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SOCIO-ECONOMIC IMPLICATIONS OF CLIMATE STABILIZATION SCENARIOS FROM MIROC EARTH SYSTEM MODEL

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Abstract

Stabilization of climate in the long-term requires significant reductions in greenhouse gas (GHG) emissions at global scale. Setting a target for climate stabilization should consider important transformations in the society, basically affecting the future patterns of energy consumption and production, as well as the patterns of land use. Moreover, the cost for achieving such climate target may be considerable, thus, requiring an optimal allocation of efforts that minimizes the economic impact. This study presents the socio-economic implications of emission scenarios aiming at long-term targets for climate stabilization, estimated with an integrated assessment model (IAM). Emission scenarios are obtained from the earth system model (ESM) Model for Interdisciplinary Research on Climate (MIROC-ESM). The outcomes on supply and demand of energy, land use, and mitigation costs are presented. The emissions scenarios considered are consistent with the representative concentration pathway (RCP), and aim at a global radiative forcing by 2100 of around 4.5 W/m^2 (RCP4.5) and 2.6 W/m^2 (RCP2.6). The GCAM-SOUSEI model is applied to study the developments in energy, land use and emissions throughout the 21st century. This model is an IAM based on a partial equilibrium approach, which resolves the balance in supply and demand across the energy, land use and agricultural sectors. Compared to the standard RCPs, the emission scenarios from MIROC-ESM presented lower levels of allowable anthropogenic CO_2 emissions for the same climate target. This is an outcome of the stronger feedback between the carbon-cycle and the climate, and the higher value for climate sensitivity assumed in MIROC-ESM in contrast to the climate model used in the development of RCPs. As a consequence, the changes in the energy and land systems are more drastic, while the cost of mitigations is higher. These differences were greater in the second half of the century for the intermediate target, while they occurred earlier for the ambitious target.

Introduction

Stabilization of climate in the long-term requires significant reductions in greenhouse gas (GHG) emissions at global scale. This involves important transformations in the drivers of human-induced GHG emissions, namely energy consumption and production, as well as land use change. Moreover, the cost for achieving climate stabilization may be considerable, thus, requiring an optimal allocation of efforts that minimizes the economic impact (Clarke et al., 2014).

The feasibility of climate stabilization is determined by the mitigation target. Setting a target for mitigation of GHG emissions is subject to several uncertainties. In general, uncertainties can be divided into those imposed by the socio-economic (or human) system, and those imposed by the climate system. While socio-economic uncertainties are related to the implementation and availability of concrete policies and technologies, climate uncertainties are related to the natural processes describing the response of the climate system to increased GHG emissions into the atmosphere. Thus, it is clear that setting mitigation targets that are consistent with the capability for implementing policies and technologies and the behaviour of the climate system, require reuniting information and perspectives from a broad range of sciences.

There are several studies assessing the socio-economic implications of climate stabilization targets. They apply integrated assessment models (IAM) and consider emission scenarios for stabilization of concentration of CO2 or GHGs, and of radiative forcing until year 2100. For example, a sample of the representative concentration pathways (RCPs) consider stabilization of radiative forcing by the end of the century (Masui et al, 2011; Thomson et al., 2011). Comprehensive studies exist analysing the effect of uncertainties within IAMs in stabilization scenarios, such as population and income projections, availability of energy resources and technologies, coverage of climate policies, among others (Rogelj et al, 2013; Kriegler et al., 2014; Luderer et al., 2014; Calvin et al., 2015). Most of these studies obtain the information on climate system from the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC), a simple climate model which is regarded as a convenient tool capturing the spread of outcomes from climate models of higher complexity (Meinshausen et al., 2011). Nevertheless, the emission scenarios and stabilization targets assessed in such framework, cannot be linked to a full representation of the climate system, neither to the stabilization of global temperatures in a timeframe beyond 2100.

This study presents the socio-economic implications of emission scenarios aiming at long-term climate stabilization targets, estimated with an IAM. Emission scenarios are obtained from the earth system model (ESM) Model for Interdisciplinary Research on Climate (MIROC-ESM). The outcomes on supply and demand of energy, land use, and mitigation costs are presented and compared to the standard set of scenarios derived from IAMs using a simple climate model.

Methods

This study assesses emission scenarios corresponding to climate stabilization targets derived from an ESM. Emission scenarios are defined as paths for allowable carbon emissions in the 21st century. The socio-economic implications of the scenarios are assessed with an IAM, in terms of energy supply and demand, land use change and mitigation costs.

The MIROC-ESM is an ESM consisting of atmosphere, land and ocean components, and including biogeochemical processes in the land and the ocean (Hajima et al., 2012). It has been applied to develop projections of climate change with high spatial and temporal resolutions, and has contributed to Coupled Model Intercomparison Project (CMIP) analyses (Watanabe et al., 2011). Compared to other models, MIROC-ESM has a higher climate sensitivity and a stronger feedback between climate and the carbon cycle, which results in more stringent emission scenarios for a given concentration path.

The GCAM-SOUSEI model is applied to assess emissions scenarios leading to stabilization of global temperatures in the long term. The assessment covers changes in energy, land use and emissions throughout the 21st century. GCAM-SOUSEI is a direct descendant of the Global Change Assessment Model (GCAM), an IAM based on a partial equilibrium approach with a detailed representation of the energy, land use and agricultural sectors (Kim et al., 2006; Clarke et al., 2007). The model features a detailed database of energy technologies and trends in energy consumption across several sectors and regions. It estimates emissions of major GHGs, including aerosols, for each sector and world region.

The emissions scenarios considered are listed in Table 1, and include a Reference scenario, and a set of scenarios aiming at radiative forcing targets. The Reference scenario considers only current policies without implementation of carbon prices. The mitigation scenarios consider intermediate and ambitious mitigation targets leading to global radiative forcing by 2100 of 4.5 W/m^2, and 2.6 W/m^2, respectively. These scenarios represent pathways of allowable anthropogenic CO_2 emissions obtained from MIROC-ESM that are consistent with global CO_2 concentrations described by the representative concentration pathways (RCP) (van Vuuren et al., 2011). These scenarios are compared with the standard scenarios developed by IAM teams during the RCP scenario development process (Thomson et al., 2011; van Vuuren et al., 2011). While standard RCP scenarios are consistent with the achievement of radiative forcing targets up to 2100 and estimated with a simple climate model, scenarios from MIROC-ESM are consistent with stabilization of global temperature during several centuries after 2100. Emission scenarios are illustrated in Figure 1. All scenarios assume population and income projections corresponding to the SSP2 scenario, included in the shared socioeconomic pathways (SSP) (O'Neill et al, 2014). This is a scenario considering intermediate values for assumptions on population and income, within the framework of the SSP scenarios.

Table 1 Scenarios considered in the study.

Scenario name	Description
Reference	No mitigation policies.
RCP4.5-MIROC	CO_2 emissions from MIROC-ESM compatible with RCP4.5.
RCP2.6-MIROC	CO_2 emissions from MIROC-ESM compatible with RCP2.6.
RCP4.5-Std	CO_2 emissions from RCP database compatible with RCP4.5
RCP2.6-Std	CO_2 emissions from RCP database compatible with RCP2.6.

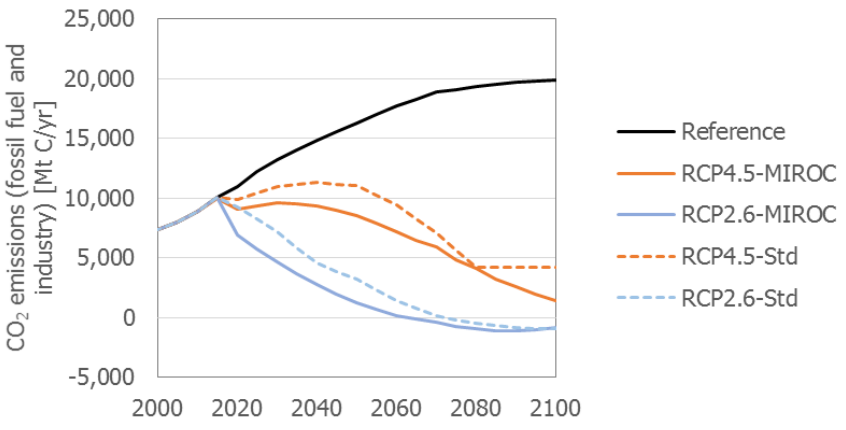


Figure 1 Emission scenarios considered in the study.

Results and discussion

Outcomes for the scenarios considered are presented in Figure 2 and Figure 3. Achieving an intermediate stabilization target, indicated by the RCP4.5 scenario, involved reductions in energy intensity in the first decades, with values up to 10% smaller compared to the Reference case. Also, electricity became more important as it changed from less than 25% of TPES in 2100 in the Reference scenario to around 34% of TPES. The share of fossil fuels in 2100 decreased to less than 50% of TPES, while renewables grew to 40% of the TPES, and power technologies with CCS covered 30% the electricity mix. Major land use changes were dominated by the expansion of biomass, croplands and forest plantations, over unmanaged lands (mainly arable land, pastures, grasslands and natural forests). Compared to the Reference scenario, expansion of land for bioenergy crops and food was larger, while the area of pastures and natural forests decreased considerably in the long-term. This scenario, required a progressive increase in carbon prices to around 850 USD/tC in 2100.

The achievement of an ambitious target, indicated by the RCP2.6 scenario, brought along changes in the energy supply that were more drastic, especially in the first half of the century. For example, in 2050 the share of fossil fuels in TPES already dropped to 50% in 2050, while CCS share in electricity supply peaked at 36%. These trends also reflected in the use of land. Bioenergy by 2050 took 50% more area compared to the scenario with an intermediate target. Mitigation costs increased sharply, especially in the first half of the century. Carbon prices in this period reached values 2 to 3 times larger than those required for an intermediate stabilization target, and converged towards a similar value by 2100 (around 970 USD/tC).

Compared to standard scenarios, mitigation scenarios from MIROC-ESM in general induced similar changes in energy supply and land use, but with larger scale. These differences were more evident in the first half of the century, while for the ambitious target (RCP2.6) outcomes were almost the same in the last decades of the century. For example, share of fossil fuels in TPES was around 10% smaller than the standard RCP scenarios. The major difference was observed in terms of carbon prices, which were in average 60% and 30% larger in the intermediate (RCP4.5) and ambitious (RCP2.6) stabilization target scenarios, respectively. These differences, which were driven by the path of allowable emissions in each scenario, were a consequence of the intrinsic assumptions of the climate models used to develop the emission scenarios. MIROC-ESM assumes a strong response of the climate system to the increase in carbon concentrations in the atmosphere. In contrast, MAGICC, the climate model used to develop the RCP standard scenarios, assumes central values within the range of values presented by climate models reviewed in the IPCC reports. For example, the value of equilibrium climate sensitivity, which is one of the main parameters representing the impact of increased carbon concentrations on the global temperatures, is assumed as 4.7 in MIROC-ESM, while it is 3.0 in the MAGICC model. This difference results in more stringent emission scenarios from MIROC-ESM.

After comparing both sets of mitigation scenarios and mitigation targets, it is clear that, whichever the approach for evaluating scenarios, achieving a stringent target requires important transformations in energy supply prior to 2050. Also, such transformations must continue throughout the century. However, depending on the approach used to develop such scenarios, namely on which climate model is used, the scale of these transformations will vary slightly. From the perspective of mitigation policy, outcomes from the standard RCP scenarios provide a way to simplify the uncertainty in climate outcomes (i.e. those from climate models), as these scenarios assume the mean values of parameters describing the behavior of multiple climate models. In contrast, from the perspective of climate modeling, MIROC-ESM scenarios provide insights on the socio-economic outcomes of scenarios that consider a comprehensive scope of natural processes related to climate change.

a)

b)

c)

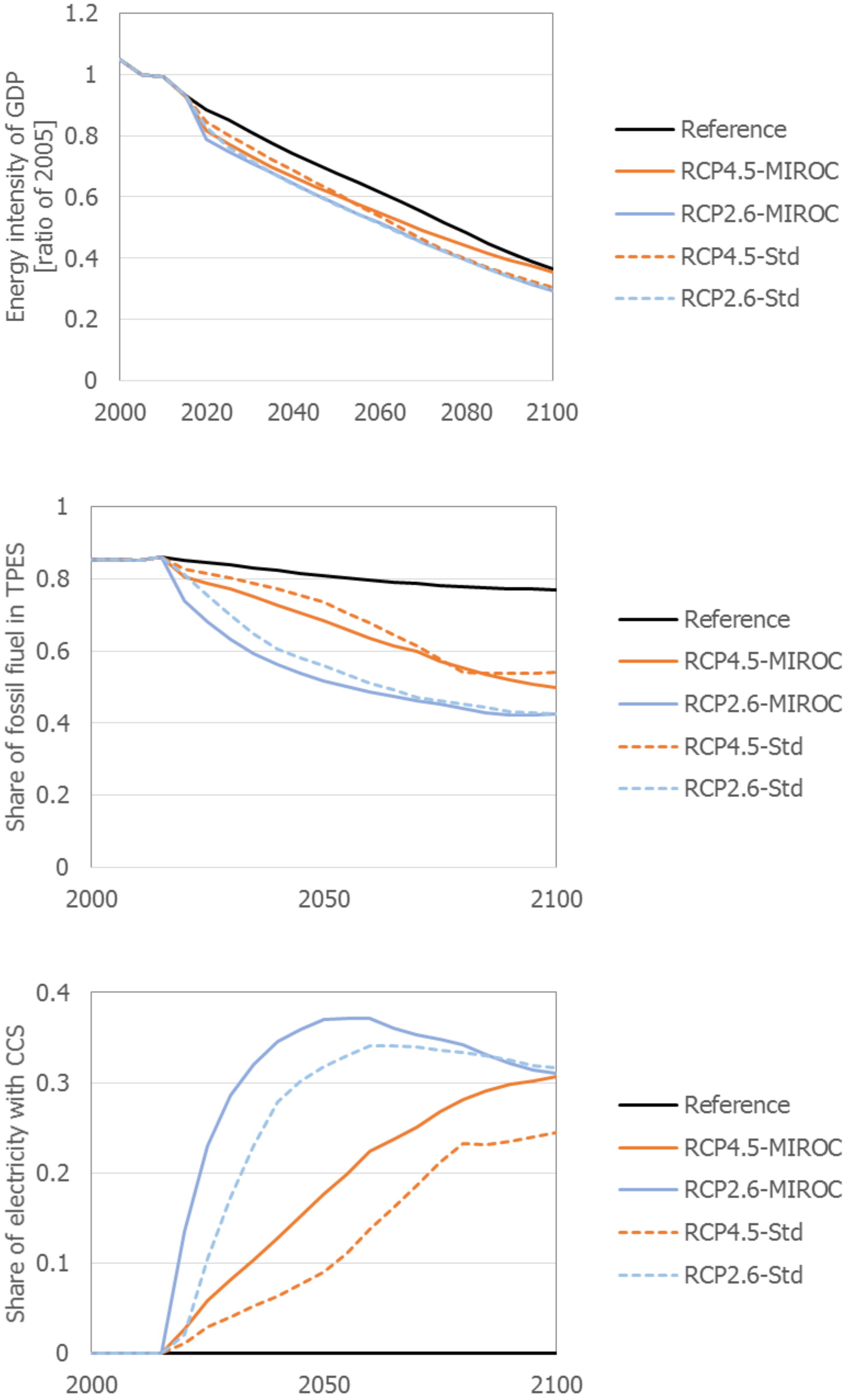
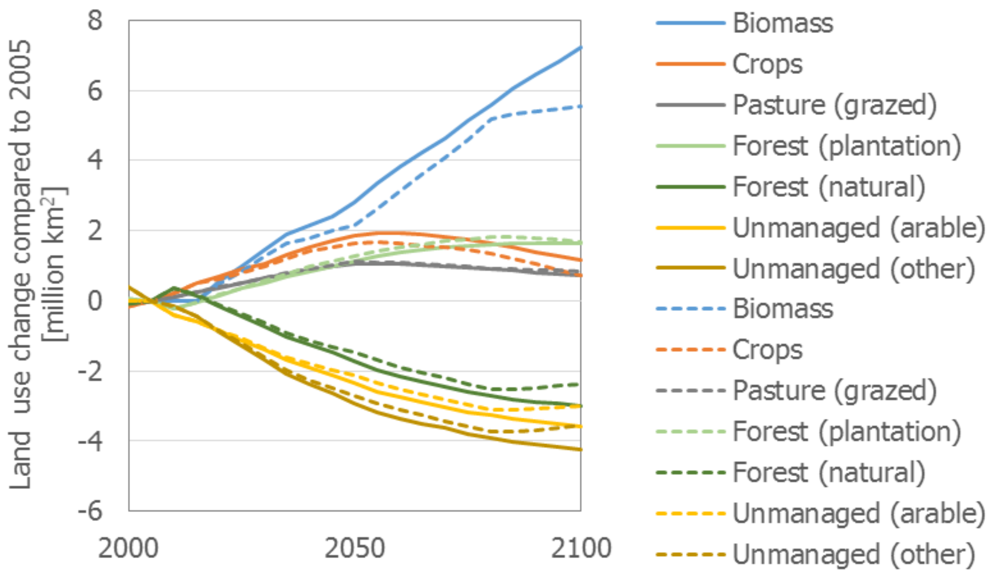


Figure 2 Outcomes from the scenarios for (a) energy intensity of GDP, (b) share of fossil fuels in TPES, (c) Share of CCS in electricity supply.

a)



b)

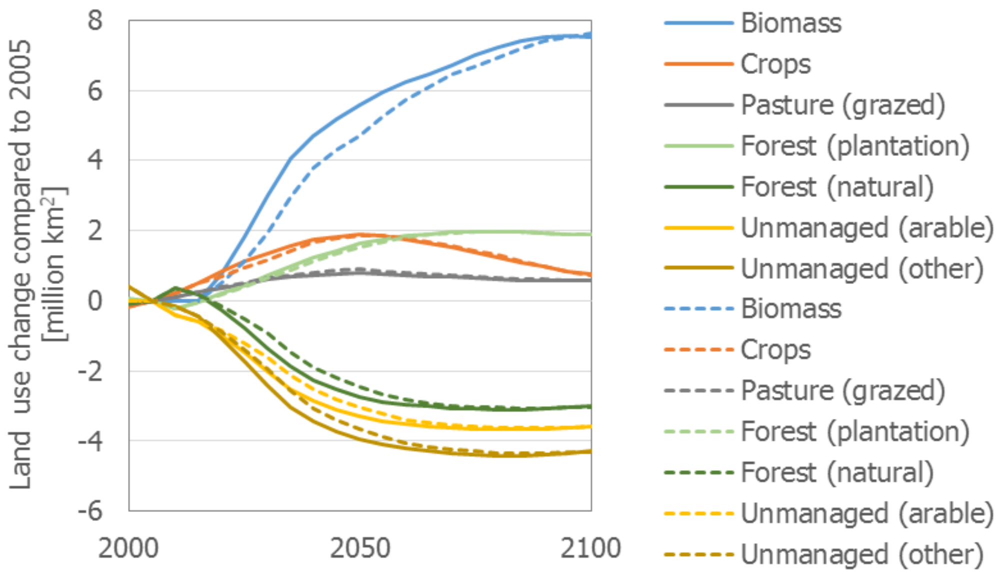


Figure 3 Land use change outcomes for (a) scenarios with intermediate mitigation target (RCP4.5-MIROC, RCP4.5-Std), (b) scenarios with stringent mitigation target (RCP2.6-MIROC, RCP2.6-Std). Continuous lines correspond to outcomes of emission scenarios from MIROC-ESM (RCP4.5-MIROC, RCP2.6-MIROC). Discontinuous lines correspond to outcomes of RCP standard emission scenarios (RCP4.5-Std, RCP2.6-Std).

Conclusions

Stabilization scenarios indicated that society can still rely on fossil fuels to a large extent, provided that CCS and low-carbon technologies are largely deployed. In addition to decarbonisation of the energy supply, lower energy intensity and increased energy efficiency resulting from the higher penetration of electricity as energy carrier, were important components of stabilization scenarios. They induced important land use changes, in particular the expansion of land for bioenergy over unmanaged lands and natural forests. Achieving an ambitious stabilization target required larger costs and sharper changes in energy and land use in the first half of the century. Compared to the standard RCPs, the emission scenarios from MIROC-ESM presented lower levels of allowable anthropogenic CO_2 emissions for the same climate target. As a consequence, the changes in the energy and land systems are more drastic, while the cost of mitigations is higher. These differences were clear in the second half of the century for the intermediate stabilization target, and occurred earlier for the ambitious stabilization target.

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