Biomass and Bioenergy 90 (2016) 230–236

Contents lists available at ScienceDirect

Biomass and Bioenergy

journal homepage: http://www.elsevier.com/locate/biombioe

Research paper

Global NPP and straw bioenergy trends for 2000–2014

M. Tum*, J.N. Zeidler, K.P. Günther, T. Esch

German Aerospace Center (DLR), German Remote Sensing Data Center (DFD), Muenchener Strasse 20, D-82234 Oberpfaffenhofen, Germany

ARTICLE INFO

Article history:
Received 24 August 2015
Received in revised form
29 March 2016
Accepted 30 March 2016
Available online 30 April 2016

Keywords:
NPP
Modelling
Bioenergy
SVAT
Remote sensing

ABSTRACT

The ability of terrestrial ecosystems to sequestrate carbon and the use of cultivated land for food and bioenergy are both affected by large scale meteorological phenomena and climate change. In this study we used the Biosphere Energy Transfer Hydrology (BETHY/DLR) model to compute global Net Primary Productivity (NPP) on 1 km^2 resolution for the fifteen years 2000–2014. We found a global average of 60.2 Pg carbon per year, with the main contribution from the Tropics. Extending pre-existing studies with our results revealed a surprisingly low positive global trend in NPP of 0.04 Pg y^{-1} for the past 30 years. To bring NPP into application we used it to derive straw bioenergy potentials. For agricultural areas we found a global average bioenergy potential of 35.9 EJ y^{-1}. On a regional level as e.g. the “Wheat belt” in Western-Australia we found an interannual variability of up to ±40%, due to climate events (i.e. ENSO).

1. Introduction

The pre-industrial atmospheric carbon dioxide (CO_2) concentration of approximately 278 $cm^3\ m^{-3}$ in 1750 [1] has increased to 404 $cm^3\ m^{-3}$ by February 2016 [2]. The 400 $cm^3\ m^{-3}$ threshold, which was first crossed in May 2013 [3] at Mauna Loa station, is likely to be permanently exceeded by the end of this decade. The increased atmospheric CO_2 concentration since the beginning of the industrialization primarily originates from the anthropogenic release of mainly fossil carbon, deforestation and other changes in land use practices [4]. Anthropogenic carbon emissions from combustion already started to influence the atmospheric concentration prior to industrialization and became the dominant source after the First World War up to the present. These emissions are an additional input to the natural carbon cycle, which interacts between the atmosphere, biosphere, lithosphere, hydro- and cryosphere in varying timescales of days to millennia [5].

Each year, approximately half of the anthropogenic CO_2 emissions (~4.0 Pg) remain in the atmosphere, representing the share which is not absorbed by land and ocean sinks [4,6]. Measurements and inverse modelling techniques show that these sinks have constantly gained strength over the last decades. However, the ocean sink shows a relatively smooth interannual behavior compared to the land sink, which has considerable interannual variability and is thus the major determinate defining the magnitude of CO_2 accumulating in the atmosphere each year [7–9]. It is still in debate whether the increasing CO_2 uptake has continued since 2000 [10–13], analogue to the 1980s and 1990s [14]. Numerous studies indicate responses of the ecosystem to a wide range of climate-related parameters which affect the complex interactions between atmosphere and biosphere. These parameters can be summarized as: meteorology [14–17], El Niño Southern Oscillation (ENSO) [18,19], changing growing seasons [20] and extreme events [10,21,22]. The relative uncertainty about the magnitude and the past and future behavior of the terrestrial carbon sink is still the highest within the global carbon cycle debate. Interestingly, the uncertainty has increased from 40% to 46% over the last three decades [4]. This might be a consequence of the high interannual variability and the response of ecosystems to changing climate forces [8].

To quantify the rate of carbon uptake in terrestrial vegetation, today's approaches mainly rely on modelling and statistical methods. To this effect the net carbon sink (net primary productivity, NPP) is estimated. NPP describes the difference of the gross amount of CO_2 accumulated by vegetation through photosynthesis and the vegetation's autotrophic respiration. To compute terrestrial primary productivity a variety of approaches exists, ranging from observations at site level [23,24] to large-scale remote sensing [10,14], light use efficiency [25,26], and, process-based modelling [27–29] to combinations of these [30,31].

However, the enormous effort spent to understand this biogeochemical cycle needs to be put into an even broader context

* Corresponding author.
E-mail address: markus.tum@dlr.de (M. Tum).

http://dx.doi.org/10.1016/j.biombioe.2016.03.040
0961-9534/

when looking at the sustainable energy debate, first discussed by von Carlowitz [32], as a respectful use of nature's goods, which is still on the agenda. The world's increasing demand for food and energy is putting rising pressure on all terrestrial ecosystems. Biomass as source for energy in heating systems, power and cogeneration plants or vehicle motors is often seen as an attractive possibility to substitute fossil energy and so reduce fossil-fuel dependencies and greenhouse gas emissions [33]. Consequently, biomass as an energy source is expected to grow considerably during the next decades [34,35]. Biomass combustion combined with subsequent carbon capture and storage strategies have also been considered to play an important role in reaching negative greenhouse gas emissions [36], which is needed to limit global warming to 2 °C by 2100. Although the overall impact of an increased global mean temperature of less than 2 °C on the global bioenergy potential is expected to be relatively small, considerable regional impacts are expected [37]. Thus, the question about the magnitude and spatial patterns of current and projected bioenergy potentials has gained increasing attention during the last years [38–40]. Since the availability of biomass - and herewith bioenergy - is solely dependent on the ability of vegetation to accumulate atmospheric carbon dioxide, a realistic estimation of this process can be used to assess and/or predict the bioenergy potential [40–43].

In this study we analyzed the historic NPP development from 2000 onwards. For the first time a remote sensing and climate driven Soil-Vegetation-Atmosphere (SVAT) model, in this case BETHY/DLR (Biosphere Energy Transfer Hydrology), was used on global scale at 1 km^2 resolution. We focused our analysis on the quantification of global and regional NPP anomalies. In addition we transferred our modelled NPP to straw energy potentials using a conservative conversion model. Finally we discussed the variability of global biomass potentials in regard to its availability for food and energy production.

2. Methods

In this study we used an enhanced version of the BETHY/DLR model [44], to calculate global NPP time series on 1 km^2 resolution for the 15 years period 2000–2014. BETHY/DLR is a Soil-Vegetation-Atmosphere (SVAT) model and is used to model photosynthesis of terrestrial ecosystems, following the combined approach of [45] and [46]. Evapotranspiration is treated following the approach of [47] against the criteria of [48]. To spin-up the model, three additional years were modelled but removed prior to the analysis. Up to now BETHY/DLR has been used to calculate NPP for several regions of the globe, but mainly for Europe where it has been validated [44,49]. The use of a bucket model for estimating soil water content was identified as a shortcoming of BETHY/DLR for regions with low annual precipitation. Therefore, we improved the parameterization of the soil water content following a concept described by Tum and Borg [50]. A one-dimensional soil water transport model is used following the van Genuchten approach for all 128 FAO '74 soil types. For all soil types individual soil depth, layering, grain size distribution and van Genuchten parameters are included in the BETHY/DLR model. In addition, the input data collection was expanded by time series of the atmospheric CO_2 concentration derived from GOSAT, an albedo map derived from SPOT-VGT, climate zones from Koeppen-Geiger and soil types from FAO/IIASA HWSD. A complete overview of all data layers used to drive BETHY/DLR for this study is presented in Table 1. To simulate global NPP on a 1 km^2 resolution in an acceptable time, optimization in memory usage and modelling time were needed.

The model was subdivided in 500 × 500 grids and concurrently run on a small Cluster with 80 CPUs. The memory footprint per CPU was reduced to 1.5 GB. The whole model run used roughly 30,000 CPU h.

To calculate straw energy potentials, we used our modelled annual NPP sums and converted them into bioenergy potentials by using region-specific conversion factors of the above-to-below ground biomass and yield-to-straw ratios following an approach introduced by Tum et al. [40], who developed a simple sustainability concept. Tum et al. [40] discussed that only 20% of agricultural straw can be considered as usable for energy production, which is even more conservative than the values reported by Weiser et al. [52], who calculated the percentage for Germany to be in the range of 23%–44%. To avoid a conflict of interests with food production, we calculated the bioenergy potentials only for cereal side products (i.e. straw). Country-specific averaged area fraction of straw-delivering crops (e.g. wheat, barley, maize, sunflower, etc.) were derived from area statistics provided by FAOSTAT [51]. The FAOSTAT database is available on an annual basis and contains information on more than 150 crop types at country level. We decided to use the averaged area fraction value instead of specific values per year in order to better fit our model crop which we defined as a globally representative, average straw producing crop. The model crop was used because crop rotation is not included in BETHY/DLR and specific crop type information are not available on a global scale. Since spatial distribution of plant functional types (PFT) is necessary to drive the model, we used the GLC2000 land cover dataset to map classes to PFTs, following the scheme presented in Ref. [53]. They used the International Geosphere-Biosphere Programme (IGBP) dataset [54] to drive the Joint UK Land Environmental Simulator (JULES; [55,56]).

3. Results and discussion

Our results show an average global terrestrial NPP of 60.2 Pg y^{-1} (±3.0 Pg y^{-1}) for the 15 year period 2000–2014, which is presented in Fig. 1. This result lies within the range of previous modelled NPP predictions which ranged between 44.4 and 66.3 Pg per year for the two decades prior to the period investigated in our study [57]. The comparison of Cramer et al. [57] included 16 different NPP models. Three models (CASA (Carnegie Ames Stanford Approach), GLO-PEM (GLObal Production Efficiency Model) and SIB2 (Simple Interactive Biosphere Model)) used satellite data as their major input. The mean annual NPP of the three model output was 54.4 Pg (±10.3 Pg). Looking in more detail at the remote sensing driven model results of Cramer et al. [57] one can see that GLO-PEM resulted in the highest modelled NPP (66.3 Pg y^{-1}) and SIB2 in the lowest NPP (47.2 Pg y^{-1}). Our global NPP is on the high end of the range of Cramer et al. [57]. One reason for this difference may be the fact that in the study of Cramer et al. [57] climate data from 1930 to 1961 were used as input while we modelled NPP for 2000–2014. Our modelled NPP is in good agreement with the global mean NPP of ORCHIDEE (64.0 Pg y^{-1}) for the period 1961–1990 [29].

In Fig. 1 we also present NPP anomalies identified for six selected regions: Southeastern USA (hereafter USA), Central Europe (CEUR), India and the Bay of Bengal (ASIA), South America (SAM), southern Africa (SAFR), and Australia (AUST). Anomalies were calculated as the difference between the actual year under investigation and the average of the 15-year time span. The geographical extend of the ASIA, AUST, SAFR, and USA region followed the divisions defined by Bastos et al. [18] who investigated annual NPP anomalies in regard to ENSO effects. In that study a special focus was on the highest global NPP in 2011 found in the Moderate Resolution Imaging Spectroradiometer record (MOD17A3) starting in the year 2000. A detailed, regional analysis revealed that these four regions showed relatively high anomalies in 2011 and are thus responsible for the global anomaly. For all four regions we found a