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# Supporting Online Material for

## Ecosystem Service Supply and Vulnerability to Global Change in Europe

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**This PDF file includes:**

- Materials and Methods
- Figs. S1 to S3
- Tables S1 and S2
- References and Notes

# – Supporting Online Material –

# Ecosystem service supply and human vulnerability to global change in Europe

Dagmar Schröter *et al.*

In the following we describe and discuss the methods and concepts used in the European vulnerability assessment. We describe the stakeholder dialogue in general, and then turn to the multiple input scenarios (socio-economic storylines and emission scenarios, climate scenarios and land use scenarios). After that we introduce the various ecosystem models that were used in this study. Finally, we explain briefly how the term vulnerability was understood in this study, and how the notion of adaptive capacity entered our assessment.

## The stakeholder dialogue

A structured dialogue between stakeholders and scientists was initiated at the beginning of the project and was continued, intensified, and evaluated throughout the project. In the course of the communication between scientists and stakeholders we subdivided the assessment into six highly interdependent sectors: agriculture, forestry, climate protection (carbon storage) and energy, water, biodiversity & nature conservation, and mountain tourism & recreation. We conducted three full, multi-day conferences with stakeholders and principal investigators from all six sectors (at the beginning, middle and end of the project) and eleven additional workshops focussed on particular sectors throughout the project. The general objective of this dialogue was to facilitate a more appropriate assessment of vulnerability, i.e. to produce results that would adequately inform the decision-making of stakeholders. In particular the aims of the stakeholder dialogue were to (a) identify indicators of changes in ecosystem services; (b) settle useful scales and units at which these indicators should be measured or modelled; (c) discuss thresholds for these indicators that represent limits outside which the adaptive capacity of the sectors is exceeded; (d) present and discuss results as well as the format they are presented in (clarity of maps, graphs, etc); and (e) train stakeholders' ability to use information derived from scenario analysis.

In our project, we understood stakeholders to be people and organisations, who have an interest in information on ecosystem services and vulnerability to global change. The identification of potential stakeholders took place by widespread inquiries via internet-search, e-mail and telephone and a survey among research partners. During the assessment 204 stakeholders were identified, 152 were invited to workshop, and 58 actually participated in at least one workshop event (these numbers do not take into consideration contact with stakeholders during dissemination and outreach activities) (*S1*). Representatives of different sectors and corporations were especially targeted, including consultants, policy advisers, environmental resource managers, park managers, farmers, foresters, NGOs, and journalists. The stakeholder involved represented different European regions as follows: 5 from the UK, 16 from Germany, 3 from France, 2 from Scandinavia, 7 from the Mediterranean, 8 from the Alpine region, and 17 had an outlook on Europe as a whole. A series of reports documenting and evaluating the stakeholder dialogue can be found at www.pik-potsdam.de/ateam.

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## Socio-economic storylines and emission Scenarios

The Special Report on Emission Scenarios (SRES) are narrative descriptions of plausible future worlds that were developed by a large group of experts in a long-term open review process as a function of major driving forces, such as population growth, economic development and technological change (*S2*). They are structured in four major families labelled A1, A2, B1 and B2, each of which emphasises a different set of social, environmental and economic ideals. These ideals are organised along two axes. The first major dimension focuses on ‘material consumption’ (dimension A; also referred to as ‘economic’), versus ‘sustainability, equity and environment’, (dimension B; sometimes referred to as ‘environmental’). The second major dimension distinguishes 'globalisation’ (dimension 1) versus ‘regionalisation’ (dimension 2). Thus the A1 scenario describes an economically oriented and globalized world. The narratives specify typical aspects and processes for each of the four quadrants identified by these dimensions. The A1 scenario was further elaborated by assuming different combinations of fuels and technology development to satisfy energy demand. A1FI remains dominated by fossil fuels. A summary of the estimated European trends in economic, demographic, technological and institutional development under these storylines is given in Table S1 (see also section on Land use scenarios). Trajectories of greenhouse gas emissions were quantified using the integrated assessment model IMAGE 2.2 (*S3*).

## Climate scenarios

Climate scenarios were developed at a monthly time resolution for five climatic variables: temperature, diurnal temperature range, precipitation, vapour pressure and cloud cover. The scenarios comprise all 16 combinations of four SRES emissions scenarios and four general circulation models (GCMs), HadCM3, NCAR-PCM, CGCM2, and CSIRO2 (*S4-S7*), using GCM outputs from the IPCC Data Distribution Centre. The 16 alternative future climates represent 93% of the range of possible global warming presented by the IPCC in 2001 (*S8*). The GCM outputs were interpolated to the resolution of the observed climate data (10'x10'). The climate scenarios of the 21st century replicate observed month-to-month, inter-annual and multi-decadal climate variability of the detrended 20th century climate. The entire climate data used in this study are the European observed climate 1901-2000, the 16 climate scenarios for 2001-2100, and a single ‘control’ scenario of unforced climate (1901-2100) based on the detrended 1901-2000 historical record. The full method is described in Mitchell et al. (*S9*). The scenarios are known as TYN SC 1.0 and are publicly available (an edited version is available from the ATEAM project) (*S1*).

Regional variation between the results of the climate models is considerable. Figure S1 shows the regional differences between the annual average temperature anomalies within Europe between the different climate models for the emission scenario A2. The relative spatial pattern projected by each climate model remains the same over different emission scenarios, and only the size of the anomaly varies between the emission scenarios for one and the same GCM. Therefore these maps demonstrate the complete relative spatial variability of the climate projection on the annual timescale, even though only one emission scenario (A2) is shown. Changes in precipitation are more complex. Whether the projected trends in precipitation were positive or negative depended on the season, the emission scenario, the GCM and on the region within Europe. Figure S2 shows the regional differences between the annual average precipitation anomalies within Europe between the different climate models for the emission scenario A2. Again, the relative spatial pattern projected by each climate model remains the same and only the size of the anomaly varies between the emission scenarios and the maps demonstrate the complete relative spatial variability of the climate projection on the annual timescale, even though only one emission scenario (A2) is shown.

## Land use scenarios

The land use categories we distinguished were: urban, agriculture (subdivided into cropland, grassland and bioenergy production), forest and protected areas (for conservation or recreation goals) (*S10-S14*). Land that is left over when the demands for all land use types are satisfied is referred to as "surplus". The approach recognised three levels in the derivation of land use scenarios that move from qualitative descriptions of global socio-economic storylines, over European sector driving forces, to quantitative projections of regional land use change. For each land use category the methodology broadly followed the same steps. First, an assessment was made of the total area requirement (quantity) of each land use, as a function of changes in the relevant drivers. This was based on outputs from the global scale IMAGE 2.2 Integrated Assessment Model on commodity demands at the European scale (*S3*). Second, scenario-specific spatial allocation rules were developed and applied to locate these land use quantities in geographic space across Europe. Third and finally, the scenarios of the broad land use types were post-processed to maintain the land use constant in designated areas. This approach was implemented using a range of techniques that were specific to each land use type, including reviews of the literature, expert judgement, and modelling. Widespread consultation was undertaken with other experts in the field. Early in the procedure the basic assumptions about land use change drivers were discussed and improved with stakeholders. A detailed description of the methodology is published elsewhere (*S14*). A summary of the estimated European trends in economic, demographic, technological and institutional development is given in Table S1. The main trends in land use change are summarised in Table S2.

## Modelling of bioenergy crop distribution

Bioenergy crops are those annual and perennial species that are specifically cultivated to produce solid, liquid or gaseous forms of energy. Twenty-six actual or potential bioenergy crops were selected: oilseed rape, linseed, field mustard, hemp, sunflower, safflower, castor, olive, groundnut, barley, wheat, oats, rye, potato, sugar beet, Jerusalem artichoke, sugarcane, cardoon, sorghum, kenaf, prickly pear, maize, reed canary grass, Miscanthus, short rotation coppice, and eucalyptus. Simple rules were derived from the literature for each crop for suitable climate conditions and elevation. The climate conditions were based on minimum and maximum monthly temperatures at various times of the year, and precipitation requirements. All crops are assumed to be rain fed (not irrigated) and not protected from frost. The approach is described in detail in Schröter *et al.* (*S1*).

## Macro-scale hydrological model

We used the Mac-pdm model, which calculates the evolution of the components of the water balance at a daily time step (*S15, S16*). Although the model was implemented at a scale of 10x10', for most of the analyses, runoff was aggregated to the 0.5°x0.5° scale. Döll and Lehner's

(*S17*) drainage direction map was used to link the 0.5°x0.5° cells together and enable the accumulation of flows along the river network. A total of 94 major river basins have been identified, based on currently proposed river basins and major topographic boundaries. Basin areas ranged from just over 10,000 $km^2$ to 373,000 $km^2$.

### Alpine case studies

High-resolution case studies in Alpine catchments were performed for the Alptal, the Hirschbichl, the Dischma, the Saltina and the Verzasca catchment (*S18*). An adapted version of the simulation system RHESSys (*S19*) was used to estimate fluxes of water, carbon and nitrogen through the catchments. The model was adapted to Alpine conditions, particularly regarding maintenance respiration, phenology, snow accumulation and melting.

### Biodiversity modelling

We used the BIOMOD framework (*S20*) to project the distribution of more than 2000 species (1350 plants, 157 mammals, 108 reptiles and amphibians, and 383 breeding birds) across Europe using five bioclimatic variables. Species distributions were projected across Europe under current and future climate change scenarios. The models were calibrated at approximately 50x50 km and then current and future species distribution were projected at 10'x10’ grid resolution. At the European scale and 50x50 km resolution, land use pattern in Europe was driven by climate alone, and the incorporation of land use variables into the species distribution models led to over-parameterisation and over-fitting (*S21*). Therefore land use change was not considered separately in the biodiversity study presented here. Niche based statistical modelling approaches such as the one applied here assume that the modelled species is in pseudo-equilibrium with its environment, i.e. that historical factors do not play a role in current distribution. Also, biotic interactions, i.e. the distribution of other species, are not taken into account, even though they may play an important role in determining species distribution. Our current knowledge of how biotic interactions such as competition, facilitation, predation, pollination, herbivory, parasitism or symbiosis influence species’ distribution is too sparse to be included in a biodiversity risk assessment of a large sample of species, as performed in this study. To plot species loss by biogeographical region, the climatic environmental stratification of Europe by Metzger *et al.* was used (*S22*).

In order to reduce the uncertainty associated with selection of methods in niche-based modelling (*S23*), eight different statistical envelope models for each species were used and for each scenario the most consensual one (the one closest to the average across models) was selected. Then projections under two extreme cases of dispersal, namely zero and unlimited instantaneous dispersal were derived. These approximations bracket the most pessimistic and optimistic estimates of future species range as a way to capture unknown actual dispersal rates. In this study we report on the indicators *potential species loss per grid cell* (Fig. 3A) and *potential species gain per grid cell* (Fig. 3B), i.e. the number of species that potentially lose or gain their habitat in a given grid cell of 10’x10’. In the case of species loss, if the species are able to migrate elsewhere, they could be safe. Please note that this indicator does neither make a statement about potential losses of the species from Europe, nor about extinction. We focus on this indicator to avoid the uncertainty inherent in assumptions about migration potential of the species (*S23, S24*). In the case of species gain, we assumed that all habitats that become suitable for a given species would be colonized instantaneously. This is unlikely to happen and provides a very optimistic scenario of change (*S23, S24*). The relative species gain per pixel was estimated by: Relative Gain = (100 x Gain)/(SR + Gain), where SR was the current species richness in a given grid cell.

Figure 3A illustrates that plant species from the Mediterranean region and from mountains were disproportionately sensitive to climate change. However, the Mediterranean South showed comparatively fewer losses. This region is characterised by hot and dry summers and occupied by species that tolerate strong heat and drought. Under the scenarios used here, these species are most likely to be well adapted for future conditions (*S25*). Under the unrealistic assumption of unlimited dispersal, the relative potential gain of Mediterranean plant species was high, especially in the Mediterranean South (Fig. S3B). This is due to the expansion of the environmental zone classified as "Mediterranean South", so that the climatic envelope of species adapted to warm and dry conditions is expanded. However, there are important uncertainties associated with dispersal, establishment and reproduction into the areas that are projected to become suitable that have not been accounted for. In the model approach applied here, species' adaptation to abiotic changes is not included. Across evolutionary time, there seems to be a considerable degree of conservatism of species' niches (*S26, S27*). Modern climate change is acting at a smaller time scale than this phylogenetic inertia has been demonstrated for. Therefore, it seems highly possible that many species will not be able to adapt to rapid climate change.

## Process-based tree-growth model

The process based model GOTILWA+ (*S28*) for managed and unmanaged forests was used to simulate the forest growth processes under the influence of climate, tree and stand structure, management techniques and soil properties. Eco-physiological processes such as photosynthesis, transpiration, autotrophic and heterotrophic respiration are simulated in a daily time steps. Results are integrated at stand level.

## Modelling of forest fires

We used a regional fire module called Reg-FIRM (*S29*), which is contained in the Dynamic Global Vegetation Model LPJ (see section Modelling terrestrial carbon storage). It explicitly considers human- and lightning-caused fires, climatic fire danger, and fire spread. Fire risk and woodland area burnt depends on the following main factors: climate and weather, source of ignition, type of vegetation, amount of fuel, landscape structure, and fire fighting. Fire risk further depends on dynamic interactions between vegetation and fire. On the one hand, $CO_2$ fertilization might dampen fire risk due to increased water use efficiencies of plants, thereby reducing the demand for water uptake from the soil and increasing litter moisture. On the other hand, climate-induced shifts in vegetation, associated with changes in fuel characteristics, can amplify fire spread (*S30*).

## Inventory-based forest model

To estimate overall; European wood production we implemented EFISCEN, a large-scale forest scenario model that uses forest inventory data as input (*S31*). Net primary production values provided by the LPJ model (see section Modelling terrestrial carbon storage) were used to scale inventory-based stem growth, in order to incorporate climate change induced growth changes. Wood demand scenarios were derived from the IMAGE 2.2 scenario documentation (*S3*). The model projects possible future development of forests on a European, national or regional scale. The inventory data used in this study cover almost 100 million hectares of forest available for wood supply and reflect the state of the forest around the mid-1990 in EU15+ (fifteen pre-2004 EU-members, plus Norway and Switzerland), without Greece and Luxembourg (due to the lack of suitable inventory data). Management regimes (age limits for thinning and final felling) were based on a country-level compilation of management guidelines. Forest management under these regimes is different in the different scenarios and depends on wood demand. When wood demand is high, management is intense (i.e. shorter rotation lengths). Assumptions about which tree species would be chosen for afforestation were based on the socio-economic storylines. It was assumed that coniferous species would be favored in the A-scenarios, due to limited environmental concern and high wood demand. It was further assumed that only autochthonous tree species would be used for afforestation in the ‘environmentally oriented’ B-scenarios.

## Modelling terrestrial carbon storage

The overall European terrestrial carbon balance was estimated with the Dynamic Global Vegetation Model LPJ (*S32-S34*), which uses input on climate, soil and atmospheric $CO_2$ concentration to calculate carbon and water fluxes through vegetation and soil. The LPJ version used was adapted to account for cropland management and tracked anthropogenic land use changes over time, as well as natural and anthropogenic fires. The net carbon flux from an area (net biome production, NBP) was determined by net primary production and carbon losses due to soil heterotrophic respiration, fire, harvesting, and land use change. Net carbon storage is the integral of NBP (sources plus sinks) over time.

## Soil organic matter model

Soil organic matter content was estimated using the Rothamsted Carbon model (*S35*) and the best available soils data (European Soils Database), historic land use reconstructions for the 20th century, outputs on potential evapotranspiration (water loss from the soil and the plant) and net primary production from the LPJ model (see section Modelling terrestrial carbon storage), as well as litter fall in forests from EFISCEN (see section Inventory-based forest model). The model was used to simulate soil organic carbon content of mineral soil ($< 200$ t C $ha^{-1}$) down to 30 cm depth. See Smith et al. (*S36, S37*) for further details.

## Vulnerability

In this study, we understood vulnerability as *the degree to which an ecosystem service is sensitive to global environmental change (potential impacts) and the degree to which the sector or region that relies on the service is unable to adapt to the changes.* To estimate vulnerability, both potential impacts and adaptive capacity need to be taken into account (*S38*). In this article we have concentrated on reporting potential impacts. However, the conclusions drawn about vulnerability were informed by considerations of adaptive capacity as described in the following.

Quantitative approaches to adaptive capacity were not readily available on a European scale. We therefore used an informal and a formal way to estimate adaptive capacity within Europe: (1) our stakeholder dialogue and, (2) a socio-economic, spatially explicit generic index to consider adaptive capacity developed as part of our assessment. The generic adaptive capacity index was constructed using the SRES based socio-economic scenarios (*S1*). Empirical and theoretical evidence of how potential impacts and adaptive capacity can be combined into measures of vulnerability is very limited. Therefore, we created visual combinations of these elements without quantifying a specific relationship. The resulting maps (not shown) illustrate vulnerability in terms of negative potential impacts and limited adaptive capacity. All results are made available to stakeholders in form of a digital atlas with spatially and temporal explicit maps of Europe (*S39*). The atlas holds over 3200 maps of vulnerability and its components, i.e. exposures, potential impacts (changing ecosystem service indicators), generic adaptive capacity, as well as summarising charts. The tool is interactive and allows simple queries. Scenarios, time slices and regions can be compared for each ecosystem service indicator. The maps are accompanied by careful documentation of the underlying assumptions and limitations of the approach. The tool can be downloaded at www.pik-potsdam.de/ateam.

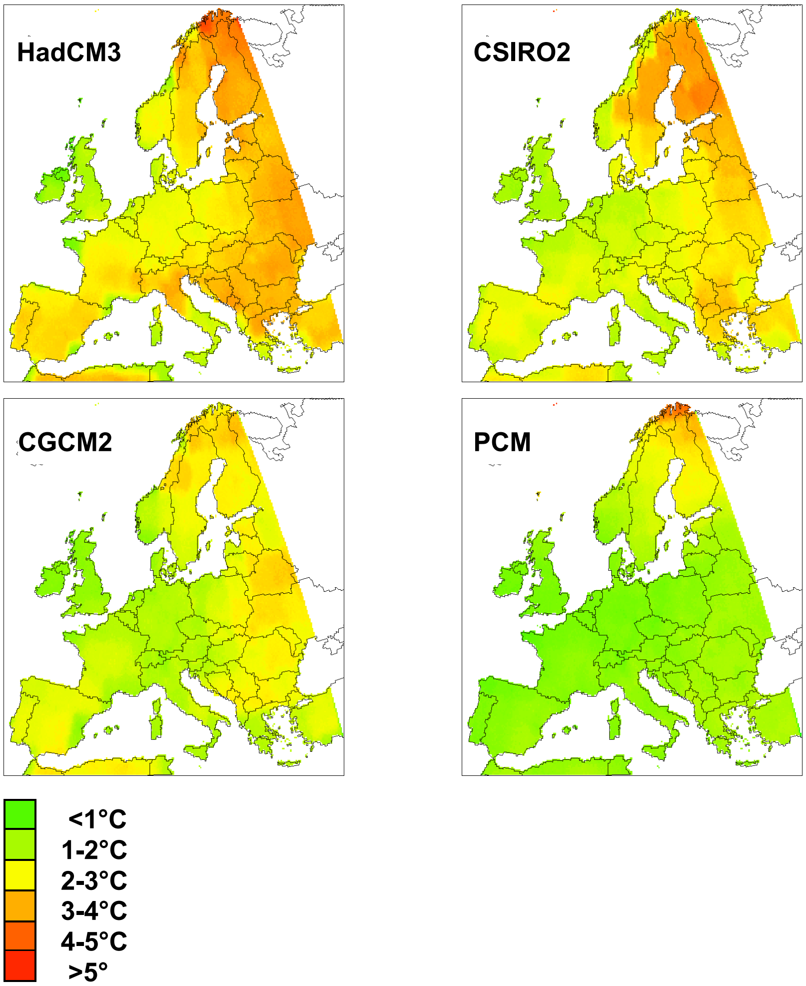


**Figure S1.** Annual average temperature anomalies (ºC) for the A2 scenario (2051-2080 compared to 1961-1990). The relative spatial pattern projected by each climate model remains the same over different emission scenarios, and only the size of the anomaly varies between the emission scenarios for one and the same GCM. Therefore these maps demonstrate the complete relative spatial variability of the climate projection on the annual timescale, even though only one emission scenario (A2) is shown.

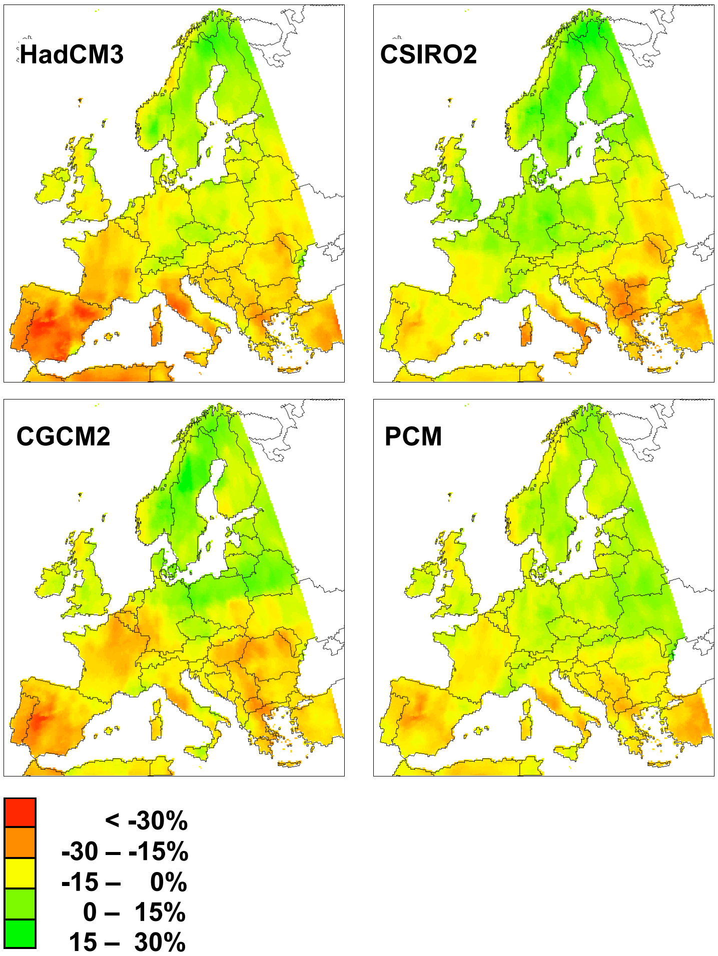
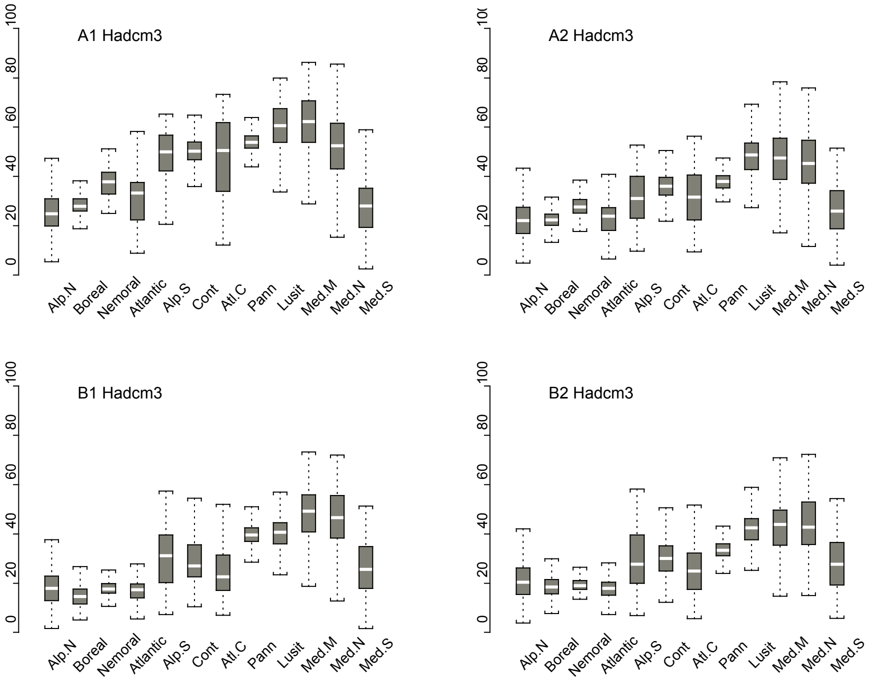


**Figure S2.** Annual average precipitation anomalies (%) for the A2 scenario (2051-2080 compared to 1961-1990). The relative spatial pattern projected by each climate model remains the same over different emission scenarios, and only the size of the anomaly varies between the emission scenarios for one and the same GCM. Therefore these maps demonstrate the complete relative spatial variability of the climate projection on the annual timescale, even though only one emission scenario (A2) is shown.

**A**


A1 Hadcm3
A2 Hadcm3
B1 Hadcm3
B2 Hadcm3
0
20
40
60
80
100
Alp.N
Boreal
Nemoral
Atlantic
Alp.S
Cont
Atl.C
Pann
Lusit
Med.M
Med.N
Med.S

**B**

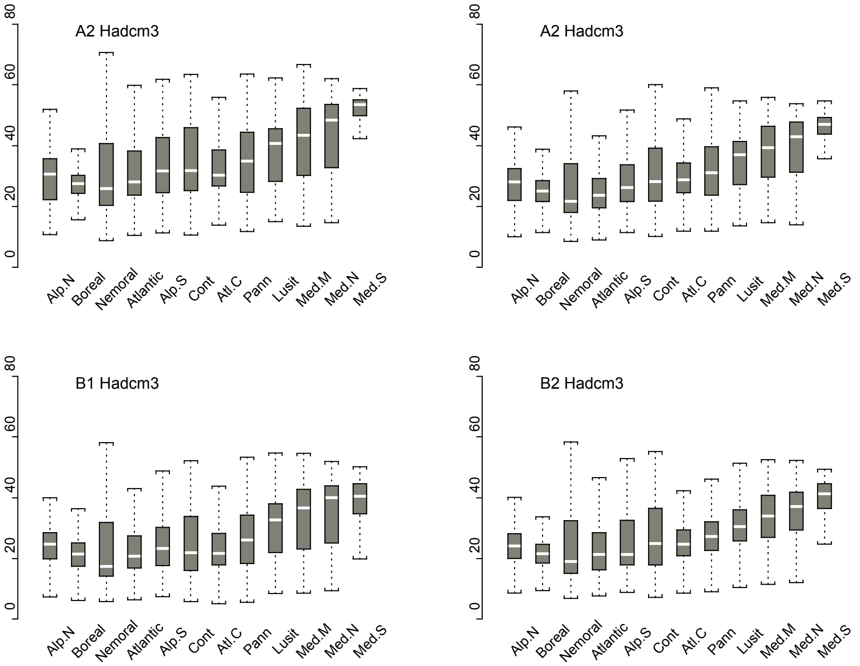

A2 Hadcm3
A2 Hadcm3
B1 Hadcm3
B2 Hadcm3
0
20
40
60
80
Alp.N
Boreal
Nemoral
Atlantic
Alp.S
Cont
Atl.C
Pann
Lusit
Med.M
Med.N
Med.S

**Figure S3.** Impacts on number of plant species *per grid cell* across European biogeographical regions (*S22*) by 2080 relative to 1990, for the four storylines (A1 is A1FI, A2, B1 and B2) based on HadCM3 climate. Upper extreme, upper quartile, median, lower quartile and lower extreme are represented for each box. (**A**) Average potential plant species loss *per grid cell* (%). Please note that this indicator records only losses from a specific grid cell and does not take potential gains into account. It does not make a statement about potential losses of the species *from Europe*, or about extinction. (**B**) Average percentage of potential plant species gain *per grid cell* (%). In this case, species are assumed to be able to disperse instantaneously to newly suitable habitat (‘full dispersal’). Please note that this indicator records only gains in a specific grid cell and does not take potential losses into account. The indicator does not make a statement about potential gains of the species *in Europe*, or about changes in total species richness.
Alp.N = Alpine North, Alp.S = Alpine South, Cont = Continental, Atl.C = Atlantic Central, Pann = Pannonian, Lusit = Lusitanian, Med. M = Mediterranean Mountains, Med. N = Mediterranean North, Med. S = Mediterranean South.

**Table S1.** Summary of European drivers for each scenario (adapted from *S1* and *S14*).

| **A1FI Europe** | |
|---|---|
| *Economy* | Very rapid economic growth and convergence between regions. European income inequalities eradicated. Material consumption and increases in income/capital lead to increased use of natural resources. |
| *Population* | European fertility rates reach 1.7 with a slight increase in population to 2050 then a decrease. |
| *Technology* | High investments in technology and high rates of innovation |
| *Institutions and government* | Governments are weak with a strong commitment to market based solutions. International co-operation flourishes. Stable political and social climate, with good health care and education. Self-sufficiency is not an issue; free trade is emphasised. |
| *Rural development* | Focus on centres and international connections, but rural development not a focus area. Increased affluence has "spill-over" effects on rural and remote areas. |
| *Recreation and tourism* | Increase in recreation areas close to urban centres, while wilderness areas are less attractive. Increases in beach resorts and locations with built facilities rather than eco-tourism. |
| *Spatial planning* | Convergence of planning policy and fewer restrictions. |
| *Nature conservation* | Emphasis on recreation within protected areas (public access). Less emphasis on protection of biodiversity. |
| *EU enlargement* | Proceeds rapidly. |
| **A2 Europe** | |
| *Economy* | Moderate GDP growth, but slower than A1FI. Economic development is regionally oriented and uneven. The income gap between developed and developing countries does not narrow. |
| *Population* | European fertility rates reach 2.1 resulting in a steady increase in the population. |
| *Technology* | Technological development is slower than in A1FI and more heterogeneous. Technology transfer and diffusion are slower. |
| *Institutions and government* | Self-reliance of regions, less mobility of people, ideas and capital. Social and political institutions diversify. Central national governments are weak, because of the "markets first" approach. A more protectionist Europe compared to the present, which could mean a stronger European Union. |
| *Rural development* | Enhanced rural development results as a by-product of the stress on regional self-reliance. |
| *Recreation and tourism* | Tourism decreases (in the long term) and is mainly regionally-oriented. Recreation increases with population increase. Demand for near urban recreation areas increases, but a dispersed population also uses distant areas for recreation. Built facilities are valued, while wilderness areas are less popular. |
| *Spatial planning* | Heterogeneity of planning policy. |
| *Nature conservation* | Conservation policy is weak. Little public concern for biodiversity. Current protection declines due to urban expansion. Networks of nature reserves are strongly fragmented. |
| *EU enlargement* | Stops or proceeds very slowly. |
| **B1 Europe** | |
| *Economy* | A convergent world with global solutions to economic, social and environmental sustainability. There is progress toward international and national income equality. GDP growth rates are moderate. |
| *Population* | European fertility rates reach 1.7 with a slight increase in population by 2050 then a decrease. |
| *Technology* | Rapid technological change. |
| *Institutions and government* | Central governments are strong with a high level of regulation. International institutions and cooperation are central. |

| | |
|---|---|
| *government* | cooperation are central. |
| *Rural development* | Rural development is a key issue with equitable income distribution and development a priority. |
| *Recreation and tourism* | Demand for tourism (including eco-tourism) and recreation increases, both near to urban centres and in remote areas. |
| *Spatial planning* | Homogeneous and restrictive policy with high level of regulation. |
| *Nature conservation* | Strict protection of areas with high biodiversity. European ecological networks established and maintained (European cooperation). Green belts around cities preserved. Land not in agricultural production developed for nature conservation. Forest areas with high biodiversity are designated as conservation areas. |
| *EU enlargement* | Proceeds at a moderate rate. |
| **B2 Europe** | |
| *Economy* | Local solutions to economic, social and environmental sustainability. Rate of development and GDP growth rate are generally low. International income differences decrease at a slower rate than in A1FI and B1. Education and welfare programmes are pursued. |
| *Population* | Population is stable. |
| *Technology* | Technological change and innovation are unevenly distributed. |
| *Institutions and government* | Local self-reliance and strong communities. Decision-making is at the local/regional level and central government is weak. Citizen participation in decision-making is high and government policies and business strategies are influenced by public participation. |
| *Rural development* | Increases because of emphasis on self-reliance and local products. |
| *Recreation and tourism* | Tourism decreases. The focus is on local destinations. Recreation increases nearer to urban areas and rural villages with access by public transportation. |
| *Spatial planning* | Restrictive and heterogeneous policy. |
| Nature conservation | International conservation policies are difficult to implement. Much attention is given to the preservation of biodiversity and wildlife at the local level. |
| *EU enlargement* | Stops. |

**Table S2.** Summary of the main trends in the European land use scenarios (*S13, S40*).

**Economic**

| | | | |
|---|---|---|---|
| | **A1FI** | **A2** | |
| | • Agricultural area for food production declines substantially by 2080. Some is used for bioenergy production.<br>• Production is concentrated in optimal locations.<br>• Forest area increases only slightly.<br>• Urban area increases due to non-restrictive planning.<br>• Protected area increases[a]. Emphasis on recreational use. | • Agricultural area for food production declines substantially by 2080. Some is used for bioenergy production.<br>• Changes are distributed equally across Europe.<br>• Forest area increases only slightly.<br>• Urban area increases due to rising population and incomes.<br>• Protected area increases[a]. Conservation networks strongly fragmented. | |
| **Global** | **B1** | **B2** | **Regional** |
| | • Agricultural area for food production declines substantially by 2080. Some is used for bioenergy production.<br>• Cropland is concentrated in optimal locations. Grassland is protected by policy.<br>• Forest area increases. New forests are located on surplus agricultural land.<br>• Urban land use pressure is low. Restrictive planning leads to compact cities.<br>• Protected area increases[a]. Strict protection of biodiversity. | • Rural development policies maintain agriculture in most places. Changes reflect a switch from food to bioenergy production or forestry.<br>• Forest area increases more than in all other scenarios.<br>• Urban area increases only slightly due to stable population and slow growth in income. Restrictive planning leads to compact cities.<br>• Protected area increases[a]. Strict protection at local level. | |

**Environmental**

[a] For all scenarios it is assumed that 20% of the area of Europe will become designated as protected by 2080. This was based on a judgement made from past and current increases in protected-areas coverage in Europe, the latter being due to member-state responses to the need for implementation of the NATURA 2000 network. Whilst this target was the same for all scenarios, it was assumed that it would be reached for different reasons: the economic scenarios require areas for recreation for a richer population, whereas the environmental scenarios require areas designated for conservation purposes.

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