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Country-level assessment of long-term global bioenergy potential

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ABSTRACT

Most long-term global energy scenarios rely on biomass for a variety of possible uses, but there is unlikely to be enough to replace the majority of fossil fuel use in all sectors. Improving the understanding of the sustainable and realistic potential for biomass is crucial.

We present a comprehensive, country-based, bottom-up assessment of the land-based global biofuel (bioethanol and biodiesel) potential, taking into account a range of scenarios with varying yield gradients, land-use change and technology development, covering energy from both lignocellulosic and food crops as well as residues from agriculture and forestry. We have also gone beyond many other studies by analysing the potential for food crop based biofuels as well as lignocellulosic-sourced biofuels.

We find a global biofuel supply potential increasing from 15–70 EJ final transport fuel energy (30–140 EJ primary energy) currently to 40–190 EJ (130–400 EJ) in 2070, depending on the development of land-use, productivity and technology mix. Over 3/4 of this potential comes from energy crops: up to 70% could come from food crops and at least 10% from lignocellulosic crops. The remaining quarter would be from agricultural and forestry residues. For comparison, current (2010) total global energy use (fuel, heat and electricity) stands at 365 EJ final energy (530 EJ primary energy). Depending on demand developments, countries such as Brazil or Russia could become net bioenergy exporters in the second half of the century, while others, such as India or Nigeria, may become net importers.

1. Introduction

Long-term (mid-to-end of century) energy scenarios rely heavily on renewable energy sources to decarbonise and diversify our energy system [1–5]. In addition to renewable electricity, such as solar and wind power, energy from biomass will have a substantial role to play in any low-carbon energy system. It is a versatile source providing not only an option for sustainable transport fuels, but also for (industrial) heat and fuel or electricity production, as well as bio-based materials and chemicals. Estimates of the resource base have varied widely in the past, anything from zero to over 500 EJ has been reported [6]. A comprehensive and detailed

Abbreviations: GAI, gross annual increment; GHG, greenhouse gas; LIIB, low indirect impact biofuels; RF, recoverable fraction; RPR, residue-to-product ratio; SRES, IPCC's Special Report on Emissions Scenarios; SRREN, IPCC's Special Report on Renewable Energy.

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assessment of the available bioenergy potential is therefore essential to determining the contribution which biomass and biofuels can realistically make to the world's energy system.

The IPCC's Special Report on Renewable Energy (SRREN) recently summarised the existing literature on biomass potential estimates [7]. Several studies have attempted to quantify bioenergy potentials in the past [8–22] but these have been either:

- Meta-studies like the IPCC SRREN report, rather than calculations from first principles [8–11]
- Assessing potential in one or several regions only, not spanning the full global potential [12,13]
- Assessing potential at regional or global level only, without significant differentiation at country level [11,14–21]
- Assessing only current potential or only potential on one particular type of land only [22]

In contrast, the work in this paper presents a new piece of research, assessing the potential for all land-based biomass (crops and residues) at global level but with significant country level detail, for current and long-term land-use in one comprehensive consistent framework. This is the first study that attempts to quantify global land-based bioenergy resource based on country based assessment of available land and which calculates the actually usable, final energy biofuel potential. The results of this work have been used in the recently published Shell New Lens Scenarios [3].

The potential we identify here is a constrained technical potential, whether expressed as primary biomass or biofuels (either biodiesel or bioethanol). Constraints include sustainability, current competitive uses and accessibility. These have not been modelled explicitly but have been included in the assumptions of land availability (crops) and recoverable fraction. The competitive uses did not include increased future demands for bio-based chemicals and materials, i.e. such demands would have to be met from within the technical potential calculated here.

2. Methods

The analysis was performed at country level for the 55 countries, and in aggregate for the remaining countries. The 55 countries were selected to include the countries which were expected to have the largest suitable land areas for bioenergy production (based on their amount of grassland, cropland and forest) and to include enough countries in each region to cover a substantive share of that region (see Fig. 1). The 55 countries were grouped into 16 regions[1] and some intermediary calculations were performed at this regional level. Land area per type and productivity[2] values per crop were differentiated at country level, most other input assumptions were set at regional or global level. To verify the validity of our approach we selected four countries (Brazil, Mozambique, Russia and Kazakhstan), with potentially significant biomass potentials, spanning different regions and climatic zones, and assessed all input assumptions at country level for these four countries. This also increased the level of precision of the overall estimate.

We assessed the biofuel potential at country level separately for

- lignocellulosic crops
- food crops
- residues from agricultural and forestry harvesting,

but linked the two approaches through a set of common scenario assumptions on land-use and productivity. This is shown diagrammatically in Fig. 2. We describe the two approaches in the following sections.

Annual biofuel potentials were assessed for a base year (2005), and two future years (2020 and 2070). The future years were chosen to include one typical near-term year (2020) and one year half-way between this and 2100, as the results were ultimately used as inputs for a model which required projections to 2100. The land-use and crop yield projections for the future years were based on the A2, B1 and B2 IPCC scenarios in the Special Report on Emissions Scenarios (SRES) from the integrated assessment model IMAGE [21,23]. The work presented here presents an incremental advance over other bioenergy studies based on these IMAGE scenarios [15,16,21].

Additional variable assumptions with a significant impact on the final results were set in a range denoted Low–Medium–High to span a range of possible values.

2.1. *Land-use and productivity scenarios*

Both the energy crop and residue potential calculations were based on land-use change and productivity forecasts in the IMAGE SRES scenarios [23]. The scenarios model future land-use based on changes in

- Food demand (population, diet, GDP)
- Crop productivity (land quality, technology improvement)
- Increase of nature reserves or urban area (GDP, social preference, population)
- Demand for forestry products (GDP, population)

The scenarios are summarised in Fig. 3. Scenarios A2, B1 and B2 were selected as the three most relevant scenarios for use in this study.

In these scenarios, changes in productivity and land-use were differentiated for the following land- (and land-use) types at regional level:

- Cropland
- Grassland
- Forest area
- Other land

[1] The regions were Canada, USA, Central America, South America, OECD Europe, Eastern Europe, Former USSR, Middle East, Eastern Africa, Western Africa, Southern Africa, East Asia, South Asia, Southeast Asia, Oceania, Rest of World.

[2] We use the term ‘productivity’ to mean yield of biomass per amount of land in tonne/ha throughout this article.