Report on the panel land-use change and biomass production: Brazil's carbon emissions today and in the future

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1. Introduction

The land cover of the earth has a central role in many important biophysical and socioeconomic processes of global environmental change. Contemporary land cover is changed mostly by human use; therefore, understanding of land-use change is essential. Land-use changes (LUC) involve several processes that are central to the estimation of climate change and its impacts, as it influences carbon fluxes and GHG emissions. LUC changes land-surface characteristics and, indirectly, climatic processes and is an important factor in determining the vulnerability of ecosystems and landscapes to environmental change. LUC, through nitrogen addition, drainage and irrigation, and deforestation may alter the properties and possible responses of ecosystems.[4]

The Panel "Land-Use Change and Biomass Production: Brazil's Carbon Emissions Today and in the Future", held in Rio de Janeiro, on June 12th, 2012, aimed to discuss Brazil's carbon emissions from land use and land-use change related to biomass production in a short versus long-term and a national versus global context. The discussion also aimed at introducing the perspective of an emissions constrained world which requires a sustainable relation among biomass/food production (and carbon emissions), environmental conservation and social well-being.

The Panel aimed also at going public with the LUC project proposal and invite people to discuss it and to collaborate.

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4 Land-Use and Land-Cover Change Scenarios. In: Intergovernmental Panel on Climate Change – IPCC. Climate change 2001: impacts, adaptation and vulnerability. Available at: http://www.ipcc.ch/ipccreports/tar/wg2/index.php?idp=132. Access: June 26, 2012.

This report summarizes the presentations and discussions that occurred during the event and, in order to contextualize it, compiles the main considerations of the Fifth Global Environment Outlook – GEO-5 (UNEP, 2012) on land use changes.

2. Geo-5 – land use changes

According to the Fifth Global Environment Outlook – GEO-5 (UNEP, 2012)[5], the pressure on land resources has increased during recent years despite international goals do improve their management. GEO4 (UNEP, 2007) highlighted the unprecedented land use changes created by a burgeoning population, economic development and global markets. The outcome of those drivers continues to cause resource depletion and ecosystem degradation.

Economic growth has come at the expense of natural resources and ecosystems. Many terrestrial ecosystems are being seriously degraded because land use decisions often fail to recognize non-economic ecosystem functions and biophysical limits to productivity. For example, deforestation and forest degradation alone are likely to cost the global more than the losses of the 2008 financial crises. The current economic system, built on the idea of perpetual growth, sits uneasily within an ecological system that is bound to biophysical limits. However, some market-based approaches that attach value to ecosystem services offer incentives to reduce environmental damage.

Competing demands for food, feed, fuel, fiber and raw materials are intensifying pressure on land. Demands for food and livestock feed are increasing rapidly due to human populations growth and changing diets. Demand for biofuels and raw materials have also risen, driven by the increases in population, greater consumption and biofuel-friendly policies. This simultaneous growth is causing land conversion, land degradation and pressure on protected areas. Climate change is placing additional stress on productive areas. One result is heightened tension between goals related to production and those related to conservation.

Globalization and urbanization are aggravating competing demands on land. These processes expand and intensify the pressure on land systems by increasing the distances between places where products originate and where they are consumed. The greater distances can obscure the drivers of resource depletion and ecosystem degradation, produce higher environmental costs due to transport and infrastructure, and complicate the negotiation of sustainable land practices. Large-scale international land deals are both an emerging outcome of and a contributor

5 United Nations Environment Program – UNEP. GEO-5 - Global Environment Outlook: Environment for the future we want. UNEP, 2012. Available at: http://www.unep.org/geo/pdfs/geo5/GEO5_report_full_en.pdf . Access on June 15,2012.

to this trend. Internationally coordinated responses are needed to address related social and environmental pressures.

Improved governance and capacity building are crucial to achieving sustainable land management. Many interventions meant to protect ecosystems have failed because they were created without recognizing local values or engaging local communities in their design and implementation. Capacity building across spatial and temporal scales is needed to improve land management. Current governance approaches include market-based strategies such as the collaborative UN Program for Reducing Emissions from Deforestation and Forest Degradation (REDD), centralizes institutional strategies such as community-based resource management. All offer both opportunities and challenges for improving land governance.

Potential exists to create more sustainable land systems. To solve these complex problems, it is critical to understand how diverse social and ecological drivers affect land systems at local, regional, national and global scales. A concerted effort by international organizations, the scientific community, and national and local institutions to coordinate their action can create the policy options needed to achieve this goal.

Urbanization and globalization contribute to the separation between places where resources and goods originate and where products are consumed. Recent research suggests that the spatial distance between production and consumption is both significant and growing (Erb et al. 2009, cited by UNEP, 2012). As a result, many of the ecological costs of consumption are borne by people and places increasingly far from the consumption sites. While urbanization draws people into densely populated spaces and concentrates demand for food, materials and consumer products, globalization and trade facilitate the movement of people and goods, making both regional and international transfers of resources and finished products possible. Large-scale land acquisitions to supply food, fodder and other forest products as well as other natural resources to markets in distant countries are both a recent outcome of and a contributor to the separation of production and consumption (Toulmim et al, 2011, cited by UNEP, 2012).

3. Land use change and agriculture program

Changes in land use and land cover are central to the study of global environmental change. Not only do they have profound regional implications that can be felt during the life span of current generations, but they also exhibit cumulative long-term global dimensions. Important issues to be addressed include loss of biodiversity, diminished land productivity, land degradation, water contamination, and receding groundwater tables.

In addition, land management and land use changes greatly affect emissions and the sequestration potential of major greenhouse gases. Future decisions concerning land use clearly play a major role in strategies for mitigation and adaptation to climate change.

The strategic goal of the Land Use Systems (LUS)[6] Group established by the International Institute for Applied Systems Analysis - IIASA[7] is to support policymakers in developing rational, science-based and realistic national, regional and global strategies for the production of food, feed, fiber and bio-energy and other services to achieve long-term sustainability of land and water resources while promoting rural development.

The research efforts of the LUS Group are geared toward making a difference both in combating global hunger and poverty and in the preservation of global natural resources.

To achieve this goal, the IIASA's LUS Group aims to advance applied science with a focus on the following strategic research objectives:

- Develop new and improved tools and databases in order to provide a spatially detailed understanding of alternative land and rural development options and strategies, against the background of global change.
- Analyze synergies and trade-offs of alternative uses of agro-resources (land, water, technology) for producing food and energy, while preserving environmental quality.
- Identify hot spots of significant environmental and rural social risks, and clarify their relation to global change.
- Validate methodologies and tools in applications for regional/national case studies needed to improve global scenarios and links with region-specific conditions, issues, and policy options.

Three areas of research, outlined below, were identified for the period 2006–2010. These cover key issues of importance for understanding the interactions between society, land use, agriculture, and climate over the coming decades.

6 IIASA. Land Use Change and Agriculture Program. Information made avalible by Land Use Systems Group at: http://www.iiasa.ac.at/Research/LUC/Homepage-News-Highlights/LUC-flyer.pdf. Access on June 15, 2012.

7 Founded in 1972, the International Institute for Applied Systems Analysis - IIASA is an international research organization that conducts policy-oriented research into problems that are too large or too complex to be solved by a single country or academic discipline: problems like climate change that have a global reach and can be resolved only by international cooperative action; or problems of common concern to many countries that need to be addressed at the national level, such as energy security, population aging, and sustainable development. The IIASA Strategic Plan outlined a new major research program, Ecosystems Services and Management (ESM). This new program is founded on research activities and experience previously covered by the LUC and FOR programs, with the aim of policy oriented applied research and systems analysis, embedded within the Food & Water research domain with strong linkages to Energy & Climate Change and Poverty & Equity.

LUS Research Areas

The first area provides a common thread for the program's global research through a "Food and Agriculture to 2100" project that unifies the themes of climate and anthropogenic impacts on soil and water resources, adaptation and mitigation strategies, and rural development.

The second area analyzes subsets of these issues in regional case studies in Europe, China, South Asia, sub-Saharan Africa, and Latin America.

The third area includes activities aimed at developing new methodologies that advance our ability to derive and manipulate spatially explicit data and provide better integration of socio-economic and bio-physical analyses.

Global level research:

- Food and Agriculture to 2100;
- Climate change, impacts, mitigation, and adaptation;
- Water and agriculture;
- Bio-fuel production and land competition.

Policy support for sustainable development of regional agricultural and rural sectors:

- Agriculture and rural development in transition economies;
- Multi-functionality of land and sustainable socioeconomic and environmental development;
- Environmental impacts of agriculture;
- Regional bio-fuel roadmap.

Methodology development:

- Sequential rebalancing methods for spatial allocation and downscaling;
- Framework for spatial ecological–economic analysis;
- Methodologies for spatial global and regional land cover change scenarios.

The LUS Group builds on established close interactions with relevant international organizations, ensuring that deliverables are of high policy relevance. International collaborations with leading climate change research institutions strengthen the Program's ability to deliver products with high scientific standards.

4. Why a luc vision? The need for a new approach[8]

There are some obvious scientific issues related to the question of land use changes:

- LU and LUC in the tropics – a workable sustainable arrangement between biomass/food production and environmental conservation is not yet in place.
- The horizontal chain related to the emissions of biomass production and consumption in not acknowledged.
- Sustainable LUC has not yet been addressed under a framework that constrains cumulative emissions in order to respond to a future global warming target
- Prognostic and target related research are not performed in tandem and are not linked

According to GEO-5 (UNEP, 2012), one key to avoiding environmental damage is to effectively monitor environmental trends, yet major data gaps limit the ability to avert unwanted outcomes. Global data on land degradations have not been updated for a long time, although new estimates using satellite material are being developed. Datasets exist for land cover but do not always adequately represent areas that have experienced selective cutting or other types of modification. Records of ecosystem change are improving, mainly through remote sensing, but reliable data on land use change are still fragmented and often not comparable.

Satellite remote sensing is an essential tool for monitoring global land resources, but no such technology exists for population patterns. National census efforts, the best current technique, are sporadic and underfunded in many countries, and there is a significant gap for population changes in rural areas. Further, it is critical to track the consequences for the environment of rapid and extensive urbanization, with its uncertain implications for land resources.

Data on biofuels – including the extent of production and use – are incomplete at the global level, although national datasets can be found for some countries. Similarly, there is a need for improved national and global monitoring of land transaction including large-scale land deals. There are also few standard indicators that governments can use to monitor the environmental impacts of different patterns of land tenure. Finally, standard methodologies for the badly needed valuation of ecosystem services are at an early stage of development.

The prognosis for 2050, as in Figure 1, shows great uncertainty: depending on the decisions we make today we can either have a reduction or an increase in carbon emissions by land use. A big issue is that part of this uncertainty is a result of the lack of reliable data and the usage of a unique

8 MATTHIAS, J.; OMETTO, J.P. Why a LUC vision? The need for a new approach. In: Panel Land-Use Change and Biomass Production: Brazil's carbon emissions today and in the future. CGEE: Rio de Janeiro, 12 June 2012. Available at: http://rio20.cgee.org.br/index.php?option=com_jdownloads&Itemid=152&view=viewdownload&catid=3&cid=31&lang=pt . Access on June 15 2012.

model. The applied system analysis developed by IIASA tries to deal with different models and to understand regional land use linked to IIASA's global approach. The applied system analysis also tries to bring together economic, politic and social aspects in order to have a broader view, and a better understanding of uncertainty and the associated risks.

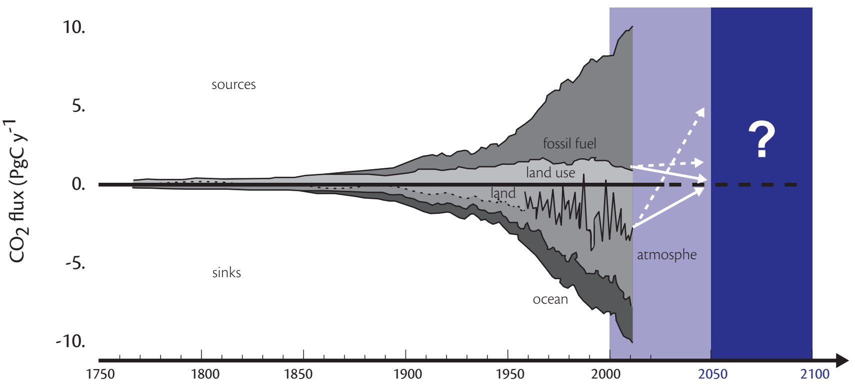

Figure 1. Carbon emissions and land use

Among the deeper scientific issues involved in LUC project, we must highlight:

- We do not handle the uncertainty in LUC emission estimates properly
- We do not handle the combined (diagnostic and prognostic) uncertainty properly [key issue: a sink reduces a source but their uncertainties still add up, impacting risk].
- The era of using a single model for addressing uncertainty related to future environmental targets faces limits methodologically.
- Even employing multiple models for addressing uncertainty and risk related to future environmental targets is not the ultimate approach of the applied systems analysis (ASA).
- Uncertainty and risk are interdependent – and we don't have the appropriate ASA in place to deal with this.

Looking at the issues presented above, both the obvious and the deeper ones, it was possible to identify some key features of the new LUC approach:

- Multi-institutional & international.
- Optimized systems approach.
- Complementary multi-model/technique approach.
- Multi-target approach to define sustainability.

- Consistent from global to sub-global and from long to short-term to have a bearing on the here and now.
- New ASA to deal with uncertainty and risk following predictive norms.
- Constraints on biomass estimates and LUC mechanisms.
- LUC scenarios that consider several social-ecological frameworks, i.e., social development and environmental sustainability.

The proposal is to conduct the project based upon four research modules as in Figure 2.

I. LUC in Brazil – Establishing the knowledge base.

II. Addressing emission and other environmental constrains of a 2050 world.

III. Addressing the science perspective of transition.

IV. Addressing the human-societal perspectives of transition.

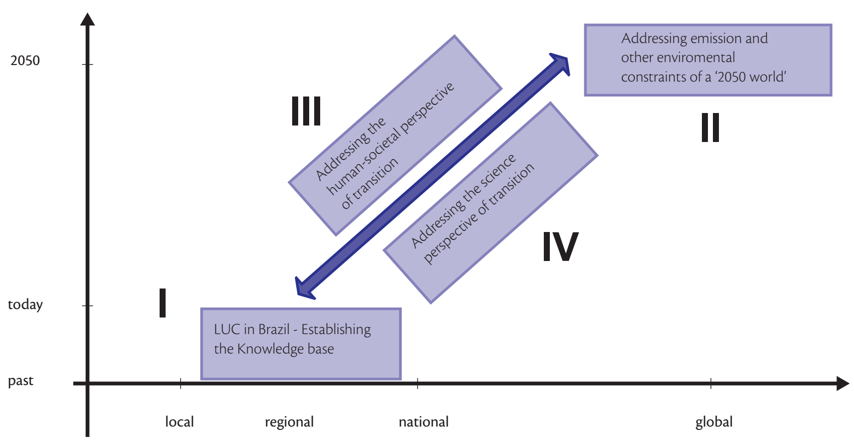

Figure 2. Key research modules of new LUC approach

Brazil's data will be used to establish the knowledge base to address, on the global level, emissions and other environmental constrains of a 2050 world.

5. Toward an emissions constrained world[9]

While previous Global Environment Outlook (GEO) reports have explored several scenarios looking at the very different futures (UNEP, 2002 and 2007), the emphasis of GEO-5 is on the choices and strategies that could, from 2012 on, lead to a sustainable future. This is advanced by looking at two very different storylines based on a review of existing scenario studies:

A view of the world in 2050 assuming business as usual paths and behaviors – "conventional world" scenario.

An alternative that leads to results consistent with our current understanding of sustainability and agreed-upon goals and targets on the road 2050 – "sustainable world" scenario.

The former documents looked into different futures based upon different groups opinions. Now, the future is seen from a sustainable framework, an integrated sustainability. The scenarios oppose the business as usual versus a sustainable world. By the new visions, there is a reduction in the consumption of fossil fuels, and also a reduction on the land use and deforestation. But the uncertainty about it is still very high and there are various points of no consensus, as the question of emissions embodied in trade.

To date, no general consensus has been reached how to measure the effectiveness of climate change mitigation in the land-use sector and how to optimally distribute the various options in the managed landscape. What constitutes the most climate-friendly land use depends on the system boundaries, the time horizon and the regional economic and environmental constraints.

CO_2 emissions from the burning of fossil fuels are conventionally attributed to the country where the emissions are produced (i.e., where the fuels are burned). However, these production-based accounts represent a single point in the value chain of fossil fuels, which may have been extracted elsewhere and may be used to provide goods of services to consumers elsewhere. Davis, Peters and Caldeira (2011)[10] present a consistent set of carbon inventories that spans the fuel supply chain of global CO_2 emissions, finding that 10.2 billion tons CO_2 or 37% of global emissions are from fossil fuels trade internationally and an additional 6.4 billion tons CO_2 or 23% of global emissions are embodied in traded goods, as in Figure 3 The geographical concentration of carbon-based fuels and relatively small number or parties evolved in extracting and refining

9 MATTHIAS, J.; OMETTO, J.P. Carbon emissions and biomass in Brazil: what do we know. In: Panel Land-Use Change and Biomass Production: Brazil's carbon emissions today and in the future. CGEE: Rio de Janeiro, 12 June, 2012. Available at: http://rio20.cgee.org.br/index.php?option=com_jdownloads&Itemid=152&view=viewdownload&catid=3&cid=19&lang=pt. Access on June 15, 2012.

10 DAVIS, S.J.; PETERS, G.P.; CALDEIRA, K. The supply chain of CO2 emissions. PNAS Early Edition, Sept. 13, 2011. Available at: www.pnas.org/cgi/doi/10.1073/pnas.1107409108. Access: 06/25/2012.

those fuels suggest that regulation at the wellhead, mine mouth, or refinery might minimizes transaction costs as well opportunities for leakage.

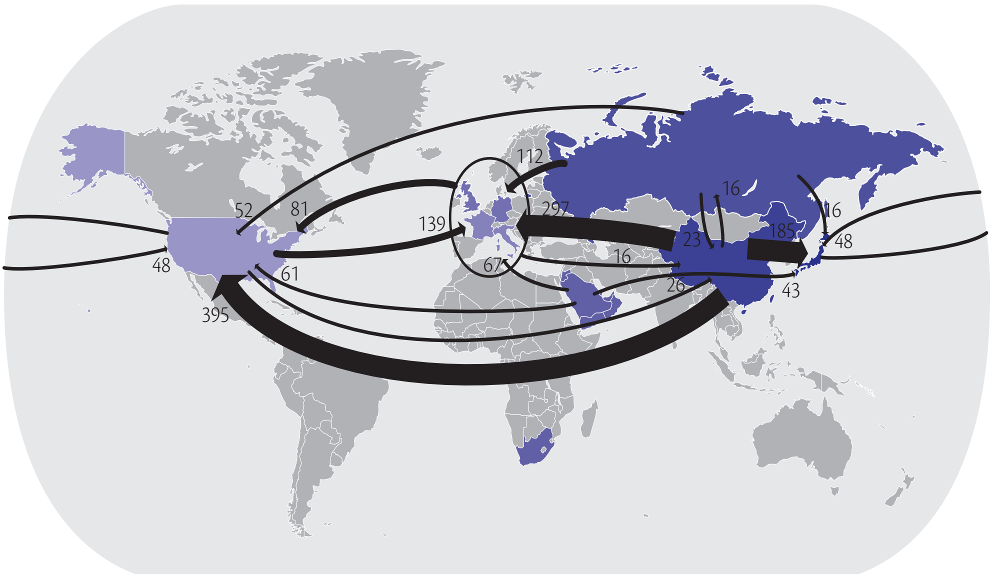

Figure 3. Fluxes of emission embodied in trade[11]

Source: Nacional Academy of Sciences

On the other hand, efforts to control climate change require the stabilization of atmospheric CO_2 concentrations. This can only be achieved through a drastic reduction of global CO_2 emissions. Yet fossil fuel emissions increased by 29% between 2000 and 2008, in conjunction with increased contributions from emerging economies, from the production and international trade of goods and services, and from the use of coal as a fuel source, as in Figure 4. In contrast, emissions from land-use changes were nearly constant. Between 1959 and 2008, 43% of each year's CO_2 emissions remained in the atmosphere on average; the rest was absorbed by carbon sinks on land and in the oceans. In the past 50 years, the fraction of CO_2 emissions that remains in the atmosphere each year has likely increased, from about 40% to 45%, and models suggest that this trend was caused by a decrease in the uptake of CO_2 by the carbon sinks in response to climate change and variability. Changes in the CO_2 sinks are highly uncertain, but they could have a significant influence on future atmospheric CO_2 levels. It is therefore crucial to reduce the uncertainties. (Le Quere et al, 2009)[12]

11 DAVIS, S.J.; CALDEIRA, K. Consumption-based accounting of CO2 emissions. PNAS, v.107, n.12, 23mar2010, p.5687-5692.

12 LE QUERE, C. ; RAUPACH, M.R.; CANADELL, J.G.; MARLAND, G. ET AL. Trends in the sources and sinks of carbon dioxide. Nature Geoscience, n.2, 831-836, 2009.

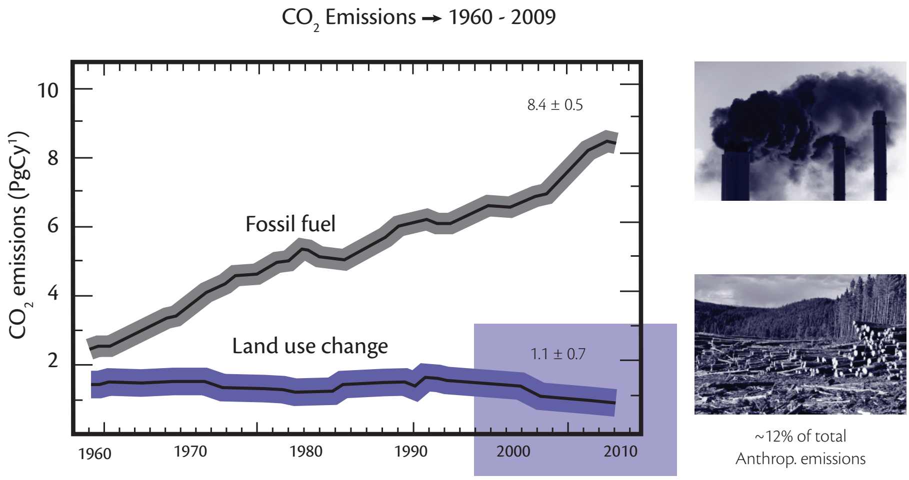

Figure 4. CO_2 emissions - 1960-2009 (after http://www.globalcarbonproject.org/)

Figure 5 shows that CO_2 emissions from land use changes are slowly decreasing due to reduced tropical deforestation and afforestation elsewhere. The estimated decrease between the time frame is 25%, with a large uncertainty, since the global trends point different signals: due to the population growth (from 6 to 9 billion), we will need more food; the increased standard of living means more meat and more food for the animals; there is also an increased need for renewable energy, which means more biofuels. On the other hand, the carbon sequestration means more forests, wood and fibers.

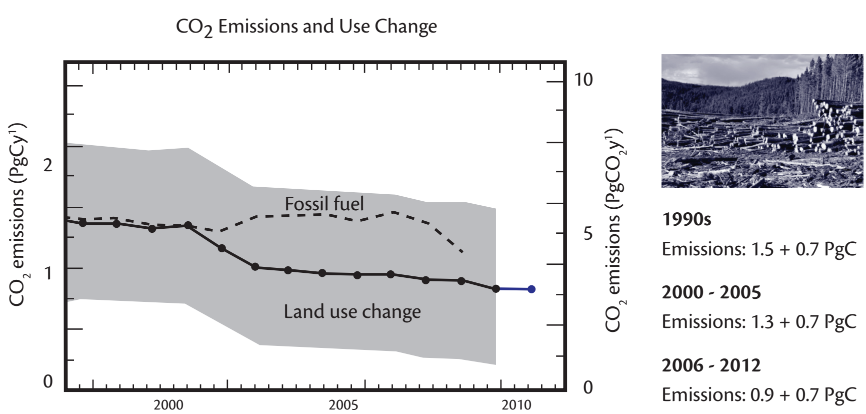

Figure 5. CO_2 emissions from land use change (after http://www.globalcarbonproject.org/)

6. Luc in an emissions constrained world: what is our current understanding?[13]

The world's total tropical area is about 56 million km², South and Central America representing 32% of land area. The Tropical Americas are dominated by humid forest (47%), followed by agricultural, managed or mosaic landscapes (25%) and herbaceous or sparse vegetation (15%). Global awareness of the significance of the role that tropical forest plays in the global carbon cycle has never been greater, but much uncertainty still exists to the exact magnitude of this role. Estimates of carbon emissions from land use change in South America's tropical forest area (humid and dry forests) were 0.44±0.13 PgC in the period 1990-1999, and 0.53±0.12 PgC from 2000 to 2005, as in Figure 6. (Mahli, 2010)[14]

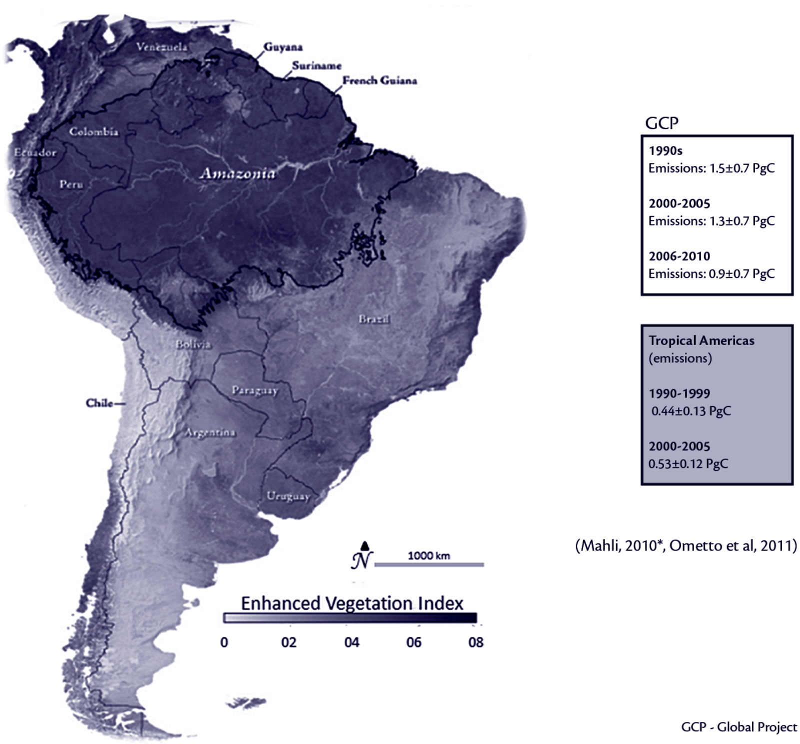

Figure 6. Carbon fluxes in South America - 1990-2005

13 MATTHIAS, J.; OMETTO, J.P. LUC in Brazil in an emissions constrained world: what is our current understanding. In: Panel Land-Use Change and Biomass Production: Brazil's carbon emissions today and in the future. CGEE: Rio de Janeiro, 12 June, 2012. Available at: http://rio20.cgee.org.br/index.php?option=com_jdownloads&Itemid=152&view=viewdownload&catid=3&cid=30&lang=pt. Access on 15 June 2012.

14 MAHLI, Y. The carbon balance of tropical forest regions, 1990-2005. Current Opinion in Environmental Sustainability, n.2, p.237-244, 2010. Available at: http://www.geog.ox.ac.uk/~ymalhi/publications/publications2010/2010-envsust-carbon-balance.pdf. Access in 28 June, 2012.

Figure 7 shows the flux estimates from South America to the atmosphere due to deforestation and fossil fuel burning, from a simplified bookkeeping model. A positive value indicates a flux to the atmosphere.

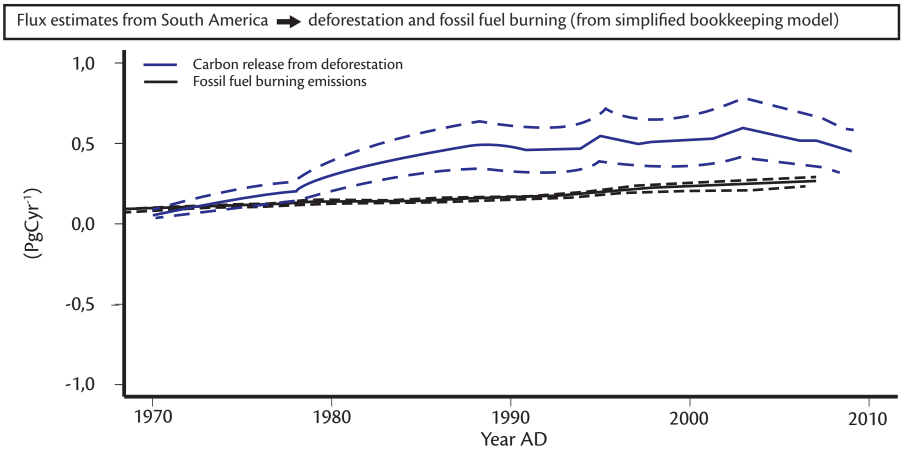

Figure 7. Flux estimates from South America (after Gloor et al, 2012)

Although Brazil has a clean energy matrix, it is still an important generator of carbon emissions. There is a constant increase in fossil fuels, but deforestation has been reduced in the last years, although there are uncertainty and lack of reliable data. To reduce uncertainty, we must keep an account of LUC activities. We must also have a map for Amazon and another one for South America and keep track of what is going on by means of a spatial vision. It is necessary an accounting that considers deforestation, biomass and emissions.

Deforestation in Amazonia has decreased significantly in the last five years, from around 27,772 km^2 in 2004 to around 6,000 km^2 in 2010. This decrease has been attributed to a net of governmental/civil society actions, and commodities market related factors. In spite of this, there is an enormous uncertainty about the fate of the forest. In the next decades, we can expect an increase in food and biofuel demands associated to global population growth and consumption patterns, which can induce both direct and indirect deforestation. Ambitious infra-structure plans also may induce occupation of unprotected areas. Possible climate change can affect the region through intensification of droughts and vulnerability to forest fires. In order to explore future scenarios for the region, there is a need to understand which institutional, political and economic conditions at multiple levels, from national to local, will be able to act as a counterforce to the commodities market pressure, reducing emissions while bringing social development.

Figure 8 presents Amazonia's instantaneous non-process CO_2 emission as well as the process-based CO_2 emission from 1990 to 2009, showing the peak in 2005 and the decrease from 2006 until 2009. The average of all four biomass data sources considered represents 0.17 $PgCyr_1$ from 1990 to 1999 and 0.19 $PgCyr_1$ from 2000 on. Figure 9 shows the differences identified in different data sources about the average biomass weighted by deforested extension, indicating the need for more consistent data collection.

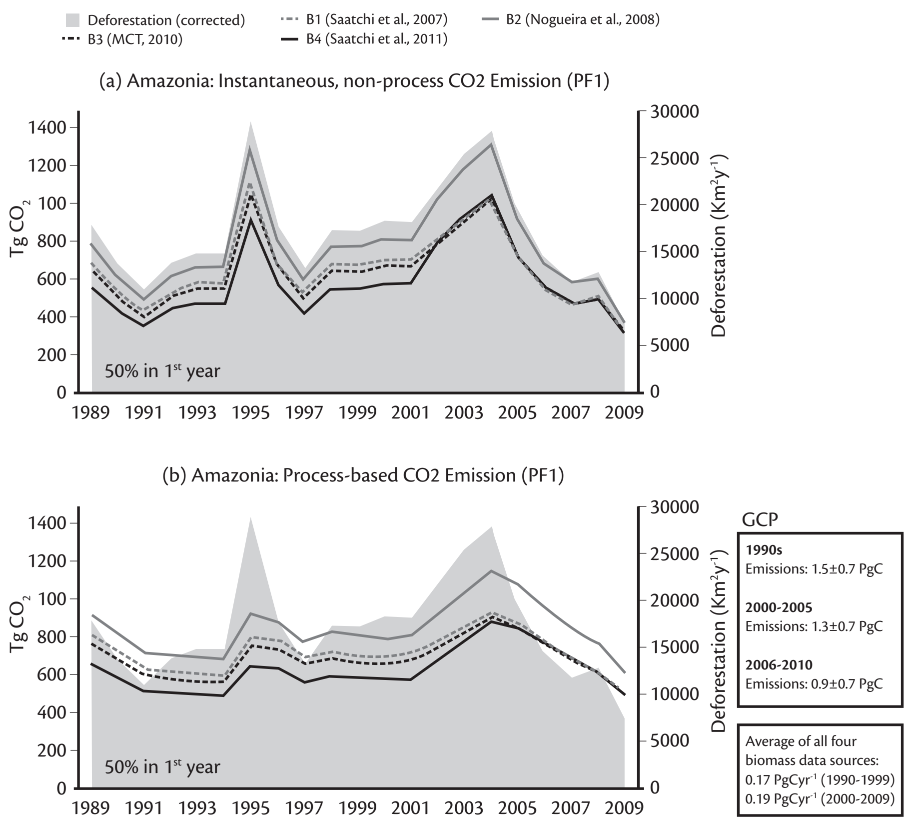

Figure 8. Amazonia's emissions - 1990-2009

According to Aguiar et al (2012)[15], "preliminary results of a project aiming at discussing sustainability scenarios for the Amazonia, combined a qualitative scenario methodology and two spatially-explicit quantitative modeling frameworks: one for land use change (LuccME) and another for

15 AGUIAR, A. et al. Scenarios for Amazonia 2050: combining emission reductions and social development. In: Planet under Pressure, London, 2012.

deforestation emission estimates (INPE-EM), both representing the heterogeneity of land change processes in the region. A panel of experts constructed storylines quantified in terms of pasture, annual/perennial crops, and secondary vegetation trajectories. INPE-EM is coupled to LuccME to estimate emission reductions resulting from spatial projections of land use trajectories under three different scenarios: (a) emission reductions without social development; (b) sustainability and social development; (c) return to uncontrolled deforestation. Initial modeling results showed that emission reduction in (a) and (b) can be of the order of 6 $GtCO_2$ or more, depending on socioeconomic incentives to the expansion and permanence of secondary vegetation as sinks of carbon."

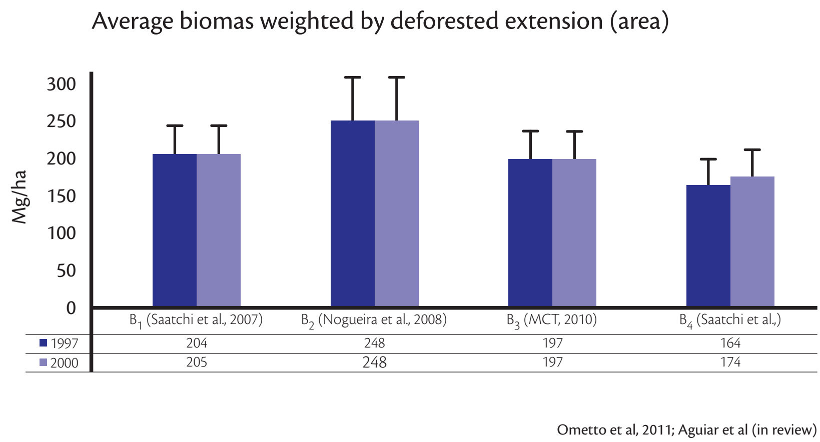

Figure 9. Average biomass weighted by deforested extension

The evaluation of impacts of land use change is in general limited by the knowledge of past land use conditions. Most publications present only a vague description of the earlier patterns of land use, which is usually insufficient for more comprehensive studies. Leite et al (2012) [16] present the first spatially explicit reconstruction of historical land use patterns in Brazil, including both croplands and pasturelands, for the period between 1940 and 1995. This reconstruction was obtained by merging satellite imagery with census data. It provides a 5' × 5' yearly data set of land use for three different categories (cropland, natural pastureland and planted pastureland) for Brazil. The results show that important land use changes occurred in Brazil. Natural pasture dominated in the 1950s and 1960s, but since the beginning of 1970s it has been gradually replaced by planted pasture, especially in southeast and center west of Brazil. The croplands began its expansion in the 1960s reaching extensive areas in almost all states in 1980. Carbon emissions

16 LEITE, C.C.; COSTA, M.H.; SOARES-FILHO, B. S.; HISSA, L.B.V. Historical land use change and associated carbon emissions in Brazil from 1940 to 1995. Global Biogeochemical Cycles, n.26, 2012.

from historical land use changes were calculated by superimposing a composite biomass map on grids of a weighted average of the fractions of the vegetation types. Net emissions from land use changes between 1940 and 1995 totaled 17.2 ± 9.0 Pg-C (90% confidence range), averaging 0.31 ± 0.16 Pg-C yr^{-1}, but reaching up to 0.47 ± 0.25 Pg-C yr^{-1} during the 1960s and through 1986–1995. Despite international concerns about Amazon deforestation emissions, 72% of Brazil's carbon emissions during the period actually came from deforestation in the Atlantic Forest and Cerrado biomes. Brazil's carbon emissions from land use change are about 11 times larger than its emissions from fossil fuel burning, although only about 18.1% of the native biomass has been lost due to agricultural expansion, which is similar to the global mean (17.7%).

7. Aiming at the big picture: what are the scientific issues?

sustainable land use change faces many difficulties. First, LUC has not yet been addressed under a framework that constrains cumulative emissions in order to respond to a future global warming target. The different scenarios point out that land emissions will go down and that fossil fuels emissions will go up, but as the available data is not reliable, the decrease is still a wishful thinking.

Prognostic and target related research are not performed in tandem and are not linked. We do not handle the combined diagnostic and prognostic uncertainty properly: we have two communities that don't talk to each other. One is looking at the short term, estimates true emissions, and aims for compliance (targets). The other looks at the long term, but as they don't have reliable data, the prognosis are not reliable as well. Combining diagnosis and prognosis we can increase reliability and contribute to better decision making. (Figure 10)

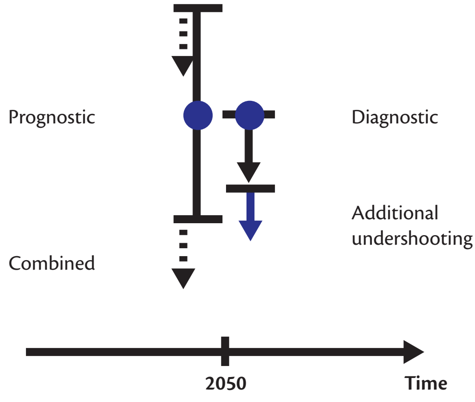

Figure 10. Diagnostic versus prognostic emissions

It is also important to understand that LUC is a complex social-ecological system, involving interactions between humans and the bio-physical world, including, for example, agriculture, forestry, climate change, exploitation of natural resources, the national economy, the society itself. Social and ecological sub-systems are co-evolving to multiple drivers of change, with positive and negative feedback, fuzzy system boundaries and emergent properties. It is also a multi-actor system, with multi levels of governance (community, local, regional, state, federal, global) and distributed decision power and plurality of world views and values. (Figure 11).

The challenge of understanding and projecting complex system behavior has risen in importance with the realization that much of the unpredictable behavior observed in real world situations is a function of the complex systems operating around us. To improve our understanding of complex system behavior, scientists have developed mathematical techniques based on computer models of these systems, to help think about them in new ways. These models reveal and explain a range of emergent system behaviors and provide a deeper understanding of entire systems and their responses, with often surprising and unexpected results.

To face complexity and reduce uncertainty we must realize that the era of using a single model for addressing uncertainty related to future environmental targets faces limits methodologically: we need multiple models to understand the multiple challenges presented by the complex systems. But employing multiple models for addressing uncertainty and risk related to future environmental targets is not the ultimate approach of applied systems analysis (ASA). Uncertainty and risk are interdependent and the ASA in place is not appropriate to deal with this.

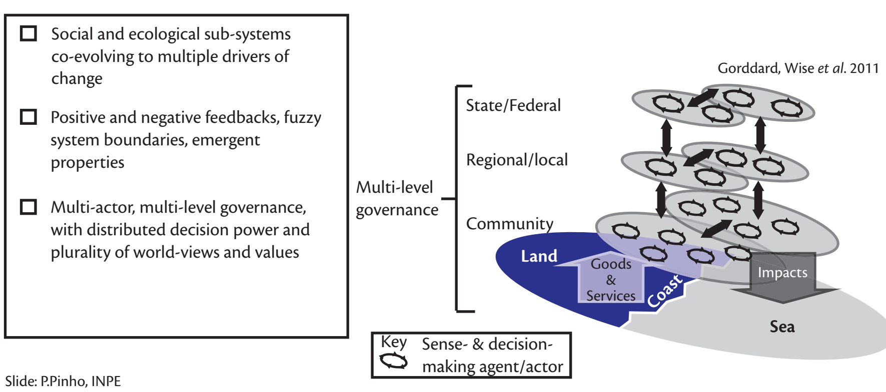

Figure 11. Complex social-ecological systems

Many countries sympathize with a global warming limit of 2 °C or below (relative to pre-industrial levels) as a guiding principle for mitigation efforts to reduce climate change risks, impacts and damages. However, the greenhouse gas (GHG) emissions corresponding to a specified maximum warming are poorly known owing to uncertainties in the carbon cycle and the climate response. (Meinshausen, 2009)[17] provide "a comprehensive probabilistic analysis aimed at quantifying GHG emission budgets for the 2000–50 period that would limit warming throughout the twenty-first century to below 2 °C, based on a combination of published distributions of climate system properties and observational constraints. For the chosen class of emission scenarios, both cumulative emissions up to 2050 and emission levels in 2050 are robust indicators of the probability that twenty-first century warming will not exceed 2 °C relative to pre-industrial temperatures. Limiting cumulative CO_2 emissions over 2000–50 to 1,000 Gt CO_2 yields a 25% probability of warming exceeding 2 °C—and a limit of 1,440 Gt CO_2 yields a 50% probability—given a representative estimate of the distribution of climate system properties. As known 2000–06 CO_2 emissions were ~234 Gt CO_2, less than half the proven economically recoverable oil, gas and coal reserves can still be emitted up to 2050 to achieve such a goal. Recent G8 Communiqués envisage halved global GHG emissions by 2050, for which we estimate a 12–45% probability of exceeding 2 °C—assuming 1990 as emission base year and a range of published climate sensitivity distributions. Emissions levels in 2020 are a less robust indicator, but for the scenarios considered, the probability of exceeding 2 °C rises to 53–87% if global GHG emissions are still more than 25% above 2000 levels in 2020."

17 MEINSHAUSEN, M. et al. Greenhouse-gas emission targets for limiting global warming to 2 °C. Nature, n. 458, p.1158-1162, 30 April 2009.

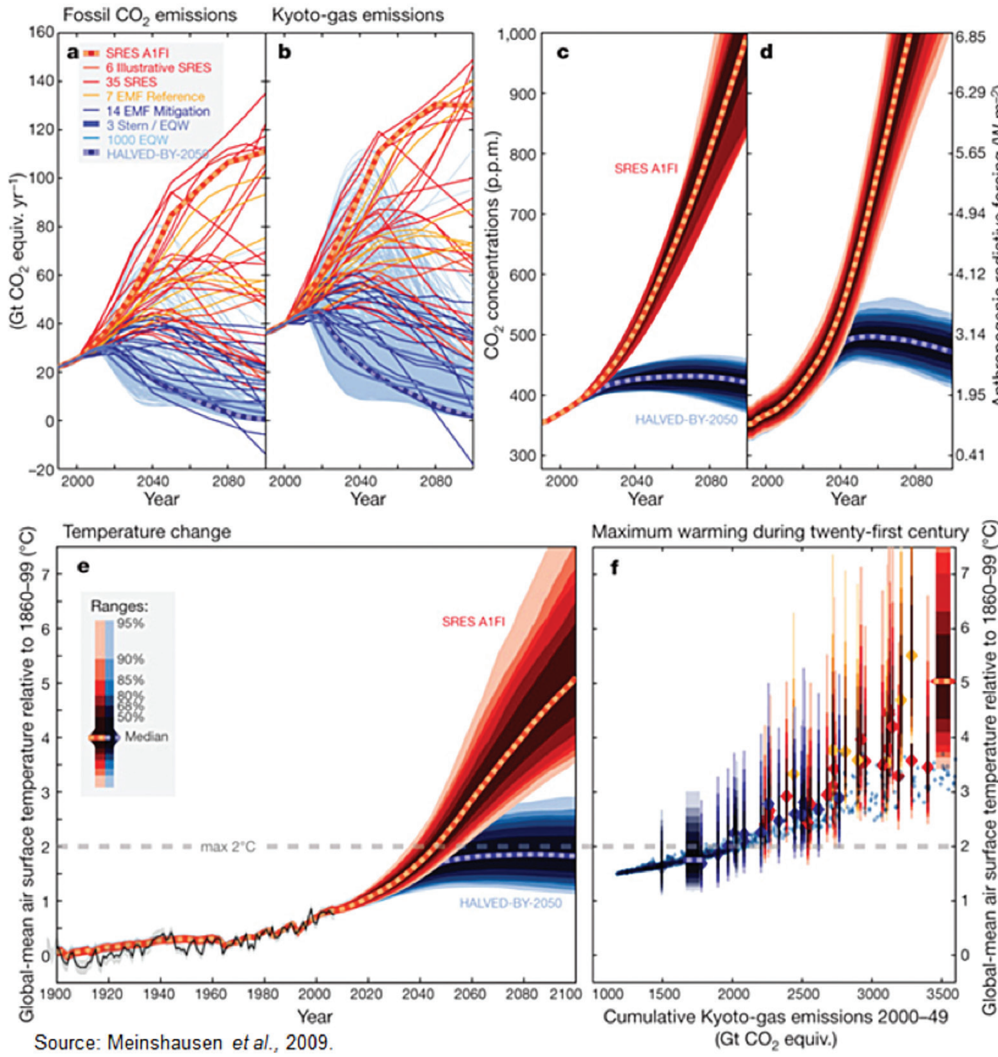

Figure 12. Emissions, concentrations and 21th century global-mean temperatures[18]

18 Figure 12 Label: a, Fossil CO2 emissions for IPCC SRES, EMF-21 scenarios and a selection of equal quantile walk (EQW) pathways analyzed here; b, GHGs, as controlled under the Kyoto Protocol; c, median projections and uncertainties based on our illustrative default case for atmospheric CO2 concentrations for the high SRES A1FI and the low HALVED-BY-2050 scenario, which halves 1990 global Kyoto-gas emissions by 2050; d, total anthropogenic radiative forcing; e, surface air global-mean temperature; f, maximum temperature during the twenty-first century versus cumulative Kyoto-gas emissions for 2000–49. Color range shown in e also applies to c, d and f. Source: Meinshausen et al (2009).

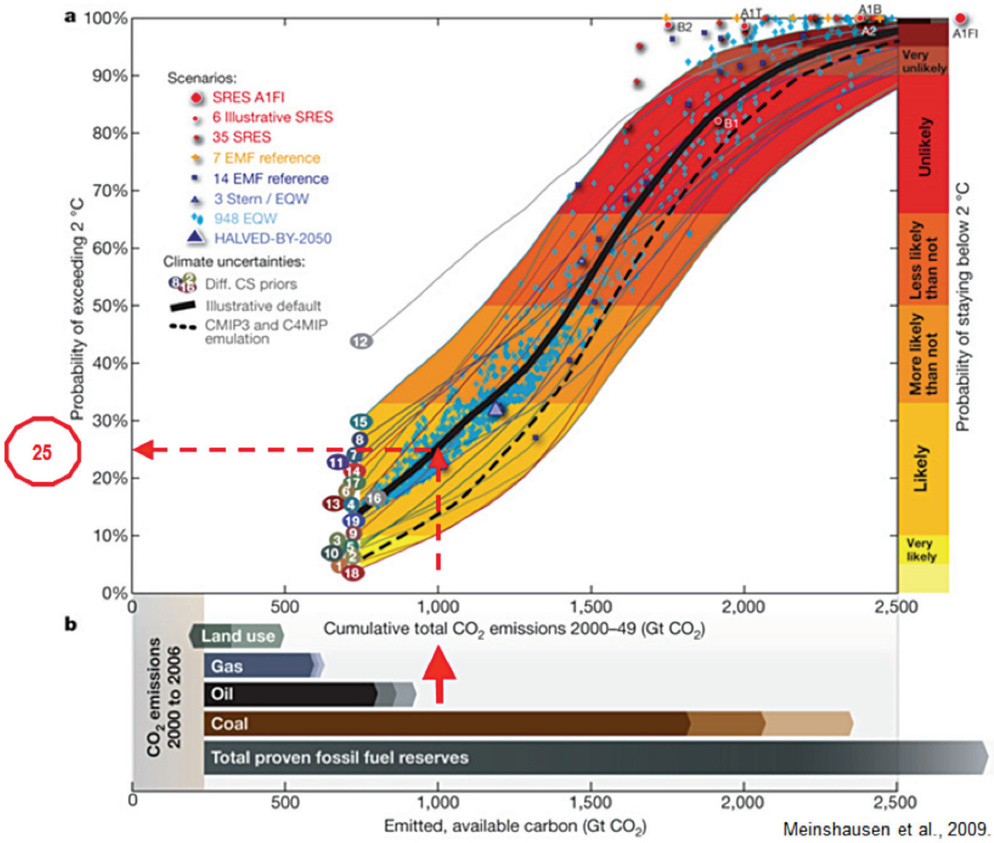

Figure 13. The probability of exceeding 2 °C warming versus CO2 emitted in the first half of the 21th century[19]

The further we are looking into the future the greater is the uncertainty and we also face our current limits of knowledge, even when we have reliable data, as it is the situation of USA, for example. Figures 14 to 17 show different scenarios of constraining emissions until 2050 for the US, a data rich country, and Brazil, which lacks reliable data, exemplifying how difficult it is for

19 Figure 13 Label: a, Individual scenarios' probabilities of exceeding 2 °C for our illustrative default (dots; for example, for SRES B1, A2, Stern and other scenarios shown in Fig. 2) and smoothed (local linear regression smoother) probabilities for all climate sensitivity distributions (numbered lines, see Supplementary Information for data sources). The proportion of CMIP3 AOGCMs26 and C4MIP carbon-cycle8 model emulations exceeding 2 °C is shown as black dashed line. Colored areas denote the range of probabilities (right) of staying below 2 °C in AR4 terminology, with the extreme upper distribution (12) being omitted. b, Total CO2 emissions already emitted3 between 2000 and 2006 (grey area) and those that could arise from burning available fossil fuel reserves, and from land use activities between 2006 and 2049 (median and 80% ranges, Methods). Source: Meinshausen et al (2009).

the decision makers to meet these constraints. This points out to the need of more trustful data and systems that really help to reduce uncertainty and risk and contribute to improve the decision making process.

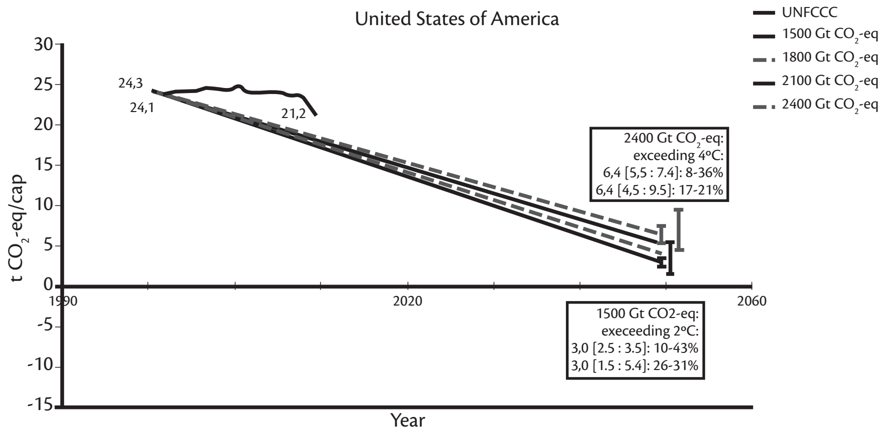

Figure 14. Emissions in USA

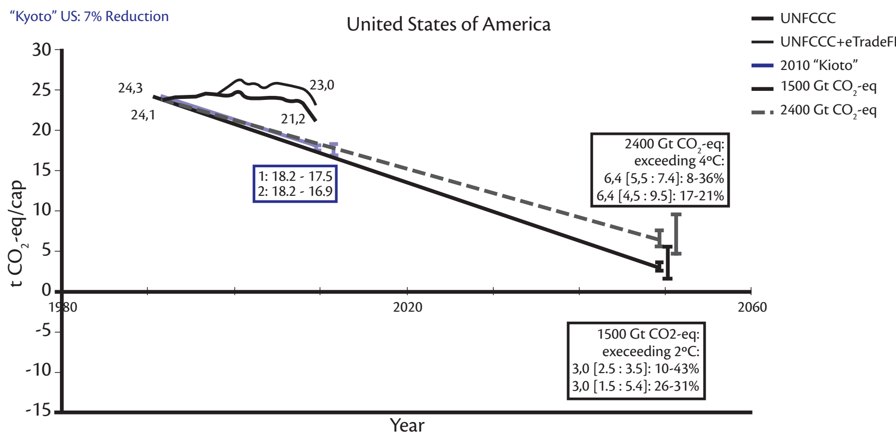

Figure 15. Like Figure 14 but with the hypothetical Kyoto target of a 7% reduction and fossil-fuel emissions embodied in trade

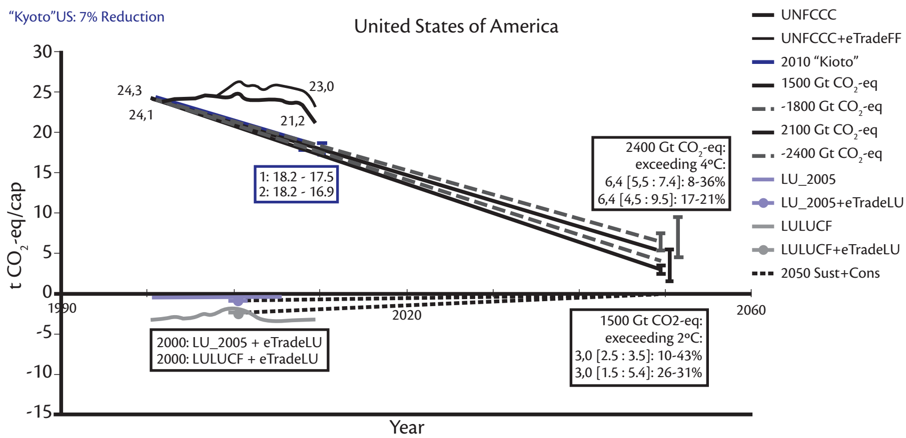

Figure 16. Like Figure 15 but with LUC

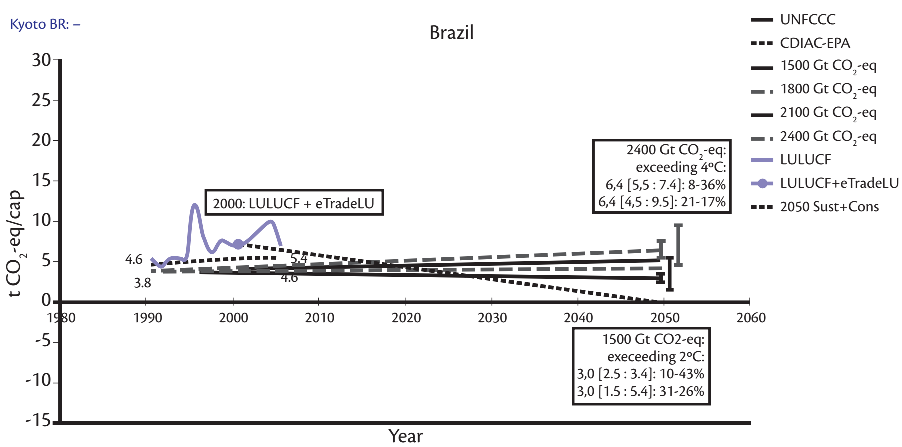

Figure 17. Like Figure 16 but for Brazil

8. Conclusions and recommendations

The changes in land use are a product of complex interactions between human actions and biophysical processes. International goals provide one set of guidelines for land management, but these are often overshadowed by other pressures and competing demands. Four major themes may explain the apparent movement away from achieving land related goals:

- Economic growth at the expense of natural capital.
- Competing demands for land.
- Increasing separation of production from consumption.
- Governance challenges related to sustainable land management.

Findings from GEO-5 reinforce the importance of setting measurable goals and targets to effectively monitor progress and advance the sustainability agenda. Goal-setting arenas at the international level include not only the public institutions such as UN system but also civil society groups and private-sector associations, among others. Global goals need to be complemented by synergized regional, national and local goals, as well as concrete national action plans.

Tropical deforestation and agricultural expansion still contribute considerably to global GHG emissions and its ecosystems future brings a lot of uncertainty.

Although simulation tools are available to address LUC and selected ecological and economic impacts, land use faces the problem of lack of reliable data, and this increases uncertainty and risk.

Understanding that LUC is a complex social-ecological system is vital for the adoption of a new approach, a multiple model that will help to improve the decision making process. It is not possible to think about the atmosphere without looking to what is happening to the land.

Local actions have a global impact, and this must be incorporated in decision making. Technical knowledge must support decision making as well and it is important to create this link in order to support policymakers in developing rational, science-based and realistic national, regional and global strategies for the production of food, feed, fiber and bio-energy and other services to achieve long-term sustainability of land and water resources while promoting rural development.

LUC needs a new approach. Integrated analysis of LUC strategies (e.g. local, regional or national) for current bioenergy, agriculture, forestry and potential options on a life cycle basis over time inform decision makers on environmental, social and economic impacts.

The LUC science community must provide information on how it wants to go about emissions resulting from land use and land-use change under an emissions constraining framework to respond to a '2 or 3 or 4ºC world'.

If this is not done, LUC emissions can also not be part of such a constraining framework, with the consequence that we have to go for a different policy approach to deal with LUC emissions and the remainder of the terrestrial biosphere.

The key features identified for this new LUC approach are:

- Multi-institutional & international
- Optimized systems approach
- Complementary multi-model/technique approach
- Multi-target approach to define sustainability
- Consistent from global to sub-global and from long to short-term to have a bearing on the here and now
- New ASA to deal with uncertainty and risk following predictive norms
- Constraints on biomass estimates and LUC mechanisms
- LUC scenarios that consider several social-ecological frameworks (i.e., social development and environmental sustainability)

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