Work plan for data exchange between the Integrated Assessment and Climate Modeling community in support of Phase-0 of scenario analysis for climate change assessment (Representative Community Pathways).

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1. Background

During its 26th meeting in Bangkok in May 2007, the IPCC requested the preparation of a new set of scenarios to facilitate future assessment of climate change. This new set (that is intended to replace and extend the scenarios used in earlier IPCC assessments) should be compatible with the full range of stabilization, mitigation and baseline emission scenarios available in the current scientific literature. The IPCC also decided that, in part because of the growing number of scenarios developed within the research community, and the research communities organizational structure, the research community itself would undertake development of scenarios for assessment in a possible AR5, while the IPCC's role would be that of catalyzing and assessing such work.

The research community has subsequently outlined three phases of scenario development: a preparatory phase and two main phases of scenario development—a parallel product development phase and an integration, dissemination, and application phase. In the preparatory phase, four integrated assessment (IA) concentration and emissions scenarios will be chosen from the existing literature and provided to climate modelers. These scenarios are referred to as "*representative concentration pathways*" (RCPs). These scenarios will be used to produce a new set of climate model simulations that will subsequently used for mitigation, impacts, adaptation, and vulnerability analysis. The primary goal of the RCPs is to provide, in a timely manner, the most up to date scenarios possible to be used to produce these new climate model simulations.

The identification of RCPs up-front is done to expedite the development of integrated scenarios by enabling climate modeling to proceed in parallel to emission and socio-economic scenario development. In the past, scenario development has been carried out as a sequential process (from socio-economics and emissions to climate projections and finally impact assessment). This sequential process prolonged the integration of information across the three research communities. The identification of RCPs will thus enable the climate modeling community to proceed with new climate change projections at the same time that new work is carried out in the Integrated Assessment Model (IAM) and Impact, Adaptation and Vulnerability (IAV) communities. The RCPs will be used for simulations by the Climate Modeling (CM) community, including Earth System Models (ESMs), Coupled Ocean Atmosphere Global Circulation Models (AOGCMs) and Earth System Models of Intermediate Complexity (EMICS

At an IPCC Expert meeting on New Scenarios, held 19–22 September 2007 in Noordwijkerhout, The Netherlands, a set of RCPs was identified. Following the Expert meeting, the CM and IAM communities began coordination on the resolution details of the RCP data that is to be exchanged. The rationale for choosing RCPs, the actual RCPs relative to the literature, guidelines on the use of the RCPs, and the overall new scenarios development timeline and products are described in the Noordwijkerhout report (Moss et al., 2008). The set of four RCPs is summarized in Table 1.1.

Table 1.1: Overview of Representative Concentration Pathways (RCPs)

	Description[1]	Publication – IA Model
RCP8.5	Rising radiative forcing pathway leading to 8.5 W/m^2 in 2100.	Riahi et al. (2007) – MESSAGE
RCP6	Stabilization without overshoot pathway to 6 W/m^2 at stabilization after 2100	Fujino et al. (2006) and Hijioka et al. (2008) – AIM
RCP4.5	Stabilization without overshoot pathway to 4.5 W/m^2 at stabilization after 2100	Clarke et al. (2007) – MiniCAM
RCP3-PD[2]	Peak in radiative forcing at ~ 3 W/m^2 before 2100 and decline	van Vuuren et al. (2006, 2007) – IMAGE

Notes:
[1] Approximate radiative forcing levels were defined as ±5% of the stated level in W/m^2 relative to pre-industrial levels Radiative forcing values include the net effect of all anthropogenic GHGs and other forcing agents.
[2] PD = peak and decline.

The four IAM groups responsible for the four published RCPs as noted in Table 1 accepted the task to generate data in such a way that it would facilitate climate modeling experiments. The data requirements include providing a full set of radiative forcing component data, including information on emissions and concentrations and accompanying land use and land cover information.

Before delivering the data to the CM community, several tasks needed further work such as harmonization of base year data, harmonizing definitions of data categories, downscaling of emission data and extension of data beyond 2100 to 2300.

The purpose of this paper is to provide a work plan to ensure that data from the Integrated Assessment groups is made available in a way that is most useful for purpose of producing new Climate Model simulations. This document outlines some of the activities that are proposed to be performed by different groups, but also identifies open questions that still need to be answered. This work plan will evolve over the next few months as the coordination efforts proceed and feedback is received from the research community.

To ensure input into the process of data exchange from both the IAM and CM communities, the Integrated Assessment Modeling Consortium (IAMC) and the Analysis, Integration and Modeling of the Earth System (AIMES) project of the International Geosphere-Biosphere Programme (IGBP) co-organized a workshop from 6-8 February, 2008 in Washington DC with representatives of both the IAM and the CM communities to discuss a process that would lead to data exchange in September 2008. The meeting on the RCPs was organized around three topics:

1) Emissions and concentrations
2) Land use and land cover
3) Extension of scenarios to 2300.

This report discusses the plans for finalizing the RCP data in each of these three topic areas. First, section 2 describes the overall timing of the data exchange process long with more general issues.

2. Overall process and general issues

2.1 The role of the data exchange and harmonisation process

One of the criteria used in the selection of the RCPs was publication in a peer-reviewed journal and subsequent assessment by the IAM community. This requirement is due to the combination of a desire to use scenarios that have been peer-reviewed and the need to produce the RCP data in a very short timeframe, a timeframe that is too short for the production of new scenarios. It should be noted, however, that the information currently available from the IAM teams cannot directly be used for CM modeling. Reasons include: 1) lack of harmonization across the different RCPs (complicating comparison across different climate scenarios – but also creating problems going from historic to future data series in climate models), 2) lack of detail on land use and land-use change (the information in published articles is very low; but also for most IAM model the information directly available is not sufficient for CM use, 3) scenarios end in 2100 – while an interest was expressed by CM community to have information available upto 2300, 4) limited harmonization to latest base-year historical information (important for consistency in both IAM and CM runs between historic and future data series). In Noordwijkerhout, a process was agreed upon in which additions would be made to the published scenarios underlying the RCPs to overcome the issues mentioned above. The final RCPs are expected to reflect the principal characteristics of the original published scenarios, with updated historical information and additional model detail. These updates will result in some differences between the RCPs and the original published scenarios. While, overall, these differences are expected to be modest, particularly at a long-term, global level, these will be documented along with the final delivered data delivered.

2.2 Timeline

The overall timeline of the RCP preparation is indicated in Table 2.1.

Table 2.1: Overall timeline for preparation of Representative Concentration Pathways

Time period in 2008	Action		
	Other/general	Emissions	Land use/Land Cover
February	• Washington DC workshop	• Define list of sectors • Provide aircraft/shipping information	
March	• Comments on different proposal coming out Washington workshop	• Finalize 1x1 2000 data set • Distribute training set	• Collecting land use definition/harmonizing definitions.
April	• Final proposal 2300 extension • Possible Bilthoven/Vienna workshop	• Final proposal emission/concentration hand-off • Perform harmonization/gridding (1x1) • Provide preliminary gridded emissions	• Final proposal land use /cover hand off
May	Provision of extended scenarios (to 2300) by individual IAMs	• Perform harmonization/gridding • Provide preliminary gridded emissions	
June	Calculate concentrations of extended scenarios with single/harmonized climate model	• Updated EDGAR inventory is released • Create new spatial emissions based on new EDGAR inventory (0.5x0.5)	• Test data set
July	• Vetting of data (review within the community)	• Create emission files for chemistry models • Perform tests and distribute	
August	• Snowmass '08	• Perform initial calculations as test	• Land use workshop Snowmass
September	• Delivery of final data	• Provide final data	

October		• Start atmospheric chemistry modeling (to create additional input data)	
November			
December			
January	• Intended start data CMC simulations		

Logistics for final data distribution

Final logistics for data distribution still need to be determined. In the meanwhile, it is proposed that emission data could be available through the GEIA website. Data on main scenario variables (drivers and emissions) from the four IAM teams will be made available via the IIASA website. Further decisions on final data dissemination will be made in due course.

2.3 Regional definitions.

Given that the primary goal of this exercise is to provide input data for climate models, the core products will be global emissions and concentrations of long-lived greenhouse gases, gridded emissions of shorter-lived species, and gridded land-use and land-use change information. Data at a regional aggregation level is also useful, both for convenience for those modeling groups that use more aggregated data, and for validation and verification purposes. Therefore, the four IAM models will also provide RCP information at a regional scale – aggregated up from the gridded data. It is proposed that IAM modeling teams report their data with a common regional disaggregation (Table 2.2). We propose that the IAMs report regional data starting with downscaled results, with regional data reported by summing the harmonized higher resolution results up to the desired regional aggregation. This methodology assures that regional definitions are consistent across models (this is particularly necessary for the regional aggregation level), that the data are automatically harmonized, and that the regional data reported is consistent with the harmonized, gridded data provided to the climate modeling community.

Table 2.2: Regional definitions

High aggregation level	**Medium aggregation level**
OECD	North America (USA + Canada)
	Western Europe (inc. Turkey)
	Australia, New Zealand and Japan
FSU and Eastern Europe	Central and Eastern Europe
	FSU
Latin America	Latin America
Developing Asia	China and Centrally planned Asia
	India/South Asia
	Rest of Asia
Africa and Middle East	Middle East + north Africa
	Sub-Sahara Africa

Note that the regional information thus produced is intended for purposes of validation and to facilitate climate modeling. This information should not be used to infer regional differences across RCP stabilization levels because regional details and modeling approaches differ between the four IAM modeling groups. Consistent regional comparisons would need to be conducted during the following research phase (the “parallel phase”, Moss et al. 2008).

2.4 Procedure

In order to facilitate further development, working groups consisting of IAM and CM representatives and other experts have been convened. Membership of these working groups is not restricted, and interested persons are invited to contact the first person listed in each group.

> *Working group 1 - Emissions and Concentrations*: Jean-Francois Lamarque, Steve Smith, Detlef van Vuuren, Keywan Riahi, John van Aardenne.
> *Working group 2 – Land use*: Detlef van Vuuren, Johannes Feddema, Peter Thornton, Kathy Hibbard, Steve Smith, George Hurtt, Steve Rose, Elena Shevliakova, Kees Klein Goldewijk, Julia Pongratz, Elke Stehfest.
> *Working group 3 – Extension:* Keywan Riahi, Mikiko Kainuma, Steven Rose, Steve Smith, Detlef van Vuuren.

3. Emissions

3.1 Introduction

Climate models have increasingly added detailed descriptions of the sources, sinks and atmospheric chemistry of both greenhouse gases and air pollutants. This creates additional data requirements for the scenarios used to drive climate modeling experiments, specifically gridded data for emissions of reactive gases and aerosol precursor compounds (SO2, NOc, VOC, BC, OC, CH4 , and NH3) in order to model atmospheric chemistry in interaction with a changing climate. Some of these calculations are performed endogenous to the climate model while other calculations may be performed off-line as “snapshots” that provide concentrations and aerosol loadings inputs to a climate model..

In response to the additional data needs of CM models, below a work plan has been described that allows harmonization of IAM output data and data generation at level that is useful for the CM community as a whole.

3.2 Workplan

The different steps in the work plan are described below first for the common elements that apply to all gases and then the additional information needed for reactive gases and aerosol precursors.

All emissions

1. **Harmonization**: Harmonization is defined as a procedure whereby emission outputs from the IAMs are adjusted such that emissions in the reference year are equal to some reference data set (with these adjustments carried into the future in some manner to assure smooth data sets). The reference year for these scenarios will be the year 2000 (scaling is done by all groups individually). We propose to use information developed for the HTAP work let by JRC. This information consists of a combination of regional data sources, national communications and the EDGAR dataset. While the emissions are currently only available at 1° (latitude x longitude), it is expected that a 0.5°-version will be available by the time final emissions are provided (currently the data is planned to be available June 2008). Additional information (e.g., sulfur dioxide - SO_2, organic

carbon/black carbon - OC/BC) will be provided by datasets for year 2000 as well (S. Smith and T. Bond, pers comm.). There will be an evaluation period during which evaluation of the year 2000 datasets will be analyzed and corrected if significant biases are found. It is proposed that if EDGAR is not used for some individual emissions, the spatial patterns from EDGAR will still be used – but scaled to the emissions of the other source (possibly with the exception of BC/OC, sulfur and aviation emissions).

2. **Temporal resolution**: Annual average RCP emissions will be provided to the CM community for 10 year time steps (up to 2100; resolution beyond 2100 still needs to be discussed). The chemistry groups will modify these emissions to produce data at a temporal resolution suitable for chemistry modeling, for example using linear interpolation to obtain yearly emissions and adding a seasonal cycle to provide final emissions at a monthly timescale.

3. **Type of emissions**: Anthropogenic emissions (including those associated with land-use and land-use change) will be made available by the IAMs (for a list of emissions, see Table 3.1). Natural emissions as assumed by the IAM will be reported as well – although CM groups might not choose to use them.

4. **Sectoral information**: We propose that IAMs provide gridded emissions (for all species) for separate sectors and selected subsectors. The minimal set of sectors will be defined by the chemistry modeling community (CMC) by May, 2008.

   Draft sector list:

   1) Air Transportation
   2) International Shipping
   3) Other transportation
   4) electric power plants, energy conversion, extraction and distribution.
   5) Solvents
   6) Waste (landfills, waste water, non-energy incineration)
   7) Industry (combustion and process emissions)
   8) Buildings (Residential and Commercial)
   9) Ag. waste burning on fields
   10) agriculture (Agricultural Soil Emissions, Other Agriculture)
   11) Savannah burning
   12) Land use change
   13) All other emissions

Definitions of emissions breakout categories need to be further defined. In large part these categories will be defined by the available HTAP/EDGAR data.

5. **Historical emissions**: in order to ensure compatibility with land-use change estimates, it is proposed that different groups working on historic emission inventories cooperate in establishing likely historic trends following agreements made in May 2008. If no agreements is reached, the EDGAR-HYDE emissions be used as default historical (1850-1990) emissions. Emissions of SO_2 and BC/OC will use the aforementioned datasets.

6. **Table 3.1: Information needed by CM groups**

Variable	Units	Spatial scale	
		Concentrations	**Regional and sectoral emissions**
Greenhouse gases			
CO_2 (fossil fuel, industrial, land use change)	ppm and Pg/yr	Global average	Sum
CH_4	ppb and Tg/yr	Global average	Grid[1]
N_2O	ppb and Tg/yr	Global average	Sum
HFCs[2]	ppb and Tg/yr	Global average	Sum
PFCs[2]	ppb and Tg/yr	Global average	Sum
CFCs[2]	ppb and Tg/yr	Global average	Sum
SF_6	ppb and Tg/yr	Global average	Sum
Aerosols[2]			
Sulfur (SO_2)	Tg/yr	Generated by CM community[3]	Grid
Black Carbon (BC)	Tg/yr	Generated by CM community[3]	Grid
Organic Carbon (OC)	Tg/yr	Generated by CM community[3]	Grid
Chemically active gases			
CO	Tg/yr	Generated by CM community[3]	Grid
NO_x	Tg/yr	Generated by CM community[3]	Grid
VOCs[2]	Tg/yr	Generated by CM community[3]	Grid
NH_3	Tg/yr	Generated by CM community[3]	Grid

Notes:

[1] The CM community has expressed an interest in specifying all RCPs at the same grid, for both the near- and long-term of 0.5° x 0.5°. This is the current plan as outlined in this document.

[2] Additional information by species and/or sector is required. The exact specification is being discussed as described in this document..

[3] The CM community will be generating this information from IAM emissions data. Ozone (O_3) concentrations are not included in the table as IAMs calculate these concentrations at a scale too coarse to be meaningful for the CM community. Emissions of O_3 precursors are provided instead. ESMs and/or chemistry-transport models will provide O_3 distributions. For the other reactive gases and secondary aerosols, a comparable approach will need to be used, since the coarse scale of IAMs does not provide meaningful information for the CM community.

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Non-CO_2

For some non-CO_2 emissions additional resolution is required:

7. **Horizontal resolution** will be 0.5° (well mixed gases will be provided only as a sum). In order to achieve this resolution, IAMs have to use regridding procedures (from their native regional information down to the required grid - see text above in section 2.2); it is expected that each IAM will use their own procedure for this regridding (if emissions are modeled at the grid level in an IAM, then regridding might be necessary as part of the harmonization procedure for 2000 emissions). While there would be some advantage to using a common gridding procedure, each IAM group represents these emissions in different ways, making it difficult to conduct a common gridding exercise without going to a “common denominator” approach, which would lose significant detail. It may be possible as a research exercise to explore at a latter date the impact of the different gridding methodologies used by each group.

8. **Shipping/aircraft emissions**: Separate emissions for future aircraft and ship transport are requested by the CMC. Emission scenarios are taken from other sources and made consistent with the original RCPs (following agreements made May 2008). When available, documentation on data sources, assumed energy consumption, and emissions factors will also be provided. Additional information (e.g., potential opening of shipping routes over the Arctic) will also be made available, if possible.

9. **Ammonia emissions**: so far, only the IMAGE group has extensively simulated NH_3 emissions. The IMAGE group has provided data on base year NH_3 emissions and emission factors to other model groups to ensure reasonable estimates of ammonia emissions.

3.3 Format information

- File format: ASCII or netCDF
- Units: kg/yr per grid cell

3.4 Concentrations

The emissions data to be provided as the primary output of this exercise will be harmonized to identical base-year 2000 values. Since emission data will be harmonized, rather than using the direct concentrations output of the IAM models, it is proposed that the harmonized emissions be run through a simple climate model (e.g., MAGICC-AR4 or Bern) in order to provide a consistent calculation of concentrations from emissions. Concentration data from a simple climate model is only useful for compounds that can be represented with global concentrations (e.g., CO_2, CH_4, N_2O, HCFCs). It is expected that the climate models in the individual IAM groups are comparable enough not to create a major inconsistency in this way with either the original underlying scenario and the stated RCP target, but this assumption will be checked by the IAM groups as part of the data review process. For compounds requiring detailed gridded fields (O_3, S-aerosols), atmospheric chemistry models will be used to generate the necessary detailed input fields for ESM and other CMC model runs.

4. Land use and land cover

4.1 Introduction

Land use and land cover change play an increasingly important role in simulations in both the IAM and the CM Community. However, compared to emissions, less attention has been paid to comparing simulations of different models both within the two communities and among them. This section identifies and outlines procedures to produce a consistent (as possible) exchange of information, ensuring compatibility between the information provided by IAMs and the required and subsequent interpretation of that data by the CM community. In this context, it is essential to distinguish between land use and land cover. Land cover refers to what is actually at the surface of the earth due to both human and natural processes, and includes categories like forests types, grass and crop lands. Land use can refer to both 1) processes that transform a land area through human modification of natural (e.g., forests, grasslands) into domesticated (e.g., crops, pastures, and urban) environments (also referred to as land-use change), and 2) these domesticated environments themselves[1].

Data exchange for the RCPs between IAMs and the CM community on land use and land cover will require comparison and evaluation across both communities (Figure 4.1). The implementation and generation of land use/land cover categorizations, base year data and gridded representation differ for each scenario and IAM. In addition, the CM models that incorporate land cover and vegetation dynamics each employ unique strategies with regard to land use/land cover definitions and data sources, and land cover information can be much more detailed in a CM model than that provided by the IAM groups. Any exchange of information, thus, needs to recognize the wide diversity of approaches within and across these communities. A number of options were available for harmonizing the characteristics of land across the IA and CM models. For this exercise, we choose to standardize IAM output into a common reporting format and each CM group will have to translate the IAM land use and land cover information as necessary to suit their own purposes.

A two-track exercise is proposed:

1. A formal track follows a relatively light approach that ensures:
    a. clear definitions of land use / land cover are provided from the different IAM groups and are consistent as much as possible,
    b. data is reported in a common data format for a minimum agreed upon data set, and;
    c. more detailed data from individual IAM modeling groups is added as attachment.
    d. This approach, thus, does not involves harmonization of the actual base year data for land use and land cover.

    This approach intends to minimize the effort required by both IAM and CM groups in this process, but ensures that all basic needs are met to develop transient ESM land cover input data. All IAM model groups are expected to provide data consistent with this first track.
2. In addition, a second, voluntary, track is proposed that takes a more ambitious approach – and aims for data harmonization (see 4.5).

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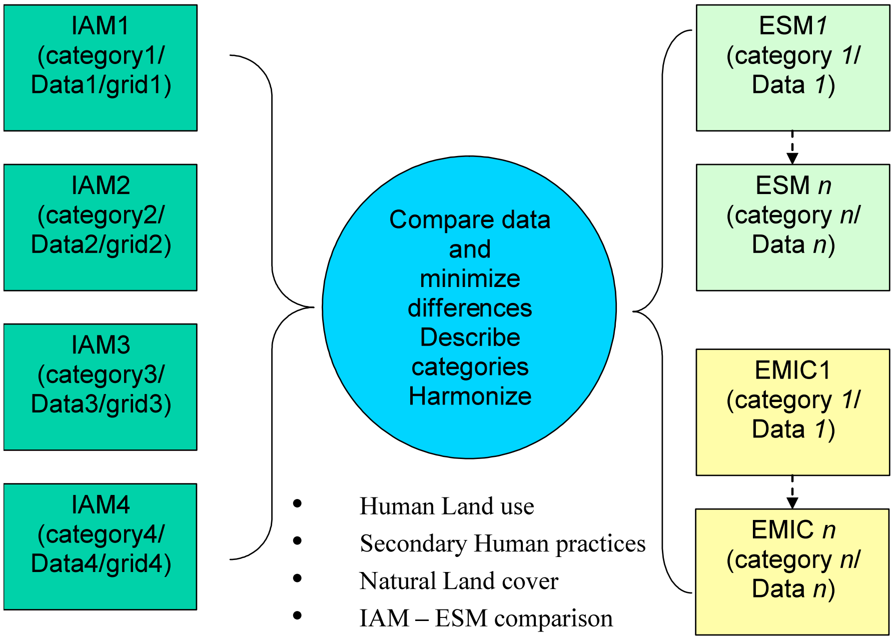
[1] The terms ‘land cover’ and ‘land use’ are sometimes used interchangeably. In contact between ESM and IAM groups, this imprecise use of terms can lead to confusion and should be avoided.

Figure 4.1: Schematic representation of the IAM to ESM/EMIC land cover information handoff



4.2 Land use and land cover in CM and IAM models

Land use is an important component of any future RCP trajectory. Within IAM models, land use plays an important role in simulating food production (cropping and grazing), production of bio-energy, and forestry products; and, with land cover simulating the exchange of carbon between the land surface and the atmosphere. Some IAM models also simulate a natural biogeography component, where vegetation changes are driven by climate, atmospheric composition, and land use change with dynamic feedbacks to the carbon cycle. In CMs that simulate vegetation dynamics, land cover interacts dynamically with the climate system through biophysical processes, emissions and uptake of greenhouse gases. While some CM groups have implemented various components of land cover change, land use is generally exogenous, or prescribed.

A number of consistency issues confront the use of land-use data. Differences at both the grid level and at at a regional level will exist in terms of: natural vegetation type, area covered, assumed land-use history, and type, and perhaps intensity, of anthropogenic land-use. Such differences will exist between the different IA models and between the IAMs and CMs.

There are a number of approaches that CM groups can follow for using the land use (and/or land cover) information from the IAMs. These include:

1. Translate all land use and land cover information to the CM's native land cover classification system to create a dataset replicating as best possible the IAM land scenarios. This is, however, not a viable option for several CM groups as the dynamic vegetation components within the CMs produce natural vegetation properties that change endogenously over time. For models, without a dynamic global vegetation model (DGVM) components, this may be a relatively straightforward approach.

2. CM groups can overlay human land use from IAMs over their land cover classification to effectively simulate the impact of human actions isolated from any changes in the natural vegetation state as simulated by the IAM.
3. Both land use and land cover information from IAMs can be directly integrated into the CM, thus supplying a complete land-cover and land-use input data set for the CM.

Key elements of modeling land use in CMs are:

- A smooth transition from historic to future land use;
- Land use data must be consistent with the characterization of land cover in each CM;
- Land use must be clearly distinguished from land cover;
- Land use and land cover categories require detailed characterizations that are based on their role in biogeophysical and biogeochemical processes.

It is expected that all CMs will need to assure that there is a smooth transition between their existing historical land-cover representation and the land-use scenario provided by the IAMs. This will likely require some adjustments to the IAM land-use scenario data.

As a result of these elements, the RCPs need to be reported with very clear definitions of the data that is provided. It is less obvious whether it is useful to harmonise the IAM base year land use data as the data still needs to be interpreted in the context of the CM model (even after harmonization). Given the timing of this exercise, however, it is likely the IAM groups will have some limitation as to the degree to which their historical land-use assumptions can be changed. This consideration is the main rationale for the two-track exercise that is proposed here: CM modeling groups may decide to use the original IAM outputs directly, or use data developed using the approach described in 4.5, which includes a higher degree of harmonization.

4.3 Parameters included in exchange

Land use

Since the purpose of this information exchange is to track the impact of human induced land cover change on climate, the IAMs will provide detailed information on anthropogenic land use changes. At a minimum, the IAMs will provide the following land use information:

1. Cropland (by type)
2. Managed forest
3. Pasture and grazing land (preferably separated)
4. Built-up land (infrastructure, urban, semi-urban etc.)

The top priority is for the land use data to be provided at 0.5 x 0.5 degree resolution. The data should also be reported at the regional level as is generated by the individual IAM, using the same classification used for regional emissions reporting. It is critical that the IAM community create at the minimum clear (by model), and preferably consistent (across models) definitions of these land use classifications. Without consistent definitions of these terms it will be difficult for the CM groups to create land use/land cover classifications that are comparable between the RCPs. Because a number of CM groups are developing crop models for specific crop types, IAMs should specify the nature of a crop. Similarly, it is preferred that managed forest types provide sufficient information for CM groups to identify a specific tree type associated with a managed forest. Also pasture grazing land needs to be clearly defined in terms translatable to CM vegetation types; and, as much as possible, consistent between groups

A first comparison illustrates that most IAM models seem to have land categories fairly consistent with that used by FAO (Table 4.1). Table 4.1 provides the FAO definitions of land use categories. Table 4.2 presents general land use/land cover types for each RCP. All IAM teams are asked to make a comparison of their definitions and data output with the FAO.

Table 4.1: Main land use categories

Category	Definition
Agricultural land	Agricultural area refers to: (a) arable land; (b) permanent crops and (c) permanent pastures.
Arable land + permanent crops (crop land)	Arable land refers to land under temporary crops (double-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (less than five years). The abandoned land resulting from shifting cultivation is not included. Data for arable land is not meant to indicate the amount of land that is potentially cultivable. Permanent crops are sown or planted once, and then occupy the land for some years and need not be replanted after each annual harvest, such as cocoa, coffee and rubber. This category includes flowering shrubs, fruit trees, nut trees and vines, but excludes trees grown for wood or timber.
Permanent pasture (pasture and grazing land)	Land used permanently (five years or more) for herbaceous forage crops, either cultivated or growing wild (wild prairie or grazing land). The dividing line between this category and the category "Forests and woodland" is rather indefinite, especially in the case of shrubs, savannah etc., which may have been reported under either of these two categories.
Built-up	Land used for dwellings, industries and other human infrastructure.
Forest plantations[2]	Plantation forests (or man-made forests): are forests established by afforestation or reforestation. Plantation forests include all types of forest tree plantations whether industrial, communal or individual covering at least an area of about half hectare. Trees on road side, canal banks and homesteads are not included; also rubber, coconut and oil-palm are excluded.

In addition to specifying human land use distributions, IAM models are also asked to provide auxiliary information to use to more precisely characterize the nature of human activity on the land surface. This information will only be made available at the regional scale. Such information includes (prioritization from CM would still be very helpful):

1. Irrigated area
2. Harvested area
3. Wood use – destination of wood harvest
    a. Percent of harvested biomass burned
    b. Percent of harvested biomass destined for wood and fiber products
4. Fertilizer usage
5. Standard of living index or a proxy indicator

Harvested area and its disposition are critical to carbon cycle modeling, as is fertilizer use through its impact on net productivity rates. The standard of living index can be useful to indicate the intensity of a human land cover, for example urban characteristics and building types typically change with aggregate standard of living indicators. Similarly, assumptions about cropping practices, fertilizer usage and intensity of land use can be linked to a standard of living index, which will be useful for both IAM and Impacts, Adaptation and Vulnerability (IAV) communities.

Further attention is probably needed to defining grazing land / pasture area across the different modeling teams.

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[2] Various alternative definitions exists from e.g FSC, expert group of the CBD and EEA.

Table 4.2: Preliminary response on IAM land use and land cover categories (land use categories currently refer to those provided by the IAM teams; terms will be harmonized further as part of the harmonization process).

	AIM	MESSAGE	MiniCam	IMAGE
MANAGED SYSTEMS				
Cropland	Agriculture land	cultivated land	Cropland (4 crop types + Hay) Other Arable Land Biomass Crops	Cropland (7 crop types) Biomass crops (3 crop types)
Pasture	Pasture including grassland	*	Permanent Pasture	Pasture Extensive grassland
Forestry	Land for forestry	Managed forests	Managed forests	Regrowth forests after timber
Other		built-up land		built-up land
UNMANAGED LAND				
Forests		Unmanaged forests	Natural Boreal forests Other primary natural forests Other secondary natural forest	Boreal forest Cool conifer Temp Mixed forest Tem. Deciduous forest Warm mixed forest Tropical woodland Tropical forests
Grasslands		grassland/shrubland/woodland	Other Grassland Other Shrubland Tundra	Grassland Shrub Savannah Tundra Wooded tundra
Other		other land (=water, desert, rocks, ice).	Non-vegetated land	Ice Desert

Unmanaged land cover

IAM models are also asked to provide information on their unmanaged, or natural vegetation characteristics and changes. In cases where human land use replaces unmanaged land cover, it is important to know the characteristics of the unmanaged land cover. For example, replacement of needle leaf evergreen trees by cropland will have a very different impact on surface albedo compared to replacement of grassland with cropland. Similarly, the change in vegetation carbon pools will also be different. To ensure that CM groups can adequately track carbon pools and better replicate physical changes, IAM groups are requested to provide the following minimal unmanaged land cover information (e.g., evergreen broadleaf trees, deciduous broadleaf trees, evergreen needle leaf trees, shrub, natural grassland). However, it is unlikely that such information can be provided by most modeling team.

Other variables

In addition, information will also be provided by IAM groups on 1) harvested area, 2) irrigated land, 3) urban land. Information is preferably available at grid level.

4.4 Special Considerations for Carbon Cycle experiments and IAM-CM comparison data

Implementation of a dynamic carbon cycle-climate simulation is a relatively new endeavor for the CM community, and has some special data considerations. While IAM models have carbon models, they range in complexity from simple global models to models with various levels of geographic detail that draw from dedicated ecosystem and Earth-system models. Therefore, careful consideration has to be given in the comparison of outcomes among CM and IAM models (after the CM model runs using the RCPs are complete). To facilitate the ability of CMs to choose between simulating various carbon cycle processes endogenously and comparing or incorporating emissions/concentrations exogenously, IAM models are asked to provide the following auxiliary data (September, 2008):

1. Information on the various carbon pools and flows by region (vegetation, soil, ocean);
2. Forest disturbance/Succession
    - Secondary growth and recovery
3. Land-use/land cover change related emissions of all species;
4. Climate variables (temperature; CO2 concentrations, precipitation) (both from the original IAM and possibly from the rerun scenario in a simple climate model as discussed in section 3).

Where possible information should also be provided as gross values instead of net values. The variables listed above will be critical in later stages to be able to evaluate consistency, feedback responses and sensitivity of different sets of models with specific scenarios. It should be noted that in comparison of carbon fluxes across models temporal and geographic scale may be important. Deforestation flows may be just shifted a bit in terms of grid cells or in time. Comparison should therefore occur at a high enough level of aggregation.

4.5 The more advanced harmonization track

The issue of data harmonization was extensively discussed during the February land use/land cover meeting. Some representatives of the CM community expressed concern that given the importance of land use change parameters for model outcomes, it would be useful to coordinate the efforts of multiple CMs regarding the representation of past, present, and future land cover and land use changes. It was realized, however, that such an exercise would likely not be to be possible for all CMs (and not all groups may want to participate), in part, due to the work entailed in incorporating a new data set into models. Based on this discussion, a voluntary track was proposed that would take a more ambitious approach to harmonization. Such an exercise could have two crucial steps: First, the groups participating would adopt a single historical dataset of land use transitions over the past several hundred years which is organized at a level of generality suitable for adaptation to the specific needs of the individual CMs. Second, the community would adopt some common methods for joining historical to present-day to future land cover and land use change datasets, to avoid abrupt transitions that would result in spurious mass and energy flux estimates.

This exercise would lead to several advances: 1) all modeling groups would have identical land cover descriptions available for historical years, and this would ensure that historical and IAM generated scenario data would transition seamlessly (in cases where both IAM and CM modeling groups are using the harmonized data), 2) the exercise could generate transition matrices of parameter sets instead of land use maps; the former are easier to use in most CMs, 3) the exercise might save work compared to doing all work in parallel and 4) it would harmonize IAM output with a description of historic land use – and make data available in the form of land use/land cover change maps and transition maps. A proposal for this harmonization exercise – developed by working group of representatives of the CM and IAM community – is attached.. The data set would provide information on land use change from 1500-2100 at a spatial resolution of 0.5 x 0.5 degree.

In any harmonization exercise the data thus generated will be different from the original scenario data produced by the IAM since the new data set has a different starting point in the base year. Note, however, that this will be the case for any CM's that do not directly use the IAM data (which his likely to be the case for most CMs). It will be important to examine the degree of consistency between the harmonized output and the original IAM output. Addressing this question should be part of the harmonization exercise.

5. Extension of the RCPs to the year 2300

5.1 Introduction

The Climate Modeling community requested scenarios that extend to 2300 in order to explore the long-term response of the climate system to greenhouse gas forcing (e.g., sea level rise). Therefore, for this purpose, it is necessary to extend the greenhouse gas emissions, concentrations, and land-use projections of the RCPs beyond their present time horizon.

5.2 Extrapolation Methodology

Given deep uncertainties associated with the long-term development of human driving forces (e.g., demography, policies, and investment), and land use and emissions beyond 2100, we developed extrapolation methods that are "as simple as possible" and highly stylized. The extensions will not provide full and complete scenarios – they are intended only to serve the purpose of allowing climate modeling calculations beyond 2100. For example, gridded or regional socioeconomic projections to 2300 will not exist. The methodologies described here shall serve as broad guidelines for the IAM modeling teams, and each team may decide to make improvements for the respective RCP given their own requirements.

Below, we first discuss methods for extrapolating emissions and concentrations, followed by methods for the land-use extrapolation. Finally, the resolution of the RCP data beyond 2100 is presented.

5.2.1 Emissions and concentrations

The main objective of the extension methodology is to provide internally plausible emissions and concentrations pathways beyond 2100, which are consistent with the main characteristic of the individual RCPs with respect to their radiative forcing trends.

The forcing pathways of the four RCPs (Figure 5.1) are characterized by either

1) long-term stabilization between 2100 to 2150 in the case of the RCP 4.5 and 6.0
2) increasing forcing over time, headed upwards by 2100 (RCP 8.5), or
3) decreasing forcing by 2100 (continuing to decrease further in the very long term) in the case of the low RCP3-PD IMAGE 2.6 and 2.9 pathways.

While the eventual level of GHG concentrations of the intermediate RCPs (4.5 and 6.0) is broadly predefined by the forcing stabilization constraint, the long-term GHG concentrations of the low and high RCP will depend on the applied extrapolation methodology. It is proposed to apply alternative methodologies for the extension, which specifically distinguish between the different forcing characteristics of the RCPs:

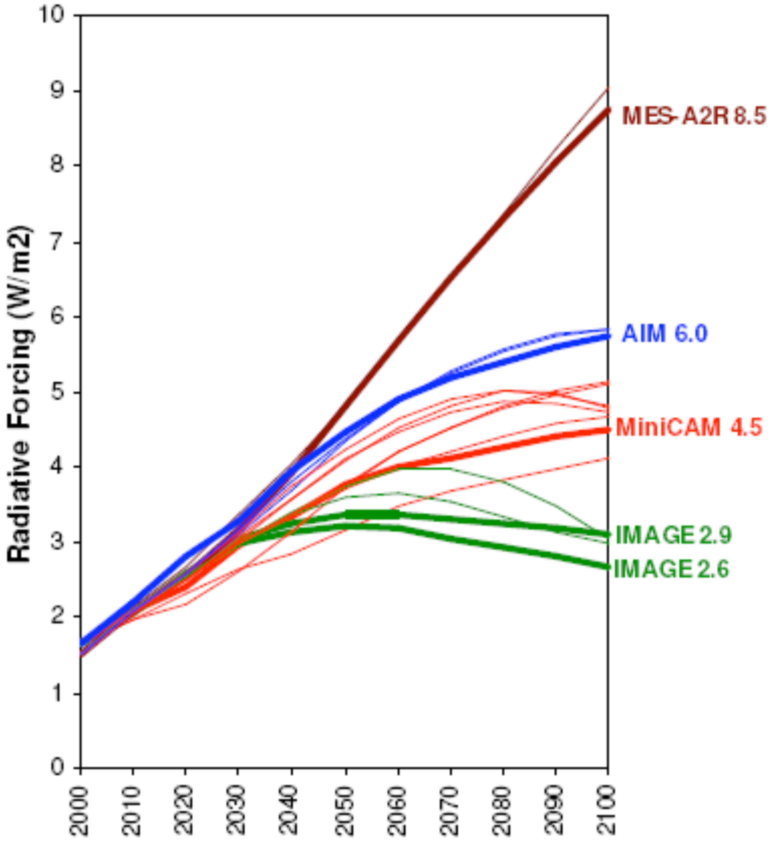

Figure 5.1: Radiative forcing compared to pre-industrial for the RCP candidates. Thick lines denote the RCPs selected for the ESM experiments, including the extension to 2300.

A) Extension of RCP 4.5 and 6.0 (forcing stabilization pathways)

GHG concentrations of the RCP4.5 and RCP6.0 approach the respective stabilization level between 2100 and 2150 and need to stay at this level until 2300. The forcing pathway is predefined by the stabilization target. Therefore, the main task for the RCP4.5 and RCP6.0 is calculation of the associated GHG emissions consistent with the constant concentrations. This can be obtained by using simple climate models or Earth system models of intermediate complexity (e.g., MAGICC or Bern) and inverse calculations to derive emissions from predefined concentration pathways. It is proposed to adopt similar methodologies as Swart et al., (2002), who employed curve fitting techniques for the extension of emissions to 2300 for a range of CO_2 concentration targets. While more sophisticated approaches may be possible as well, it is suggested that each IAM modeling team should select its own preferred extension algorithm for the GHG emissions.

For other radiatively active gases, such as aerosols and pollutant emissions beyond 2100, it is proposed that they broadly follow the trend of fossil-fuel CO_2 emissions.

B) Extension of RCP3-PD IMAGE 2.6/2.9 pathways (decreasing forcing by 2100)

The extension of IMAGE 2.6/2.9 needs to take into account two important characteristics of the RCP pathway. First, the 2.6./2.9 scenarios are characterized by a peak of radiative forcing around 2050 followed by a decline of forcing until 2100, which is expected to continue. In addition, the extension of 2.6/2.9 needs to take into account that the initially rapid emissions decline of GHGs in the second half of the 21st century is slowing down considerably as emissions are approaching very low levels by 2100.

Given the flat and very low (and perhaps even negative) emissions by 2100, it is suggested to simply extend all GHG emissions by keeping them constant at their 2100 levels. Similar to the case of the intermediate RCPs it is proposed to use simple climate models to calculate the resulting GHG concentration pathway beyond 2100. Keeping emissions constant at their 2100 level will result in further reduction of the forcing (to about 2.5 and 1.2 W/m2 by 2300 for the 2.9 and 2.6 respectively).

Other extension possibilities for 2.9 include a further reduction of CO_2 emissions to either about zero or negative emissions (as occurs in 2.6). Such extensions would have the advantage of reducing long-term forcing further (to about 2 and 1.45 Wm^{-2} by 2300), and hence result in a pronounced peaking pathway through 2300 similar to the 2.6 extension. See Figure 5.3 for a preliminary comparison of the resulting forcing pathways of all RCPs.

C) Extension of RCP 8.5 (increasing forcing trend by 2100)

Following the Noordwijkerhout report, the RCP8.5 is defined as a “high” forcing pathway. The main aim for the extension of this scenario is thus to define the long-term level of GHG emissions, which would retain the RCP’s high forcing characteristic through 2300.

Another important characteristic of RCP8.5 is that GHG emissions are increasing over time during the 21st century approaching very high levels by 2100. Emissions growth however, is slowing down considerably in the latter half of the century resulting in an almost flat emissions profile by the end of 2100. Given the latter emissions characteristic, it is thus proposed to extend RCP8.5 by simply keeping GHG emissions constant at their (high) 2100 levels. The extension by constant emissions will result in a further increase of radiative forcing to more than 13 W/m2 by the end of 2300, which is considerably higher than the forcing of the other RCPs (see Figure 5.2). The IAM modeling team of RCP8.5 may conduct back of the envelope calculations to explore the consistency of the proposed extension with the main underlying “short-term” trends of the RCP to 2100 (e.g., exploring consistency of the suggested constant emissions approach with alternative extension of the RCP8.5 for fossil resource depletion).

Due to assumed air pollution control, emissions of aerosols and other pollutant emissions of RCP 8.5 are decoupled from the increasing CO_2 emissions already during the 21st century (and are thus approaching relatively low levels by 2100). These emissions are thus also suggested to stay constant at their respective 2100 levels.

5.2.3 Land use

It is proposed for land use to scale both crop land and pasture land with population levels (assuming population goes down in all scenarios). For the extrapolation of land-use it is proposed to use long-range population projections from IIASA as a proxy driver for land-use changes. Each IAM modeling team will select the appropriate long-term population projection that would best fit the underlying RCP population trend to 2100. For RCP3, 4.5 and 6.0 this is likely to be an intermediate population trajectory (given the development of population trends up to 2100). Since RCP8.5 is based on a high population projection, it is proposed that the RCP8.5

population trajectory is extended using a relatively high IIASA extension that would be consistent with the RCP 8.5 trend to 2100. The population trajectories of the RCPs and preliminary IIASA extensions to 2300 are illustrated in Figure 5.2. Additional IIASA extensions are under preparation.

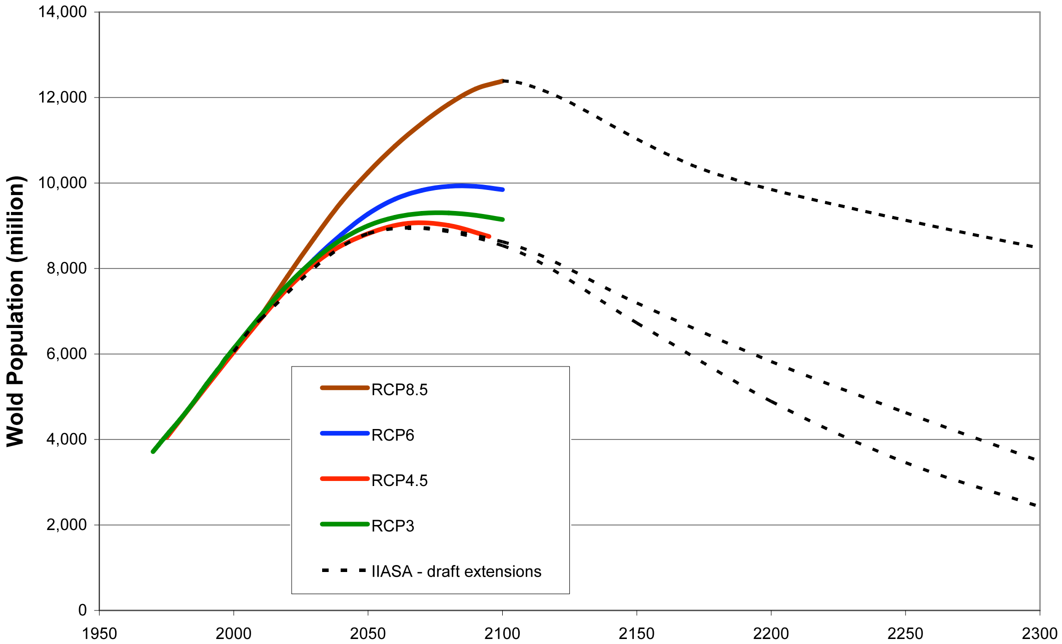

Figure 5.2: Population trajectories according to various scenarios. Colored lines denote original RCPs to 2100, and dashed lines preliminary IIASA extensions to 2300.

5.3 Final remarks:

In summary, the different extension methodologies correspond to either keeping emissions or concentrations broadly constant beyond 2100. It is thus important to note that the extensions should not be understood as full-fledged IAM scenarios, but rather illustrative emissions and concentration pathways with the aim to generate long-term forcing profiles of high, low and intermediate levels of forcing as predefined by the RCP characteristics of the Noordwijkerhout report. For an indicative comparison of resulting forcing trends of the four RCPs see Figure 5.3.

As described above, each IAM team will perform the extension independently employing their own assumptions about the relationship between emissions and concentrations. As these assumptions might differ across IAMs, it is proposed to run all the extended IAM emissions through a standard climate model of intermediate complexity (e.g., MAGICC or Bern) to obtain consistent emissions and concentrations across all four RCPs. The IAM emissions and the concentration pathways from the standard climate model will be provided to the ESM teams.

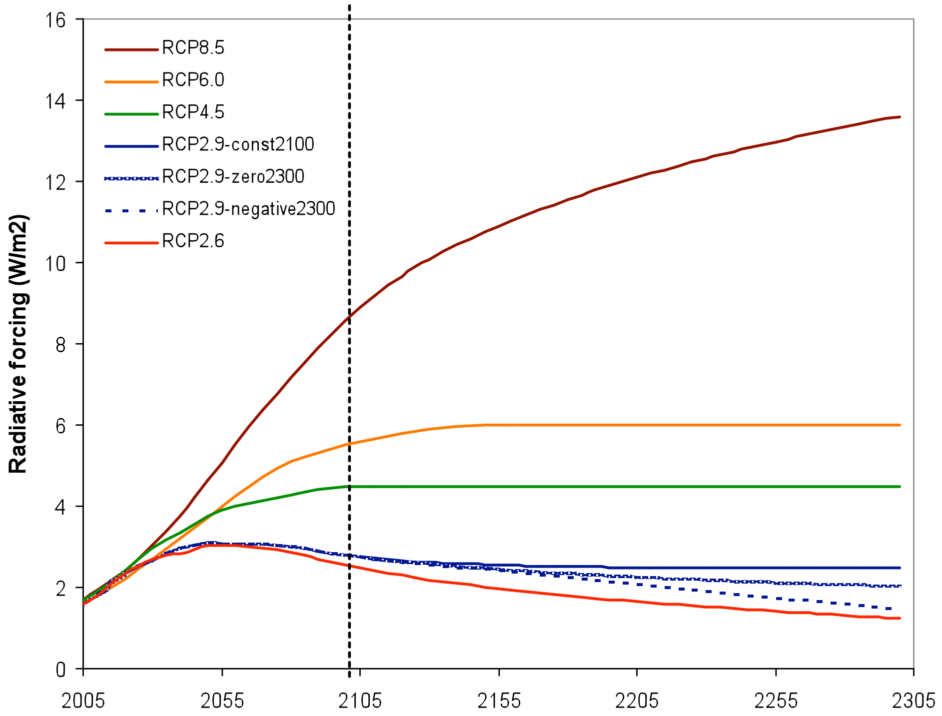

Figure 5.3: Global average radiative forcing (values are indicative and may change given the extension by individual IAM teams).

In addition to providing radiative forcings and concentrations beyond 2100 to climate modeling communities, the primary products of this exercise will be regional data for land-use change and gridded reactive gas/aerosol emissions to 2300. Open issues that need further discussions include the exact data formats for land-use change, and the treatment of potential discontinuities at the regional level due to the proposed global scaling algorithm beyond 2100 (the latter may require in some cases that the IAM teams use regional population estimates for scaling).

5.3 Resolution of data beyond 2100:

The methodologies described above will provide GHG emissions and concentrations as well as projections for other radiatively active gases on the global scale only. Similarly, land-use change projections will be scaled using global population data only (which implies proportional scaling of regional land-use according to global population trends).

For emissions categories, where climate models would require spatial information beyond 2100, it is proposed to apply simple proportional scaling of the spatial patterns of the year 2100. This methodology can provide also regional information if necessary. Calculation of spatial land-cover beyond 2100 will be performed by CM teams (based on the global land-use change provided by the IAM teams).

Due to the simplicity of the extension methodologies, the RCPs will not provide any socioeconomic or technology specific detail beyond 2100 (except for global population). Initial exchange with the IAV experts indicates that such detail would also be less relevant beyond

2100, since impact analysis over such time-frames are primarily focusing on vulnerabilities of natural systems.