Background information
on Shared Socioeconomic Pathways
for use in MACSUR case studies

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Abbreviations

RCP: Representative Concentration Pathways (climate-relevant scenarios)
SSP: Shared Socioeconomic reference Pathways (socio-economic scenarios)
RAP: Representative Agricultural Pathways (extensions of SSPs to agriculture)
SPA: Shared climate Policy Assumptions (assumptions that link a SSP group and a RCP)

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Introduction

MACSUR members decided at the Regional Pilots Workshop in June 2013 in Braunschweig to focus on SSP groups 2 and 3 combined with both current climate and RCP-8.5 climate [16].

This document is intended to aid in the development of regional Representative Agricultural Pathways in Europe for use in MACSUR case studies, especially the regional pilot studies. We present overviews of existing characterisations of RCPs, SSPs, SPAs, RAPs and more detailed descriptions of the scenarios and assumptions relevant for MACSUR. Please refer to the MACSUR workshop report [16] for information on how the scenarios and assumptions are linked.

Representative Concentration Pathways (RCPs)

For the latest comparison of Global Climate Models the approach of Representative Concentration Pathways (RCPs) was chosen, a change from the emission driven scenarios (SRES) used for previous assessments. RCPs assume different levels of radiative forcing (2.6, 4.5, 6.0, 8.5 W/m^2) in the year 2100 that are more closely correlated with global warming (Fig. 2). RCPs start to differ only after about 2030 because of the inertia of the global carbon cycle and climate system.
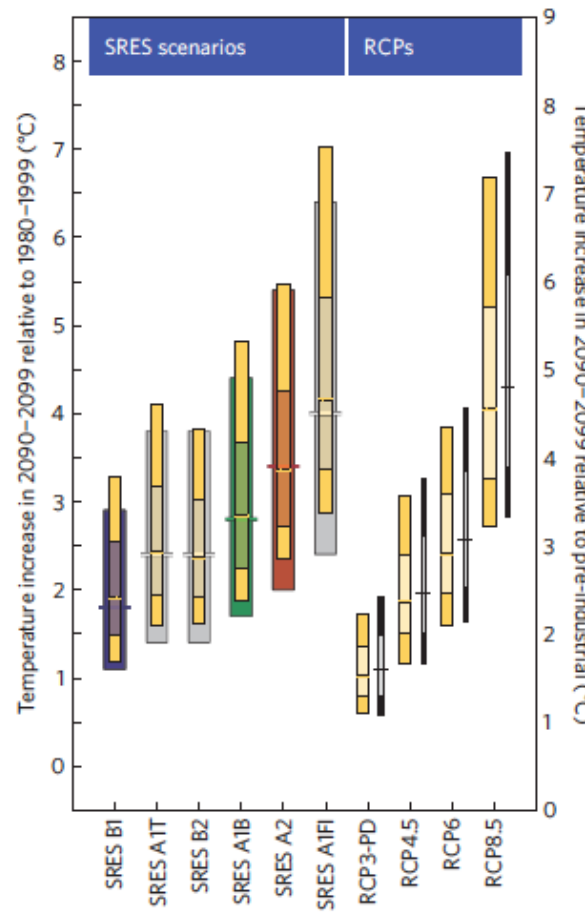
Fig. 1. Comparison of SRES and RCP scenarios (Fig. 3b of Rogelj et al. 2012 [5]). Ranges of estimated average temperature increase between 2090 and 2099 for SRES scenarios and RCPs respectively. Note that results are given both relative to 1980-1999 (left scale) and relative to pre-industrial (right scale). Yellow and thin black ranges indicate results of this study; other ranges show the AR4 estimates (see legend at right-hand side). Colour-coding of AR4 ranges is chosen to be consistent with the AR4 (see Figure SPM.5 in ref. 1 of [5]). For RCPs, yellow ranges show concentration-driven results, whereas black ranges show emission-driven results.
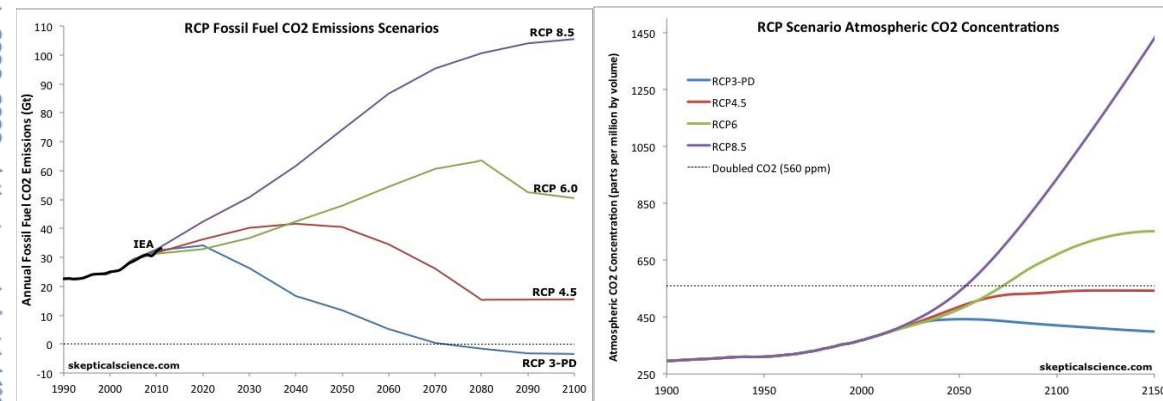

Fig. 2. Mean annual CO2 emissions and projected CO2 concentrations according to the RCPs[1]. 'Some resource experts — such as Jean Laherrère, a petroleum geologist retired from French oil company Total — say this is unrealistic, because people won't be able to produce enough oil, coal and gas to produce that much carbon dioxide. Nebojsa Nakicenovic agrees, but for different reasons: "the high end is impossible," he says, because the impacts would be so severe that it's inconceivable that the world would not take some kind of action.' [9]

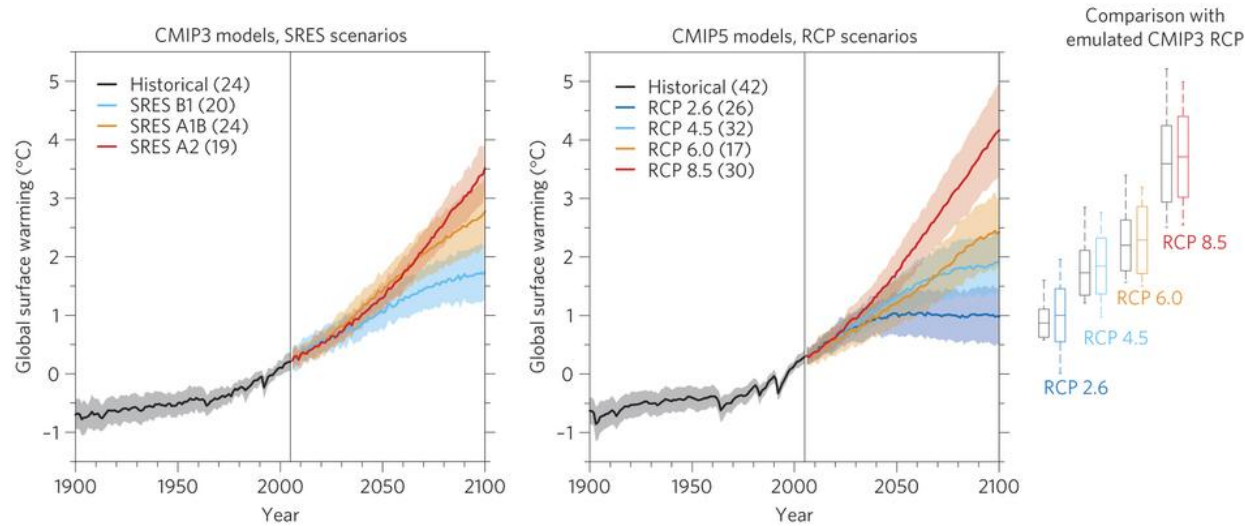[1] http://skepticalscience.com/climate-best-to-worst-case-scenarios.html

Fig. 2b. (from Knutti & Sedláček 2013 [10]) Global temperature change (mean and one standard deviation as shading) relative to 1986-2005 for the SRES scenarios run by CMIP3 and the RCP scenarios run by CMIP5. The number of models is given in brackets. The box plots (mean, one standard deviation, and minimum to maximum range) are given for 2080-2099 for CMIP5 (colours) and for the MAGICC model calibrated to 19 CMIP3 models (black), both running the RCP scenarios.

Tab. 1. Overview of scenarios based on information by Semenov (CO_2, MACSUR presentation) and Rogelj et al. (2012) [5]; RCP in 2100 by Edenhofer et al., 2010 [3] and Moss et al. (2010) [6].

	CO_2 in 2100	CO_2 equivalent	ΔT (K)	Radiative forcing (W m^{-2})	Rate of change in radiative forcing	comparable SRES	Model providing RCP*
RCP 2.6	400 ppm	450 ppm	1.5	2.6	Declining	—	IMAGE
RCP 4.5	500 ppm	650 ppm	2.4	4.5	Stabilizing	B1	GCAM
RCP 6	600 ppm	850 ppm	2.9	6.0	Stabilizing	B2 (A1B)	AIM
RCP 8.5	950 ppm	1350 ppm	4.6	8.5	Rising	A1FI	MESSAGE

* MESSAGE, Model for Energy Supply Strategy Alternatives and their General Environmental Impact, International Institute for Applied Systems Analysis, Austria; AIM, Asia-Pacific Integrated Model, National Institute for Environmental Studies, Japan; GCAM, Global Change Assessment Model, Pacific Northwest National Laboratory, USA (previously referred to as MiniCAM); IMAGE,Integrated Model to Assess the Global Environment, Netherlands Environmental Assessment Agency, The Netherlands.

Shared Socioeconomic reference Pathways

Radiative forcing used in RCPs can be explained by socioeconomic scenarios (Shared Socio-economic Pathways, SSPs) and associated greenhouse gas emissions. It is a key feature of SSPs that they make no assumptions about climate policies [11].

Tab. 2. Short description of SSPs [2]. Detailed descriptions are available as storylines (next page) and in Tables A1-A5. SSPs marked yellow will be used in MACSUR.

SSP group	SSP 1	SSP 2	SSP 3	SSP 4	SSP 5
Keyword	*Sustainability*	*Middle of the Road*	*Fragmentation*	*Inequality*	*Conventional Development*
mitigation/ adaption	well suited		large challenges	relatively manageable mitigation, difficult adaption	large mitigation (few options); challenges, well equipped to adapt
technology	high pace development; environmentally friendly change (lower carbon energy sources, high land productivity)		development slow in energy sector (unmitigated emissions)	development rapid in low carbon energy sources (large mitigation capacity); slow development in other regions	low investments in energy sector (high energy demand, carbon-based fuels)
economy	less inequalities		high inequality; regionalized world (reduced trade flows); moderate growth	high inequality; isolated economies	rapid economic development; high investments in human capital
policies and institutions			unfavorable institutional development		no climate policies
population and human resources			rapid growth		slow growth
		future dynamics could follow historical trends	many people vulnerable to climate change, many parts low adaptive capacity	highly vulnerable regions with limited adaptive capacity	equitable resources distribution, stronger institutions, less vulnerable, better adaption to climate impacts

Tab. 3. Indicators of land use and agriculture development in the SSP groups. (Contributed by F. Piontek, PIK).

SSP element	Country income groupings	SSP1	SSP2	SSP3	SSP4	SSP5
	Low				Weak	
Land use change regulation	Med	Strong	Medium	Weak	Medium	Medium
	High				Strong	
	Low	Rapid			Slow	
Land productivity growth	Med	Rapid	Medium	Slow	Medium	Rapid
	High	Medium			Rapid	
Environmental impact of food consumption	Med	Low	Medium	High	Medium	High
	Low				Limited access	
International trade	Med	Globalized	Regionalized	Regionalized	Globalized	Globalized
	High				Globalized	

SSP Storylines

SSP 2 _Summary_: In this world, trends typical of recent decades continue, with some progress towards achieving development goals, reductions in resource and energy intensity at historic rates, and slowly decreasing fossil fuel dependency. Development of low-income countries proceeds unevenly, with some countries making relatively good progress while others are left behind. Most economies are politically stable with partially functioning and globally connected markets. A limited number of comparatively weak global institutions exist. Per-capita income levels grow at a medium pace on the global average, with slowly converging income levels between developing and industrialized countries. Intra-regional income distributions improve slightly with increasing national income, but disparities remain high in some regions. Educational investments are not high enough to rapidly slow population growth, particularly in low-income countries. Achievement of the Millennium Development Goals[2] is delayed by several decades, leaving populations without access to safe water, improved sanitation, medical care. Similarly, there is only intermediate success in addressing air pollution or improving energy access for the poor as well as other factors that reduce vulnerability to climate and other global changes.

- Slowly decreasing fossil fuel dependency
- Reductions of resource and energy intensity
- Uneven development of low-income countries
- Few weak global institutions
- Slow continuation of globalization with some barriers remaining
- Well regulated information flow
- Medium economic growth, slow convergence
- High income disparities in some regions
- Medium population growth related to medium educational investments
- Delay of achievement of MDGs;

Full Version: In this world, trends typical of recent decades continue, with some progress towards achieving development goals, reductions in resource and energy intensity at historic rates, and slowly decreasing fossil fuel dependency. Some international cooperation and investments in technology development and transfer support moderate economic growth in low-income countries, with slower economic growth in high-income countries. Technology development proceeds in industrialized countries, but is not shared with low-income countries. There is evidence of degradation of the environment.

Development of low-income countries proceeds unevenly, with some countries making relatively good progress while others are left behind. Urbanization follows a similar pattern, with some countries moving towards more planned settlements as they develop and some seeing

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[2] http://siteresources.worldbank.org/DATASTATISTICS/Resources/MDGsOfficialList2008.pdf

increases in unplanned settlements. Population growth is moderate, with higher growth in low-income countries. Most economies are politically stable with partially functioning and globally connected markets. A limited number of comparatively weak global institutions exist. Globalization trends continue slowly, although trade barriers in primary energy, agricultural and capital markets remain. The flow of information and global access to markets are rather well regulated in most countries, with the exception of least developed countries, some resource producing countries and islands of protectionism. Per-capita income levels grow at a medium pace on the global average, with slowly converging income levels between developing and industrialized countries. Intra-regional income distributions improve slightly with increasing national income, but disparities remain high in some regions with high income disparities today.

Education investments are not high enough to rapidly slow population growth, particularly in low-income countries.

Unmitigated emissions are moderately high, driven by population growth, use of local energy resources, and moderate technological change in the energy sector. Driven by security concerns, there is no reluctance to use unconventional energy resources. While local environmental concerns, such as air quality, ranks high on the agenda of many countries, implementation lags behind the ambitions. Globally this leads to an intermediate pathway for pollutant emissions.

Current trends in urbanization in all parts of the world continues, along with similar middle of the road assumptions about population growth, technological change, and economic growth. **High income countries continue their practices in urban development**; developing countries generally follow the historical urbanization experiences of the more developed countries. All countries follow the central urbanization pathway, with various forms and patterns depending on their current practices and their stages of urbanization.

Achievement of the Millennium Development Goals is delayed by several decades, leaving populations without access to safe water, improved sanitation, medical care, and other factors that reduce vulnerability to climate and other global changes.

The storylines for "Agriculture and land use" of SSP 2 assume
- incomplete regulation of land use,
- slow decline in tropical deforestation,
- slow increase of crop yields,
- medium calorie consumption,
- regionalization of trade.

SSP 3 _Summary_: The world is separated into regions characterized by extreme poverty, pockets of moderate wealth and a bulk of countries that struggle to maintain living standards for a strongly growing population. Regional blocks of countries have re-emerged with little coordination between them. This is a world failing to achieve global development goals, and with little progress in reducing resource intensity, fossil fuel dependency, or addressing local environmental concerns such as air pollution. **Countries focus on achieving energy and food security goals within their own region.** The world has de-globalized, and international trade, including energy resource and agricultural markets, is severely restricted. Little international cooperation and low investments in technology development and education slow down economic growth in high-, middle-, and low-income regions. Population growth in this scenario is high as a result of the education and

economic trends. Growth in urban areas in low-income countries is often in unplanned settlements. Unmitigated emissions are relatively high, driven by high population growth, use of local energy resources and slow technological change in the energy sector. Governance and institutions show weakness and a lack of cooperation and consensus; effective leadership and capacities for problem solving are lacking. Investments in human capital are low and inequality is high. A regionalized world leads to reduced trade flows, and institutional development is unfavorable, leaving large numbers of people vulnerable to climate change and many parts of the world with low adaptive capacity. Policies are oriented towards security, including barriers to trade.

- Very slowly decreasing fossil fuel dependency
- Slow or no reduction of resource and energy intensity
- Some wealthy countries, many poor countries
- Few weak global institutions, lack of cooperation
- Regionalized economy with restricted international trade
- Policies are oreinted towards regional security
- Slow economic growth across all regions
- Emergence of regional blocks with little cooperation
- High population growth related to regionally restricted investments
- Failing to achieve MDGs;

Full version: The world is separated into regions characterized by extreme poverty, pockets of moderate wealth and a bulk of countries that struggle to maintain living standards for a strongly growing population. Regional blocks of countries have re-emerged with little coordination between them. This is a world failing to achieve global development goals, and with little progress in reducing resource intensity and fossil fuel dependency. Countries focus on achieving energy and food security goals within their own region. Little international cooperation and low investments into technology development and education slow down economic growth in low- and high-income regions. Growth in urban areas in low-income countries is often in unplanned settlements. Population growth is high as a result of the education and economic trends. Unmitigated emissions are relatively high as well, driven by high population growth, use of local energy resources and slow technological change in the energy sector. There is serious degradation of the environment, including high levels of pollutant emissions with severe impacts for human health and the ecosystem. Driven by security concerns, there is no reluctance to use unconventional energy resources. A regionalized world leads to reduced flows of trade and technology transfer.

Urbanization follows the slow pathway due to slow economic growth, limited international migration, and poor urban planning that make cities unattractive destinations. In the high income countries, low population growth (especially aging), slow economic growth and technological changes, combined with low international migration, reduce the incentives for urban expansion. In the developing regions, population grows rapidly, particularly in rural areas, but migration to the cities is nonetheless limited due to slow economic growth and technological progress leading to underdeveloped urban manufacturing and service sectors in this region. Furthermore, unfavorable economic conditions in the high income countries do not offer employment opportunities for the growing labor-age population in the developing countries, which contributes to

small flows of rural-to-urban and international migration. Urban planning and infrastructure construction is underdeveloped and also limits the capacity of the cities. **The large and continuously increasing rural populations combined with low agricultural productivity generate heavy pressure on arable land and cause significant land use change and environmental degradation.** The vicious circle of rapid population growth, slow socioeconomic development, and environmental degradation further limit the mobility of the poor rural population, and consequently urban development [4].

Fertility rates are high in less developed countries, resulting in stalled demographic transitions; fertility rates are medium in more developed countries. Mortality rates also are high, with many children dying from preventable diseases (malnutrition, diarrheal disease, malaria). The Millennium Development Goals are not achieved or are achieved much later than planned, resulting in poorly educated populations with many people without access to safe water, improved sanitation, medical care, and other factors that affect vulnerability to climate and other global changes. Development proceeds slowly, with high inequalities within and across countries.

Disadvantaged populations continue to move to unplanned settlements around large urban areas, often in places that are particularly vulnerable to weather and climate events.

Governance and institutions are relatively weak, with poor cooperation and consensus. In addition, effective leadership and capacities for problem solving are lacking. Investments in research and development and in human capital are low. Institutional development is unfavorable, leaving large numbers of people vulnerable to climate change and many parts of the world with low adaptive capacity. Policies are oriented towards security.

The storylines for "Agriculture and land use" of SSP3 assume
- no regulation of land use change,
- decline of crop yield increase rates (little investment),
- high animal shares in diets,
- large waste,

regionalized world (local food security).
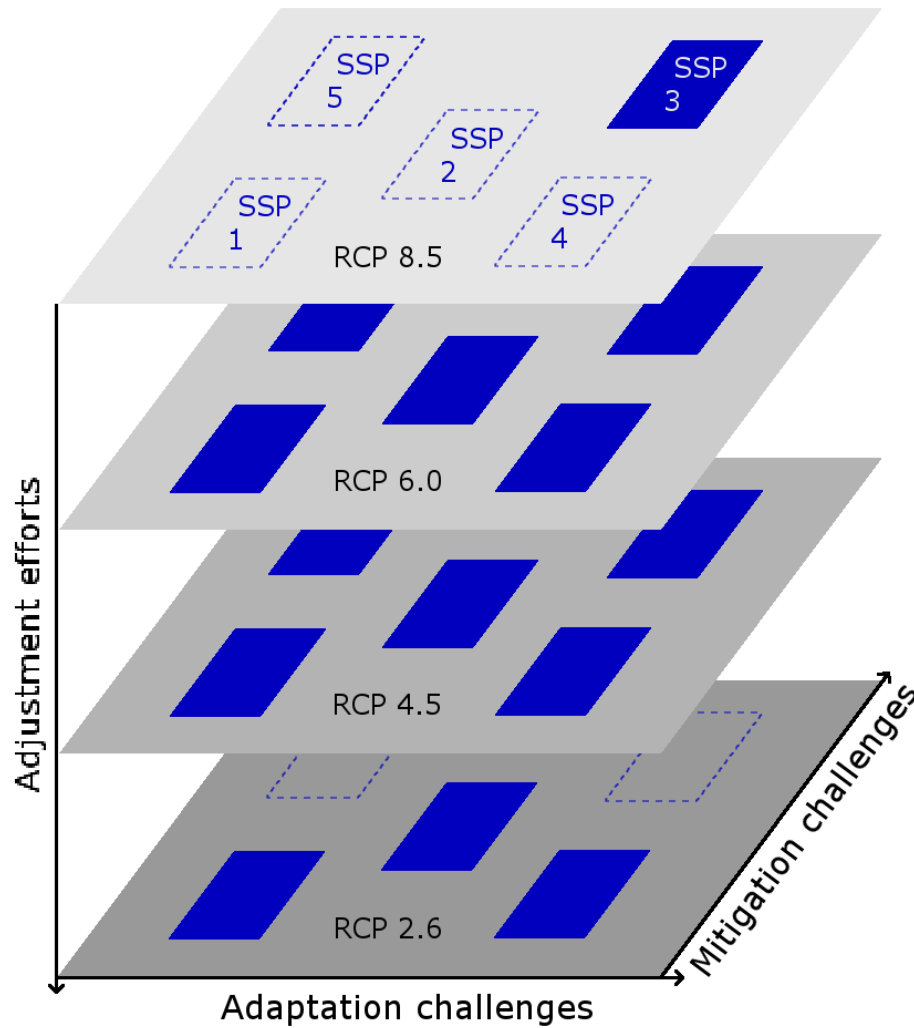
SSP × RCP combinations

Different socio-economic models using the same SSP may result in different levels of radiative forcing depending on additional assumptions in the models. Therefore, one RCP can be consistent with several SSPs. Some combinations, however, are less likely or inconceivable.

Fig. 3. SSP "space"-range of socioeconomic challenges for mitigation and adaption as well as conceivable combinations with RCPs (areas filled in blue) and less likely combinations with RCP (outline areas) (different authors have different ideas about which SSP-RCP combinations are conceivable; see [12], [14], [15])

Representative Agricultural Pathways

Representative Agricultural Pathways are extensions of SSPs. They
- include assumptions consistent with the associated SSP about pathways of farming management development and adaptation capabilities,
- are consistent across climate, economics and field level farming management practices,
- describe synergies and trade-offs between biophysical and social dimensions of global food production,
- can be translated into scenarios of farming intensification levels and world agricultural trade policies to meet future food demand,
- define socioeconomic dimensions including technology, prices, policy [3].

RAPs are being developed on the set of SRES emissions scenarios and RCPs used in the IPCC AR4/5 [7]. There are no further descriptions available at this time (August 2013). The FP7 project VOLANTE developed scenarios for land use change in Europe compatible with the SRES scenarios [13].

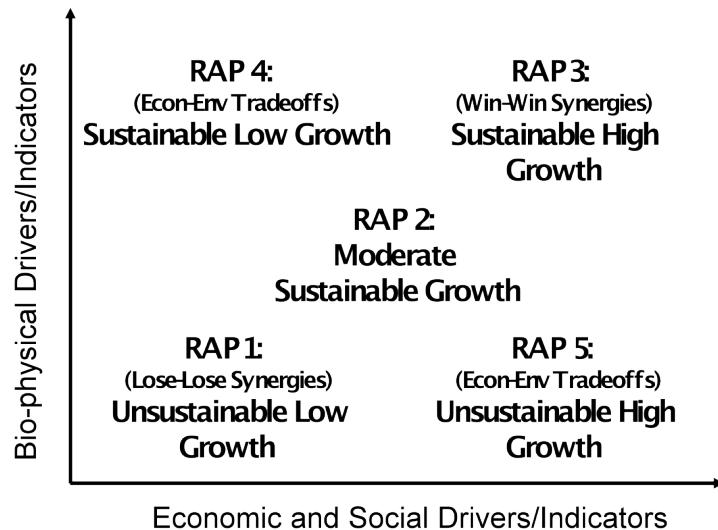Fig. 3. RAP matrix in line with the SSP matrix (Fig. 3 of the MACSUR workshop report). (Contributed by F. Piontek, PIK).

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[3] http://research.agmip.org/download/attachments/3866652/17_RAP+breakout_Oct11.pdf?version=1&modificationDate=1354499395004

Shared climate Policy Assumptions

Shared Climate Policy Assumptions (SPAs) may be specified in addition to SSPs [10]. "To separate socio-economic reference developments from the effects of climate policy, shared socio-economic pathways should only include socio-economic 'reference assumptions'. This will make climate policy analyses utilizing shared socio-economic pathways more flexible. It allows, e.g., studying the impact of different climate policies for a given pathway, or the impact of different pathways on effects of climate policies." [10]. SPAs are in a very early stage of development. SPA3 will be used in MACSUR in order to allow a direct comparison among climate and SSP2 and SSP3 scenarios.

Tab. 4. Shared Policy Assumptions (Elmar Kriegler, pers. comm.).

	SPA 1	SPA 2	SPA 3
Level of global cooperation	High	Intermediate	Low
Start of cooperation	Early	Mid term	Late

Tab. 5. Suggested consistent combinations of SSPs and SPAs (Elmar Kriegler, pers. comm.).

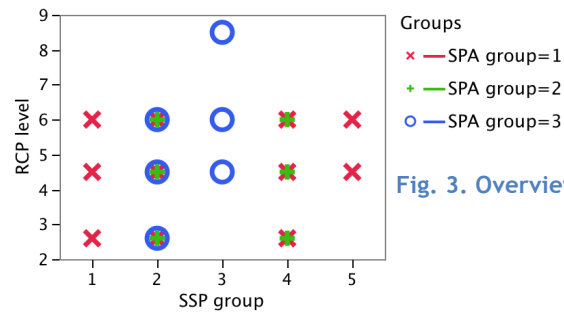|	SSP 1	SSP 2	SSP 3	SSP 4	SSP 5
SPA 1	x	x		x	x
SPA 2		x		x	
SPA 3		x	x		

Fig. 3. Overview of conceivable SSP × RCP × SPA combinations.

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Appendix

SSP Element	SSP 1			SSP 2			SSP 3			SSP 4			SSP 5		
	Country Income Groupings														
	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High
Demographics															
Population															
Growth		*Relatively low*			*Medium*			*Relatively high*			*Mixed*			Peak and decline	
Fertility	Low	Low	Medium		Medium		High		Medium	High	Low/ Medium		Low/ Medium	Low	Replace-ment
Mortality		Low			Medium			High		*High*	Medium	Medium		Low	
Migration		Medium			Medium			Low			*Low*			High	
Urbanization															
Level										High	High/ Medium	Medium		High	
Type		Planned		Mixed				Unplanned		Unplanned			Well planned, possibly sprawl		
Education		High			Medium			Low		Low/ unequal	Medium/ unequal	Medium/ unequal		High	

Tab. A2. SSP Element table [1].

SSP Element	SSP 1			SSP 2			SSP 3			SSP 4			SSP 5		
	Country Income Groupings														
	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High
Economy & Lifestyles															
Growth (per cap)	Medium		Fast	Medium		Slow		Slow		Low	Medium	Medium/High		High	
Structure	Rapid service sector growth												Limited shift toward services, high demand for mnfd prdts		
Inequality							High (within/across country not specified)								
Across regions	Convergence, but retaining diversity										High			Convergence to high levels	
Within country	Becoming more equitable, less stratification										High			Becoming more equitable, less stratification	
Intl. Trade								Barriers to trade		*Unclear/not specified*				High, with regional specialization in production	
Globalization														High	
Consumption	Low growth in material consumption			material intensive consumption			material intensive consumption			Elites: high consumption lifestyles; Rest: low consumption, low mobility			Materialism, consumerism. Focus on status consumption, including tourism, recreation, mobility.		
Diet	Low meat consumption												High meat consumption		
Policies & Institutions															
Intl Cooperation	High level of political will									*High in favor of global elite and corporations, low otherwise*			High, based on national interests		
Envtl Policy	Environmental protection; *stringent, effective air quality policies*			*Intermediate policies and progress on air quality*			*Little regard for air quality*			*Focus on local environment where elites live, mainly urban; geographically mixed air quality policies*			Focus on local environment, little concern with global problem; *strong and pervasive air quality policies*		
Policy Orientation	Toward sustainable development							Toward security		*Toward the benefit of the elite*			Toward development, free markets, human capacity building		
Institutions								Ineffective		Effective for elite, not for the rest of society			Effective		

Tab. A3. SSP Element table[1]

SSP Element	SSP 1			SSP 2			SSP 3			SSP 4			SSP 5		
	Country Income Groupings														
	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High
Technology															
Development		Rapid			*Medium?*			Slow		*Rapid in industries controlled by large corporations*				Rapid	
Transfer		Rapid			*Medium?*			*Slow*		Little transfer within countries to poorer populations				Rapid	
Energy Tech Change	Directed away from fossils; rapid low carbon tech change; reluctance to use unconventional fossils			*Balanced across fuels?*			Slow low-carbon tech change; no reluctance to use unconventional fossils; security concerns; low fossil fuel price			*Fast tech change in low-C supply or mitigation options such as CCS; hedge by corporations against fossil resource scarcity and/or mitigation policy*			tech change biased toward fossil fuels; high discount rates impose barriers on energy and resource efficiency improvements.		
Carbon Intensity										Ambiguous; low-C supply could penetrate in baseline or be available for mitigation when necessary				High	
Energy Intensity										*Unclear*				High	
Environment & Natural Resources															
Fossil Constraints										*Perception (and possibly reality) of strong constraints*			None for coal and gas, possible for oil		
Environment								Serious degradation						Highly engineered	
Land Use								High		*Probably low, given high ag productivity*			High demand for land due to consumption patterns		
Agriculture										Ag productivity high for large scale industrial farming, low for small-scale farming			Highly managed, resource and water intensive (possibly including desalinization). Rapid increase in productivity.		

Tab. A4. Main assumptions for the SSP population projections [4].

SSP Element	SSP 1			SSP 2			SSP 3			SSP 4			SSP 5		
	HiFert	LoFert	Rich-OECD	HiFert	LoFert	Rich-OECD	HiFert	LoFert	Rich-OECD	HiFert	LoFert	Rich-OECD	HiFert	LoFert	Rich-OECD
Demographics															
Population															
Fertility	Low	Low	Med	Med	Med	Med	High	High	Low	High	Low	Low	Low	Low	High
Mortality	Low	Low	Low	Med	Med	Med	High	High	High	High	Med	Med	Low	Low	Low
Migration	Med	Med	Med	Med	Med	Med	Low	Low	Low	Med	Med	Med	High	High	High
Education	High (FT)	High (FT)	High (FT)	Med (GET)	Med (GET)	Med (GET)	Low (CER)	Low (CER)	Low (CER)	V.Low (CEN)	Low (CER)	Med (GET)	High (FT)	High (FT)	High (FT)

Tab. A5. Main assumptions for the SSP urbanization projections [4].

SSP Element	SSP 1			SSP 2			SSP 3			SSP 4			SSP 5		
	High	Middle	Low	High	Middle	Low	High	Middle	Low	High	Middle	Low	High	Middle	Low
Urbanization	Fast	Fast	Fast	Central	Central	Central	Slow	Slow	Slow	Central	Fast	Fast	Fast	Fast	Fast

Tab. A6. Main assumptions for the SSP GDP projections [4].

SSP Element	SSP1	SSP2	SSP3	SSP4*	SSP5
TFP growth at frontier	Medium high	Medium	Low	Medium	High
Speed of Convergence	High	Medium	Low	LI: Low MI: Low HI: Medium	High

* In SSP4, the speed of convergence differs across country groupings with different income levels. LI: low income countries, MI: middle income countries, HI: high income countries

Tab. A7. Overview of SRES scenario quantifications. Shown for each scenario is the name of the storyline and scenario family, the name of the scenario group, number of harmonized scenarios in the respective group and the main (qualitative) characteristics of each of the scenario groups. Please note that A1C and A12G were combined into one fossil- intensive A1FI group in the SPM [8].

Set	SRES							Total
Family	A1				A2	B1	B2	
Scenario Group	A1C	A1G	A1B	A1T	A2	B1	B2	
Globally Harmonized Scenarios[a]	2	3	6	2	2	7	4	26
Scenario characteristics:[c]								
Population growth	low	low	low	low	high	low	medium	
GDP growth	very high	very high	very high	very high	medium	high	medium	
Energy use	very high	very high	very high	high	high	low	medium	
Land- use changes	low-medium	low-medium	low	low	medium/high	high	medium	
Resource availability[d]	high	high	medium	medium	low	low	medium	
Pace and direction of technological change favoring	rapid coal	rapid oil & gas	rapid balanced	rapid non-fossils	slow regional	medium efficiency & dematerialization	medium "dynamics as usual"	