Funded by the European Union within the
7th Framework Programme, Grant Agreement 603378.
Duration: February 1st, 2014 – January 31th, 2018

Deliverable 2.1 Four manuscripts on the multiple stressor framework: Report on the MARS scenarios of future changes in drivers and pressures with respect to Europe's water resources (4/4)

Lead beneficiary: Deltares (8)
Contributors: Marta Faneca Sanchez (Deltares), Harm Duel (Deltares), Ana Alejos Sampedro (Deltares), Katri Rankinen (SYKE), Maria Holmberg (SYKE), Christel Prudhomme (NERC), John Bloomfield (NERC), Raoul Marie Couture (NIVA), Yiannis Panagopoulos (NTUA), Teresa Ferreira (UTL), Markus Venohr (FVB-IGB), and Sebastian Birk (UDE).

Due date of deliverable: **Month 12**
Actual submission date: **Month 12**

Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Contents

Preface

This document is part of task 2.6 Definition of future scenarios of the FP7 project MARS (Managing Aquatic ecosystems and water Resources under multiple Stress). The document includes the work done to define qualitatively and quantitatively the scenarios and storylines that will be used within MARS.

Abstract

Experiments and predictive models at local, basin, and European scale will be used in MARS to assess the combined impacts of multiple stressors affecting water quantity and quality, ecological status, ecological functions, and ecosystem services under contrasting scenarios. These predictive models will run several scenarios in order to predict future impacts. Fur such purpose, various future climatic and socio-economic scenarios were chosen to define three storylines at the European level, based on the latest versions of the Shared Socio-economic Pathways and the Representative Concentration Pathways. The combinations SSP5 and RCP8.5, SSP3 and RCP8.5 and SSP2 and RCP4.5 were selected through a participatory process as starting points. These storylines differ mainly in four main aspects; main drivers in the economy, economic growth, policies regarding the environment, and public concern about the environment and protection of ecosystem services. The storylines were downscaled to the three basin regions defined within MARS using the expert knowledge of the scientists working in the basins, and the stakeholders within those basin regions. In order to simulate the future scenarios at both basin and European scale, and to assess the impacts of multiple stressors, quantitative values for the input parameters and variables for each scenario are required. Several projects and modelling tools were reviewed with the aim of identifying quantitative data fitting the selected storylines. The data was derived mainly from previous projects and tools, including CLIMSAVE, ISIMIP, BASE, SCENES, and IMAGE. Values for diverse climate variables, runoff, water abstraction, potential flood plains, nutrient diffuse source emission, land use, population and GDP were collected. The result is a suite of quantitative values for diverse parameters and variables in gridded or vector format, which range from daily to yearly time steps at resolutions ranging from 5 by 5 arc minutes to a 0.5 by 0.5 degrees spatial resolution across Europe. These quantitative values can be used to drive the simulations of the three storylines defined within the MARS project.

1. Introduction

In MARS, experiments and predictive models at local, basin, and European scale will be used to assess the combined impacts of multi stressors affecting water quantity and quality, ecological status, ecological functions, and ecosystem services under contrasting scenarios of water resources management, land use and climate change.

The multiple combinations of drivers and pressures for a given aquatic system for the current situation are given by the historical and present climatic, managerial and socio economic conditions around the given system. Within MARS, the historical and present conditions will be identified by the stakeholders and scientists working on the system, and will be filled with data readily available such as historic and actual climate data, land use, or water abstractions and demand.

Future combinations of the drivers and pressures depend on the future climatic and socio-economic scenarios considered plausible for a given aquatic system. Various future climatic and socio-economic scenarios have been chosen within MARS to define three storylines at European level. Each storyline frames the conditions leading to certain combinations of drivers and pressures for Europe. These storylines have been downscaled to basin region level using the expert knowledge of the scientists working on the basins, and the stakeholders of those basin regions.

But what are storylines and scenarios within MARS?

A storyline is a narrative about a fictive sequence of events that could take place in the near future. Within MARS storylines describe several aspects of economic, environmental, political and climatic developments and are mainly defined focusing on the different fashions to manage and regulate drivers and pressures impacting aquatic systems.

A scenario is a coherent description of alternative hypothetical futures that reflects different perspectives on past, present and future developments, which can serve as a basis for action (Van Notten, 2005). Within MARS, we used climatic and socio-economic projections as scenarios that served as basis to define our storylines.

In this document we present the work done within this task to define storylines for MARS from a qualitative and quantitative perspective. The following chapters present a literature review of future storylines and scenarios (chapter 1), the approach taken to define the future scenarios and storylines for MARS (chapter 2), the description of the future storylines and scenarios for MARS (chapter 3), the process to acquire quantitative data for the storylines and a description of the data (chapter 4), and some conclusions and remarks on the work done regarding data availability (chapter 5).

2. Storylines and scenario review

This chapter summarizes the work done until date by different organizations and projects in the definition of scenarios and storylines for future scenarios. This review aims to give the reader a clear overview of the proponents and instigators of the first scenarios, the existing storylines and scenarios approaches, the last developments in this topic and the available knowledge.

Review of storylines and scenarios

Scenarios have been used for many organizations in the last years in order to describe possible futures for different variables such as climate, demography, politics, economy, land use, management of ecosystems and ecosystem services, etc. The first official report on scenarios was published by the Shell Scenarios Group in 1973. The Shell team saw the need to understand the factors affecting the business and the possible directions that these factors could take. The main drive was to help managers to be prepared to ensure the continuity of the business in different "what if?" situations. Since then, scenarios are a crucial planning part in the business of Shell. The success of the use of the scenarios encouraged others to work with those as well.

The International Panel of Climate Change (IPCC) has been coordinating the development of scenarios regarding the future anthropogenic climate change (AR 1990, SR 1994, and SRES 2000) since the nineties. Parallel to these development and often also in collaboration with the IPCC (as in the last Assessment Report), the scientific community has developed a series of scenarios and storylines some of them linked to specific projects. The project defined scenarios are often created keeping the main objectives of the project as a reference.

The most common methodology to define scenarios is a sequential stepwise approach starting by the definition of socioeconomic storylines, continuing with the match of the storylines with the green-house gas emission scenarios and the radiative forcing scenarios (as for example those of IPCC). Then the greenhouse emission scenarios are used as input for the Climate Models (CM) and the Integrated Assessment Models (IAMs). These models give the value ranges (sometimes with spatial resolution) for different climate variables such as precipitation and temperature, and the value ranges for other variables such as agricultural land use abandonment or expansion of cities.

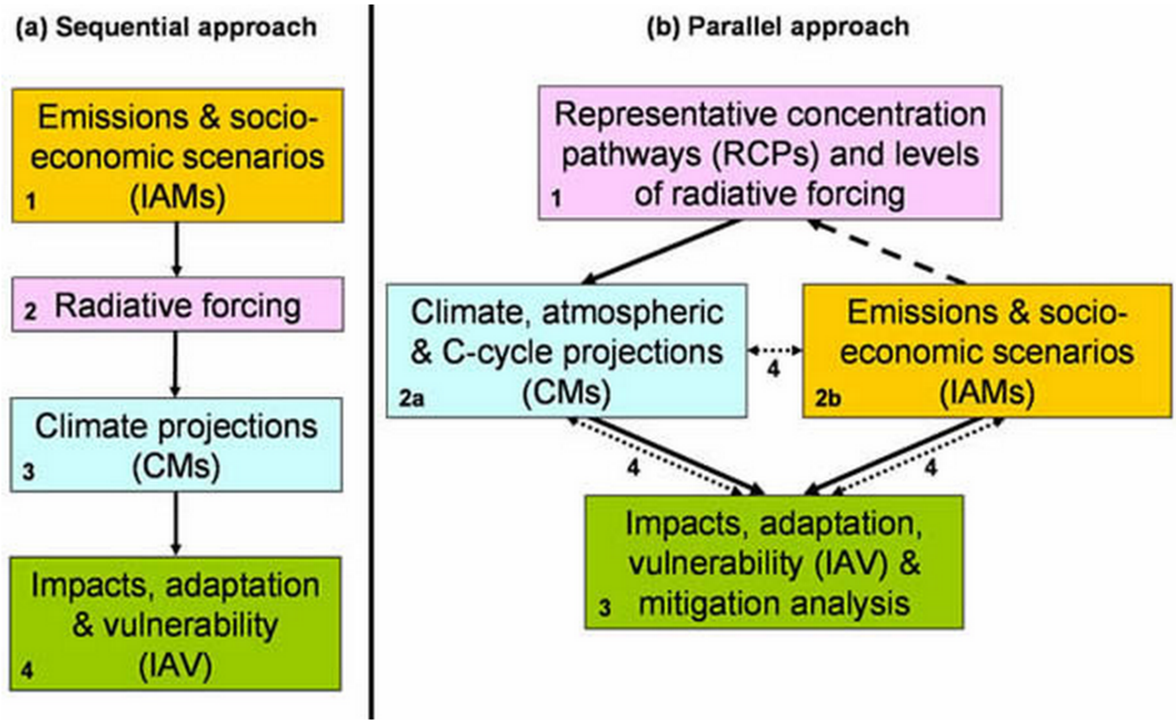


Figure 1 Approaches to the development of global scenarios: a) previous sequential approach; b) proposed parallel approach. Numbers indicate analytical steps. Arrows indicate transfers of information (solid), selection of RCPs (dashed), and integration of information and feedbacks (dotted). Source: Moss et al (2008)

The sequential approach (Figure 1a)) was used to create for example the scenarios of the Special Report on Emissions Scenarios (SRES) (Nakicenovic, et al 2000). However, the need for new scenarios as pointed out by Moss et al. (2010) induced the IPCC to request the scientific community to develop a new set of scenarios. The IPCC acted as a catalyst of the process and assessor of the scenarios. In the last Assessment Report of IPCC, the AR5, the approach to define the scenarios has been different and has not followed a sequential approach. Instead, the emissions and socioeconomic scenarios are developed in parallel (Figure 1b)). The starting points of the new scenarios are radiative forcing pathways that describe an emission trajectory and concentration by the year 2100. These radiative forcing trajectories are termed "Representative Concentration Pathways" (RCPs). The RCPs can either be or not be associated with unique socioeconomic and policy assumptions. They can also result from different combinations of economic, technological, demographic, policy, and institutional futures.

The new integrated scenarios framework

The new framework developed to define integrated scenarios (van Vuuren et al, 2013), takes the form of a matrix with 3 dimensions: climate and climate model projections, socioeconomic conditions and climate policies. The first dimension of the matrix is represented by the RCPs (van Vuuren et al 2011) ant the climate projections based on them. The second axis is determined by the Shared Socioeconomic Pathways (SSPs; O'Neill et al 2014), a set of socioeconomic future assumptions. The third dimension is the Share climate Policy Assumptions (SPAs; Kriegler et al 2013).

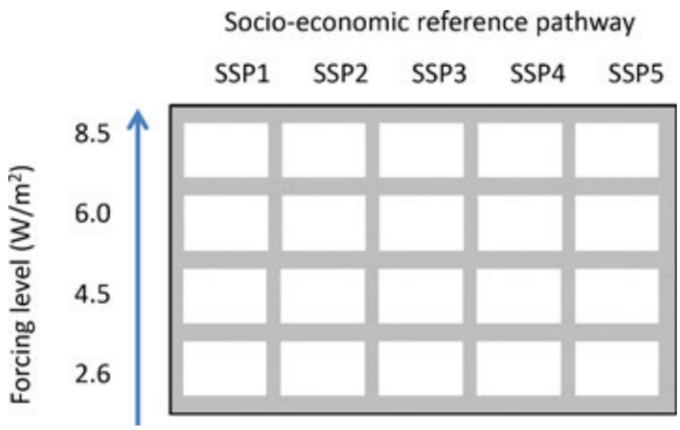


Figure 2 Scenario matrix. Every cell represents a possible scenario that combines policies of adaptation and mitigation.

The Representative Concentration Pathways (RCPs)

The radiative forcing scenarios are 4 and are defined depending on the total radiative forcing in year 2100 relative to 1750. The production of the RCPs resulted in a broad data set with high spatial and sectoral resolution. Land use and emissions of air pollutants and greenhouse houses are in its majority available at 0.5x0.5 degree spatial resolution. The four scenarios are:

Table 1 Representative pathways in the year 2100 (source van Vuuren et at 2013)

	Radiative forcing	CO_2 equivalent concentration	Rate of change in radiative forcing	Key reference
RCP 8.5	8.5 W/m^2	1350 ppm	Rising	(Riahi et al. 2011)
RCP 6.0	6.0 W/m^2	850 ppm	Stabilizing	(Masui et al. 2011)
RCP 4.5	4.5 W/m^2	650 ppm	Stabilizing	(Thomson et al. 2011)
RCP 2.6	2.6 W/m^2	450 ppm	Declining	(Van Vuuren et al. 2011b)

Scenario 2.6 is a mitigation scenario the emissions of which peak and decline before 2100. Scenarios 4.5 and 6.0 are stabilization scenarios and scenario 8.5 is a rising scenario with very high greenhouse gas emissions. Each of the scenarios provides a dataset of land use change, air pollutants per sector and greenhouse emissions.

These four RCPs are based on previous available in the literature scenarios, and they were built on specific socioeconomic assumptions. However, as these assumptions are not consistent in the 4 RCPs, they are further not used and can be substituted by the SSPs. Still, the socioeconomic assumptions behind the RCPs, can help understanding the scenarios (see references on Table 1 for more information on the predecessor scenarios of the four RCPs).

The IPCC has generated a new set of data based on the new climate simulations carried out with the climate model ensemble under the framework of the Coupled Model Intercomparison Project Phase 5 (CMIP5) and using as basis the RCPs.

Some of the outcomes are shown in the next figures:

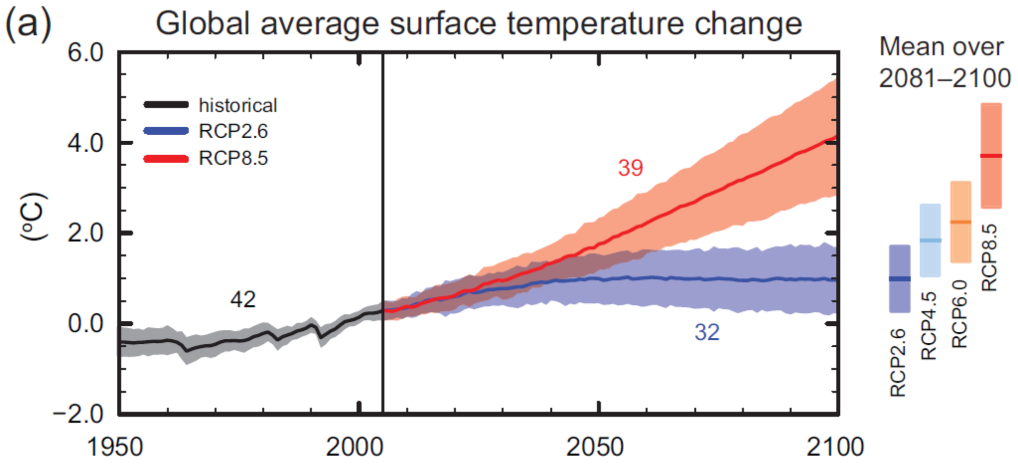


Figure 3 CMIP5 simulated global average surface temperature change from 1950 to 2100.

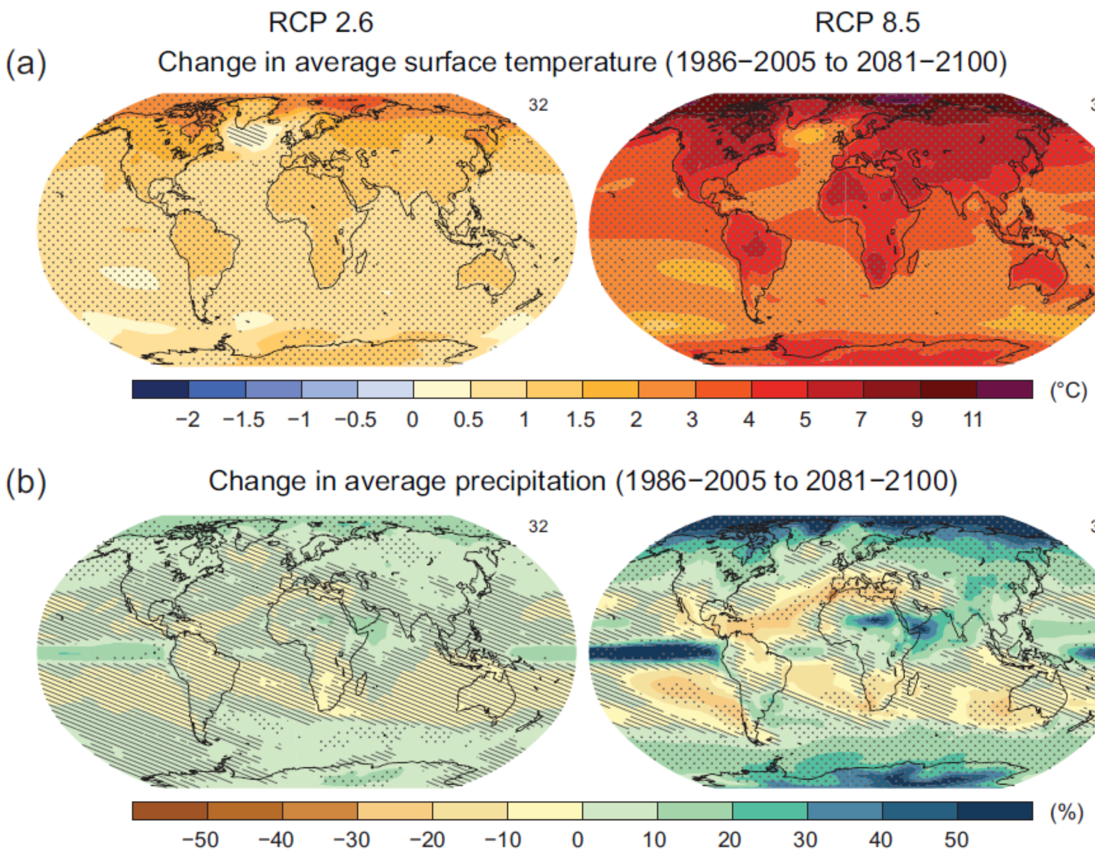


Figure 4 Spatial distribution of the change in average temperature (a) and precipitation (b) as calculated with the CMIP5 multi model projections.

	Scenario	2046–2065 Mean	2046–2065 *Likely* range[c]	2081–2100 Mean	2081–2100 *Likely* range[c]
Global Mean Surface Temperature Change (°C)[a]	RCP2.6	1.0	0.4 to 1.6	1.0	0.3 to 1.7
	RCP4.5	1.4	0.9 to 2.0	1.8	1.1 to 2.6
	RCP6.0	1.3	0.8 to 1.8	2.2	1.4 to 3.1
	RCP8.5	2.0	1.4 to 2.6	3.7	2.6 to 4.8
	Scenario	**Mean**	***Likely* range[d]**	**Mean**	***Likely* range[d]**
Global Mean Sea Level Rise (m)[b]	RCP2.6	0.24	0.17 to 0.32	0.40	0.26 to 0.55
	RCP4.5	0.26	0.19 to 0.33	0.47	0.32 to 0.63
	RCP6.0	0.25	0.18 to 0.32	0.48	0.33 to 0.63
	RCP8.5	0.30	0.22 to 0.38	0.63	0.45 to 0.82

Figure 5 Projected change in global mean surface air temperature and Source: Climate Change 2013 Summary for Policymakers, 2013

Regarding Land Use in the RCPs it is worth it to mention that the RCPs cover a broad range of land uses. The next tables give a coarse summary of the characteristics of the four RCPs with regards to the evolution of the land use (Table 2) and the situation of the land use in the world by the year 2100 (Table 3) as given in Van Vuuren et al 2011.

Table 2 Evolution of the land use up to the year 2100

RCP	Grassland	Cropland	Pasture
RCP8.5	Increase due to an increase of population	Increase due to an increase of population	
RCP6.0		Increase	Decrease
RCP4.5	Decrease due to reforestation programs	Decrease due to reforestation programs	
RCP2.6	Constant use	Increase as a result of bioenergy production	

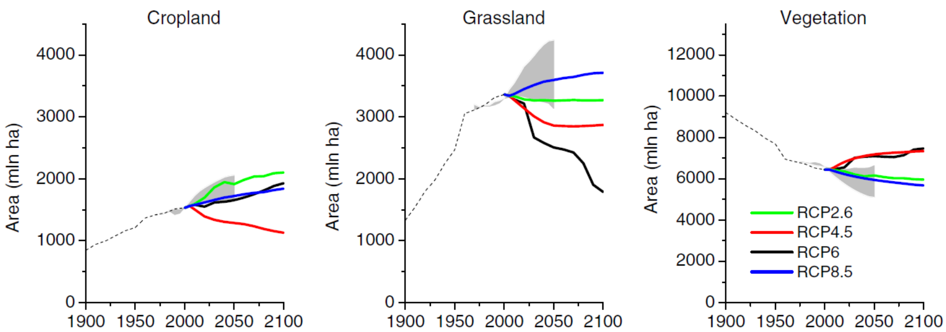


Figure 6 Development of primary energy consumption (direct equivalent) and oil consumption for the different RCPs. The grey area indicates the 98th and 90th percentiles (light/dark grey) (AR4 database (Hanaoka et al. 2006) and more recent literature (Clarke et al. 2010; Edenhofer et al. 2010). The dotted lines indicate four of the SRES marker scenarios

Table 3 Patterns for land use by 2100

RCP	Cropland	Pasture	Forest
RCP8.5	High density of cropland in United States, Europe, South-East Asia.	Western United States, Eurasia, South Africa and Australia.	Concentrated in northern high latitudes and parts of Amazonia. Secondary vegetation in United States, Africa, South America and Eurasia.
RCP6.0	Increase	Similar to RCP8.5 but less pasture in the United States, Africa, Eurasia an Australia	High density areas of secondary vegetation in United States, Africa and Eurasia.
RCP4.5	Less cropland than RCP2.6, RCP6 and 8.5		
RCP2.6	Similar to RCP8.5		

Shared Socioeconomic Pathways (SSPs)

The SSPs are defined by O'Neill et al as "reference pathways describing plausible alternative trends in the evolution of society and ecosystems over a century timescale, in the absence of climate change of climate policies". The approach followed to define the SSPs is an inverse approach combined with the complementary forward approach. It starts by defining the outcomes of interest for a climate change research and then finding the combination of socioeconomic elements that are likely to be the cause of those outcomes. Five SSPs have been defined as a function of different levels of challenge for mitigation and adaptation of a society to climate change. The level of the challenge to mitigation and adaptation is linked to the characteristics of the society to define and apply policies for mitigation and adaptation. The definition of policies for such matters is not included in the SSPs but in the SPAs.

The SSPs set the starting point for other scenarios that can be developed to meet specific objectives of its application. The scenarios or qualitative "narratives" that can be constructed need to cover the space of socioeconomic challenges to mitigation and adaptation that is set by the correspondent SSP. Currently initial starting points for SSP narratives have been set based on Kriegler et al 2012.

The next table shows a short description of the SSPs, the starting points for narratives, and the analogy to the SRES scenarios as described in O'Neill 2014.

Table 4 Initial starting points for the SSP narratives, based on Kriegler et at (2012)

SSP	Challenges	Illustrative starting points for narratives	Possible SRES analogue
SSP 1	Low for mitigation and adaptation	Sustainable development proceeds at a reasonably high pace, inequalities are lessened, technological change is rapid and directed toward environmentally friendly processes, including lower carbon energy sources and high productivity of land.	B1, A1T
SSP2	Moderate	An intermediate case between SSP1 and SSP3.	
SSP 3	High for mitigation and adaptation	Unmitigated emissions are high due to moderate economic growth, a rapidly growing population, and slow technological change in the energy sector, making mitigation difficult. Investments in human capital are low, 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.	A2
SSP 4	High for adaptation, low for mitigation	A mixed world, with relatively rapid technological development in low carbon energy sources in key emitting regions, leading to relatively large mitigative capacity in places where it mattered most to global emissions. However, in other regions development proceeds slowly, inequality remains high, and economies are relatively isolated, leaving these regions highly vulnerable to climate change with limited adaptive capacity.	No analogue
SSP 5	High for mitigation, low for adaptation	In the absence of climate policies, energy demand is high and most of this demand is met with carbon-based fuels. Investments in alternative energy technologies are low, and there are few readily available options for mitigation. Nonetheless, economic development is relatively rapid and itself is driven by high investments in human capital. Improved human capital also produces a more equitable distribution of resources, stronger institutions, and slower population growth, leading to a less vulnerable world better able to adapt to climate impacts.	A1FI

Besides this description of the SSPs as starting points, there is a larger process being developed with the collaboration between different communities including Integrated Assessment Model Communities and Impact Adaptation and Vulnerability communities to define SSP narratives and quantitative information. In the summary report of the Workshop on The Nature and Use of New Socioeconomic Pathways for Climate Change Research (O'Neill 2012), the international scientific community described the five SSPs. These descriptions include a qualitative part; the narratives, and a quantitative part; numerical pathways for important variables of the SSPs. The SSPs are built in 'blocks' containing 'elements' that are variables, processes or components that provide qualitative or quantitative information about the SSPs.

The blocks used to build the SSPs are the following: Demographics, Economic development, Welfare, Environmental and ecological factors, Resources, Institutions and governance, Technological development, broader societal factors, and Policies.

In the next lines, the narratives of the SSPs are summarized (O'Neill 2014):

SSP1 – Sustainability – Taking the Green Road: *The world shifts gradually, but pervasively, toward a more sustainable path, emphasizing more inclusive development that respects perceived environmental boundaries. Increasing evidence of and accounting for the social, cultural, and economic costs of environmental degradation and inequality drive this shift. Management of the global commons slowly improves, facilitated by increasingly effective and persistent cooperation and collaboration of local, national, and international organizations and institutions, the private sector, and civil society. Educational and health investments accelerate the demographic transition, leading to a relatively low population. Beginning with current high-income countries, the emphasis on economic growth shifts toward a broader emphasis on human well-being, even at the expense of somewhat slower economic growth over the longer term. Driven by an increasing commitment to achieving development goals, inequality is reduced both across and within countries. Investment in environmental technology and changes in tax structures lead to improved resource efficiency, reducing overall energy and resource use and improving environmental conditions over the longer term. Increased investment, financial incentives and changing perceptions make renewable energy more attractive. Consumption is oriented toward low material growth and lower resource and energy intensity. The combination of directed development of environmentally friendly technologies, a favourable outlook for renewable energy, institutions that can facilitate international cooperation, and relatively low energy demand results in relatively low challenges to mitigation. At the same time, the improvements in human well-being, along with strong and flexible global, regional, and national institutions imply low challenges to adaptation.*

SSP 2 - Middle of the Road: *The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns. Development and income growth proceeds unevenly, with some countries making relatively good progress while others fall short of expectations. Most economies are politically stable. Globally connected markets function imperfectly. Global and national institutions work toward but make slow progress in achieving sustainable development goals, including improved living conditions and access to education, safe water, and health care. Technological development proceeds apace, but without fundamental breakthroughs. Environmental systems experience degradation, although there are some improvements and overall the intensity of resource and energy use declines. Even though fossil fuel dependency decreases slowly, there is no reluctance to use unconventional fossil resources. Global population growth is moderate and levels off in the second half of the century as a consequence of completion of the demographic transition. However, education investments are not high enough to accelerate the transition to low fertility rates in low-income countries and rapidly slow population growth. This growth, along with income inequality that persists or improves only slowly, continuing societal stratification, and limited social cohesion, maintain challenges to reducing vulnerability to societal and environmental changes and constrain significant advances in sustainable development. These moderate development trends leave the world, on average, facing* *moderate challenges to mitigation and adaptation, but with significant heterogeneities across and within countries.*

SSP 3 – Regional Rivalry – A Rocky Road: *Growing interest in regional identity, regional conflicts, and concerns about competitiveness and security push countries to increasingly focus on domestic or, at most, regional issues. This trend is reinforced by the limited number of comparatively weak global institutions, with uneven coordination and cooperation for addressing environmental and other global concerns. Policies shift over time to become increasingly oriented toward national and regional security issues, including barriers to trade, particularly in the energy resource and agricultural markets. Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development, and in several regions move toward more authoritarian forms of government with highly regulated economies. Investments in education and technological development decline. Economic development is slow, consumption is material-intensive, and inequalities persist or worsen over time, especially in developing countries. There are pockets of extreme poverty alongside pockets of moderate wealth, with many countries struggling to maintain living standards and provide access to safe water, improved sanitation, and health care for disadvantaged populations. A low international priority for addressing environmental concerns leads to strong environmental degradation in some regions. The combination of impeded development and limited environmental concern results in poor progress toward sustainability. Population growth is low in industrialized and high in developing countries. Growing resource intensity and fossil fuel dependency along with difficulty in achieving international cooperation and slow technological change imply high challenges to mitigation. The limited progress on human development, slow income growth, and lack of effective institutions, especially those that can act across regions, implies high challenges to adaptation for many groups in all regions.*

SSP 4 – Inequality – A Road Divided: *Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries. Over time, a gap widens between an internationally-connected society that is well educated and contributes to knowledge- and capital-intensive sectors of the global economy, and a fragmented collection of lower-income, poorly educated societies that work in a labor intensive, low-tech economy. Power becomes more concentrated in a relatively small political and business elite, even in democratic societies, while vulnerable groups have little representation in national and global institutions. Economic growth is moderate in industrialized and middle-income countries, while low income countries lag behind, in many cases struggling to provide adequate access to water, sanitation and health care for the poor. Social cohesion degrades and conflict and unrest become increasingly common. Technology development is high in the high-tech economy and sectors. Uncertainty in the fossil fuel markets lead to underinvestment in new resources in many regions of the world. Oil and gas prices rise and volatility increases. Energy companies hedge against price fluctuations partly through diversifying their energy sources, with investments in both carbon-intensive fuels like coal and* *unconventional oil, but also low-carbon energy sources. Environmental policies focus on local issues around middle and high income areas. The combination of some development of low carbon supply options and expertise, and a well-integrated international political and business class capable of acting quickly and decisively, implies low challenges to mitigation. Challenges to adaptation are high for the substantial proportions of populations at low levels of development and with limited access to effective institutions for coping with economic or environmental stresses.*

SSP 5 – Fossil Fueled Development – Taking the Highway: *Driven by the economic success of industrialized and emerging economies, this world places increasing faith in competitive markets, innovation and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development. Global markets are increasingly integrated, with interventions focused on maintaining competition and removing institutional barriers to the participation of disadvantaged population groups. There are also strong investments in health, education, and institutions to enhance human and social capital. At the same time, the push for economic and social development is coupled with the exploitation of abundant fossil fuel resources and the adoption of resource and energy intensive lifestyles around the world. All these factors lead to rapid growth of the global economy. There is faith in the ability to effectively manage social and ecological systems, including by geo-engineering if necessary. While local environmental impacts are addressed effectively by technological solutions, there is relatively little effort to avoid potential global environmental impacts due to a perceived trade off with progress on economic development. Global population peaks and declines in the 21st century. Though fertility declines rapidly in developing countries, fertility levels in high income countries are relatively high (at or above replacement level) due to optimistic economic outlooks. International mobility is increased by gradually opening up labor markets as income disparities decrease. The strong reliance on fossil fuels and the lack of global environmental concern result in potentially high challenges to mitigation. The attainment of human development goals, robust economic growth, and highly engineered infrastructure results in relatively low challenges to adaptation to any potential climate change for all but a few.*

The Shared climate Policy Assumptions (SPAs)

These assumptions are defined by Kriegler et al 2014 as assumptions that "capture key policy attributes such as the goals, instruments and obstacles of mitigation and adaptation measures". Kriegler et al 2014 defined two groups of SPAs, a first group of SPA which includes the "full SPAs" with all mitigation and adaptation policy targets (embeds RCP and SSP), and a second group of "reduced SPAs" that excludes the mitigation policy goals, so it has to be used if policy assumptions can vary for a given RCP-SSP combination.

The next table shows key components of the narratives for the SPAs. These narratives include information on the nature of climate policies, the participation of regions and countries, the constraints for setting policies, etc. In the rows the policy attributes are summarized and in the columns, the reduced SPAs are listed.

Policy attribute	Reference policy	Cooperation and moderate adaptation	Middle road and aggressive adaptation	Fragmentation and moderation adaptation
Mitigation: level of global cooperation	low	high	medium	Low
Mitigation: start of global cooperation	never	early	Mid term	Late
Mitigation: sectorial coverage	Focus on electric and industry sectors. No significant inclusion of land use based mitigation options	Carbon pricing on land. Full coverage of energy supply and end use sectors	Forest protection and bioenergy constraints. Energy supply, transport and industry covered	Limited forest protection, no limitation on bioenergy use. Electricity and industry covered
Adaptation: Capacity building	small	moderate	large	moderate
Adaptation: International insurance	Only via international markets, with limited access for some countries	Insurance available for least developed countries	Global insurance provided	Only via international markets, with limited access for many countries

Scenarios prior to the RCPs, SSPs and SPAs

Most projects until now have used the older approach of the IPCC SRES scenarios; the sequential approach. They based their scenarios on storylines that were defined along two axes in most cases (IPCC SRES, GEO3/4, SCENES, REFRESH, etc) and more axes in other cases (PRELUDE scenarios EEA, 2007).

IPCC SRES scenarios were defined based on two axes; axis 1 global versus local and axis 2 economic versus environmental. Within IPCC SRES, four storylines were defined (A1, A2, B1, and B2).

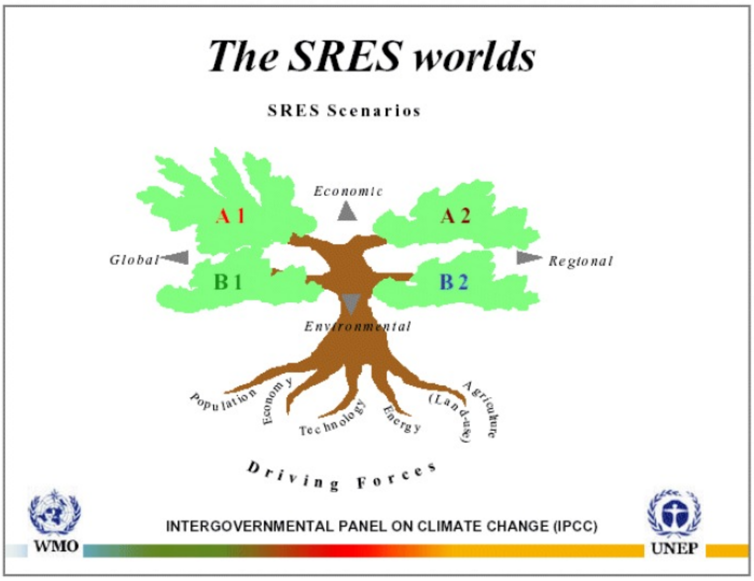


Figure 7 IPCC SRES scenarios

The UNEP's third and four global environmental outlook (GEO3 and 4), are based the same axes and include four storylines termed *markets first*, *policy first*, *security first* and *sustainability first*.

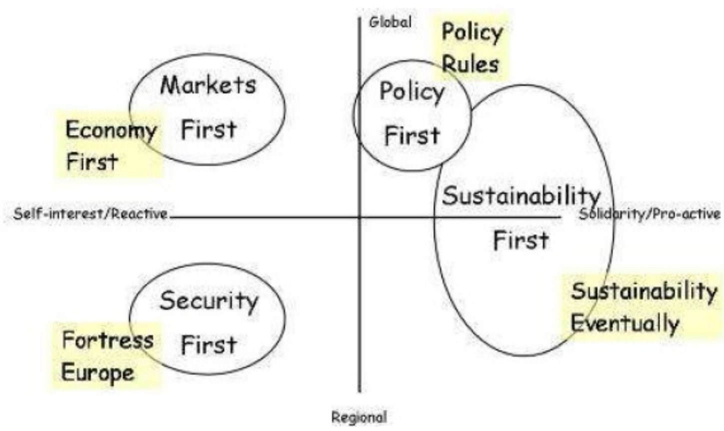


Figure 8 The GEO scenarios

Projects SCENES and REFRESH created own scenarios based on the SRES and GEO scenarios.

The next table summarizes the scenarios used in previous projects.

Classification	IPCC SRES	GEO3/4	SCENES	Millennium Ecosystem Assessment
The Global Market	A1	Markets First	Economy First	Global Orchestration
Continental Barriers Fortress	A2	Security First	Fortress Europe	Order from Strength
Continental Barriers Collapse				
Global Sustainability Policy	B1	Policy first	Policy Rules	(elements of Order from strength)
Global Sustainability Technology		Sustainability First (global)	Sustainability Eventually (global)	Techno Garden
Regional Sustainability	B2	Sustainability First (regional)	Sustainability Eventually (regional)	Adapting Mozaic

Besides, the UN has developed a set of scenarios described within the document "World Water Scenarios to 2050, exploring alternative futures of the world's water and its use to 2050". In this work, Gallopin (2012), present five scenarios build on a multi-axis approach which evaluates the evolution in the futures of drivers such as economy, demography, technology, etc., and the interaction between these drivers. The five scenarios are: Conventional World, Conflict World, Techno-world, Global Consciousness, and Conventional World Gone Sour.

Water Management Scenarios

Water management scenarios are often site specific. Therefore in the literature there is little information available about water management scenarios with global data. Instead, water demand and availability data and projections for the next 30 and 50 years are available (SCENES, 2011).

At basin level, the following water management scenarios are proposed:

- Change in technologies for irrigation. Impact on water use efficiency
- Change in river discharges due to increase of the water use
- Change in pesticides use. Impact on chemicals released to the water bodies
- Adaptation measures such as the ones described in BASE ?
- Building dikes for flood protection
- Building dams for hydroelectric power
- Measures regarding water use for industry and energy

- Conjunctive use of surface and groundwater sources through:
    - Use of groundwater if low flows
    - Artificial recharge of groundwater if high flows or small flooding
- Environmental flows to improve riparian zones and ecosystems
- Increase use of groundwater

3. MARS scenario framework

Introduction to the chapter

This chapter summarizes the approach taken to choose the scenarios and to define the storylines for MARS.

The Framework

MARS scenarios and storylines are used within MARS to calculate the impacts of multiple stressors on aquatic ecosystems. Therefore they must deliver a qualitative framework and where possible, quantitative data that modellers can use to run simulations.

The process followed to define the storylines and quantify them is described in Figure 9 and Figure 10. As a first step and through a participatory internal process we developed the storylines. A workshop was held in Helsinki with representatives of several works packages of MARS in which scenarios are relevant. During the workshop the main features of the storylines were defined and the first draft of the storylines was produced. Those storylines were sent to other MARS team members who were asked to share them with the stakeholders at basin scale. In order to get some idea of the acceptance of the defined storylines by the European stakeholders, we will send out some questionnaires asking for feedback. The objective is to understand the vision of the stakeholders on the utility of these storylines in policy building for aquatic ecosystems at European scale. The results of the questionnaires will be added to this report as an addendum as soon as they are available. Parallel to that process, we explored which projects and modelling tools could be used to extract data from socio-economic and climate variables (See chapter 4). After choosing the most suitable data sets according to MARS storylines and MARS modellers' needs, the data was pursued and provided to MARS team members for its use in the simulations. This data will be used within packages 3 to 7 to run the predictive models.

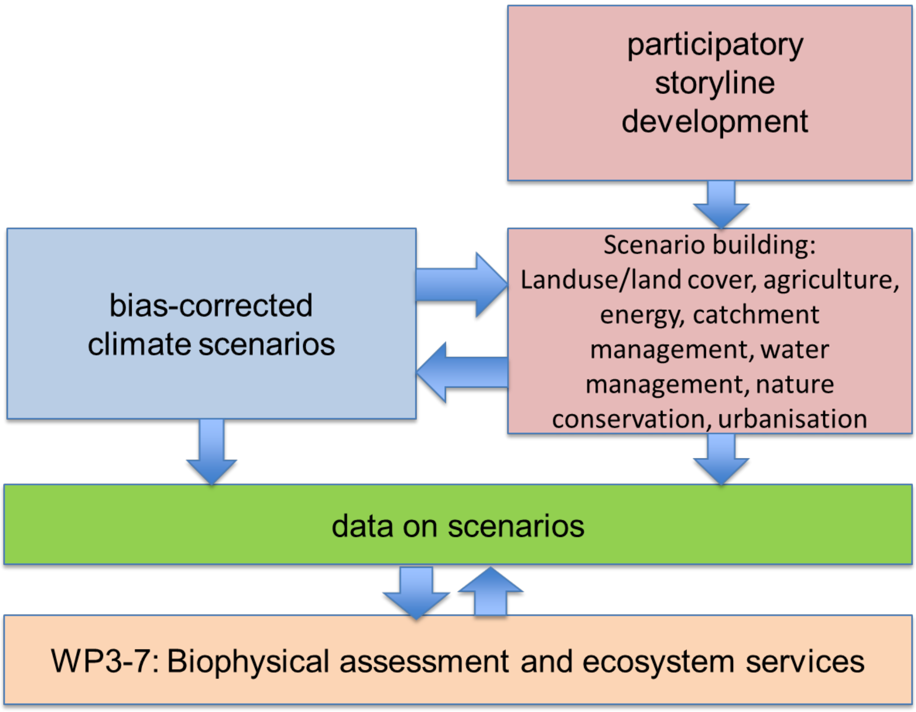


Figure 9 MARS scenario framework

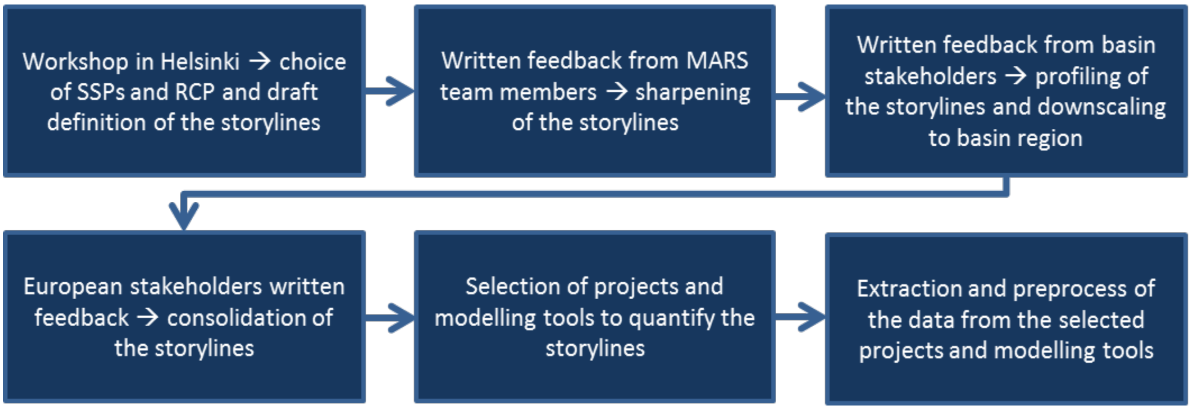


Figure 10 MARS storylines creation process

The choice of the storylines

Storylines in MARS are built on scenarios. The combination of certain climate scenarios and socio-economic scenarios set the basis for the narratives. The criteria used to select the scenarios were the following:

Scenarios must be plausible, but not desirable per se.

- The time horizon for the scenarios is 2030 and 2060. The reason for these horizons the update of the Water Framework Directive on 2027. One of the objectives of MARS is to support managers and policy makers in practical implementation of the WFD, therefore our predictions need to cover the period between now and the next update of the WFD. 2060 is chosen to show the impacts of climate change, as by 2030 climate projections show little change of climate variables in comparison with the now.

- Scenarios should represent future worlds of Europe where the impacts of the relevant stressors are showing significant differences.
- Water management measures, land use changes and the policy framework, are the main drivers to choose a scenario. The reason is the time horizon (2030 and 2060); by then the differences between climate scenarios are minimal and fit within the range of uncertainty.
- In order to identify the effect of socio-economic changes, the use of the same climate scenario might be desirable.
- Mitigation[1] and adaptation[2] challenges need to be in all storylines; however there will be significant differences between the storylines.
- Scenarios do not need to be extremes, but changes should be strong enough to cause effects for stressors studied in MARS.
- Stakeholders must support the choice of the scenarios.

In order to choose the scenarios and define the storylines, we made some assumptions (What is the current situation in EU?):

- Europe already cares to a certain extent about environment and tries to balance economic developments with a sustainable use of environmental resources. Policies are strong to protect the environment and biodiversity, and to promote sustainable and efficient use of resources available.
- Economic development goes along with environmental protection up to a certain level – world-wide: poorest countries- bad environmental quality problems vs. rich countries – high quality standards.
- Mitigation measures in Europe will only influence global climate change to a minor extent – In spite of mitigation measures in Europe we might end up with considerable climate change.
- We live in an economic driven world – farmers and industries operate within regulatory frameworks and focus on maximizing financial benefits.

In an internal workshop with MARS partners, 3 storylines were chosen and defined. The process to choose and define the storylines included intensive discussions on how to make the storylines unique, characteristic, suitable for MARS objectives, and different enough between them. The chosen storylines differ mainly on three main aspects: main driver in the economy

[1] Mitigation: measures to reduce climate change (basically reduction of CO_2-emissions)
[2] Adaptation: measures to reduce the impacts of climate change
o Local reactive measures, to prevent direct damages: dikes, reservoirs, …
o Decentralized, extensive, provident measures: unsealing cities, increasing water holding capacity of soils, floodplains, riparian zones, restoration of rivers, water saving irrigation, natural water retention measures, …

(markets, Europe centrally, or Europe state members), economic growth (fast, same pace as now, unequally within Europe), policies regarding the environment (poor in Europe as a unit, strong and continuing current trends, or unequally within Europe), and concern about the environment and protection of ecosystem services (local and people driven, government driven and as much as now, or unequally in Europe).

The option of choosing a storyline in which both the economy and the environment are first priority and in which both are highly stimulated and protected, has been discarded for MARS. The main reason is that this future is not considered plausible. Besides, a society that needs and stimulates ecosystem services (through high technological and economic development), can probably not achieve a good development of the ecosystems at the same time. Figure 11 is a graph showing the relation between ecosystem services level and ecosystem development. It shows that the more use we make of ecosystem services, in the long run, the less they develop and are preserved. By maximizing the provisioning services, we can expect a decrease of regulating services.

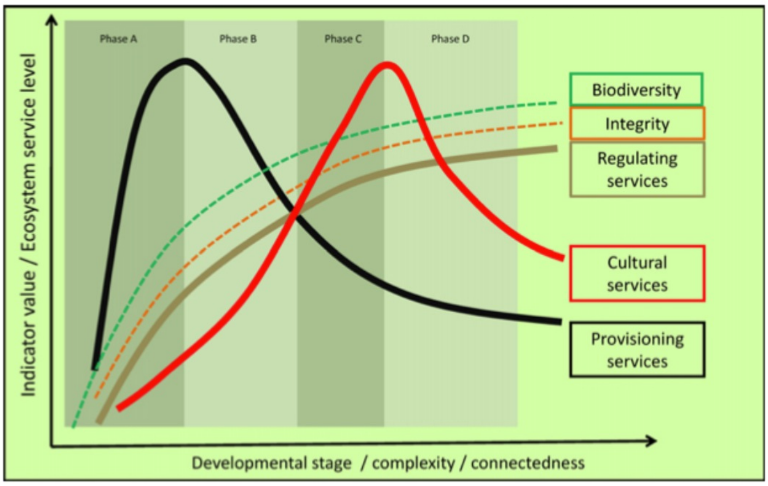


Figure 11 Hypothetical developmental traits of integrity, biodiversity and ESS (Kandziora et al. 2013)

The defined storylines are based on combinations of the SSPs and the RCPs. Annex1 shows the tables containing information on the climate change effects for the different RCPs.

Storyline 1 – Techno world - or Economy rules

Economy: the economy is growing fast. The main objective of the government and the citizens is an economic growth. Governments and EU are stimulating and facilitating companies and industries in developing innovative technologies and solutions to increase the capital. There are plenty of economic resources available; however they are invested mostly to generate more economic resources.

Energy: due to high economic development, energy demands are high; extended use of fossil fuels; oil and gas resources that are currently difficult to exploit are exploited in near future due to technological innovations. As a consequence of the use of more resources, there is an increase of CO2 emissions. In addition, increasing energy demand is fulfilled due to increase in energy production by hydropower and other alternative energy sources such as biofuel crops. The development of renewable energies is not because of environmental regulations, but because of financial stimulation programs to develop innovative technological solutions.

Environment: high awareness on society but poor regulation of environmental protection by the governments. Most actions to protect or improve the environment are taken ad hoc. Individuals and NGO's are active as there are enough resources available. Most actions are the result of individual or commune interest on protecting the environment, but they are not regulated strongly by the government. Some provisioning services are of high priority (e.g. biofuel crops, hydropower). Cultural services are locally important (recreation opportunities close to the cities). Regulating services (requiring basin-wide regulation) are neglected.

Policies: the current environmental policies and guidelines are not renewed after they expire in the next decade and no new environmental policies are set. The governmental focus is on enhancing trade and benefitting the economic growth. Therefore there are almost no policies regarding environmental flows, protection of nature areas, ecological status, etc. With respect to nature conservation, governments focus on assigning projects that aim at increasing the recreation potential of current nature conservation and protection areas.

Water management strategies: most strategies to protect against flooding and droughts or to minimize human health risks are based on technological solutions. Water resources management is focusing on getting the water needed for economic development and production of drinking water. Little effort is done to apply long term sustainable measures; measures are rather focused on the current need and development.

This world is based on a combination of SSP5 and climate scenario 8.5.

Storyline 2 – Consensus world

Economy: the economy and the population are growing at the same pace as now. The main objectives of the government and citizens are to stimulate economic growth on the one hand and to promote sustainable and efficient use of resources on the other hand. The focus is not per se on innovation, but assuring that everything keeps on moving and there is no recession. The available resources are limited and no risky investments are made.

Energy: mix of use of fossil fuels and renewable energies, including bio-energy crops (production level increases significantly). There are regulations to save energy in favour of reducing emissions.

Environment: awareness and interest for preservation, but mostly due to the existing and extended strong regulations. Greening measures being discussed within the EU take shape in this scenario.

Policies: the current guidelines and policies are continued after 2020 (EU strategy on Adaptation to Climate Change, EU Biodiversity Strategy to 2020, EU Habitats and Birds, Directive on industrial emissions, Regulation on European Pollutant, Flood directive, Directive on Environmental Quality Standards and Dangerous Substances, Water Framework Directive, etc), but in a more integrated manner. As a result policy objectives and targets are integrated as well, and therefore realistic to achieve.

Water management strategies: most strategies are set to comply with the regulations. Cheap solutions sustainable at mid-long term are the first choice, but there is a trend towards building with nature solutions (green infrastructure by benefiting from natural processes and structures).

This world is based on a combination of SSP2 and climate scenario 4.5.

Storyline 3 – Fragmented world

Economy: the economy grows in some countries (especially in Northern and Western – Central Europe) and decreases in others (Southern part). There is a high difference between the developments of the different countries because of no international trade agreements. The focus is set to survive as a country instead of as Europe. Each country chooses a different way to achieve that. A consequence is that Europe in general suffers from a lack of resources, and mostly the countries with current debts suffer from real scarcity of resources.

Energy: extended use of fossil fuels, investments in renewable energy to meet increased energy demands, only there where enough financial resources are available and no other alternatives are available.

Environment: no attention is paid to the preservation of the ecosystems. Both government and citizens are too busy with other issues. In rich countries there is awareness and resources, so some measures are implemented, especially local scale solutions. No attention for transboundary issues.

Policies: the current environmental policies and guidelines are broken in 2020-2025. Each country sets its own rules. But national institutions focus on economic development and forget about the environment. Rich countries do support local scale solutions.

Water management strategies: there are no strategies but actions. Actions are set just looking at short term effects and make sure that the current generation will have enough water and food and that the regions/locations with high economic value are protected against floods.

This world is based on a combination of SSP3 and climate scenario 8.5.

Ranking of the criteria to define scenarios

In the following table a set of criteria that will be used to shape the scenarios is shown. These criteria have been chosen based on 1) the input parameters of different models used in MARS (see Annex2), and 2) the discussions during the MARS workshop in Helsinki.

The scores that each criterion gets in each scenario is fruit of the description of the storyline above, the respective SSP, the description of other scenarios such as those of Climsave and SCENES (which partly can be comparable to the MARS scenarios), and the discussions during the MARS workshop in Helsinki.

The scores go from 3+ to 3- and include the 0. This range of scores gives the possibility to distinguish between significant, moderate, slight and no change in comparison with the current situation:

Table 5 Explanation of the scores given to the criteria used to define the storylines

Score	Description
+++	Significant increase compared to the current situation
++	Moderate increase compared to the current situation
+	Slight increase compared to the current situation
0	No change compared to the current situation
-	Slight decrease compared to the current situation
--	Moderate decrease compared to the current situation
---	Significant decrease compared to the current situation

Table 6 Ranking of the criteria used to define the storylines

Criteria	Element	Techno World - MARS ad hoc World	Consensus World - MARS World	Survival of the fittest - No MARS World
Environment, Biodiversity and Ecosystems	Protection of environment	+	+++	---
	Protection of coastal zones	+	+++	---
	Building with nature solutions	+	+++	---
	Preservation of natural habitats	+	+++	---
	Fish passages	0	++	---
	Loss of riparian zones in favour of touristic areas, agriculture, etc	+	0	+++
	Habitat loss	++	+	+++
	Desertification	++	+	+++
	Sediments in water due to erosion	++	+	+++

	Prevention of invasion alien species	-	+	---
	Shift of ecoregions	+	0	++
	Risk of superweeds	+	0	++
Land use change	Growth of non-native plantations	++	+	+++
	Urbanization	+++	++	+++
	deforestation	++	+	+++
	Landscape greening	-	++	---
Agriculture	Sustainable meat production	+	++	---
	Use of pesticides	+++	+	+++
	Use of new pesticides (less env. effects)	+	+++	0
	Nutrient load	++	+	+++
	Efficient use of resources	+++	++	---
	Reuse of manure and byproducts	++	++	---
	Abandonment of land	-	++	+++
	Recovery of eroded/degraded soils	-	++	---
	Control drainage	+	++	---
	Agricultural areas for crops	-	0	--
	Organic farming	0	++	---
	Genetically modified crops	+++	+	+++
	Crop rotation	0	+	0
	Use of crops to prevent erosion	0	++	---
	Efficient irrigation	++	++	---
	Production level	+++	++	+++
	Industrialization	+++	++	+++
	Use of fertilizers	+	++	+++
	Salinization of soils	+	+	+++
	Water pollution	+	+	+++
	Local agriculture	++	+	+++
Water management	Environmental flow needs covered	+	++	---

	Water transfer from water rich to water poor	++	+	0
	Natural flood retention	+	++	---
	Considerable difference in water levels in different seasons	+++	+	+++
	Water level extremes	+++	+	+++
	Increase water reservoirs and weirs	+++	+	+++
	ASR (Aquifer storage and recharge)	+	+++	---
	Use of dikes	+++	++	+++
	Overexploitation of water resources	++	+	+++
	Water use efficiency	+++	+	---
	Waste water reuse	+	++	---
	Green roofs	+	++	---
	more water use in touristic areas	+++	++	+++
Hydropower energy	Less and bigger hydropower plants	+++	-	+++
	Bigger reservoirs	+++	-	+++
	Small and more hydropower plants	-	++	---
	Compromise between hydropower and maintenance of environmental flows	+	+++	---
Water pollution control: eutrophication and water treatment	Water treatment plants	++	++	+
	Restoration of riparian zones	-	++	---

4. Data availability

Introduction to the chapter

The aim of this chapter is to provide an overview of the data available to run predictive models of the three future storylines developed within MARS.

In order to simulate the future scenarios, quantitative values for the input parameters and variables for each scenario needed to be assigned. The required data comprises mainly climate and socio-economic data as these parameters are the ones that vary most with each scenario. Specific data to set up each model that is not dependent on the MARS scenarios (elevation models, river network etc.) is outside the scope of work of this task and will need to be determined by the modellers.

The quantitative values of the inputs for the predictive models provided were derived from existing projects and modelling tools.

The variables and parameters needed as an input for the European scale and river basin level models were identified by the different participants; the focus was set on the main drivers and pressures impacting the modelled area.

It was prioritized to find data for the three European scale models, MONERIS, GREEN and PCR-GLOBWB, for which quantitative ranges of input variables and parameters have been identified. This data can also be used at river basin scale for the 16 catchments of MARS, as the data provided geographically covers all the catchments and in some cases has a high resolution. Table 7 summarizes the input parameters and variables required for each of the European models for which this task provides quantitative data.

Table 7: Input parameters/variables for each European model

Input parameter/variable	MONERIS	GREEN	PCR-GLOBWB
Surface air temperature			x
Precipitation	x	X	x
Evapotranspiration	x		
Runoff	x		
Water abstraction	x		
Water addition	x		
Potential flood plain	x		
Atmospheric deposition (NOx and NH4)	x		
Nutrient point source emissions	x	x	

(N and P)			
Nutrient diffuse source emissions (N and P)		X	
Nitrogen surplus	x		
Phosphorous accumulation	x		
Land use/cover classes	x		x
Population and GDP	x		

The next paragraphs briefly describe the models used in MARS at European Scale.

MONERIS

MOdelling Nutrient Emissions in RIver Systems (MONERIS) was developed by the Leibniz Institute for Freshwater Ecology and Inland Fisheries (IGB) in order to perform watershed and water quality-based studies. The model addresses three objectives: to identify the source of nutrient emissions on a regional basis, to analyse transport and retention of nutrients in river systems and to provide a framework for examining management alternatives.

MONERIS is an empiric model, which allows the quantification of nutrients emissions via various point and diffuse pathways into river basins (see Figure 12). The model has successfully been applied for diverse river basin studies such as the Danube (Schilling et al., 2005), the Elbe (Behrendt et al., 2002) or the Baltic sea (Schernewski et al., 2011).

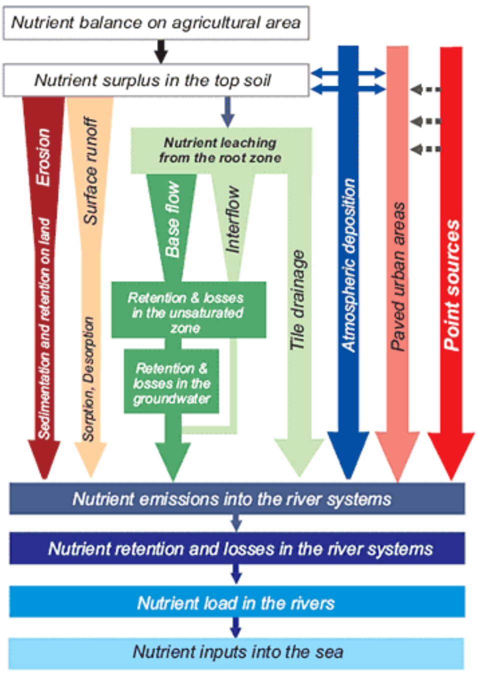


Figure 12: Pathways and processes in MONERIS (Source Behrendt et al., 2007)

GREEN

The model GREEN (Geospatial Regression Equation for European Nutrient losses) is a simplified empiric model which relates the nutrient loads to spatially referenced nutrient sources and river basin characteristics.

It was developed at the European Commission's Joint Research Centre, inspired from the SPARROW model (Smith et al., 1997). The goal was to provide a modelling tool that can be readily applied to medium and large river basins using data routinely collected; in particular, to quantify the nutrient emissions to surface water, quantify the contribution by different sources to the total nutrient export to the rivers and to estimate the retention of nutrients in the river systems.

GREEN has already been used to analyse nutrient pressures at the European scale (Grizzetti & Bouraoui, 2006).

PCR-GLOBWB

PCR-GLOBWB is a large-scale hydrological model intended for global to regional studies and developed at the Department of Physical Geography, Utrecht University (Netherlands).

The model PCR-GLOBWB (Sperna Weiland et al. 2010) is a leaky bucket type hydrological model that provides a grid-based representation of terrestrial hydrology with a spatial resolution of 0.5 by 0.5 degrees and 10 by 10 arc minutes on a daily basis. For each grid cell, PCR-GLOBWB uses process-based equations to compute moisture storage in two vertically stacked soil layers as well as the water exchange between the soil and the atmosphere and the underlying groundwater reservoir. Exchange to the atmosphere comprises precipitation, evapotranspiration and snow accumulation and melt, which are all modified by the presence of the canopy and snow cover (Figure 13).

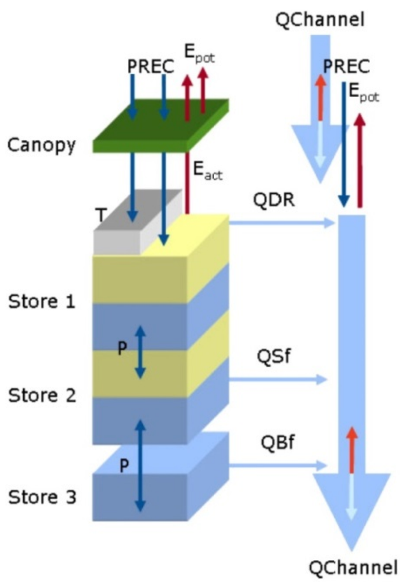


Figure 13: Model concept of PCR-GLOBWB (Source: PCRaster, 2014)

PCR-GLOBWB has successfully been used in recent years for such different purposes as to estimating groundwater recharge (Wada et al., 2010) or specification of wetland hydrological conditions (Petrescu et al., 2010). Some of the projects/modeling tools reviewed for this reports, including ISI-MIP, IMAGE and BASE, make use of PCR-GLOBWB to perform hydrological modeling.

PCR-GLOBWB has a double application in MARS since it will be one of the European scale models employed and it will also provide runoff data as input for the other two European-scale models; although the data won't be accessible until end-2015.

Economic model

An economic model at European scale is also planned to be built within the scope of MARS. However, it will employ a statistical modelling approach and run had-hoc scenarios on water quality and change in ecological status of lakes that are different from the storylines developed for MARS.

Models at river basin scale

The models that are going to be used at the river basin level are very diverse and include, among others, SWAT, PhytoFluss, QUESTOR, PROTECH, Persist, INCA, MyLake, MAGIC, PCLake, DYRESM-CAEDYM, Delft 3D, SOBEK, MOHID etc.

The variables and parameters needed as input for the river basin level models are, in many cases, the same as the ones for the European models. Those parameters that have not been quantified in this task will need to be calculated by the modellers of each river basin, based on the qualitative criteria used to shape each MARS storyline (refer to the MARS Storylines Memo from the scenario workshop held in Helsinki in May 2014) and their expert knowledge .

Literature Review

In order to evaluate existing data on the selected parameters and variables for the predictive models, a review of literature and on-going projects that assess possible futures of Europe was carried out. The following projects/modelling tools were revised:

- ISI-MIP
- CLIMSAVE
- SCENES
- IMAGE
- GLOBAQUA
- REFRESH
- BASE

According to its suitability, data and information on a range of parameters and variables was derived from the above mentioned literature as a starting point for analysis and assessment of the impacts of future multistressor conditions on water quantity, chemical and ecological status of Europe's water bodies at EU and river basin level.

The criteria used to assess the suitability of the data of the different projects and models was:

- similarities of the storylines and scenarios used in the projects/models with the storylines and scenarios defined for MARS
- novelty of the used scenarios and storylines and match with the last IPCC report, SSPs and RCPs
- temporal and spatial resolution
- use of the data in previous successful projects

A summary of the specifications of the projects and modelling tools that were reviewed is given in Table 8, followed by a more detailed description below.

Table 8: Summary of specifications of reviewed projects and modelling tools

Project/ modelling tool ID	Is it a project or a modelling tool?	Emission scenario used	Socio-economic scenario used	Climatic model used	Impact model used
ISI-MIP	Project	RCP's	SSP's	GFDL-ESM2M[3] HadGEM2-ES IPSL-CM5A-LR MIROC-ESM-CHEM NorESM1-M	Various (LPJmL, ORCHIDEE, WaterGAP, PCR-GLOBWB, PEGASUS etc.)
CLIMSAVE	Both	A1 A2 B1 B2	We are the world Icarus Should I Stay or Should I Go Riders on the Storm	HadGEM GFCM21 IPCM4 CSMK3 MPEH5	Various (WaterGAP, CFFlood. SFARMOD, GOTILWA+ etc.)
SCENES	Project	A2	Economy First Fortress Europe Policy Rules Sustainability Eventually	IPSL-CM4 (IPCM4) MICRO3.2 (MIMR)	WaterGAP HABITAT and CGMS
IMAGE	Modelling tool	Any	Any	MAGICC	Various (LPJmL, GLOBIO, PCR-GLOBWB etc.)
GLOBAQUA	Project	Not defined yet	Not defined yet	RCA4	Various (RWQM,

[3] ISI-MIP is the only project reviewed that has run the specified climate models to obtain data; the rest of the projects and modelling tools have employed existing data from the different climate models.

Project/ modelling tool ID	Is it a project or a modelling tool?	Emission scenario used	Socio-economic scenario used	Climatic model used	Impact model used
					InVEST, SWAT, LISFLOOD, LISQUAL etc.)
REFRESH	Project	A1B	World Market National Enterprise Global Sustainability Local Stewardship	ECHAM5-KNMI HadRM3-HadCM3Q0 SMHIRCA-BCM	SWAT, INCA-N, INCA-P and PERSiST
BASE	Project	RCP4.5 RCP8.5	SSP2 SSP5	A set of models from CMIP5 (or CMIP3)	AD-WITCH, Climate-Crop, WAPA, PCR-GLOBWB and PRIMATE.

ISI-MIP

The Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) is a community-driven modelling effort bringing together impact models across sectors and scales to create consistent and comprehensive projections of the impacts of different levels of global warming. ISI-MIP uses a common set of input data and a common modelling protocol to provide the basis for a cross-sectoral integration of impact projections. The project is coordinated by the team at PIK (Potsdam Institute for Climate Impact Research) (Warszawski et al., 2013).

The ISI-MIP models are based on the RCP's and SSP's used in the IPCC's Fifth Assessment Report and five of the CMIP5 Global circulation models (GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM and NorESM1-M). Different impact models (LPJmL , WaterGAP, MPI–HM, Hybrid4, MAgPIE etc.) are being used to produce different simulation data that can be used for cross-sectoral comparison (Davie et al., 2013 and Schewe et al., 2013)

Climate data such as surface air temperature and precipitation for MARS was extracted using the ISI-MIP approach as it provided the best temporal and spatial resolution.

CLIMSAVE

CLIMSAVE or Climate Change Integrated Assessment Methodology for Cross-Sectoral Adaptation and Vulnerability in Europe, is a pan-European project that is developing a user-friendly, interactive web-based tool that will allow stakeholders to assess climate change impacts and vulnerabilities for a range of sectors, including agriculture, forests, biodiversity, coasts, water resources and urban development (Harrison et al., 2012). CLIMSAVE is coordinated by the University of Oxford and funded by EU FP7.

The CLIMSAVE Integrated Assessment Platform (IAP) allows the user to set specific future scenarios by selecting among five CMIP3 climate models (HadGEM, GFCM21, IPCM4, CSMK3 and MPEH5), four SRES emission scenarios (A1, A2, B1 and B2) and four socio-economic scenarios, specifically developed for the project (We are the world, Icarus, Should I Stay or Should I Go and Riders on the Storm). Among the various linked impact models that CLIMSAVE is able to run WaterGAP, CFFlood and SFARMOD-LP are the most relevant to water related issues (see Figure 14).

WaterGAP (Water – Global Assessment and Prognosis) is a global water assessment model developed at the Centre for Environmental Systems Research of the University of Kassel (Alcamo et al., 2003, Döll et al., 2003). WaterGAP consists of two main components: a Global Hydrology Model to simulate the terrestrial water cycle and a Global Water Use Model to estimate water withdrawals and water consumption of different sectors

The CFFlood (Coastal Fluvial Flood) meta-model within CLIMSAVE provides estimates of the socio-economic and environmental impacts of future flooding, such as potential flood plains, that are attributed to climate change and sea-level rise in Europe's coastal and fluvial floodplains.

SFARMOD-LP is a land-use model able to produce outputs on environmental burdens such as nitrate leaching, pesticide use or nitrogen use. SFARMOD-LP (also known as the Silsoe Whole Farm Model) is a mechanistic farm-based optimising linear programming model of long-term strategic agricultural land use that is based on profit maximisation, subject to the constraints of soil, precipitation and sound agronomic practice (Annetts & Audsley, 2002).

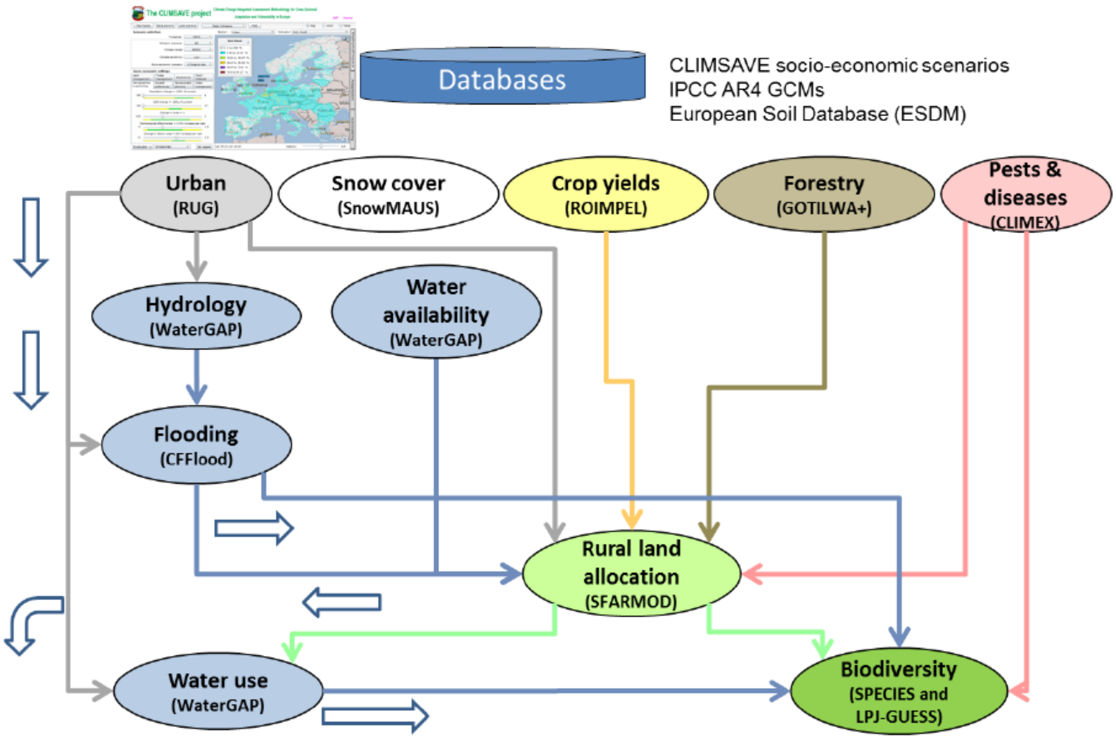


Figure 14: Simplified structure of the linked models within the CLIMSAVE IA Platform (Source: Holman et al., 2013)

CLIMSAVE has already been put into practice for measuring impacts in water resources (Wimmer et al., 2014) or evaluating robustness of climate change adaptation measures (Jäger et al., 1014).

Input data for the European scale models on potential floodplain and nutrient diffuse sources was derived from CLIMSAVE as it was the only project/modelling tool that could readily provide such information.

SCENES

SCENES (Water Scenarios for Europe and for Neighbouring States) was a European FP6 research project developing scenarios on the changes in the quantity and quality of fresh water resources in pan-Europe due to climate change, land use change and socio-economic development (Kämäri et al., 2008). SCENES aimed to provide relevant results directly to the science-policy interface that would allow a better management of water resources.

The project's approach was to combine the IPSL-CM4 and MICRO3.2 climatic models with the SRES A2 emission scenario (worst case emission scenario) and four purpose-built socio-economic scenarios (Economy First, Fortress Europe, Policy Rules and Sustainability Eventually). The project was coordinated by The Finnish Environment Institute (SYKE).

In order to compute the impact of climate change and water use by different sectors on future water resources, the WaterGAP3 version (Verzano, 2009) was applied in SCENES. This is the same model used in CLIMSAVE.

Indicators such as water abstraction, runoff and land use have been extracted from SCENES.

The rationale and assumptions behind the calculations of water abstraction data in SCENES were the most comprehensive and documented ones among all the projects/modelling tools reviewed and therefore, it was decided to derive that information from this project.

Runoff data will be extracted from PCR-GLOBWB as it is the most comprehensive hydrological model but since that data won't be available until the end of 2015, SCENES was also used to derive the information.

Land use data was also extracted from SCENES as it provided the most detailed spatial resolution.

IMAGE

IMAGE is an Integrated Model to Assess the Global Environment developed under the authority of PBL Netherlands Environmental Assessment Agency. The IMAGE model (version 3.0, released in 2014) has three main objectives: to analyse large-scale and long-term interactions between human development and the natural environment to gain a better insight into the processes of global environmental change, to identify response strategies to global environmental change based on assessment of options for mitigation and adaptation and to indicate key interlinkages and associated levels of uncertainty in processes of global environmental change.

IMAGE is an Integrated Assessment Modell (IAM) characterized by relatively detailed biophysical processes and a wide range of environmental indicators but it has less detail on economics and policy instruments than other IAM models.

Figure 15 shows the components of the IMAGE framework. Multiple models representing dynamics and impacts on a wide range of systems/sectors are interlinked within IMAGE.

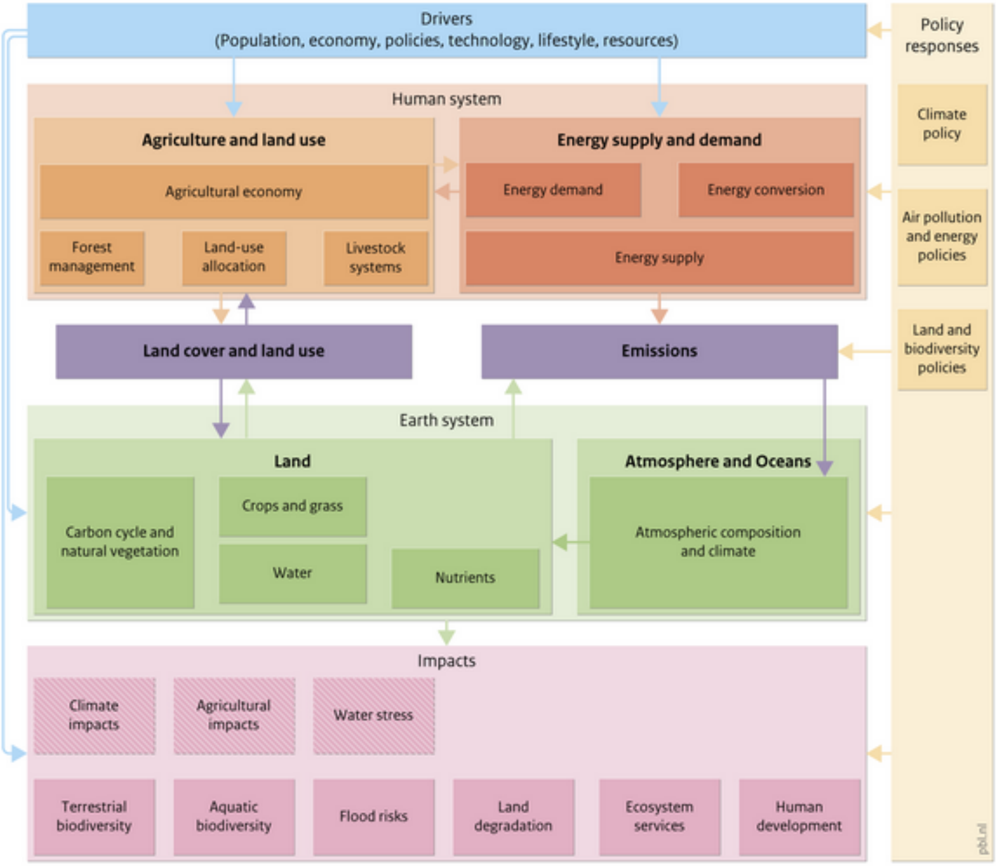


Figure 15: IMAGE 3.0 framework (Source: PBL, 2014)

IMAGE has progressively been developed since the 1980's and it has been used for a vast variety of purposed and studies: The Millennium Ecosystem Assessment project, where IMAGE framework was used to focus on the role of ecosystem services to support human development (Millennium Ecosystem Assessment, 2005), to develop the RCP2.6 for the IPCC's Fifth Assessment Report (Van Vuuren et al., 2011), the Eururalis project which assessed alternatives to the current EU Common Agricultural Policies (Eickhout et al., 2007) etc.

It's worth noting that IMAGE has participated in the ISI-MIP project; it was used to measure the effect of climate change on crop yields (Rosenzweig et al., 2013).

At the moment of the publication of this report, data derived from IMAGE has not been available for this project. However, quantitative values for atmosphere deposition, nutrient point source emission, nitrogen surplus, phosphorous accumulation and land use changes could be extracted with this modelling tool.

GLOBAQUA

The GLOBAQUA project (Managing the effects of multiple stressors on aquatic ecosystems under water scarcity) has assembled a multidisciplinary consortium in order to study the interaction of multiple stressors within the frame of strong pressure on water resources. The aim of GLOBAQUA is to identify the prevalence, interaction and linkages between stressors, and to assess their effects on the chemical and ecological status of freshwater ecosystems affected by water scarcity in order to improve water management practice and policies (Navarro-Ortega et al., 2014).

The main objectives of GLOBAQUA match those of MARS, and as such it was identified as a project of special importance. A framework for collaboration between both projects has been agreed and, if possible, the same scenarios will be used in GLOBAQUA and MARS.

GLOBAQUA is an EU FP7 funded project that started in February 2014. Since it's still on its early stages of development it hasn't yet generated any data that could be used in MARS.

REFRESH

Adaptive Strategies to Mitigate the Impacts of Climate Change on European Freshwater Ecosystems or REFRESH builds on a previous EU FP6 Project; Euro-limpacs. The key objective of this EU FP7 project is to develop a framework that will enable water managers to design cost-effective restoration programmes for freshwater ecosystems. This will account for the expected future impacts of climate change and land-use. REFRESH will evaluate a series of specific adaptive measures that might be taken to minimise adverse consequences of climate change on freshwater quantity, quality and biodiversity.

Six different catchment case studies across Europe were chosen to undertake scenario analysis. In all the catchment modelling activities the output from three Global Circulation Model-Regional Climate Model combinations derived during the ENSEMBLES project were used (ECHAM5-KNMI, HadRM3-HadCM3Q0 and SMHIRCA-BCM), as well as the A1B emission scenario which was also used in ENSEMBLES. Additionally, four different storylines were produced; each one linked to a different quadrant of the IPCC SRES scenarios: World Market (A1), National Enterprise (A2), Global Sustainability (B1) and Local Stewardship. The storylines were further adapted to local conditions based on the expert knowledge of modellers of each catchment.

Different impact models were utilized in each catchment case study depending on the anticipated impact to be analysed (Lepistö et al., 2013).

No input parameters to be used in the European models of MARS were derived from REFRESH as the data utilized in this project was specific for the selected catchment case studies.

BASE

BASE (Bottom-Up Climate Adaptation Strategies Towards a Sustainable Europe) aims to foster sustainable adaptation in Europe by improving the knowledge base on adaptation and making this information easier to access, understand and act upon. It will do so by undertaking an interdisciplinary assessment of costs, benefits, effectiveness, challenges and opportunities of adaptation across diverse sectors.

BASE is an ongoing EU project funded under the FP7 and coordinated by Aarhus University (AU). A natural precursor of BASE is the CLIMATECOST project which analysed the cost of long-term mitigation policies and the costs of inaction in the EU, but only dealt with the costs and benefits of adaptation to a limited extent; BASE thus complements CLIMATECOST.

In order to gather insights from the local level, the BASE project will examine climate change adaptation case studies from across Europe. There will be a common study methodology were all case study models will be run for a set of climate scenarios (CMIP5, if available, otherwise CMIP3) and employ RCP4.5 and RCP 8.5 and SSP2 and SSP5 from the IPPC's Fifth Assessment Report for the emission and socio-economic scenarios. BASE also foresees to develop narratives (storylines) of a plausible future including climate change, socio-economic developments and adaptation pathways with the participation of a stakeholder panel (Bosello et al., 2013).

Within BASE different types of impact models will be used: the AD-WITCH economy model to describe EU-wide economic implications of different climate strategies, diverse sector models (Climate-Crop, WAPA and PCR-GLOBWB) which will provide the direct damages and effects of climate adaptation by sector and finally, the decision support tool PRIMATE (interactive software for Probabilistic Multi-Attribute Evaluation).

The BASE project is currently generating scenario's data such as flooding recurrence times, but due to timing, the data/information could not be adapted for MARS.

In summary, among the literature examined, PCR-GLOBWB and IMAGE are the only strictly modelling tools revised; PCR-GLOBWB focuses on the hydrological cycle, while IMAGE covers a wider range of systems/sectors. CLIMSAVE has also developed a modelling tool that allows assessing climate change impacts associated with different sectors. The ISI-MIP project brings together diverse impact models in order to perform inter-sectorial comparisons. SCENES, GLOBAQUA and REFRESH (as well as MARS) are all projects which aim to support sustainable water resource management under varying water stress and climate change scenarios. BASE also deals with future climate change scenarios but focuses on adaptation strategies across diverse sectors, including the water sector.

Selected climate models and scenarios

The scenarios and climate models employed in the projects/modelling tools that were used to derive data from, namely, ISI-MIP, SCENES and CLIMSAVE, differ from each other and from the ones specifically developed for MARS in some cases. In order to be able to employ data extracted from the different projects/modelling tools, an approximation between their scenarios and the ones from MARS needed to be done. The following table provides a summary of the scenarios and climate models selected as best match to MARS:

Table 9: Summary of selected climate models and scenarios

MARS				ISI-MIP			SCENES			CLIMSAVE		
Storyline	**Climate model**	**Emission scenario**	**Socio-economic scenario**	**Climate model**	**Emission scenario**	**Socio-economic scenario**	**Climate model**	**Emission scenario**	**Socio-economic scenario**	**Climate model**	**Emission scenario**	**Socio-economic scenario**
Storyline 1	GFDL-ESM2M[4] HadGEM2-ES IPSL-CM5A-LR MIROC-ESM-CHEM NorESM1-M	RCP8.5	SSP5	GFDL-ESM2M HadGEM2-ES IPSL-CM5A-LR MIROC-ESM-CHEM NorESM1-M	RCP8.5	NA	MIMR	A2	Economy First	CSMK3	A1	Icarus
Storyline 2	GFDL-ESM2M HadGEM2-ES IPSL-CM5A-LR MIROC-ESM-CHEM NorESM1-M	RCP4.5	SSP2	GFDL-ESM2M HadGEM2-ES IPSL-CM5A-LR MIROC-ESM-CHEM NorESM1-M	RCP4.5	NA	MIMR	A2	Policy Rules	CSMK3	B1	Riders on the Storm
Storyline 3	GFDL-ESM2M HadGEM2-ES IPSL-CM5A-LR MIROC-ESM-CHEM NorESM1-M	RCP8.5	SSP3	GFDL-ESM2M HadGEM2-ES IPSL-CM5A-LR MIROC-ESM-CHEM NorESM1-M	RCP8.5	NA	MIMR	A2	Fortress Europe	CSMK3	A1	Should I Stay or Should I Go

[4] It has yet to be decided data from which climate model(s) will be employed in the MARS predictive models.

In relation to the climate data, ISI-MIP is the only project evaluated within MARS that has run climate models to obtain data; SCENES and CLIMSAVE employed existing data from diverse climate models. Since all three project/modelling tools applied different climate models, it was not possible to use data from the same climate model to extract the required parameters.

All available climate models were used in ISI-MIP to derive data from. Regarding the use of this data within MARS, it has not been decided yet if an ensemble with all the data will be employed in all the models or each participant will be free to choose the data from the model they consider more appropriate. From the models used in SCENES, MIMR was chosen as it produced precipitation projections across Europe that best corresponded to the RCP4.5 and RCP8.5 used in MARS. As for CLIMSAVE, from all the available climate models, the Global Circulation Model (GCM) that was closest to the multi-GMC mean was selected; this is CSMK3.

The emission scenarios were again different in each project/modelling tool. In ISI-MIP it was possible to select the same emission scenarios as in MARS. But both SCENES and CLIMSAVE utilised emission scenarios from the IPCC's Special Report on Emission Scenarios (SRES) instead of the RCP's of the Fifth Assessment Report, as they were developed beforehand. However, they are believed to still be valid. According to Rogelj et al., 2012, although RCP's were not developed to mimic specific SRES scenarios, pairs with similar temperature projections over the twenty-first century can be found between the two sets. RCP8.5 would yield temperature projections close to those of SRES A1(F1) scenario, RCP6 temperature projections are similar to those of SRES B2 and, likewise, RCP4.5 temperature projections of those of SRES B1.

As for the socio-economic scenarios, they were not considered in ISI-MIP as only climate data was derived from this project and both SCENES and CLIMSAVE employed specifically develop scenarios. Some of the socio-economic scenarios have similar characteristics to the storylines developed for MARS and consequently it was possible to match them as indicated in Table 9.

The time horizons considered in SCENES and CLIMSAVE for the future scenarios were 2025 and 2050 and 2020 and 2050 respectively, which vary slightly from the ones chosen in the storylines developed for MARS (2025-2030 and 2050-2060).

Input parameters

Surface air temperature

Surface air temperature values have been obtained from ISI-MIP as provided the best spatial and temporal resolution.

The following table summarizes the data provided:

Table 10: Temperature data specifications

Units	Spatial Resolution	Time Step	Format
K	0.5 by 0.5 degree	Daily (2006 to 2099)	Grid

The surface air temperature data was extracted with the GFDL-ESM2M climatic model for RCP4.5 and RCP8.5 as the three storylines developed in MARS are based on those emission scenarios.

Climate data from the rest of the models available in ISI-MIP (HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM and NorESM1-M) will be distributed shortly.

For all data provided by ISI-MIP, the geographic coverage is the following:

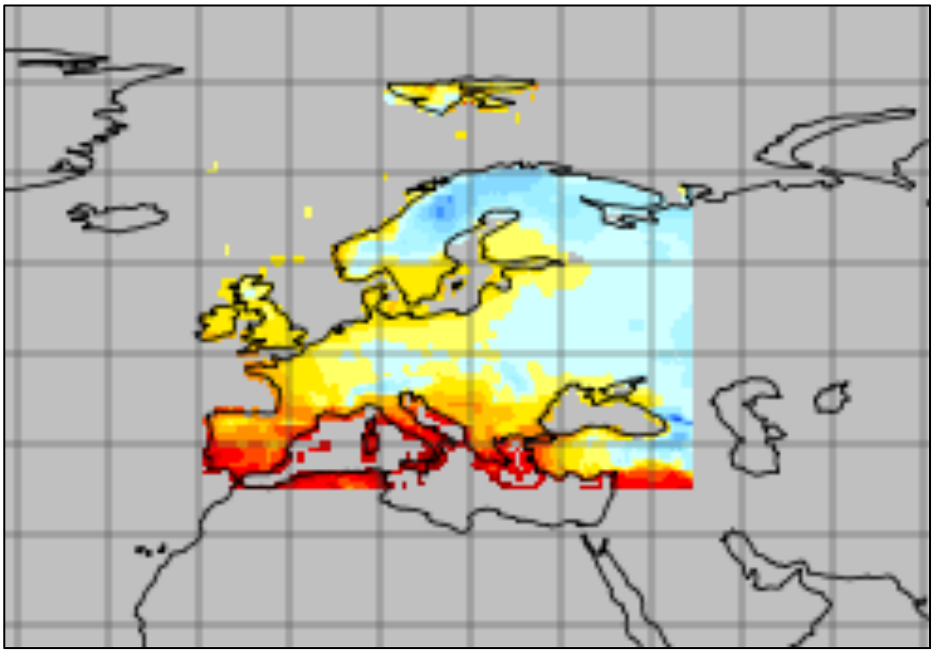


Figure 16: ISI-MIP data geographical coverage

Precipitation

Precipitation data, just as the surface air temperature data, was derived from ISI-MIP as it provided the best spatial and temporal resolution.

The following table summarizes the data provided:

Table 11: Precipitation data specifications

Units	Spatial Resolution	Time Step	Format
Kg/m2/s	0.5 by 0.5 degree	Daily (2006 to 2099)	Grid

Rainfall and snow precipitation data for RCP4.5 and RCP8.5 was derived with the GFDL-ESM2M climatic model.

Climate data from the rest of the models available in ISI-MIP (HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM and NorESM1-M) will be distributed shortly.

Additional atmospheric data

Together with temperature and precipitation, values for the following variables were also extracted from ISI-MIP and are available for the European scale and river basin level models:

- Surface radiation
- Near-surface wind speed
- Surface air pressure

The data can be employed to estimate evapotranspiration values.

The following table summarizes the data provided:

Table 12: Other climate data specifications

Variable	Units	Spatial Resolution	Time Step	Format
Surface radiation	W/m2	0.5 by 0.5 degree	Daily (2006 to 2099)	Grid
Near-surface wind speed	m/s	0.5 by 0.5 degree	Daily (2006 to 2099)	Grid
Surface air pressure	Pa	0.5 by 0.5 degree	Daily (2006 to 2099)	Grid

All values were extracted with the climate model GFDL-ESM2M for RCP4.5 and RCP8.5 emission scenarios.

Climate data from the rest of the models available in ISI-MIP (HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM and NorESM1-M) will be distributed shortly.

Water abstraction

Quantitative values for this indicator have been extracted from SCENES.

The following table summarizes the data provided:

Table 13: Water abstraction data specifications

Variable	Units	Spatial Resolution	Time Step	Format
Total abstraction	Million m3/ and million m3/km2	5 by 5 arc minutes	2025 and 2050	Vector
Abstraction for domestic use	Million m3	5 by 5 arc minutes	2025 and 2050	Vector
Abstraction for electricity	Million m3	5 by 5 arc minutes	2025 and 2050	Vector
Abstraction for irrigation	Million m3	5 by 5 arc minutes	2025 and 2050	Vector
Abstraction for livestock	Million m3	5 by 5 arc minutes	2025 and 2050	Vector
Abstraction for manufacturing	Million m3	5 by 5 arc minutes	2025 and 2050	Vector
Abstraction for agriculture	Million m3	5 by 5 arc minutes	2025 and 2050	Vector
Abstraction for industry	Million m3	5 by 5 arc minutes	2025 and 2050	Vector

All the parameters were calculated with WaterGAP3 which computes both water availability and water uses by sectors on a 5 by 5 arc minutes grid (longitude and latitude; 6 x 9 km in Europe), covering the whole Europe. In SCENES, water abstraction only accounts for water withdrawn from the rivers (both for consumptive use and the return flows), thus groundwater abstraction is not represented in the model.

Figure 17 to Figure 19 show the projected surface water abstraction at catchment level for the proposed MARS scenarios.

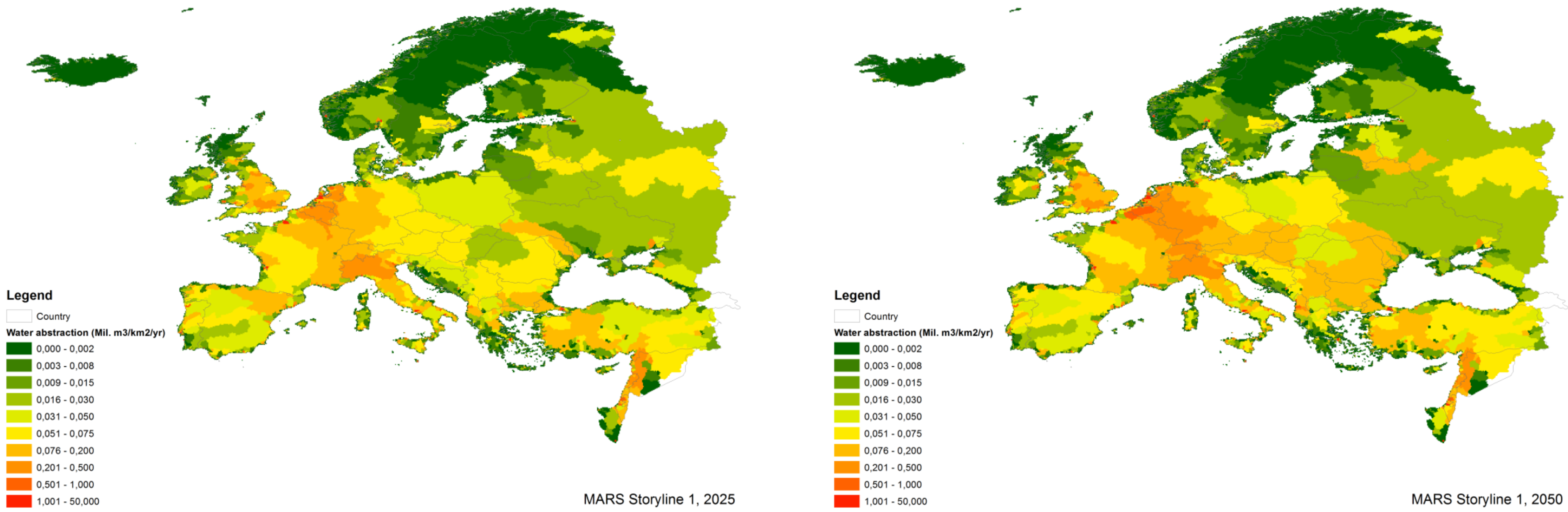


Figure 17: Water abstraction across Europe for MARS Storyline 1

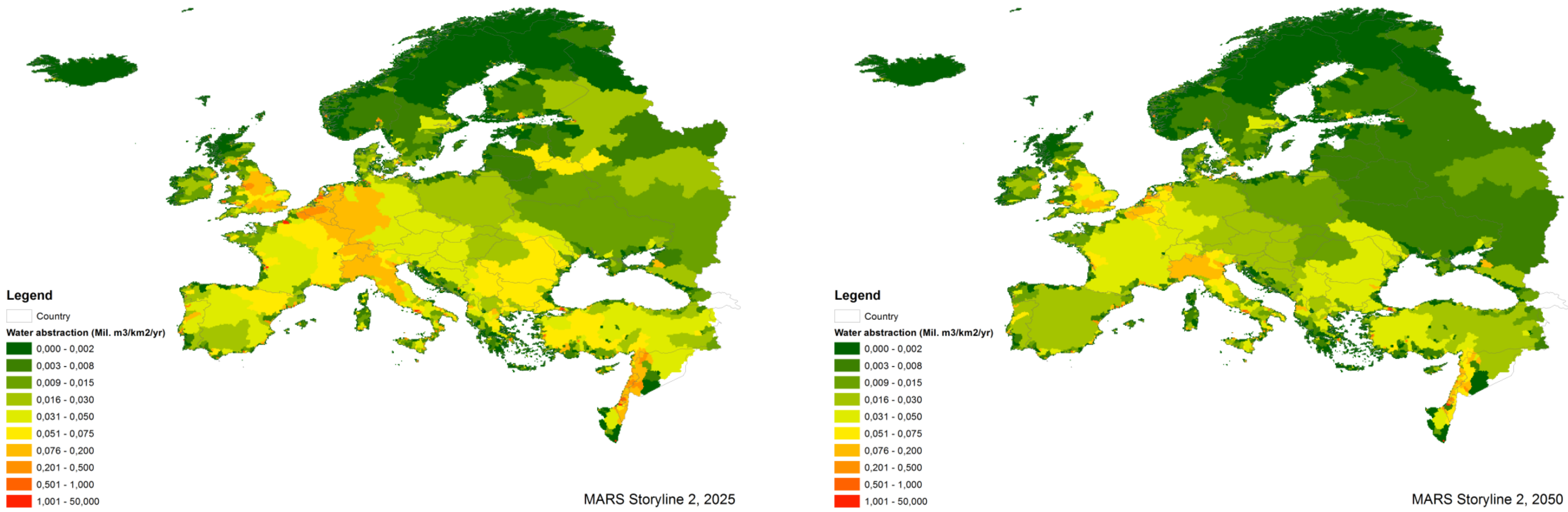


Figure 18: Water abstraction across Europe for MARS Storyline 2

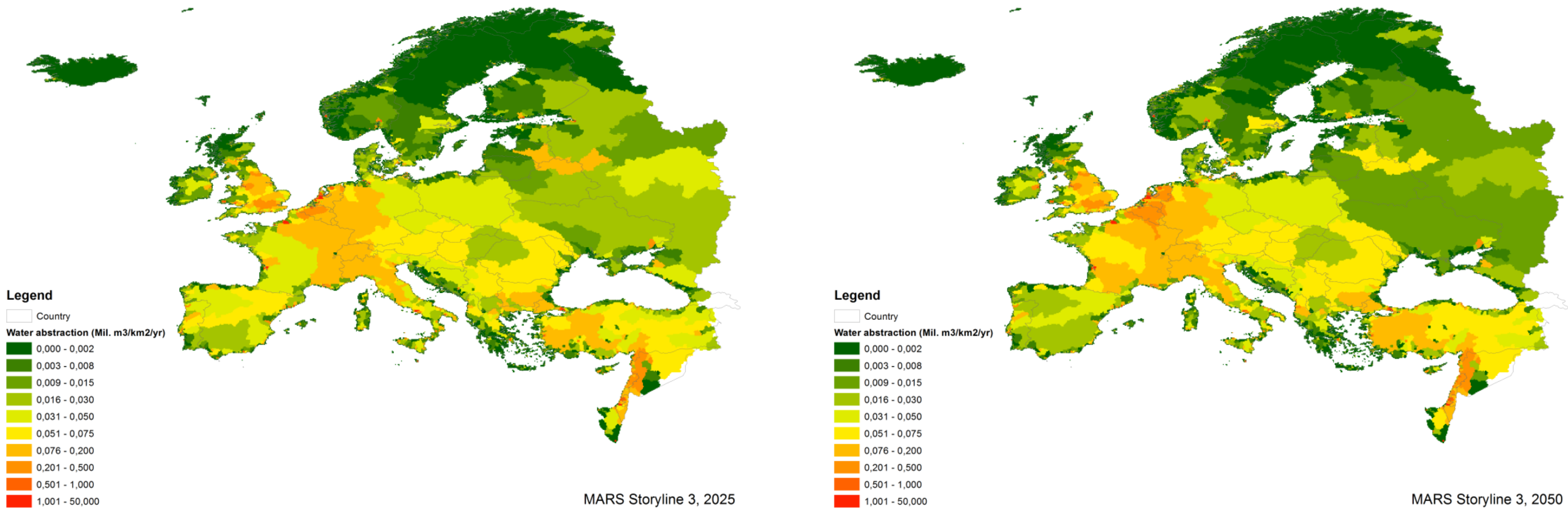


Figure 19: Water abstraction across Europe for MARS Storyline 3

Storylines 1 and 3 show greater impacts on water abstraction in the 2050's time horizon, while in Storyline 2 there is a slight decrease on water withdrawal with time. The highest water abstraction rates are presented in the 2050's of Storyline 1 which is consistent in a scenario based on a fast growing economy.

Regional differences are noticeable in all scenarios. The Scandinavian Peninsula is the area where impacts are less clear.

Water addition

No quantitative values were found for water addition and as such, the indicator will need to be determined by the modellers of each river basin, based on the qualitative criteria used to shape each MARS scenario (refer to the MARS Storylines Memo from the scenario workshop held in Helsinki in May 2014) and their expert knowledge .

Runoff

The most accurate runoff data can be obtained from PCR-GLOBWB. This data will be available after publication of this report and therefore it is not included here.

CLIMSAVE also calculates runoff; since both SCENES and CLIMSAVE employ the same model for the calculation (WaterGAP) but SCENES provides a better spatial resolution (5 by 5 arc minutes grid versus 10 by 10 arc minutes grid) it was decided to derive the runoff data from SCENES.

The following table summarizes the data provided:

Table 14: Runoff data specifications

Units	Spatial Resolution	Time Step	Format
Million m3/ and million m3/km2	5 by 5 arc minutes	2025 and 2050 (monthly and total annual)	Vector

The total runoff is defined in SCENES as the sum of surface runoff and groundwater recharge.

Runoff data at catchment level for the proposed MARS scenarios for 2025 and 2050 is shown in Figure 20 to Figure 22.

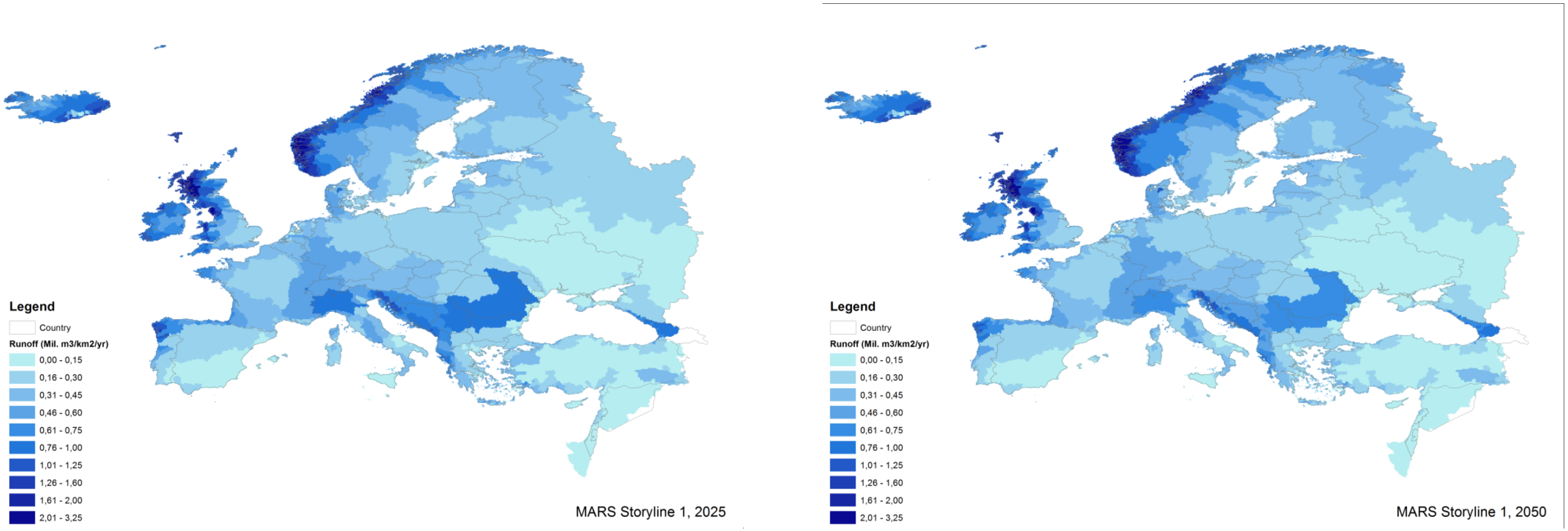


Figure 20: Runoff across Europe for MARS Storyline 1

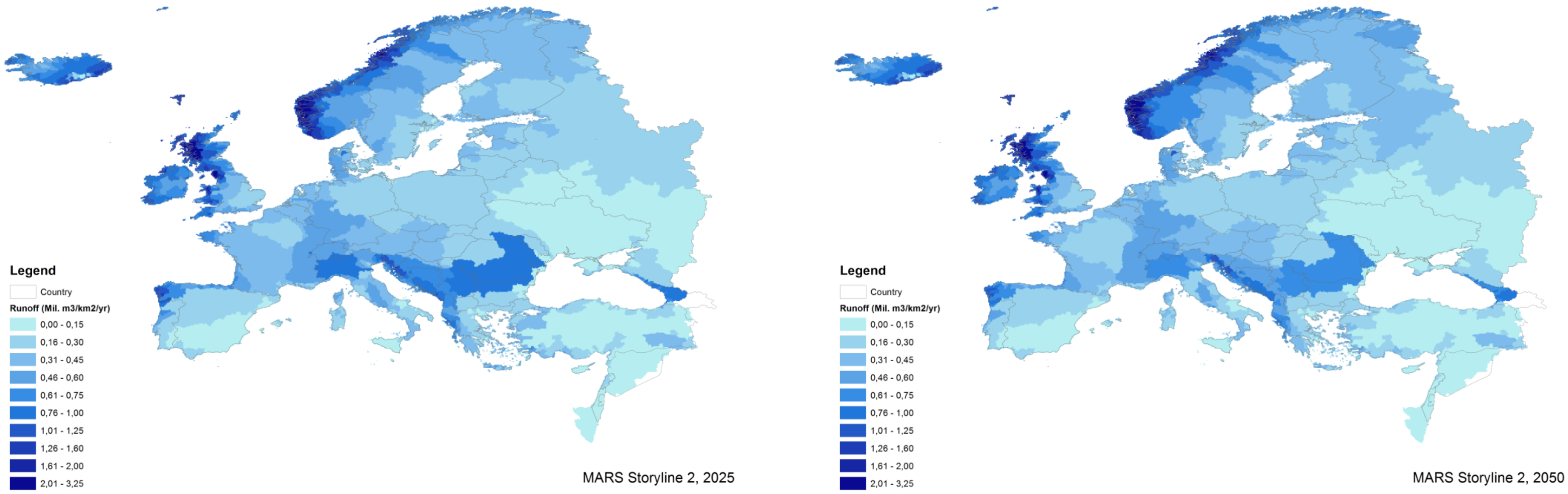


Figure 21: Runoff across Europe for MARS Storyline 2

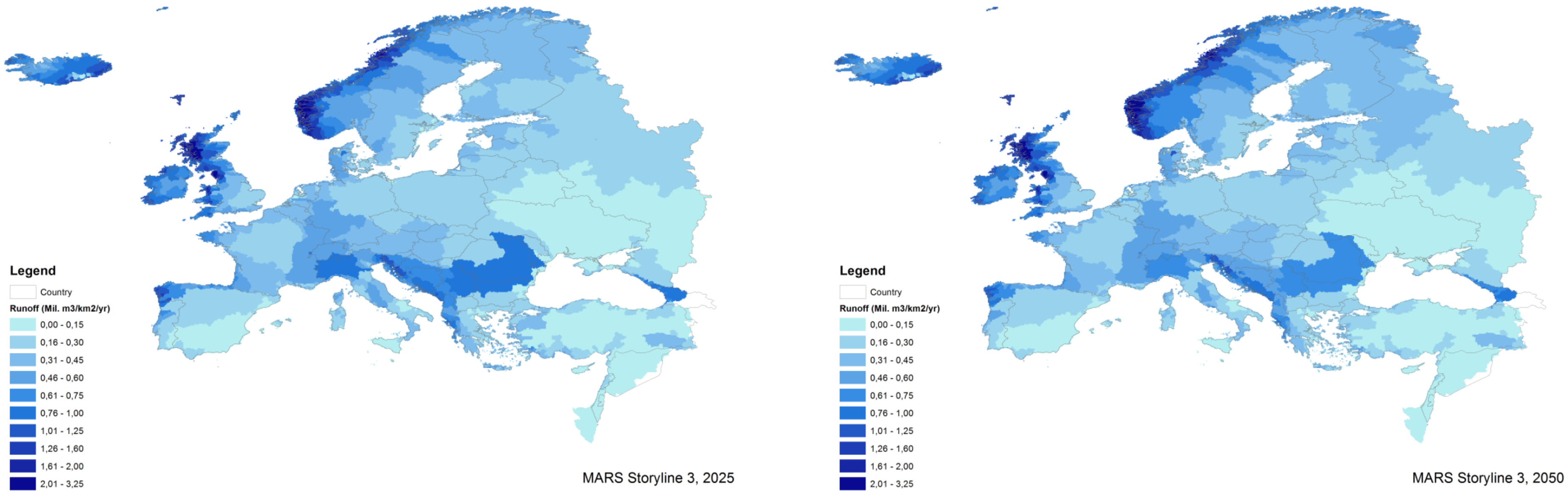


Figure 22: Runoff across Europe for MARS Storyline 3

In relation to water runoff, all scenarios are very similar.

The differences between storylines in the 2025's time horizon is almost negligible, although a slight decrease in total runoff across southern Europe and a slight increase in northern Europe can be detected with time (2050) in all three storylines.

Potential flood plain

Quantitative values for this indicator have been extracted from CLIMSAVE as it was the only modelling tool that quantified the parameter as such.

The following table summarizes the data provided:

Table 15: Potential flood plain data specifications

Units	Spatial Resolution	Time Step	Format
Ha	10 by 10 arc minutes	2020 and 2050	Vector

The parameter was calculated with the CFFlood (Coastal Fluvial Flood) model. The CFFlood model consists of three main components: coastal flood, fluvial flood and habitat changes/loss. Potential flood plain data is derived from the fluvial flood sub-model, which uses the European fluvial flood maps produced by the JRC Institute using LISFLOOD simulations at 100 m resolution (Feyen et al., 2011). These simulations provide flood maps for fluvial catchments assuming no flood defences. These maps, gridded at the 10 arc minutes (longitude and latitude; 12 x 18 km in Europe) spatial resolution, have been used as indicative maps of the flood risk zones in the CLIMSAVE project.

Figure 23 to Figure 25 show the potential flood plain or areas at risk of flooding for the projected MARS scenarios in 2020 and 2050.

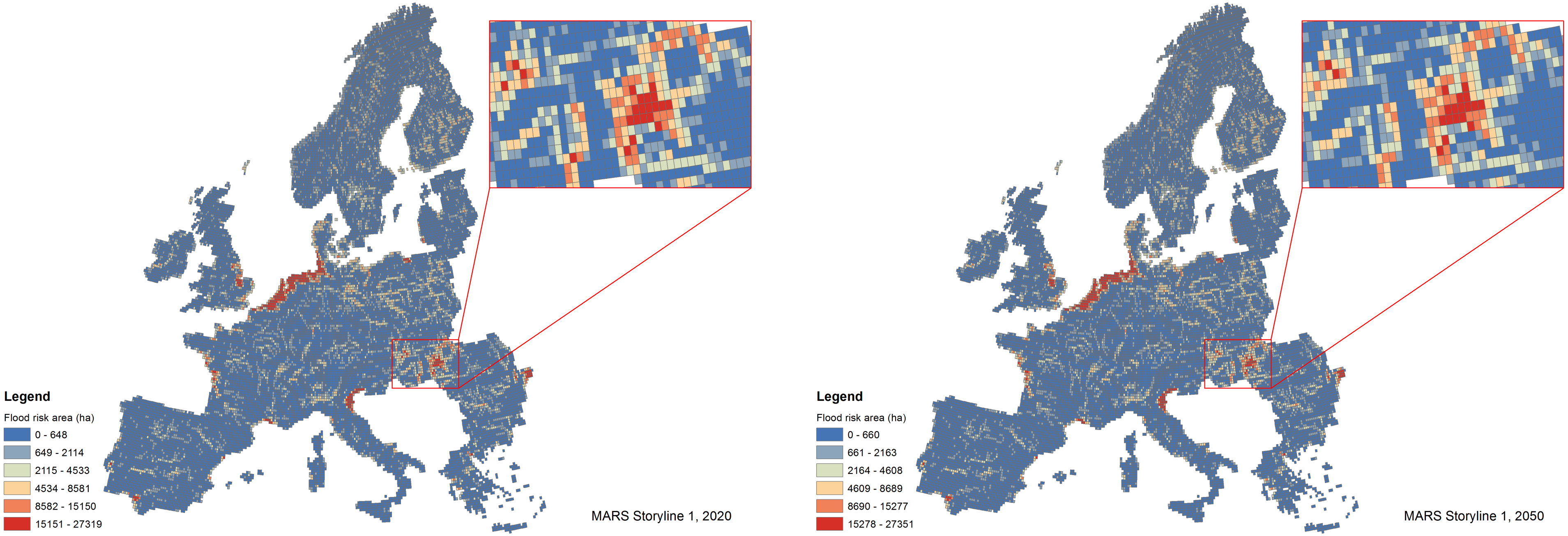


Figure 23: Flood risk areas across Europe for MARS Storyline 1

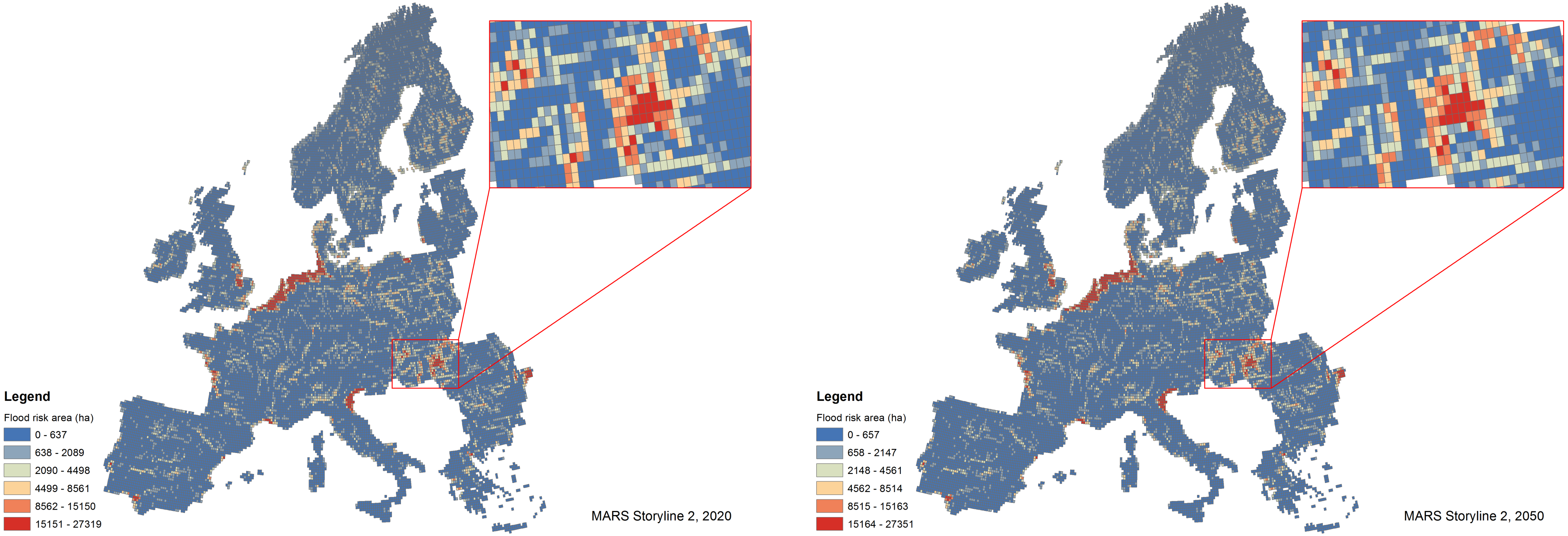


Figure 24: Flood risk areas across Europe for MARS Storyline 2

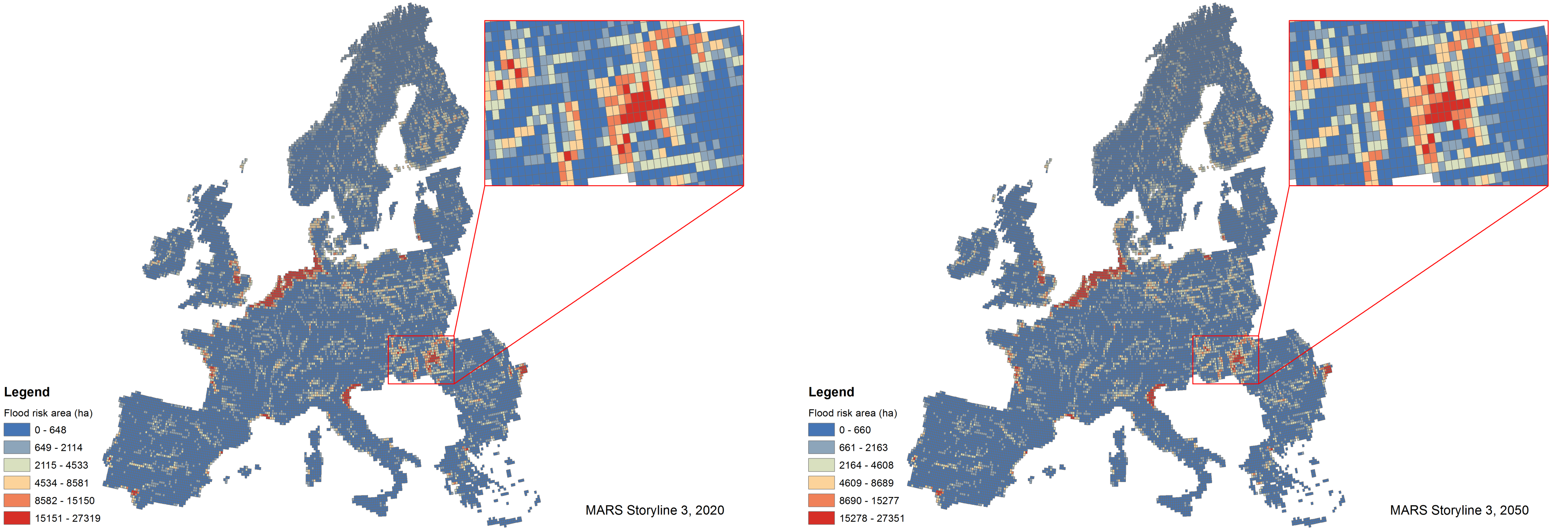


Figure 25: Flood risk areas across Europe for MARS Storyline 3

Areas at risk of flooding across Europe show very limited and localized changes. A detail around Hungary is shown in the figures in order to belter illustrate the minor variations.

Atmospheric deposition

Atmospheric deposition data can be extracted from IMAGE but access to this data has not been confirmed at the moment of the publication of this report.

Nutrient diffuse source emissions

Quantitative values for this indicator have been extracted from CLIMSAVE as it was the only project/modelling tool that quantified the parameter as such.

The following table summarizes the data provided:

Table 16: Nutrient diffuse source emissions data specifications

Units	Spatial Resolution	Time Step	Format
kg N /ha	10 by 10 arc minutes	2020 and 2050	Vector

The SFARMOD-LP model within CLIMSAVE calculates nitrate losses from agricultural activities in a 10 by 10 arc minutes (longitude and latitude; 12 x 18 km in Europe) spatial resolution.

Figure 26 to Figure 28 show nitrate losses for the projected MARS scenarios in 2020 and 2050.

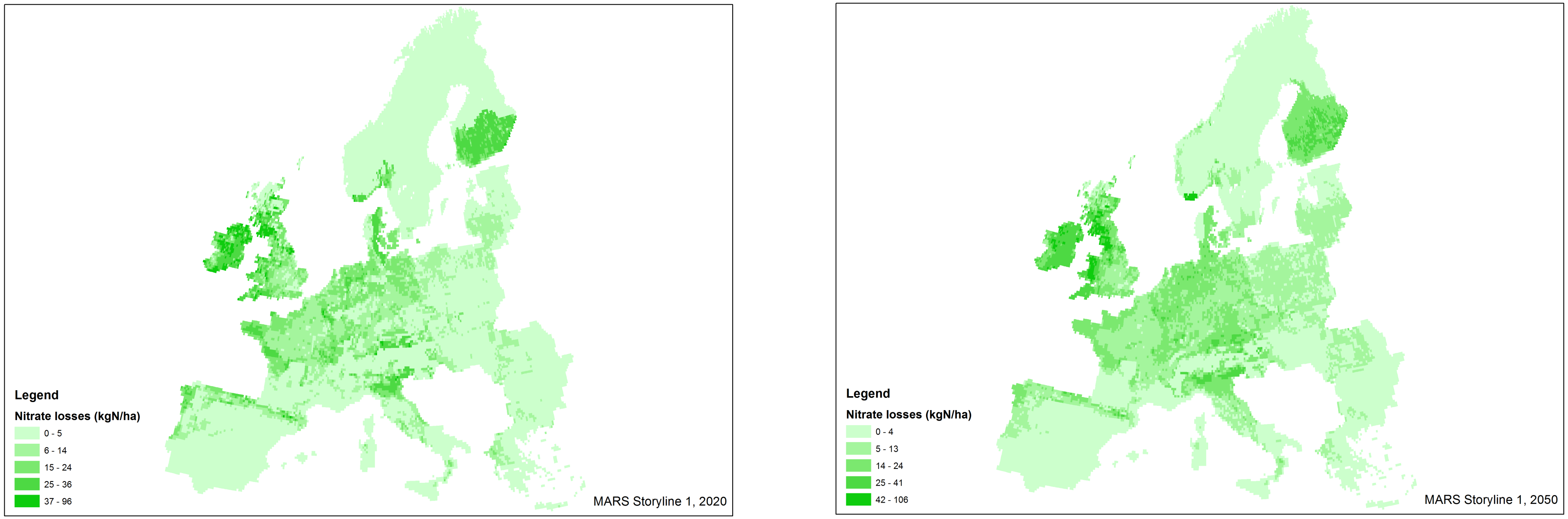
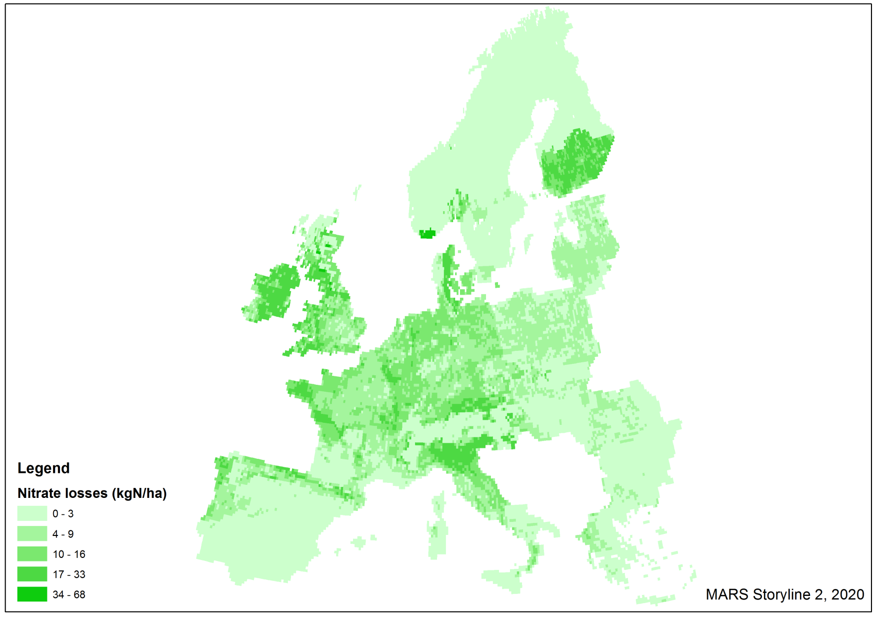


Figure 26: Nitrate losses across Europe for MARS Storyline 1



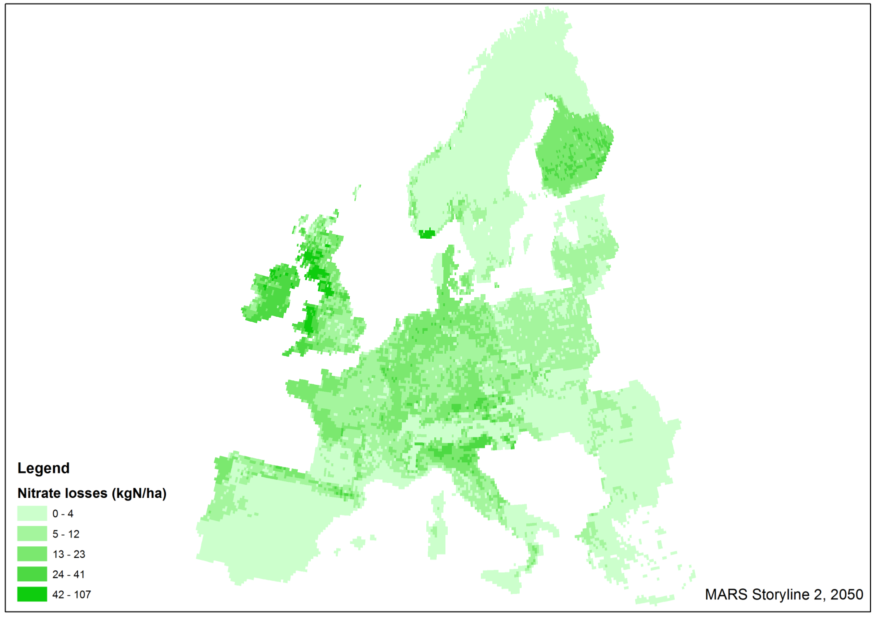


Figure 27: Nitrate losses across Europe for MARS Storyline 2

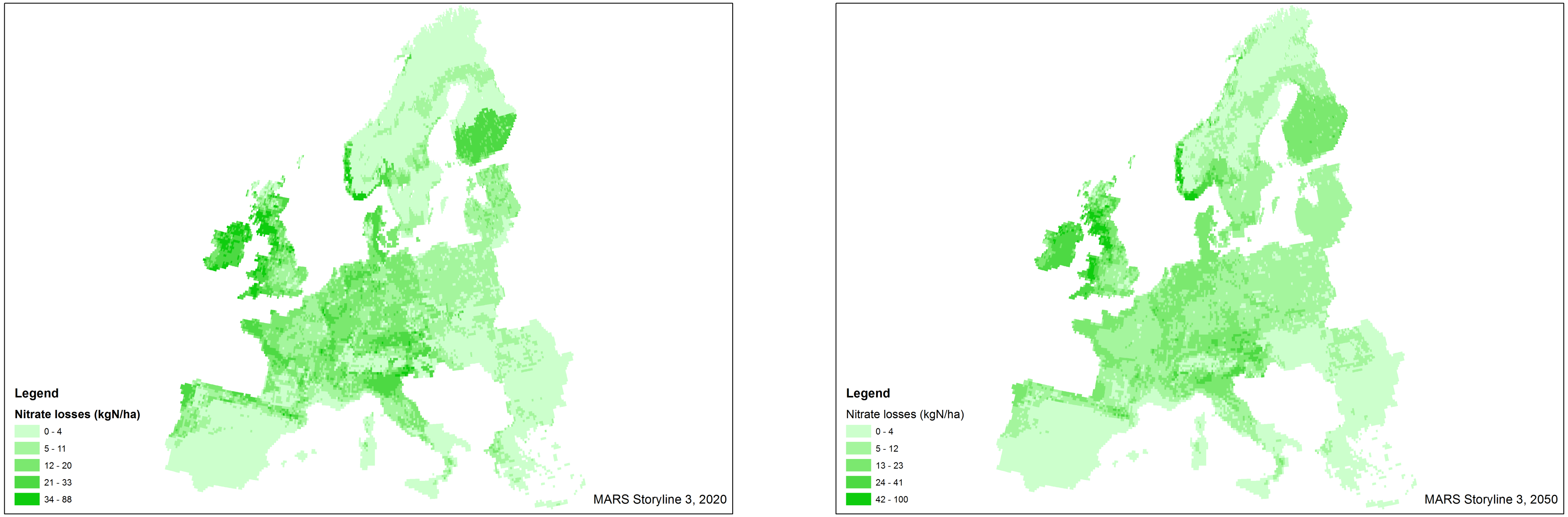


Figure 28: Nitrate losses across Europe for MARS Storyline 3

In general, in all three scenarios nitrate losses across Europe appear to extend further with time and the total amount slightly increase.

The biggest variations are detected in the central area of Europe where agriculture is one of the main economic sectors.

Nutrient point source emissions

Quantitative values for this parameter can be obtained from IMAGE but access to this data has not been confirmed at the moment of the publication of this report.

Nitrogen surplus

Nitrogen surplus data can be extracted from IMAGE but access to this data has not been confirmed at the moment of the publication of this report.

Phosphorous accumulation

Quantitative values for phosphorous accumulation can be obtained from IMAGE but access to this data has not been confirmed at the moment of the publication of this report.

Land use change

Changes on land use were derived from SCENES as it provided the most detailed spatial resolution from all the modelling tools/projects reviewed.

IMAGE could provide improved land cover and land use information but access to this data has not been confirmed at the moment of the publication of this report.

The following table summarizes the data provided:

Table 17:Land use data specification

Units	Spatial Resolution	Time Step	Format
Ha	5 by 5 arc minutes	2025 and 2050	Vector

Figure 29 to Figure 31 show land use across Europe for all three MARS storylines.

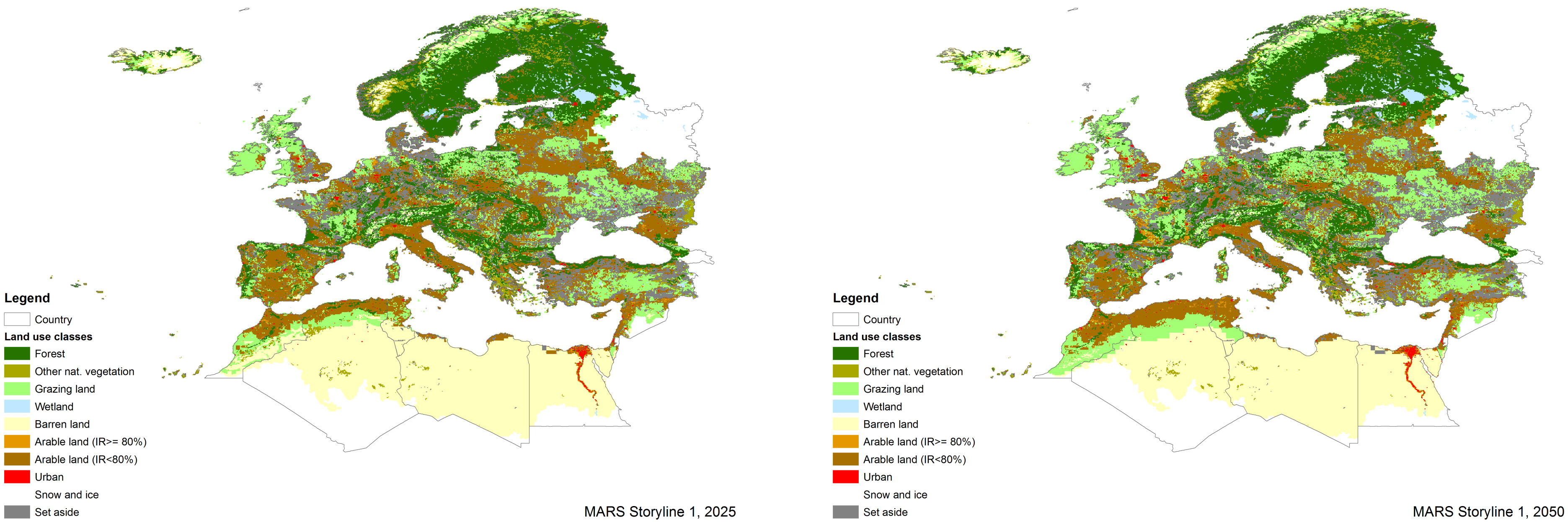


Figure 29: Land use across Europe for MARS Storyline 1

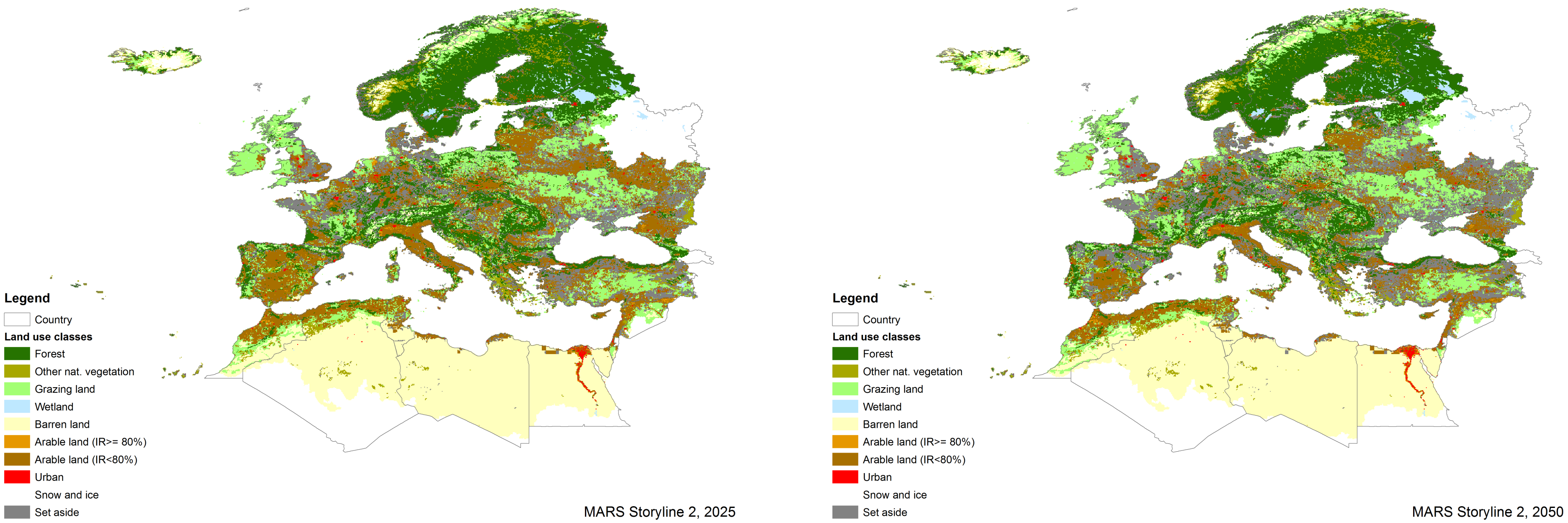


Figure 30: Land use across Europe for MARS Storyline 2

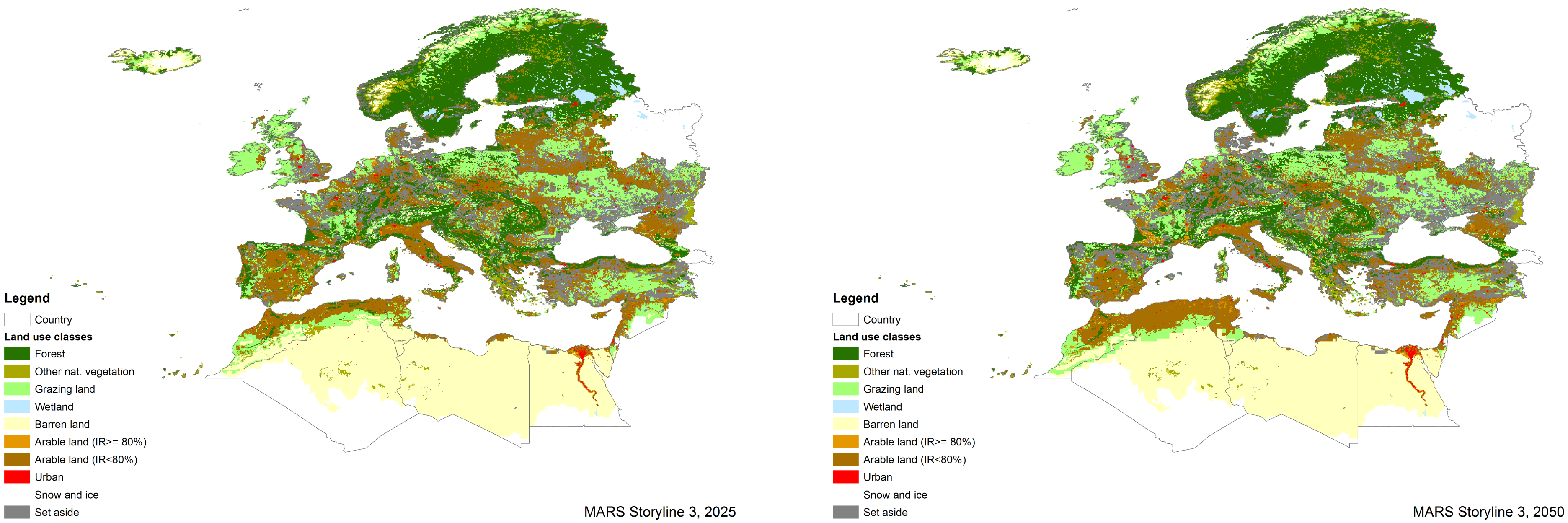


Figure 31: Land use across Europe for MARS Storyline 3

Land use changes across Europe seem to be quite localized. In general, more set aside land is observed in the 2050's time horizon in all three scenarios.

All three storylines show a decrease of non-irrigated arable land with time (2050); Storylines 1 and 3 indicate a shift to irrigated arable and grazing land, while in Storyline 2 the area of grazing land augments but the irrigate-arable land does not.

There are no noticeable changes in the Scandinavian Peninsula.

Population and GDP

Population and GDP data have been extracted from the IIASA (International Institute for Applied Systems and Analysis) SSP database.

The following table summarizes the data provided:

Table 18:Population and GDP data specification

Variable	Units	Spatial Resolution	Time Step	Format
Population	billion US$2005/yr	Country	2010 to 20100 (every 5 years)	Spreadsheet
GDP	Million inhabitants	Country	2010 to 20100 (every 5 years)	Spreadsheet

Data was extracted for SSP2, SSP4 and SSP5 as the three storylines developed in MARS are based on those socio-economic scenarios.

Conclusions on the chapter

In order to provide an overview of the data available to run the predictive models under the three future scenarios developed for MARS a literature review was carried out. Seven concluded and on-going projects and modelling tools that assess possible futures and impacts on Europe's freshwater were examined.

The aim was to assess the possibility of extracting suitable quantitative values for the parameters and variables required as input data for the models. The required data included principally climate and socio-economic data for each MARS scenario. The focus was put on finding data for the European scale models, which in many cases coincide with those necessary at river basin scale.

Although it was not possible to find data for all the required parameters, values for diverse climate variables, runoff, water abstraction, potential flood plains, nutrient diffuse source emission, land use, population and GDP were collected. It is expected that data for a few more parameters will soon be available. Those parameters that have not been quantified in this task will need to be calculated by the modellers of each area, based on the qualitative criteria used to shape each MARS storyline and their expert knowledge .

ISI-MIP, SCENES, BASE and CLIMSAVE were selected to extract the data from. Since the climate models and emission and socio-economic scenarios of these projects/modelling tools are different from each other and from the ones specifically developed for MARS, some comparison and approximation exercises had to be carried out.

The result is a suite of quantitative values for diverse parameters and variables on grid or vector format, which range from daily to yearly time steps and 5 by 5 arc minute to 0.5 by 0.5 degree spatial resolution, that are readily available to be distributed to the MARS modelling partners.

5. References

Alcamo, J., Döll, P., Heinrichs, T., Kaspar, F., Lehner, B., Rosch, T. & Siebert, S., 2003. *Global estimates of water withdrawals and availability under current and future business-as-usual conditions*. Hydrological Sciences Journal, 48, pp. 339-348.

Annetts, J.E. & Audsley, E., 2002. *Multiple Objective Linear Programming for Environmental Farm Planning.* The Journal of the Operational Research Society, 53, pp. 933-943.

Behrendt, H., Venohr, M., Hirt, U., Hofmann, J., Opitz, D. & Gericke, A., 2007. *The model system MONERIS, Users Manual.* Leibniz Institute of Freshwater Ecology and Inland Fisheries.

Behrendt, H., Kornmilch, M., Opitz, D., Schmoll, O. & Scholz, G. (2002): *Estimation of the nutrient inputs into river systems - experiences from German rivers*. Regional Environmental Changes, 3, pp. 107-117.

Bosello, F., Bower, L., Chiabai, A., Iglesias, A., Gebhardt, O., Guan, D., Jeuken, A., Markandya, A., Meyer, V. & Taylor, T., 2013. *Model catalogue and data exchange plan*. BASE Project. Deliverable 3.1.

Brian C. O'Neill, Elmar Kriegler, Kristie L. Ebi, Eric Kemp-Benedict, Keywan Riahi, Dale Rothman, Bas van Ruijven, Detlef P. van Vuurenh, Joern Birkmann, Kasper Kokk, Marc Levy, William Soleckim (2014) The Roads Ahead: Narratives for Shared Socioeconomic Pathways describing World Futures in the 21st Century

Brown, R. M., McLelland, N. J., Deininger, R. A. & Tozer, R. G., 1970. *A Water Quality Index – Do We Dare?* Water and Sewage Works, pp. 339-343.

Davie, J. C. S., Falloon, P. D., Kahana, R., Dankers, R., Betts, R., Portmann, F. T., Wisser, D., Clark, D. B., Ito, A., Masaki, Y., Nishina, K., Fekete, B., Tessler, Z., Wada, Y., Liu, X., Tang, Q., Hagemann, S., Stacke, T., Pavlick, R., Schaphoff, S., Gosling, S. N., Franssen, W. & Arnell, N., 2013. *Comparing projections of future changes in runoff from hydrological and biome models in ISI-MIP*. Earth Syst. Dynam., 4, pp. 359-374.

Döll, P., Kaspar F. & Lehner B., 2003. *A Global Hydrological Model for Deriving Water Availability Indicators: Model Tuning and Validation*. Journal of Hydrology, 270, pp. 105-134.

Duel, H., Meijer, K., 2011. Socio-economic and environmental impacts of future changes in Europe's freshwater resources. Main report. D4.6. SCENES – Water Scenarios for Europe and for Neighboring States.

Ebi et al (2014) A new scenario framework for climate change research: background, process, and future directions. Clim Chang. doi:10.1007/s10584-013-0912-3

Eickhouta, B., Van Meijlb, H., Tabeaub, A., & Van Rheenenb, T., 2006. *Economic and ecological consequences of four European land use scenarios.* Land Use Policy, 24, pp. 562–575.

Feyen, L., Dankers, R., Bódis, K., Salamon, P. & Barredo, J.I., 2011. *Fluvial flood risk in Europe in present and future climates*. Climatic Change, 112, pp. 47-62.

Grizzetti, B. & Bouraoui, F., 2006. *Assessment of nitrogen and phosphorus environmental pressure at European scale.* Joint Research Centre, Institute for Environment and Sustainability.

Harrison, P. A., Holman, I. P., Cojocaru, G., Kok, K., Kontogianni, A., Metzger, M.J. & Gramberger, M., 2012. *Combining qualitative and quantitative understanding for exploring cross-sectoral climate change impacts, adaptation and vulnerability in Europe.* Reg Environ Change, 13, pp. 761–780.

Holman, I., Cojocaru, G. & Harrison, P., 2013. *Guidance report describing the final version of the CLIMSAVE Integrated Assessment Platform*. CLIMSAVE.

Jäger, J., Rounsevell, M. D. A., Harrison, P. A., Omann, I., Dunford, R., Kammerlander, M. & Pataki, G., 2014. *Assessing policy robustness of climate change adaptation measures across sectors and scenarios*. Climatic Change.

Kämäri, J., Alcamo, J., Bärlund, I., Duel, H., Farquharson, F., Flörke, M., Fry, M., Houghton-Carr, H., Kabat, P., Kaljonen, M., Kok, K., Meijer, K.S., Rekolainen, S., Sendzimir, J., Varjopuro, R. & Villars, N., 2008. *Envisioning the future of water in Europe – the SCENES project*. E-Water, 3, pp. 1-28.

Kriegler E, O'Neill BC, Hallegatte S, Kram T, Lempert R, Moss R, Wilbanks T (2012) The need for and use of socio-economic scenarios for climate change analysis: a new approach based on shared socioeconomic pathways. Glob Environ Chang 22:807–822

Lepistö, A., Etheridge, J.R., Granlund, K., Kotamäki, N., Malve, O., Rankinen, K. & Varjopuro, R., 2013. *Report on the biophysical catchmentscale modelling of Yläneenjoki – Pyhäjärvi demonstration site.* REFRESH Project. Deliverable 5.5.

Millennium Ecosystem Assessment, 2005. *Methodology for Developing the MA Scenarios*. Millennium Ecosystem Assessment.

Moss, R. H., Edmonds, J. A., Hibbard, K. A., Manning, M. R., Rose, S. K., van Vuuren, D. P., Timothy, R., Carter, T. R., Emori, S., Kainuma, M., Kram, T., Meehl, G. A., Mitchell, J. F. B., Nakicenovic, N., Riahi, K., Smith, S. J., Stouffer, R. J., Thomson, A. M., Weyant, J. P., Wilbanks, T. W. 2010. The next generation of scenarios for climate change research and assessment. Nature, 463, 747-756.

Nakicenovic, N. et al (2000). Special Report on Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change, Cambridge

University Press, Cambridge, U.K., 599 pp. Available online at:http://www.grida.no/climate/ipcc/emission/index.htm

Navarro-Ortega, A., Acuña, V., Bellin, A., Burek, P., Cassiani, G., Choukr-Allah, R., Dolédec, S., Elosegi, A., Ferrari, F., Ginebreda, A., Grathwohl, P., Jones, C., Rault, P.K., Kok, K., Koundouri, P., Ludwig, R.P., Merz, R., Milacic, R., Muñoz, I., Nikulin, G., Paniconi, C., Paunović, M., Petrovic, M., Sabater, L., Sabaterb, S., Skoulikidis, N.T., Slob, A., Teutsch, G., Voulvoulis, N. & Barceló, D.,2014. *Managing the effects of multiple stressors on aquatic ecosystems under water scarcity. The GLOBAQUA project*. Sci. Total Environ.

O'Neill BC et al (2014) A new scenario framework for climate change research: the concept of shared socioeconomic reference pathways. Clim Chang. doi:10.1007/s10584-013-0905-2

PCRaster, 2014. PCRaster *Software for environmental modelling.* [Online] Available at: http://pcraster.geo.uu.nl/projects/applications/pcrglobwb/

PBL - Netherlands Environmental Agency, 2014. *IMAGE Integrated Model to Assess the Global Environment.* [Online] Available at: http://themasites.pbl.nl/models/image/index.php/Framework_overview

Petrescu, A. M. R., Van Beek, L. P. H., Van Huissteden, J., Prigent, C., Sachs, T., Corradi, C. A. R., Parmentier, F. J. W. & Dolman, A. J., 2010. *Modeling regional to global CH 4 emissions of boreal and arctic wetlands*. Global Biogeochem. Cycles, 24, pp. 1-12.

Rogelj, J., Meinshausen, M. & Knutti, R., 2012. *Global warming under old and new scenarios using IPCC climate sensitivity range estimates.* Nature Climate Change, 2, pp. 248-253.

Rosenzweig, C., Elliott, J., Deryng, D., Ruane, A. C., Müller, C., Arneth, A., Boote, K. J., Folberth, C., Glotter, M., Khabarov, N., Neumann, K., Piontek, F., Pugh, T. A. M., Schmid, E., Stehfest, E., Yang, H. & Jones, J. W., 2013. *Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison.* Proceedings of the National Academy of Sciences, 111, pp. 3268–3273.

Schernewski, G., Neumann, T. & Behrendt, H,2011. *Sources, dynamics and danagement of phosphorus in a southern Baltic estuary.* Central and Eastern European Development Studies (CEEDES), 5, pp. 373-388.

Schewe, J., Heinke, J., Gerten, D., Haddeland, I., Arnell, N. W., Clark, D. B., Dankers, R., Eisner, S., Fekete, B. M., Colón-González, F. J., Gosling, S. N., Kim, H., Liu, X., Masaki,Y., Portmann F. T., Satoh, Y., Stacke, T., Tang, Q., Wadar, Y., Wisser, D., Albrecht, T., Frieler, K., Piontek, F., Warszawski, L. & Kabat, P., 2013. *Multimodel assessment of water scarcity under climate change.* Proceedings of the National Academy of Sciences, 111, pp. 3245–3250.

Schilling, C., Behrendt, H., Blaschke, A., Danielescu, S., Dimova, G., Gabriel, O., Heinecke, U., Kovacs, A., Lampert, C., Postolache, C., Schreiber, H., Strauss, P., & Zessner, M., 2005. *Lessons learned from investigations on case study level for modelling of nutrient emissions in the Danube basin*. Water Sci Technol., 11, pp. 183-191.

Smith, R.A., Schwarz, G.E. & Alexander, R.A., 1997. *Regional interpretation of water-quality monitoring data*. Water Resources Research, 33, pp. 2781-2798.

Sperna Weiland, F. C., van Beek, L. P. H., Kwadijk, J. C. J., & Bierkens, M. F. P., 2010. *The ability of a GCM-forced hydrological model to reproduce global discharge variability*. Hydrol. Earth Syst. Sci., 14, pp. 1595-1621.

Van Vuuren, D. P., Stehfest, E., Den Elzen, M. G. J., Kram, T., Van Vliet, J., Deetman, S., Isaac, M., Goldewijk, K. K., Hof, A., Mendoza Beltran, A., Oostenrijk, R. & Van Ruijven, B., 2011. *RCP2.6: exploring the possibility to keep global mean temperature increase below 2°C.* Climatic Change, 109, pp. 95-116.

van Vuuren DP et al (2011) The representative concentration pathways: an overview. Clim Chang 109:5–31

van Vuuren DP, Riahi K, Moss R, Edmonds J, Thomson A, Nakicenovic N, Kram T, Berkhout F, Swart R, Janetos A, Rose SK, Arnell N (2012) A proposal for a new scenario framework to support research and assessment in different climate research communities. Glob Environ Chang 22:21–35

van Vuuren DP et al (2014) A new scenario framework for climate change research: scenario matrix architecture. Clim Chang. doi:10.1007/s10584-013-0906-1

Verzano, K., 2009. *Climate change impacts on flood related hydrological processes: further development and application of a global scale hydrological model*. Reports on Earth System Science, 71.

Warszawski, L., Frieler, K., Huber, V., Piontek, F., Serdeczny, O. & Schewe, J., 2013. *The Inter-Sectoral Impact Model Intercomparison Project (ISI–MIP): Project framework.* Proceedings of the National Academy of Sciences, 111, pp. 3228-3232.

Wada, Y., Van Beek, L. P. H., Van Kempen C.M., Reckman, J. W. T. M., Vasak, S. & Bierkens, M. F. P., 2010. *Global depletion of groundwater resources*. Geophysical Research Letters, 37, pp. 1-5.

Wimmer, F., Audsley, E., Malsy, M., Savin, C., Dunford, R., Harrison, P.A., Schaldach, R., & Flörke, M., 2014. *Modelling the effects of cross-sectoral water allocation schemes in Europe*. Climatic Change.

6. Annex1

Projected changes of the climate parameters (IPCC WGII AR5 Chapter 23).

Table SM23-2: Projected changes of selected climate parameters and indices for 2071-2100 with respect to 1971-2000 spatially averaged for European sub regions based on RCP 4.5 and RCP 8.5. Numbers are based on 9 (RCP8.5) and 8 (RCP4.5) regional model simulations. The "*likely* range" defines the range of 66% of all projected changes around the ensemble median. The definition of indices is described below.

	Climate Para-meters	Measure	Alpine		Southern		Northern		Continental		Atlantic	
Scena-rios			**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**
2071-2100 minus 1971-2000	**Mean annual tem-perature in K**	*Median*	*2.4*	*4.6*	*2.0*	*4.2*	*2.9*	*5.2*	*2.1*	*4.1*	*1.7*	*3.2*
		Lower bound	1.8	3.8	1.9	3.8	2.0	4.1	1.6	3.6	1.3	2.5
		Likely in the range	**1.9 to 3.4**	**3.9 to 6.0**	**1.9 to 2.7**	**3.9 to 5.4**	**2.0 to 4.2**	**4.1 to 6.2**	**1.6 to 3.2**	**3.7 to 5.2**	**1.4 to 2.1**	**2.7 to 3.6**
		Upper bound	3.6	6.3	3.2	5.7	4.3	6.5	3.2	5.3	2.9	4.2
	Frost days per year	*Median*	*-40*	*-70*	*-22*	*-43*	*-40*	*-68*	*-34*	*-62*	*-28*	*-40*
		Lower bound	-47	-93	-31	-51	-52	-93	-41	-73	-33	-60
		Likely in the range	**-41 to -26**	**-85 to -57**	**-29 to -11**	**-51 to -23**	**-43 to -26**	**-83 to -60**	**-40 to -18**	**-65 to -50**	**-30 to -15**	**-50 to -26**
		Upper bound	-25	-55	-10	-22	-24	-58	-16	-46	-12	-21
	Summer days per year	*Median*	*8*	*19*	*27*	*54*	*4*	*13*	*20*	*37*	*11*	*24*
		Lower bound	3	10	21	43	2	5	11	27	6	17
		Likely in the range	**4 to 14**	**12 to 24**	**25 to 33**	**46 to 60**	**2 to 16**	**6 to 22**	**13 to 24**	**30 to 46**	**6 to 14**	**22 to 28**
		Upper bound	18	25	37	67	23	28	28	49	33	38
	Tropical nights per year	*Median*	*1*	*4*	*20*	*45*	*1*	*1*	*9*	*22*	*3*	*7*
		Lower bound	0	1	7	23	0	0	2	11	0	3
		Likely in the range	**1 to 3**	**2 to 5**	**11 to 24**	**25 to 57**	**0 to 5**	**1 to 3**	**9 to 27**	**17 to 31**	**1 to 5**	**3 to 12**
		Upper bound	8	6	41	58	7	13	30	37	18	17
	Growing season length in days per growing season	*Median*	*31*	*61*	*27*	*49*	*23*	*55*	*26*	*58*	*39*	*58*
		Lower bound	23	52	16	34	17	37	17	52	24	41
		Likely in the range	**23 to 39**	**52 to 83**	**17 to 33**	**38 to 53**	**19 to 33**	**41 to 60**	**20 to 38**	**53 to 71**	**27 to 43**	**47 to 68**
		Upper bound	45	95	38	58	42	78	41	75	45	75

Warm spell duration index in days per year	*Median*	*34*	*96*	*34*	*124*	*35*	*82*	*23*	*73*	*20*	*65*
	Lower bound	26	73	28	90	22	64	16	52	17	46
	Likely **in the range**	**29 to 55**	**77 to 136**	**32 to 69**	**98 to 177**	**23 to 42**	**75 to 114**	**18 to 42**	**58 to 93**	**20 to 31**	**49 to 87**
	Upper bound	69	162	83	186	63	130	54	106	55	102
Cold spell duration index in days per year	*Median*	*-5*	*-5*	*-5*	*-5*	*-7*	*-6*	*-6*	*-6*	*-5*	*-5*
	Lower bound	-7	-6	-6	-6	-8	-7	-7	-8	-6	-6
	Likely **in the range**	**-7 to -4**	**-6 to -4**	**-5 to -3**	**-5 to -4**	**-8 to -6**	**-7 to -5**	**-7 to -4**	**-8 to -5**	**-6 to -3**	**-5 to -4**
	Upper bound	-3	-3	-3	-4	-4	-4	-3	-5	-2	-4
Annual total precipi-tation in %	*Median*	*4*	*11*	*-3*	*-11*	*10*	*22*	*9*	*10*	*1*	*4*
	Lower bound	3	4	-10	-23	7	17	0	0	-2	-2
	Likely **in the range**	**3 to 7**	**6 to 13**	**-9 to 1**	**-19 to -3**	**8 to 17**	**18 to 32**	**1 to 12**	**4 to 18**	**-1 to 6**	**1 to 7**
	Upper bound	9	15	2	-1	21	33	13	24	8	9
Annual total precipi-tation where RR>99p of 1971/2000 in %	*Median*	*34*	*70*	*27*	*35*	*31*	*69*	*35*	*55*	*29*	*60*
	Lower bound	14	29	14	20	22	57	11	29	15	42
	Likely **in the range**	**17 to 55**	**32 to 85**	**18 to 40**	**26 to 46**	**22 to 58**	**59 to 98**	**24 to 41**	**37 to 65**	**17 to 64**	**43 to 97**
	Upper bound	56	99	62	51	63	107	59	90	65	107

7. Annex2

Input parameter/variable European Models
Precipitation
Nitrogen diffuse sources
Nitrogen point sources
Phosphorus diffuse sources
Phosphorus point sources
Temperature
Water Quality Index
Land use change
Water abstraction
Water addition
Runoff
River network
Discharge
DEM
Planned potential flood plain
Human Influence index

Input parameter/variable Basin Models
Precipitation
Temperature (max and min)
Insolation
Discharge (inflow/outflow)
P and N deposition
Land use type
Number of animals
Air pressure
Relative humidity
Wind speed
Cloud coverage
Inflow P, DOC, chlorophyll, No3, NH4, S
Acid deposition
Soil map
Water level
Irrigation
Topography / digital elevation
Water abstraction (ground and surface)
Fertilization
Water use
Evapotranspiration
Nutrient concentration
bathymetry
Nutrient concentration sewage treatment work
Lake temperature profiles

Lake algal concentrations
Drainage level
Agricultural management (Crop rotation)
Population
Dams and weirs
Trees in riparian strip
Volume per water body
Sediment input