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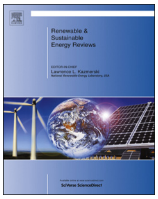

Availability assessment of bioenergy and power plant location optimization: A case study for Pakistan

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ABSTRACT

In terms of land use competition, bioenergy is often subject to controversial discussions. This paper presents a study, which addresses the scope of geographic discrete biomass growth, optimal bio-energy plant locations, and related biomass supply areas. In a first step, annual biomass growth is calculated with the BETHY/DLR model on a spatial resolution of 1 km^2. In a second step, the ASECO model is utilized to identify optimal plant locations with related biomass supply areas, determined by biomass growth rates and available road infrastructure. The case study is carried out for Pakistan. Scenarios have been investigated on district level, with a special focus on total supply areas for single power plants at identified locations, as well as supply area deviations over the years due to varying biomass growth rates. Achieved results are relevant for the political debate on an optimal bioenergy strategy for Pakistan.

Contents

1. Introduction

Access to energy and a steady, stable energy supply are important requirements for socio-economic development. During the last decades, global energy resources—mainly fossil fuels—were massively exploited, to meet the growing energy demands of the growing world population, and the increase of economic welfare [33]. When discussing future perspectives of energy availability, two concerns usually come in focus. One is carbon output and its influence on climate change. The other is the question of whether existing resources will meet the projected increase in energy demand, especially in non-OECD countries. When dealing with bioenergy, a third concern needs to be discussed: the dilemma of “food versus fuel”. However, although widely discussed, the finite answer to this question still remains open [14]. This paper presents an analysis for the energy-food nexus, with a special focus on energy availability and sustainable resource exploitation.

Recent studies showed that areas available for bioenergy production until 2050 are highly dependent on the scenario considered. The scenarios presented in Thrän et al. [36] mainly found substantial

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decreases of potential areas for bioenergy production. In contrast, Zeddies et al. [42] report increasing areas for bioenergy of up to 440.5 million ha until 2050. Both studies investigated scenarios based on the continuation of current business, diets, etc., and a variety of other scenarios comprising substantial changes in the behavior. A similar study was also conducted by Poudel et al. [30], who found comparable patterns. Further studies focused on the assessment of globally available and projected bioenergy potentials from agricultural residuals, and report a range of 27–77 EJ yr^{-1} [6,12,10].

When looking at regional scales, a realistic assessment of available biomass potentials becomes even more relevant. This is especially true for countries with low average incomes, since aside from access to energy, nutritional security might be limited. One example is Pakistan, with a per capita income 2011: US$1201 ([16]), on which our study is focused. Being based on an agricultural economy, the share of agriculture and fishery related employees in Pakistan was about 45.1% in 2011, contributing to the gross domestic production ([29]) with 21.1%. Pakistan is one of the ten largest wheat and the five biggest sugar cane producers. Thus huge amounts of straw and bagasse are available each year. Especially in rural areas the population (67%) is historically dependent on biomass use. A study by Mirza et al. [26] estimated an average household to consume of 2325 kg of firewood, 1480 kg of dung, or 1160 kg of crop residues per year, mainly for heating and boiling. The consistently growing urban population, however, predominately use fossil energy carries, resulting in costs which already consume 20% of the total foreign exchange [32]. With the current energy share and consumption, Pakistan is at the point where energy demand exceeds supply, which inevitably will lead to a decrease of national growth [2]. Projections estimated a tripling of the current energy consumption by 2030, which will require a massive increase of energy imports ([28]). Thus the use of renewable energy sources, especially biomass, is seen as vital to meet increasing energy demands [2].

Pakistan's government decision to increase the share of renewables until 2030 from 0 to 2.5% will save the country up to 400 million US$ [32]. The Energy Security Plan [20] suggests increasing biogas production to 4000 MW by 2030. Presently more than 5000 small sized biogas units are installed, which cannot even exploit 1% of the estimated biogas potential of 12–16 million $m^3 d^{-1}$ [3]. In 2010, the Alternative Energy Development Board (AEDB) was established by the Government of Pakistan to develop a national strategy, policies, and plans for the utilization of alternative and renewable energy resources. At present, six biomass power plants with a capacity of 9 to 12 MW are planned to be established ([1]). Three of them are designed to be exclusively driven by agricultural waste (i.e. straw, bagasse).

The availability of agricultural side products depends on its use competitions (e.g. animal housing, soil fertilization). Furthermore, the efficiency of such biomass power plants is highly dependent on transport costs. Thus it is necessary to estimate the technical availability of biomass, and assess economically reasonable locations for a power plant. Recent studies proposed various methods to quantify biomass/bioenergy availability. Jiang et al. [17] proposed a GIS based approach and calculated bioenergy potentials from crop residues for China. Scarlat et al. [34] and Herr and Dunlop [15] used statistical methods and performed studies for Romania and Australia. Tum et al. [39] used a vegetation model to assess annual Net Primary Productivity (NPP) for Germany, and calculated energy potentials for straw using conversion factors on the yield-to-straw ratio. A further approach to assess this topic is provided by earth observation. Earth observation and in-situ data can be integrated with ground surveys, historical records and market information, and assimilated with geographic information systems (GIS) analytical tools to illuminate short- and long-term trends on bioenergy demand and supply, at regional and local scales.

Optimization approaches are currently developed to find suitable locations for e.g. bioethanol refineries or biomass power plants. Leduc et al. [23] used a mixed integer linear programming model and focused on optimal locations of lignocellulosic ethanol refineries in Sweden, which was also used for Finland by Natarajan et al. [27]. The model is based on a minimum cost approach, covering all levels of biofuel production and the production chain, like biomass and methanol production, transport, and investments for the production plants and gas stations [24]. A similar approach was developed by Celli et al. [7], who did a study for Sardinia, Italy.

2. Method and models

The current study was subdivided into two tasks. First we assessed time-series of bioenergy potentials (2001–2010) from agricultural side products for Pakistan, on a spatial resolution of 1 km^2. For this we used the Biosphere Energy Transfer Hydrology (BETHY/DLR) model, operated at the German Aerospace Center (DLR), to calculate time series of Net Primary Productivity (NPP). NPP was validated using empirical data on acreage and yields, as already proposed by Tum and Günther [37]. NPP was then transferred to energy potentials, using country specific conversion factors on e.g. the above-to-below ground biomass, yield-to-straw ratios and lower heating values. In a second step we introduced the new biomass power plant location optimization tool ASECO, to identify potential power plants and their supply range. Following the suggestions of [1], we will thus contribute to the energy planning directive of Pakistan.

2.1. BETHY/DLR

BETHY/DLRis a Soil–Vegetation–Atmosphere–Transfer (SVAT) model. It can be used to track the transformation of atmospheric carbon dioxide into energy storing sugars, a process known as photosynthesis. BETHY/DLR has recently been used to assess Net Primary Productivity (NPP) for parts of Europe and Asia [9,37], and has been validated and cross-compared with other process based models for agriculture [38] and eddy covariance data [40]. The scheme of modeling photosynthesis with models like BETHY/DLR is widely accepted and serves as an input to global dynamic vegetation models, such as the Jena Scheme of Atmosphere Biosphere Coupling in Hamburg (JSBACH) by Knorr and Heimann [21], and the Lund–Potsdam–Jena (LPJ) by Prentice et al. [31] and Bondeau et al. [5].

Photosynthesis is modeled using the integrated approach of Farquhar et al. [11] and Collatz et al. [8]. Following this approach, the enzyme kinetics are parameterized on a leaf level, taking into account the different behavior of C3 and C4 plants in their way of carbon fixation. Since C4 plants are able to fix more atmospheric carbon dioxide at higher temperatures than C3 plants, and Pakistan yields on average (2000–2010) ~50.4 million tons sugar cane (C4 plant), and ~20.8 million tons of wheat (C3 plant), this distinction needs to be taken into account. The rate of photosynthesis is then extrapolated from leaf to canopy level, respecting both the canopy structure and the interactions of vegetation with soil and atmosphere. Sellers' [35] two-flux approach is used to consider the absorption of radiation in the canopy. A detailed parameterization of the processes of evapotranspiration, stomatal conductance, soil water balance, and autotrophic respiration is also included in the model formulation. Details on the model approach can be found in Knorr and Heimann [21].

BETHY/DLR is driven by time series of the Leaf Area Index (LAI), derived from remote sensing and meteorology. LAI data is taken from geoland2, and is globally available from 1999 onwards at a 1 km^2 resolution. The data is provided free of charge as 10-day composites. We pre-processed the data to eliminate outliers and gaps, using time series analysis. For this we used harmonic analysis,