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Energy, land-use and greenhouse gas emissions trajectories under a green growth paradigm

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ABSTRACT

This paper describes the possible developments in global energy use and production, land use, emissions and climate changes following the SSP1 storyline, a development consistent with the green growth (or sustainable development) paradigm (a more inclusive development respecting environmental boundaries). The results are based on the implementation using the IMAGE 3.0 integrated assessment model and are compared with a) other IMAGE implementations of the SSPs (SSP2 and SSP3) and b) the SSP1 implementation of other integrated assessment models. The results show that a combination of resource efficiency, preferences for sustainable production methods and investment in human development could lead to a strong transition towards a more renewable energy supply, less land use and lower anthropogenic greenhouse gas emissions in 2100 than in 2010, even in the absence of explicit climate policies. At the same time, climate policy would still be needed to reduce emissions further, in order to reduce the projected increase of global mean temperature from 3 °C (SSP1 reference scenario) to 2 or 1.5 °C (in line with current policy targets). The SSP1 storyline could be a basis for further discussions on how climate policy can be combined with achieving other societal goals.

1. Introduction

Model-based scenarios are often used to explore possible environmental trends in relation to uncertain development of driving forces. These driving forces include population and income development, technology development, lifestyle change and evolving production and consumption patterns (see for an overview Van Vuuren et al., 2012). Recently, the Shared Socio-economic Pathways (SSPs) have been proposed as a new set of scenarios to be used as a basis of future climate research (Van Vuuren et al., 2014; O'Neill et al., 2014). The SSPs describes five possible future development trajectories that result in fundamentally different positions of human societies with respect to the ability to mitigate and/or adapt to climate change. The scenarios can be used in combination with additional, climate specific, policy assumptions to explore the costs and benefits of climate policies in different situations or to assess the effects of climate change. The narratives of these scenarios were recently published by O'Neill et al. (2014). The five SSPs include scenarios following a green growth strategy (SSP1), a more middle-of-the-road development pattern (SSP2), further fragmentation between regions (SSP3), an increase in inequality across and within regions (SSP4) and fossil-fuel based economic development (SSP5) (see Section 2).

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Recently, the SSPs have been elaborated using six different integrated assessment models (IAMs) to show possible quantifications of these scenarios for energy, land use, emissions and climate change – and to explore the associated uncertainties (Riahi et al., 2016). These quantified projections facilitate impact analyses of climate change and other environmental or sustainable development problems. They can also assist in analyses of potential climate change mitigation and adaptation strategies (Van Vuuren et al., 2014; O'Neill et al., 2014).

In this paper, we describe the assumptions and results of the work by the IMAGE 3.0 integrated assessment model (Stehfest et al., 2014). We explicitly focus on the SSP1 results, as for this scenario, the IMAGE SSP1 implementation is the marker scenario. The marker scenario is selected from the various quantifications of the storyline by different IAMs as it clearly represents the overall storyline and is recommended for use when a single quantification for a SSP is selected (so for each SSP there is one marker). We will compare the results for SSP1 with the two other SSPs that have been elaborated by the IMAGE model, i.e. the SSP2 and SSP3 scenario. The main research focus of this paper is thus to explore how various trends consistent with a more green growth paradigm – i.e. a more inclusive development respecting environmental boundaries – (SSP1) could evolve in terms of trends for energy use, land use and emissions.

The concept of 'green growth' (and thus the SSP1 storyline) directly relates to the similar concept of 'sustainable development' (Pezzey, 1992). Recently, key global international organizations have embraced these concepts including UNEP, the OECD, the European Commission and the Global Green Growth Institute (OECD, 2011; European Commission, 2011; UNEP, 2011). Moreover, in September 2015 the United Nations adopted the '2030 Agenda for Sustainable Development' (UN, 2015b). Central to this agenda are the Sustainable Development Goals (SDGs) that express the ambition to end poverty and create a sustainable economic growth path and protect the planet from degradation. While the SDGs build on earlier commitments (e.g. the Millennium Development Goals, the Strategic Plan for Biodiversity and Sustainable Energy for All), their adoption signals the interest of countries worldwide to further cooperate on sustainable development issues. It should be noted, however, that, although some improvement with respect to global poverty can be observed, historical development patterns especially for environmental issues have mostly been at odds with this ambition (Van Vuuren et al., 2015; UNEP, 2012). Furthermore, the 2030 Agenda does not state how to deal with the trade-offs and synergies of the various goals. This paper describes a coherent quantification of a sustainable development storyline and compares the outcomes to alternative socio-economic developments (SSP2 and SSP3). It should be noted, however, that in our implementation of SSP1, we have not explicitly addressed the achievement of specific targets, such as defined by the SDGs. Instead, we explored the impact of a set of assumptions derived from the SSP1 storyline regarding 'reasonably ambitious' improvement in resource efficiency, human development and preferences regarding consumption and production patterns within the energy- and land-system. By definition, the "reference" SSP1 does not implement climate policy: greenhouse gas emissions are therefore mitigated on the basis of efficiency assumptions and technology development, but mostly likely not enough to meet ambitious climate targets (see Section 5).

The paper first briefly describes the IMAGE 3.0 model, and the storylines and implementation of the various SSPs (Section 2). Subsequently, we present the results of these scenarios, focusing on the IMAGE implementation of SSP1, but also comparing results to SSP2 and SSP3 and the SSP1 quantification from other IAMs (Section 3). Section 4 discusses the impacts of stringent climate policy. In Section 5 we briefly discuss the consequences of some key assumptions made in the quantification, while finally, in Section 6 conclusions are presented.

2. Methods

2.1. IMAGE 3.0 model

IMAGE is an integrated assessment model framework that simulates global and regional environmental consequences of changes in human activities (Stehfest et al., 2014) (see also Supplementary information). The model is a simulation model, i.e. changes in model variables are calculated on the basis of the information from the previous time-step. The model includes a detailed description of the energy and land-use system and simulates most of the socio-economic parameters for 26 regions and most of the environmental parameters, depending on the variable, on the basis of a geographical grid of 30 by 30 min or 5 by 5 min (respectively around 50 km and 10 km at the equator). The model has been designed to analyse large-scale and long-term interactions between human development and the natural environment and to identify response strategies to global environmental change based on assessment of options for mitigation and adaption. Earlier, the IMAGE model was used to develop the SRES B1 scenario (De Vries et al., 2000) and the RCP2.6 (Van Vuuren et al., 2011).

IMAGE is a framework with a modular structure, with some components linked directly to the model code of IMAGE, and others connected through soft links (where models run independently with information exchange via data files). The IMAGE framework is structured around to the causal chain of key global sustainability issues and comprises two main systems: 1) the human or socio-economic system that describes the long-term development of human activities relevant for sustainable development; and 2) the earth system that describes changes in natural systems, such as the carbon and hydrological cycle and climate. The two systems are linked through emissions, land-use, climate feedbacks and potential human policy responses.

Important inputs to the model are descriptions of the future development of so-called direct and indirect drivers of global environmental change: Exogenous assumptions on population, economic development, lifestyle, policies and technology change form a key input into the energy system model TIMER and the food and agriculture system model MAGNET (Woltjer et al., 2014). TIMER is a system-dynamics energy system simulation model describing key trends in energy use and supply. MAGNET is a computable general equilibrium (CGE) model (Van Meijl et al., 2006; Woltjer et al., 2014) that is connected via a soft link to the core model of IMAGE. MAGNET uses information from IMAGE on land availability and suitability and on changes in crop yields due to climate change and agricultural expansion into heterogeneous land areas. The results from MAGNET on production and endogenous yield (management factor) are used in IMAGE to calculate spatially explicit land-use change, and the environmental impacts on carbon, nutrient and water cycles, biodiversity, and climate. In IMAGE, the main interaction with the earth system is by changes in energy, food and biofuel production that induce land-use changes and emissions of carbon dioxide and other greenhouse gases. A key component of the earth system is the LPJmL model (Bondeau et al., 2007) that is included in IMAGE 3.0 (see also Müller et al. (2016) for details). LPJmL covers the terrestrial carbon cycle and vegetation dynamics in IMAGE 3.0. This model is used to determine productivity at grid cell level for natural and cultivated ecosystems on the basis of plant and crop functional types. Based on the regional production levels and the output of LPJmL, a set of allocation rules in IMAGE determine the actual land cover. The calculated emissions of greenhouse gases and air pollutants are

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