomass were conducted from the regional to global level. Hoogwijk et al. (2005) estimated the timeline of the production and consumption of biomass and land use at the global level using their model (IMAGE mode, Hoogwijk et al., 2003) and considering several Intergovernmental Panel for Climate Change (IPCC) scenarios. Moreover, Hoogwijk et al. (2009), applying the economic cost-supply analysis, indicated a region at global level that is of interest for its low production cost and high potential of biomass energy. Ericsson and Nilsson (2006) analyzed the potential biomass supply in 15 EU countries. Henry (2010) discussed a possibility for replacement of fossil fuel by biofuel using high-yielding crop and biotechnology at a global level.

Previous studies have also suggested that the analysis of biomass supply may be conducted at a small scale as well as at a country level using geospatial analysis. This is because management and production costs affecting the potential (or available) amount of target biomass also depend on geospatial conditions including ecosystem distribution, access roads, distance to the production factory, and location of demand for the biomass; the cost should also include the disadvantages of using the biomass as energy resource. Sacchelli et al. (2014) analyzed the socio-economic and environmental effects of multiple factors on wood residue energy, including geographical conditions on a local scale. They concluded that both the implementation of advanced technology and environmental parameters related to allocation of

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sources and demands were important. Delivand et al. (2015) also carried out geographical analysis, and the effects of logistics costs and greenhouse gas emissions were discussed. The availability of land for bioenergy crops in Mozambique, in the timeframe 2005–2030, was modeled by van der Hilst et al. (2012). From geographical detailed analysis, the most suitable locations for bioenergy production were determined based on agro-ecological suitability and accessibility and partly based on the most suitable locations for current agricultural practices. Ooba et al. (2012, 2015) described the relationship between the cost of woody biomass production and the geographical location of forests in two different regions in Japan.

Detailed assessments of the effects of biomass production and consumption on ecosystems and social systems, taking into account ecological processes and regional characteristics, have not yet been conducted in Japan. After the great earthquake and nuclear accident in 2011, renewable energy received more attention compared to the period before these disasters. The Japanese government developed a new policy to promote the use of biomass (Ministry of Economy, Trade and Industry of Japan, 2014), and local governments, especially in the areas damaged by the earthquake, began planning the development of biomass boilers and electric generators (Kaji et al., 2013). Japan introduced a feed-in tariff (FIT) scheme for renewable energy in 2012 to promote the use of these energy sources; hence, the demand for biomass is now higher than it was before the earthquake. Under such conditions, more changes in land use (e.g., conversion from forest to cropland) and development (e.g., conversion from natural forest to plantation forest) may occur to enhance biomass production.

Ecosystems that might be used as a source of energy-related biomass already provide a variety of goods and services to humans widely known as ecosystem services (ES; MEA, 2005). Many studies have stressed the negative effects on ecosystems due to production of biomass without considering the ecosystem services and biodiversity. Several studies have indicated that the assessment of environmental impact of biomass production for energy must consider the existing ecosystems and biodiversity of the potential production areas. Hanafiah et al. (2012) found that inclusion of the impacts on biodiversity is needed for calculating the production footprint by comparing the ecological footprint and biodiversity footprint. Myllyviita et al. (2012) mentioned less impact of imported biomass compared to local biomass production in Finland, as inferred from the life cycle assessment and the multicriteria decision analysis. Cao et al. (2015) performed an impact assessment of land use based on economic values and ecosystem services at country level. The distribution of ecosystems appropriate for production of biomass is neither uniform nor coherent with the current land use. Ecological impact assessment is also needed in relation to the development of biomass production, as already pointed out in previous studies on biomass potential (e.g., Hoogwijk et al., 2005).

To suggest a conservation or development in specific areas, geospatial analysis may be needed at a local scale. Many geographical software programs have been used in conservation planning of the biodiversity in ecosystems under particular socioeconomic constraints (e.g., Moilanen et al., 2012). They can indicate hot spots and cold spots under certain conditions and constraints (e.g., management cost, cost effectiveness, and subjective weight of various services). These tools are also used to determine geographical priority in terms of biomass development and to resolve conflicts between development and conservation.

The objective of this study was to assess the impact of biomass production on ecosystem services in the eastern region of Japan using geographical information system (GIS). Datasets were collected and indices created by which to estimate the geographical distribution of energy-related biomass and the current state of ecosystem services. Various indices were used to map potential supplies of biomass energy and proxy variables for ecosystem services provided in the region. These indices were analyzed using a multivariate statistical technique to identify specific key factors for the use of biomass and ecosystem services. To detect potential hot spots of these resources and areas of conflict with the current ecosystem, the potential supplies of biomass energy and ecosystem services were assigned a rank using Zonation software (Moilanen et al., 2012). A comparison of ranks with or without the FIT weighted prices was also carried out to estimate the effect of the FIT system on ecosystem services. The results provided useful planning and zoning information for promoting the production of biomass and conservation of ecosystem.

In this study, the potential for biomass energy was evaluated for two energy-producing processes: direct combustion of biomass, and fermentation of biomass to produce methane. These methods are not the latest technology (Naik et al., 2010), but they are relatively common in Japan.

2. Models and study site

2.1. Study area

The eastern part of Japan that was selected as the study area includes Kanoto, Tohoku, and Jouetsu regions (14 prefectures; area: 110,000 km^2). The islands located far from the Tokyo metropolitan area were omitted from this study because of the difficulty in transporting the biomass produced on these islands.

2.2. Data sources

Biomass data: A comprehensive biomass dataset from 2011 used in this study was provided by the New Energy and Industrial Technology Development Organization (NEDO). This dataset was initially developed by Iuchi (2004) for 15 types of biomass. Table data at the municipality level published by the NEDO were downloaded and subdivided as follows (Table 1): wood residual from forest (wf, two types); wood residual from other ecosystems (we, two types); agricultural residual (aa, four types); grassland residual (ae, two types); livestock manure (ma, five types); sludge (sl, three types); and food processing waste (fw, three types). The biomass dataset provided the annual maximum potential, available amount (dry weight), and heat energy (GJ/y). In this study, the available heat energy of the biomass was used for realistic estimation. For livestock manure, sludge, and food processing waste, heat energy was generated by methane fermentation, and for other types of biomass, heat energy was calculated using their lower calorific value.

These biomass data were represented in thermal units, on the assumption that they would be used for combustion in boilers and in methane fermentation (NEDO, 2011). Woody and agricultural biomass was combusted in biomass or multi-fuel combustion boilers with combustion efficiency set to 1.0. Manure and food processing waste were consumed in a methane fermentation plant; the detailed conditions of the fermentation are given in Table 1. The energy of biomass-derived methane was used as heat. These assumptions were not fully realistic, but they were effective for estimating the maximum potential amount of biomass in the local areas considered.

Data on natural and social parameters about the study area were also obtained and used as variables in calculations of biomass energy and ecosystem services (Table 2).

Biological data (Table 2): Vegetation maps (Vg) and data on the occurrence of mammalian species (Sp) were obtained from the