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D. E. Reusser

Tabea Lissner

Luis Costa

Flavio Augusto Pinto Siabatto

Anselmo Garcia Cantu Ros

See next page for additional authors

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Presenter/Author Information
D. E. Reusser, Tabea Lissner, Luis Costa, Flavio Augusto Pinto Siabatto, Anselmo Garcia Cantu Ros, and Jürgen Kropp

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Interdependence of mitigation, adaptation and sustainable development

D. E. Reusser [a] **, Tabea Lissner**[a]**, Luis Costa** [a]**, Flavio Augusto Pinto Siabatto** [a]**, Anselmo Garcia Cantu Ros** [a]**, and Jürgen P. Kropp** [a]

[a] *Potsdam Institute for Climate Impact Research, Research Domain 2: Climate Impacts & Vulnerabilities, P.O.Box 60 12 03, 14412 Potsdam, Germany*

Abstract: Managing the interdependence of climate mitigation, adaptation and sustainable development requires a good understanding of the dominant sociotechnical and earth system processes that have determined the pathways in the past. Key variables include for example water and food availability which depend on climate and overall ecosystem services, as well as energy supply and social, political and economic conditions.

Here we attempt an overview of existing model components and globally available data sources and look for gaps in existing approaches. This overview lies the foundation for building a model at the country level that integrates mitigation and adaptation with the ultimate goal to derive pathways that keep social and environmental systems within save limits of severe change.

Keywords: climate change; model integration; data sources

1 INTRODUCTION

It is by now broadly accepted that anthropogenic climate change is a reality and discussion is ongoing whether the first damages can already be observed [e.g. Hulme et al., 2011; Pall et al., 2011]. Due to the delayed response of mitigation efforts, climate impacts are expected to increase and climate adaptation can not be avoided [Schellnhuber et al., 2006]. To cope with climate change and its impacts, mitigation and adaptation provide complementary pathways of action. Both will require substantial societal change. A good understanding of the governing mechanisms is essential to facilitate a good management of both strategies in an integrative manner.

However, understanding societal changes related to climate change is challenging, due to the interaction between climate mitigation, climate adaptation and development [Klein et al., 2005] and unexpected consequences may occur if actions are seen in isolation. These interaction may both be positive or negative. There are actions, such as plantation of mangrove forests, that result in climate mitigation by CO_2 fixation and adaption by increased protection against storm surges at the same time. Another example for such a win-win strategy is building land slide retaining walls from scrap tires, which reduces emissions as tires are not burned, increases economic benefits because new markets are developed and also reduces risk of land slides from potentially increasing heavy rainfalls [1]. Other actions might cause conflicts between adaptation and mitigation. For example, additional infrastructure causes additional greenhouse gas emissions or air conditioning as adaptation to increased temperatures will also rise energy demand and related emissions and thus counterbalance mitigation efforts.

[1] Both examples are projects included in the adaptation database at `www.cigrasp.org`

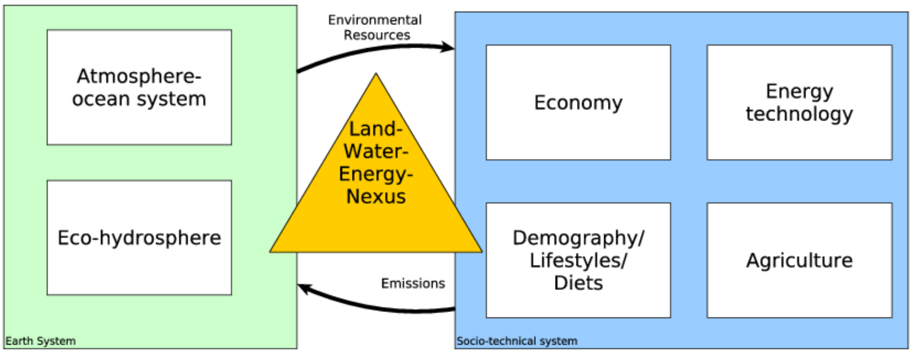

Figure 1. Main model components

Models are tools to explore such interaction between adaptation, mitigation and development. Currently these models are used to to understand the effects of climate change in the earth system [Solomon et al., 2007] and to understand effects from climate policies [Edenhofer et al., 2010, see also next section]. However, models at the country level that integrate adaptation, mitigation and development processes are currently missing. We are in the process of building such a model at the country level, that aims at deriving pathways that keep social and environmental systems within save limits of severe change.

We want to discuss some of the questions to be addressed during the model building:

- What are current models and model components that are used to describe societal changes related to climate change? Two subquestions deserve special attention since it is mainly climate mitigation and climate adaptation that will cause changes in policies.

  How is climate mitigation represented in models? And how could this be related to a country level?

  How is climate adaptation represented in models? And how could this be related to a country level?

- What are existing global data sources that can serve to parametrize and calibrate our planned country level model?

We conceptualize the human-environment system in the context of climate change and review existing model components in Section 2, with a special focus on mitigation (Section 2.1) and adaptation (Section 2.2). A rough sketch as a base for discussion is drafted in Section 3. A range of existing data sources for parametrization and calibration is presented and discussed in Section 4. Section 5 concludes the paper with a discussion of how this builds the foundation for our planned model.

2 Model components

To conceptualize causes and consequences of climate change, two interacting main domains can be differentiated. The Earth system encompasses environmental processes, while the socio-technical domain describes the major societal processes (Figure 1).

Two important components represent the Earth System within our framework: The atmosphere-ocean system (coupled global circulation models) describe the flow of air and water and basic atmosphere chemistry based on conservation of mass and energy [Solomon et al., 2007]. The eco-hydrosphere system is usually described using dynamic global vegetation models (e.g. LPJml and JSBACH), which calculate vegetation growth considering the exchange of carbon, water and nutrients between soil, plants and the atmosphere and horizontal water flow [Sitch et al., 2008]. Moreover, the eco-hydrosphere is influenced by human induced land use change, which is described for example in the models MagPIE and IMAGE. Land, water and energy are closely interlinked since they are in conflicting usages [land, water, energy nexus Hoff, 2011].

The socio-technical system (Figure 1, right-hand side), can be disaggregated into four parts describing demographical development O'Neill et al. [2010], world economy [Metz et al., 2007], the food production system and food demand [Tilman et al., 2011] as well as the energy supply and demand (Section 2.1).

Important interactions between the earth and the socio-technical system for the purpose of our study are mainly related to the already mentioned land use change and emissions and the induced changes in the earth system [Parry et al., 2008], as well as the occurrence and change in resources. Thus, the development of the socio-technical system is shaped by limited environmental resources [e.g. Meadows et al., 2004] and environmental protection policies, especially emission reduction targets. Integrated assessment models have recently been reviewed by Füssel [2010] and they already integrate a number of the components shown in Figure 1. Since climate mitigation and adaptation processes are likely to cause policy changes and thus are especially important to understand societal changes related to climate change, the next two subsection will further explore this claim.

2.1 Climate mitigation

Models for mitigation assessment include demography, economy and energy technology (Figure 1) [model comparison of Edenhofer et al., 2010]. Mitigation can broadly be assessed according to two approaches. On the one hand, economic development, emissions and resulting climate change may be calculated under different policies. On the other hand the economic development may be constrained by a certain emission threshold, assuming that appropriate policies are available. The economic model may be run as optimal growth model (e.g. REMIND) or econometric based model (e.g. E3MG).

The bottom-up energy system models have representations of the different technologies based on coal, oil, gas, biomass, nuclear energy, renewables and hydrogen, as well as carbon capture and storage technologies. Assumptions related to these technologies for 5 models have been reviewed by Edenhofer et al. [2010]. The existing models furhter differ in the representation of the economic development and the degree of details used to describe end-use of energy. Economic development can be used as external driver (IMAGE), solved econometrically (E3MG) or optimized over a certain time frame (REMIND).

Energy demand can be modelled depending on population, economic activity and energy efficiency for multiple sectors and the different energy carrier (TIMER - the energy module of IMAGE, POLES). In REMIND, the energy demand is modelled as one of the production factors (capital, energy and labour) and the required amount of energy is supplied while minimizing costs. As previously mentioned, household type specific consumptions and emissions are most often not considered [O'Neill et al., 2010]. However, this is an important improvement in order to be more explicit on the role of changes in consumption patterns and their translation into changes in the demand of food, water, energy, and goods. This could for example be achieved by a Leontiev's-like input-output model for the release of pollutants.

We see two alternatives for representing mitigation in our country level model. For the first method, the strategy will depend on the country to be assessed. For countries with a large influence on global markets and CO_2 budgets, mitigation needs to be modelled in a similar way as described above on a global level and consequences for the country level can then be related to global processes. For small countries that will not have a large influence on global markets and CO_2 budgets, world economy can be treated as exogenous variables. If this assumption can not be made, a full coupling between a global and a country level model is necessary. On the other hand, we may base the analysis on the new scenario process for the fifth assessment report and use the representative concentration pathways (RCP) as scenarios for global mitigation targets [Vuuren et al., 2011].

2.2 Adaptation to climate change

Inclusion of adaptation in models is a complex task, which is reflected by the very limited number of existing adaptation models [Dickinson, 2007]. A large number of sectors require adaptation and it is generally not possible to single out a small number of most important processes, such that all model components listed in Figure 1 are needed. For example, Dickinson [2007] list agriculture, coastal management, economy, forestry, human health, hydrology as adaptation relevant sectors.

Moreover, assessment of adaptation in general has a number of shortcomings, that become evident when adaptation cost assessments are reviewed. For example, the role of institutions (e.g. practices, risk sharing) in shaping adaptation aspects in the agricultural sector is not reflected appropriately [Gupta et al., 2010]. Second, for the coastal sector there is no strong evidence that on a practical level coastal protection strategies are considered to the extent suggested by current models [Poumadère et al., 2008]. Third, for water management, current assessments disregard the challenges posed my multi-level (country/sector) cooperation required for adaptation in the water sector [Perdomo and Omar, 2011].

Correspondingly, Patt et al. [2009] find many ways in which adaptation can be improved in existing models by including a number of details:

> "the highly disaggregated nature of vulnerability and adaptive response; the importance of extreme events as triggers for adaptation; the scale dependence of adaptation; the role of non-market values; the non-optimal use of information by agents; and the central role of uncertainty in shaping private adaptation action."

While existing models for adaptation costs assume that knowledge and political and economic structures are adequate to quickly start adaptation, widespread evidences exists that adaptation to climate change will not be immediate and that several barriers exist in terms of institutional structures [Carter, 2011], ecology [Murthy et al., 2011] or knowledge [Moser and Ekstrom, 2010]. This implies that a number of sub-processes need to be considered and financed before the implementation of a concrete adaptation option [Moser and Ekstrom, 2010].

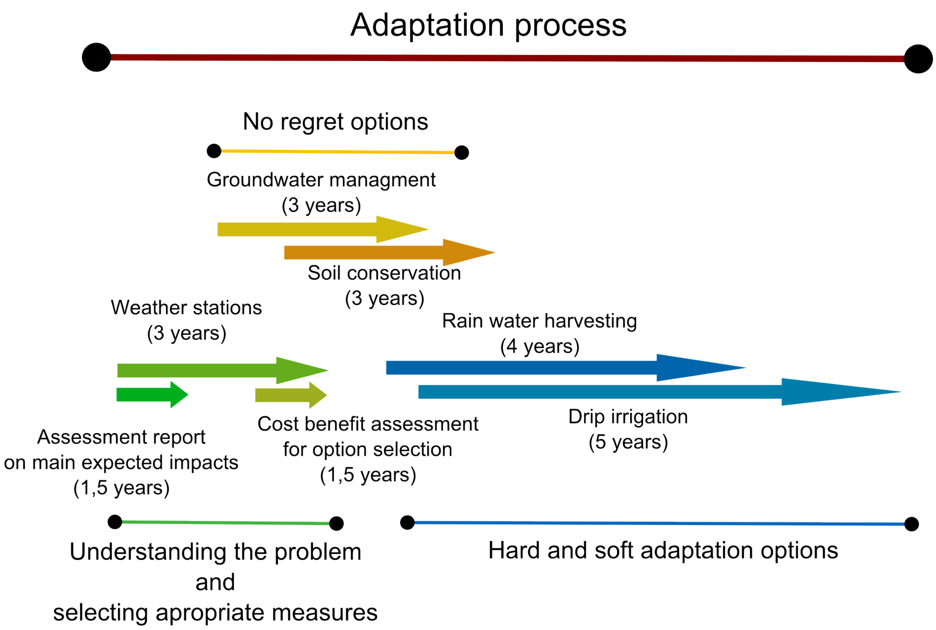

Figure 2. Generic adaptation process in agriculture based on ci:grasp portfolio of adaptation projects in the agricultural sector

To better represent adaptation, we will aim at a more explicit representation of such sub-processes. Based on our literature review and the adaptation project database in the online-platform cigrasp [approximately 300 projects Lissner et al., 2012a], we have started constructing generic adaptation processes prototypes that take into account the steps and time delays associated with the adaptation process – understanding, planning and implementation. Figure 2 shows an example for agriculture with the understanding phase in green (e.g. assessment report with main impacts in agriculture, 1.5 years), the planning phase in yellow (e.g. cost benefit analysis for selecting adequate adaptation options, 1.5 years), and the implementation phase in blue (soil conservation measures for 3 years and rain water harvesting, 4 years). Due to dependencies in the implementation order, the overall adaptation process in agriculture can be expected to last for at least one decade.

3 Sketching the country level model

The model under development reflects all the components from Section 2 except for the atmosphere-ocean system, which will be represented by simulation results from existing atmosphere-ocean models for the recent RCPs [Vuuren et al., 2011]. It is based on system dynamic modelling and is inspired by the World3 model [Meadows et al., 2004]. However, we plan to resolve the dynamics to a country level, constraining the possible dynamics to be compatible with global development and limits.

A number of models at the country level are available, such as for example Threshold 21, MIMES and the International Futures Simulator (IFS). For an overview see Costanza et al. [2007]. One key goal of the new model is to allow an evaluation of conditions as livelihood conditions [Lissner et al., 2012b], going beyond the human development index [UNDP, 1990]. A bases for discussion about the planned model structure is given in Figure 3. The figure shows, where modules for adaptation and mitigation will be linked into the new model.

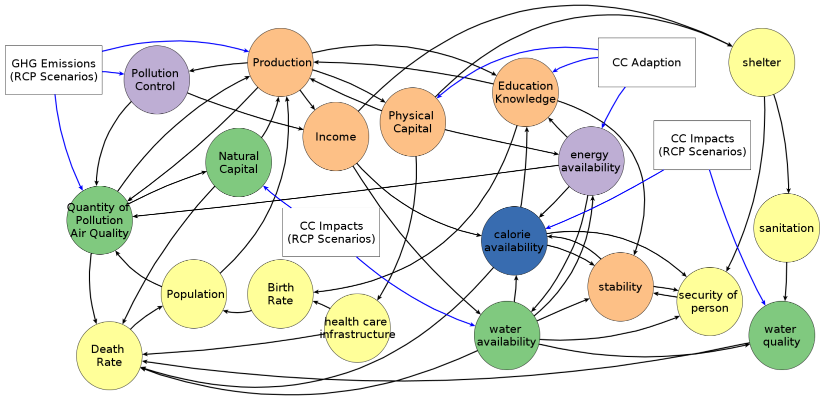

Figure 3. Causal loop diagramm as discussion basis for the planned country model. Elements relate to the eco-hydrosphere (green), economy (orange), energy (purple), agriculture (blue), and demography and lifestyle (yellow) (Figure 1)

4 Global data sets

Without good quality data, model parametrisation and calibration is impossible. Factors such as the free availability, its quality and documentation limit the usability and applicability of data [Arzberger et al., 2004]. Most international organizations have a broad resource base of global data and together with other databases, several sources are available for each component of the model proposed in Section 3 (we highlight some of these global data sources in Table 1, the source and a short description). For example, population data from the UN database is used as a base for demographic modelling in IMAGE [MNP, 2006]. An assessment of cropland expansion with MAGPIE made use of GTAP data [Krause et al., 2009]. Data from the IPCC data distribution center is regularly used for climate modelling.

Data harmonization initiatives will make access in the future easier, such as the forthcoming European INSPIRE[2] infrastructure, the 'Global Earth Observation System of Systems (GEOSS[3])' and the US-based Data Observation Network for Earth DataOne[4]. A mainstreaming of data is increasingly observable: international organizations share databases and make information accessible in a common format, providing bigger databases as a 'one-stop-shop' (e.g. The WorldBank Data Catalogue or UNEPs Environmental Data Explorer) [Parsons et al., 2011]. Mostly country-level resolution is available, with some data sets available in higher resolution for selected regions.

5 Discussion and Conclusion

Models exist for all the main components that we used to conceptualize the coupled human-earth system in Figure 1. When looking at each domain separately, understanding of processes is fairly good and models are well established and very detailed. Of course for each component improved representation of certain processes is topic of current research. For example in the climate mitigation models reviewed by Edenhofer et al. [2010], none of the models included damages from climate change impacts.

[2] inspire.jrc.ec.europa.eu/
[3] www.earthobservations.org/geoss.shtml
[4] www.dataone.org

Table 1. Several databases provide access to data sets at various temporal and spatial scales. The overview lists important sources of information for openly accessible data. Databases are grouped according to the main modules of the model (subheadings).

Database	Description	Source
General Sources		
The World Bank Data Catalogue	The database provides access to Worldbank statistics and related databases, featuring over 1000 indicators from a range of fields and sectors.	`data.worldbank.org/indicator`
Earth Trends (World Resources Institute)	EarthTrends provides an interface to access to a range of data from different sources including environmental, social, and economic trends.	earthtrends.wri.org/
UNDP Environmental Data Explorer	The Environmental Data Explorer, providing data used by UNEP and its partners in the Global Environment Outlook (GEO) report, gives access to over 500 variables from a range of fields.	`geodata.grid.unep.ch/`
Atmosphere-Ocean System		
AQUASTAT	AQUASTAT is FAO's global information system on water and agriculture.	`www.fao.org/nr/water/aquastat/main/index.stm`
IPCC Data Distribution Centre	The DDC provides climate, socio-economic and environmental data, both from the past and also in scenarios projected into the future.	`www.ipcc-data.org/ddc_gcm_intro.html`
Eco-hydrosphere		
LPJmL	The Lund-Potsdam-Jena managed Land Model LPJmL simulates vegetation composition and distribution as well as stocks and land-atmosphere exchange flows of carbon and water, for both natural and agricultural ecosystems. It computes spatially explicit processes such as photosynthesis, plant growth, maintenance and regeneration losses, fire disturbance, soil moisture, runoff, evapotranspiration, irrigation and vegetation structure at monthly time steps.	`www.pik-potsdam.de/research/projects/lpjweb`
Anthromes	Anthropogenic Biomes (or Anthromes) are the globally significant ecological patterns created by sustained interactions between humans and ecosystems. They provide a more comprehensive way to integrate humans into global ecology [Ellis and Ramankutty, 2008].	`http://ecotope.org/anthromes/v1/data/`
Economy		
GTAP Database	GTAP includes bilateral trade information, transport and protection linkages, as well as access to the GTAP model.	www.gtap.agecon.purdue.edu/databases/default.asp
G-Econ	The G-Econ research project has developed a geophysically based data set on economic activity for the world. The basic metric is the regional equivalent of gross domestic product, provided as Gross cell product (GCP) d at a 1-degree resolution at a global scale.	`http://gecon.yale.edu/`
Demography/Lifestyle		
Institutional Profiles Database	The Institutional Profiles Database 2009 presents a broad range of indicators on the institutional characteristics of 123 developed and developing countries covering 96% of the world population and 99% of world GDP.	`www.cepii.fr/anglaisgraph/bdd/institutions.htm`
WHO data and statistics	WHO's portal provides access to data and analyses for monitoring the global health situation.	`www.who.int/research/en/`
Socioeconomic Data and Application Center (SEDAC)	SEDAC focuses on human interactions in the environment and provides data at the interface of earth and social sciences, including detailed disaggregated population data.	`http://sedac.ciesin.columbia.edu/data/sets/browse`
Energy Supply and Demand		
World Energy Outlook	The World Energy Outlook presents analytical insights into trends in energy markets and what they mean for energy security, environmental protection and economic development.	`www.iea.org/weo/`
Enerdata: Global Energy Statistical Yearbook	Enerdata provides energy data, forecasts, market reports, research, news, consulting and training on the global energy industry.	`yearbook.enerdata.net/`
Food Production and Consumption		
FAOSTAT	FAOSTAT provides time-series and cross sectional data relating to food and agriculture	`faostat.fao.org/default.aspx`

Looking at coupled systems, the conclusion is quite different. As has been discussed by other studies, differences in temporal and spatial scales make model integration difficult [van Delden et al., 2011]. An alternative that is emerging is the provision of model components as web services for flexible sharing of available model components. Comprehensive integrated models that include both, changes in energy system and land use are not common - IMAGE seems to be an exception [Edenhofer et al., 2010]. The challenge of integration is one of the reasons why representation of adaptation is still limited, because every component from Figure 1 is relevant for understanding adaptation and trade-offs between adaptation and mitigation. A more comprehensive review of required improvements in the representation of adaptation is given by Patt et al. [2009], which requires more work on conceptualizing adaptation.

One approach to improve conceptualization may be mutual learning between assessment of adaptation and a field called sustainability transition research. While climate adaptation science may provide further case studies to transitions research, it may learn from approaches and frameworks used in sustainability transitions. Research on sustainability transitions originated in studies about environmentally friendly technologies. It successively broadened the scope of problem framing (towards systems innovation – referring to interrelated institutions, technologies and consumption patterns) and analytical frames (considering modes of operation as societal regimes) [Smith et al., 2010] Two main analytical frameworks are currently debated, the 'multi- level perspective' (MLP) and the 'technological innovation systems' (TIS) approach, which are compared and reviewed by Markard and Truffer [2008]. Under these frameworks, transition management can help to set up conditions that support adaptation actions.

One limitation of this study is that the scope of integrating mitigation and adaptation is too broad to provide a comprehensive review of existing models and model components and we were only able to present a selection of the literature. Nevertheless, we hope that we are succeeding to give an overall picture of the current state and limitations.

This review lays the foundation for our development of a model at the country level that integrates adaptation, mitigation and development processes. The main tasks will be to integrate multiple model components to our need and to work on a better representation of climate adaptation.

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