BASE

BOTTOM-UP CLIMATE
ADAPTATION STRATEGIES
TOWARDS A SUSTAINABLE EUROPE

Uncertainty analysis in integrated assessment modelling

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BASE BOTTOM-UP CLIMATE ADAPTATION STRATEGIES FOR EUROPE

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Summary:

Some of the most difficult issues related to integrated assessment modelling is to capture the social economic implications of climate change impacts and policy in the presence of uncertainty. Uncertainty is paramount in climate change sciences and stems from different levels: uncertainty about climate responses, uncertainty about environmental responses (impacts) to climatic stimuli, uncertainty about the social economic responses to both environmental impacts and climate change policies, (i.e. on their costs and effectiveness). Against this background, it is particularly important to explicitly consider the spatial specificities of both climate-change impacts and, consequently, adaptation option. Both are highly differentiated geographically, therefore an appropriate spatial resolutions in assessment exercises (and models) is equally important for the "right" evaluation and prioritisation of adaptation actions.

In the light of this, in its first part, this deliverable proposes one specific method to incorporate uncertainty in the WITCH integrated assessment model. The approach followed is that of "risk premium". By estimating and explicating risk aversion attitudes in representative agents affected by climate change damages it is possible to construct a climate change social damage function "augmented" by the perceived risk. This new function will then be used to investigate how risk can influence both mitigation and adaptation choices as part of the analysis developed in WP6.

In its second part, this deliverable develops and tests a method to investigate spatial differences in climate change impacts on agriculture in terms of land use changes. Agriculture is obviously one sector where spatial heterogeneity plays a major role both in the definition of impacts and in the choice of adaptation strategies. Furthermore, it is one of the key impact areas that the BASE project analyses with a sectorial approach. The deliverable describes the methodology followed to develop an integrated modelling framework (SARA) that will allow for an integrated analysis of adaptation pathways also part of the research activity developed in BASE WP6.

These two lines of research are at the moment parallel, however they will be integrated, later on, in WP6. More specifically, the macroeconomic investigation on the strategic complementarity between mitigation and adaptation conducted with the AD-WITCH model, with and without risk, will also incorporate information provided by all the sectorial analyses developed within BASE, thus including also those performed with the SARA framework. In particular, AD-WITCH will incorporate in the calibration of its impact-adaptation functions related to agriculture, cost and effectiveness information provided by the SARA framework.

Contents

1 Part 1: Building Uncertainty into the Adaptation Cost Estimation in Integrated Assessment Models (IAMs)

1.1 Introduction

The research described in this section of the deliverable aims at developing in an integrated assessment modelling framework, a methodology to evaluate the policy implications of climate change impacts uncertainty on the optimal adaptation response, on the costs of adaptation, and on its interaction with mitigation.

The estimated costs of climate impacts are highly uncertain. The *sources of uncertainty* can be divided into uncertainties on *input data*; *model uncertainty*; *context uncertainty*, i.e. the boundaries of the systems to be modelled, such as future climate and regulatory conditions if these aspects are not explicitly included in the modelling study; and *uncertainty due to multiple knowledge frames*, reflecting that different persons may have different perceptions of what the main problems are, what is at stake, which goals should be achieved. The simultaneous presence of multiple frames of reference to understand a certain phenomenon may cause ambiguity. The uncertainty cascade in the climate modelling community includes uncertainties from emission scenarios, global models and regional models. If we use the term in a broader climate change adaptation context (Figure 1) we should also include uncertainties due to statistical downscaling, systems impacts and socio-economic impacts. For further details see Refsgaard et al. (2013).

In spite of this, most research in the climate area is based on average values, especially in macro models or Integrated Assessment Models (IAMs). When working at the project or sector level, some account is taken of uncertainty using sensitivity analysis, robust methods and others but even there much of the work is based on average values[1]. For instance, previous EU-funded projects, such as the Climatecost project[2], have developed updated monetary estimates of climate change impacts, using “standard” albeit consolidated approaches to uncertainty treatment. Specifically, one of the model used in the study, PAGE (Hope, 2011) included Monte Carlo analysis to model climate change risk, estimate its ranges, as well as its expected value. The FUND (Tol, 1996) and the WITCH (Bosetti et al. 2006) models, also used in Climtecost, accounted for uncertainty by means of extended sensitivity analyses on model behavioural parameters.

The RESPONSES project[3] aiming as well to mainstream mitigation and adaptation into EU policies and to analyse trade-offs and conflicts between the two did not focus primarily on uncertainty. Moreover, in that project the use of integrated assessment models was meant to

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[1] This is one topic of investigation of the MEDIATION project.

[2] http://www.climatecost.cc/

[3] http://www.responsesproject.eu/

generate emission scenarios, rather than developing an integrated joint assessment of adaptation and mitigation responses.

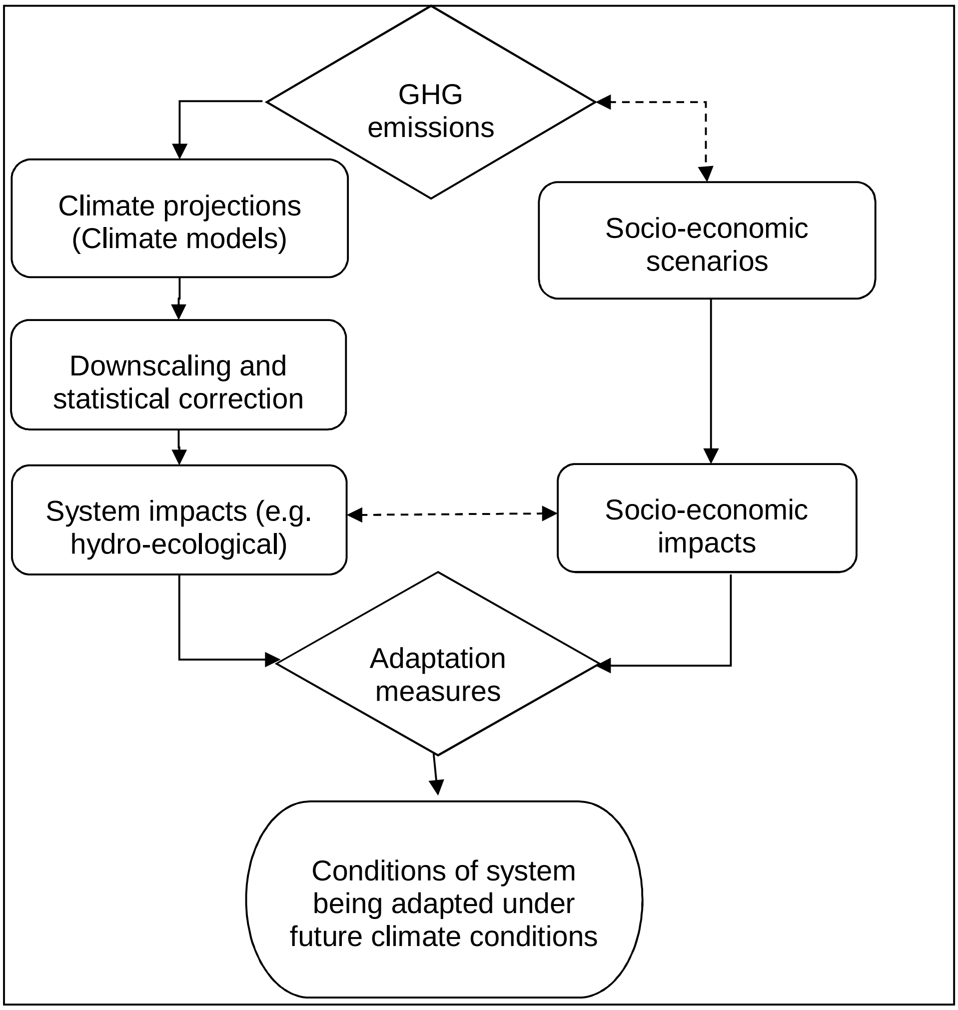
The MEDIATION project,[4] finally, addressed the issue of uncertainty with respect to climate change vulnerability, impacts and adaptation. Its focus however was on the decision process from a bottom-up perspective and on developing tools and methods for robust decision making under uncertainty. It did not aim to suggest methods for modelling uncertainty into integrated assessment models, which is, instead, the main aim of the following work.

Here we build on the results from the ClimateCost project, which is an important data source for the calibration of our damage functions (see Deliverable 3.3), but we make a step forward by accounting for the damage mark-up associated with risk aversion and by analysing how such mark-up varies with degree of aversion to risk. The objective of this study is to develop some fundamental thinking about how to incorporate uncertainty into the assessment of adaptation options using an integrated assessment model (the modified WITCH version presented in BASE D3.1. (Bosello et al. 2013) and D3.3 (Bosello et al., 2014)) that make it possible to explore the connections between adaptation and mitigation.

There are many approaches to incorporate uncertainty. This exercise adopts the particular perspective and concept of risk premium to account for risk aversion in the affected population. The reasons for choosing it over other options are: (a) it is relatively simple to model and (b) it allows us to reflect public attitudes to aversion to risk uncertainty in a transparent way.

[4] http://mediation-project.eu/

Figure 1: Steps in Adaptation where Uncertainty Arises

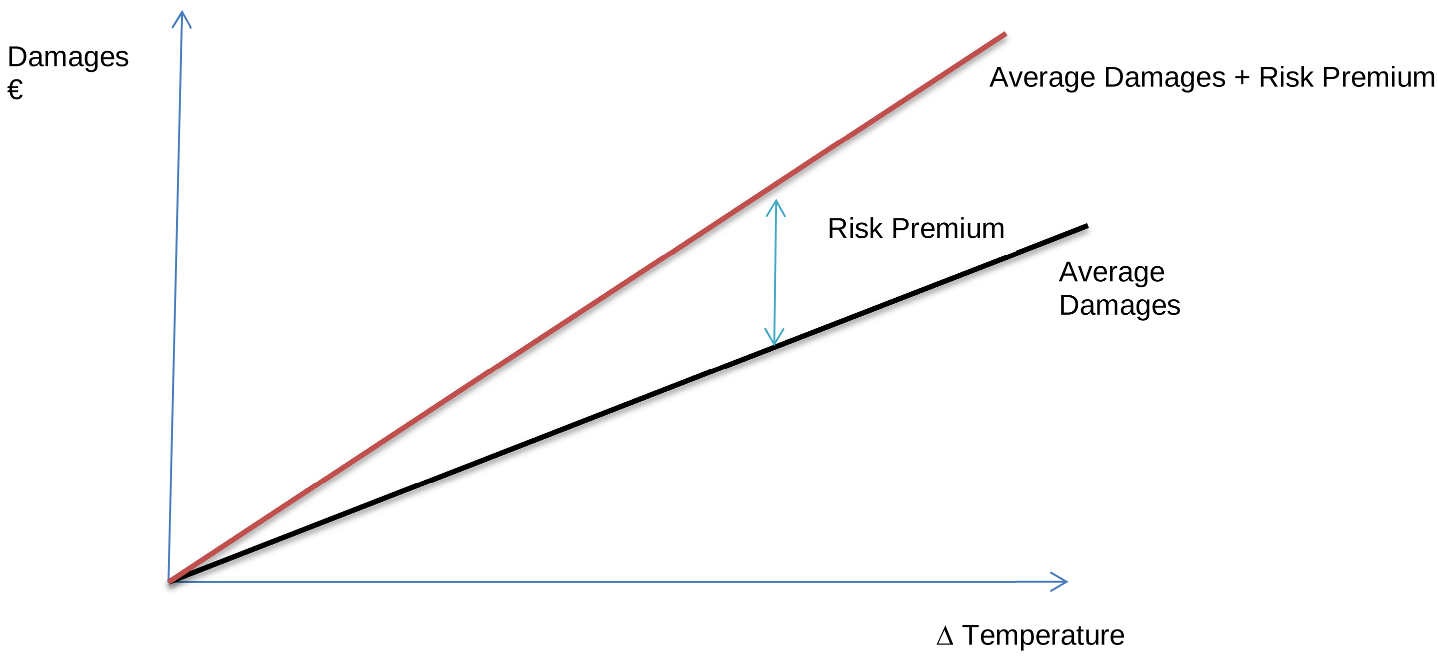


This deliverable presents the chosen framework and describes model development proceeding as follows. The next section explains the methodology and introduce the steps followed to calculate the premium to be included in models such as AD-WITCH. The procedure is general enough to be applied also to the assessment of adaptation options at the project level. Section 3 gives the damage functions currently used in AD-WITCH. Section 4 calculates how the damage curves currently used in AD-WITCH would be changed if a risk premium were to be added. Section 5 implements the new curves for three levels of risk aversion into the model and compares the results with those without risk premium. Section 6 concludes the paper with reflections on how the approach may be taken further.

1.2 Risk Premium: Conceptual Issues

The basic idea of a risk premium is very simple: people are willing to pay a certain amount to reduce the riskiness of a given event, irrespective of whether it is one that has on average a benefit to them or a cost. When faced with a prospect of winning €10,000 if a "fair" coin comes down heads and nothing if it comes down tails the expected return that most people can easily compute is €5,000. Yet if offered a choice between a certain return of €5000 and tossing a coin in this manner most will choose the certain €5,000 (especially if the figures are a matter of their way of life). Indeed most people will take a little less than €5,000 rather than play the game. If the minimum they would accept with certainty is €4,500 then we say that €500 is the risk premium associated with that game. Similarly when faced with a potential loss of €10,000 with probability of half and no loss with a probability of a half, people might pay an insurance company a premium of, say, €500 to be guaranteed an outcome of €5,000 irrespective of which state of the world prevails. The insurance company then has an expected payout of €0 but it makes a profit of €500 on the premium and both sides are happy. This €500 is the risk premium associated with the uncertain event and the true cost of the event is not €5,000 but €5,500.In the case of climate impacts a similar argument can be made. In Figure 2, average damages from (say) flooding are plotted against temperature.

Figure 2: Premium for Risk in Climate Cost Estimation



The average damages are shown by the bold black line in Figure 2 while the damages with the risk premium are shown by the bold red line. The higher line represents the real damages, when risk is accounted for and adaptation should be carried out to reduce that line. This can be done in a number of ways, which include measures to reduce average damages but it can also be done through measures that reduce the risk premium associated with the damages. The latter could be achieved, for example, through public insurance schemes or through actions that reduce the uncertainty associated with the event in the first place, e.g. by undertaking research on the different steps in chain that goes from temperature increase to the physical impacts to the monetary damages.

The use of this framework has been questioned, especially by psychologists who note that risk aversion cannot be represented in such a simple way. In particular individuals have asymmetric attitudes to losses and gains and they are value the risk of potential losses more than potential gains (Kahneman, 2011). Furthermore, the evaluation of losses and gains varies according to what people consider to be their reference point. These important findings are the central propositions of prospect theory, which of course we accept. However, we note that, for the purposes of this assessment of risk we are seeking a social representation of the aversion in a single direction (i.e. that of possible losses) and so it should be possible to use a consistent representation that reflects those losses. Furthermore, we would argue that a social representation, which we are seeking, can be based on principles that can choose to exclude those aspects of individual decision-making that are considered to be excessively irrational. Some behavioural economics findings of how choices are made fall into that category.

1.3 Measuring the Risk Premium

How can we obtain an idea of what this premium is? One way is simply to ask people and there is a major line of research that does just that, using methods of conjoint choice (Green et al. 2001). The current deliverable does not undertake such empirical approach, but focuses instead on a theoretical perspective. When empirical data is available from the case studies we may revisit the issue and see what can be said about the premium.

We use evidence on risk aversion from other areas of consumer choice and apply it to this area of climate change and adaptation[5]. The standard treatment for modelling choices under risk is to use the expected utility framework. If there is an uncertain future set of outcomes represented by different values of a variable **x**, and where the frequency distribution of that variable is given by f(**x**), we can represent the risk premium **r** by solving the equation:

$$E(U) = \int U(\boldsymbol{x}) f(\boldsymbol{x}) dx = U(\overline{\boldsymbol{x}} - \boldsymbol{r}) \qquad (1)$$

Where $\overline{\boldsymbol{x}}$ is the expected or average value of the variable **x:**

$$\int(\boldsymbol{x}) f(\boldsymbol{x}) dx = (\overline{\boldsymbol{x}}) \qquad (2)$$

[5] Applications of the theory to understand investments decisions in finance are commonplace. See for example, Levy (1994) and Blake (1996) as well as the excellent notes of Professor Norstad. http://www.norstad.org/finance/util.pdf. An application to environmental decision-making is Krupnick, Markandya and Nickell, 1993.

U(**x**) is the individual's utility function.

For the specific problem of climate impacts we can take the distribution of **x** to be log normal if it is derived from the multiplicative linkages from temperature to physical impacts and from physical impacts to values. The representation of this process was developed by Rabl and Spadaro (1999), in which the authors note that if the final number (damages) is the outcome of a process as the one described above and if the variable at each step has an independent distribution with a given geometric mean, then the geometric mean of the log of the final figure is the sum of the logarithms of the individual means and the standard deviation of the final figure is the sum of the squares of the geometric standard deviations of each process that gives rise to the final product.

The form that the utility function can be represented by the following family of functions:

$$U(x) = \frac{x^{1-\eta} - 1}{1-\eta} \quad (3)$$

The value of the coefficient of relative risk aversion, η, and has been estimated to take values of between 1 and 4. Note that when η is equal to one the above function reduces (by L'Hôpital's Rule) to:

$$U(x) = \log(x) \quad (4)$$

In order to show how equation (2) turns out in the specific case when the frequency distribution is lognormal and the utility function takes the form (4) we present the functions below. The expression for expected utility $E(U)$ is given by:

$$E(U) = U(x) f(x;\mu,\sigma) dx \quad (5)$$

where $f(x;\mu,\sigma)$ is the lognormal distribution density function:

$$\frac{1}{x\sigma\sqrt{2\pi}} e^{-\frac{(\ln x-\mu)^2}{2\sigma^2}} \quad (6)$$

We define the certainty equivalent as x^* where:

$$U(x^*) = E(U) \quad (7)$$

The risk premium is $\bar{\boldsymbol{x}} - x^*$, where $\bar{\boldsymbol{x}}$ is the expected value of **x.**

$U(x)$ has the form:

$$U(x) = \frac{x^{1-\eta} - 1}{1-\eta} \tag{8}$$

$$\lim_{\eta \to 1} \frac{x^{1-\eta} - 1}{1-\eta} = \ln x \tag{9}$$

In the general case:

$$\int_0^\infty \frac{x^{1-\eta} - 1}{1-\eta} \frac{1}{x\sigma\sqrt{2\pi}} e^{-\frac{(\ln x - \mu)^2}{2\sigma^2}} dx = \frac{1}{1-\eta} \int_0^\infty x^{1-\eta} \frac{1}{x\sigma\sqrt{2\pi}} e^{-\frac{(\ln x - \mu)^2}{2\sigma^2}} dx - \frac{1}{1-\eta} = \frac{E(x^{1-\eta}) - 1}{1-\eta}$$

Where $E(x^{1-\eta})$ is expected value of $x^{1-\eta}$.

In the case $U(x) = \ln x$:

$$E(U) = \ln x \times f(x; \mu, \sigma) dx = \mu \tag{10}$$

$$\ln x^* = \mu \tag{11}$$

$$x^* = e^{\mu} \tag{12}$$

And $\bar{\boldsymbol{x}}$ is the expected value of **x** is given by

$$\bar{\boldsymbol{x}} = e^{\mu + \sigma^2/2} \tag{13}$$

For example with $\mu = 10$ and $\sigma = 1$ we obtain directly from the above that: x* = 22,206 and $\bar{x}$ = 36,316, yielding a value of the risk premium r of 14,110. In other words for a case where the individual or social group faces a distribution of future returns with a mean of 36,316 and a log normal distribution of those returns as specified here, the risk premium is 14,110, or 38.8%.

1.4 Estimated Damage Functions in the AD-WITCH Model

FEEM and CMCC have generated a distribution of regional damages by applying the AD-WITCH[6] (Bosetti et al. 2006) regional damage functions (Bosello and De Cian 2014) to probabilistic temperature projections obtained from the CMIP5 archive.

Temperature projections for any given emission scenario during the current century have a spread which comes from geophysical uncertainties. The CMIP5 exercise has produced a large set of temperature projections using a lot of models to track these uncertainties. To be able to emulate the CMIP5 models and the underlying uncertainty, we calibrate a simple climate model using a Bayesian inversion technique based on a Monte Carlo Markov chain (MCMC). Another uncertainty arises about the climate policy implementation, so we extract from the AR5 scenario database a set of 911 emissions scenarios for the next century. They are the results of integrated assessment models and cover a broad range of climate policy implementation with different delay of action, technology availability, level of cooperation and climate targets. We compute the probabilistic temperature projections for all these scenarios and we also compute the associated expected temperature in 2100. For each scenario, we apply the regional damage function from AD-WITCH on the generated temperatures to obtain the regional damage distribution for a given expected temperature. We fit these distributions to a log-normal form, where the fit is found to be good as shown in Figure 3. Finally, we relate the parameters of the log-normal distribution (mean log and standard-deviation log) to the expected temperature increase

[6] See also the model websites, www.witchmodel.org and http://witchdoc.like-spinning-plates.com/. We here refer to the WITCH model as AD-WITCH to emphasize the module of the model which is at the core of the research presented here, namely the adaptation module.

Figure 3: Akaike Information Criteria (AIC) of the fitting of damages with different distribution (the lower the better)

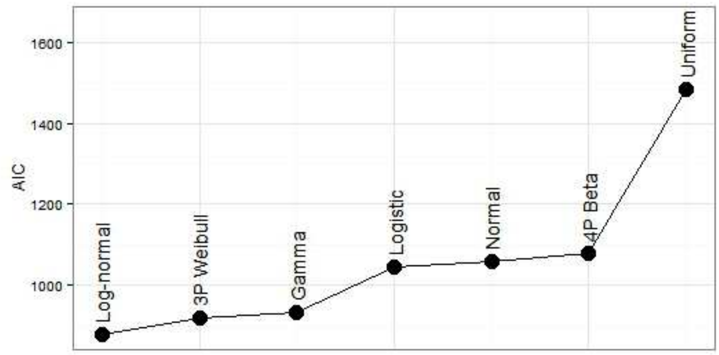
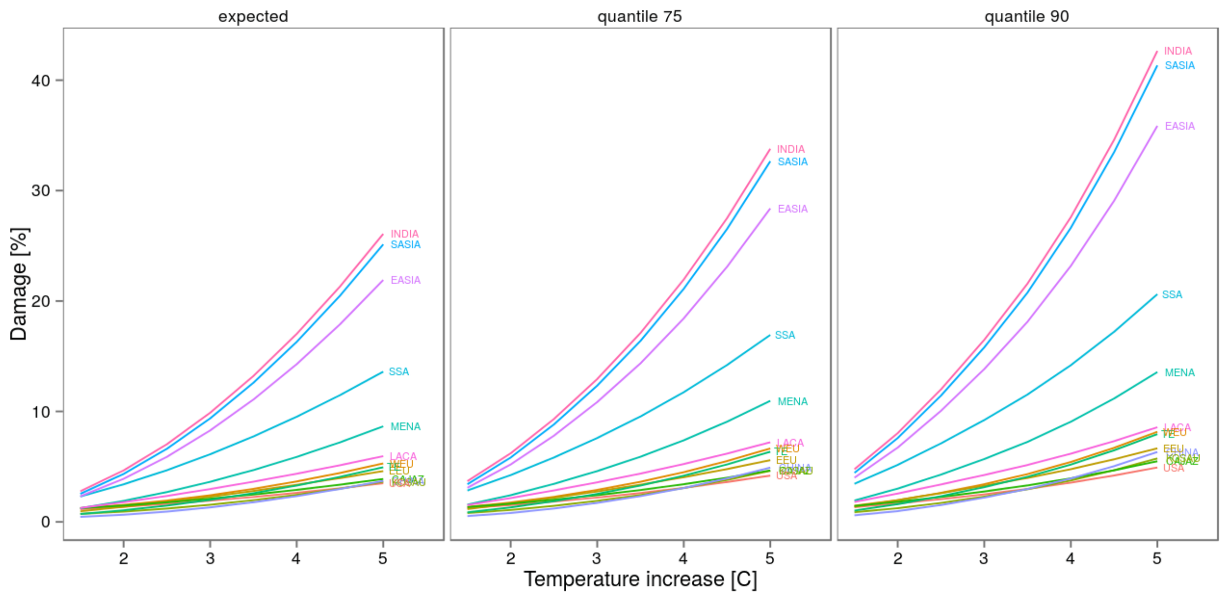


Figure 4 presents in three panels the expected regional damage, which correspond to AD-WITCH default expected damage, the 75th and the 90th quantiles of the regional damage distributions, respectively , as functions of the temperature increase. Damage is expressed as percentage (%) of GDP loss. The results are also provided in Annex I.

Figure 4: Damage measured as % loss in regional Gross Domestic Product (GDP) as a function of temperature. Expected values and 705th and 90th quintile



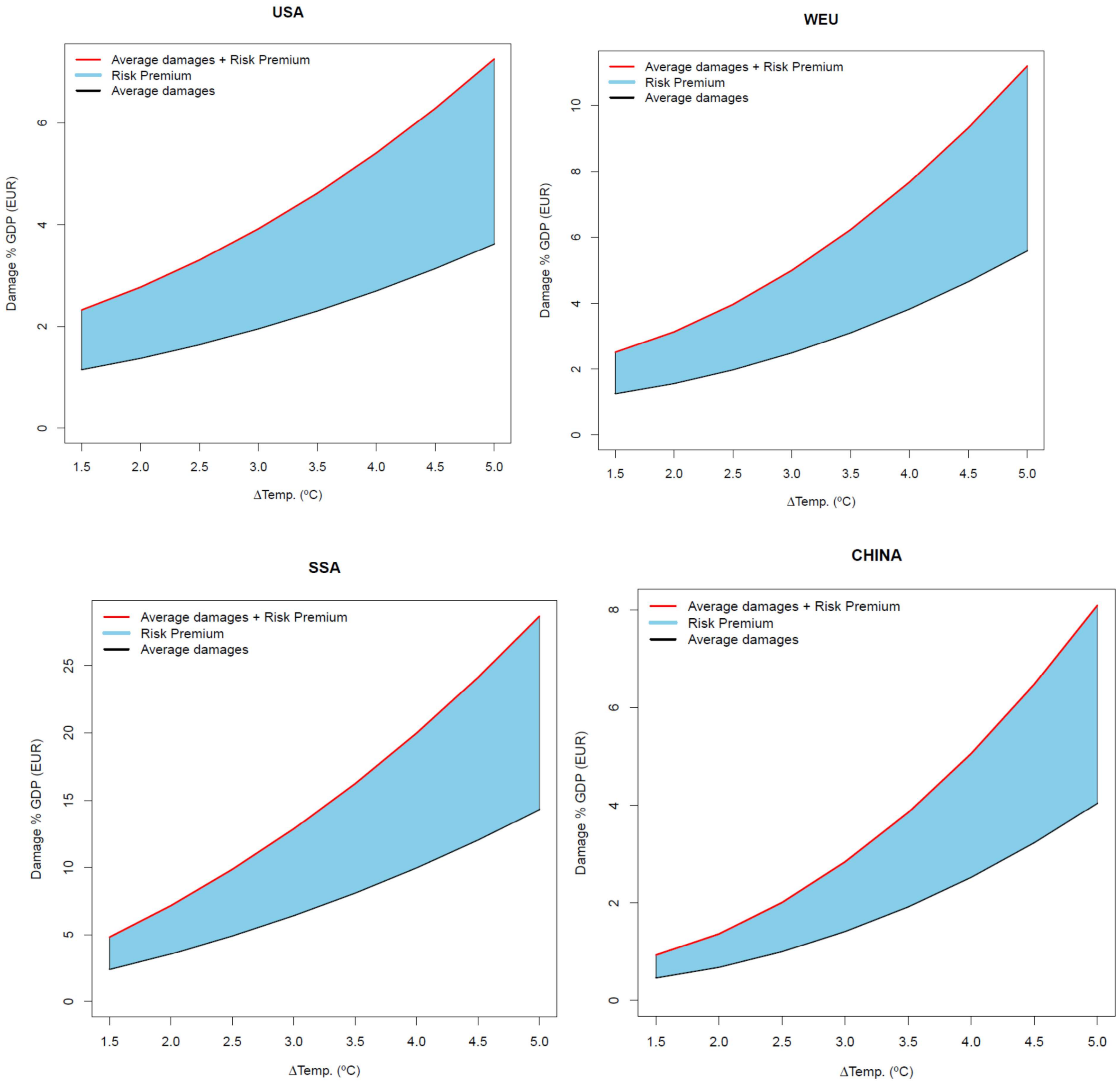
1.5 Estimation of the Risk-Adjusted Damage Functions

Based on the data provided in Annex I we have calculated the risk-adjusted damages for three values of the coefficient of relative risk aversion (η): 1, 1.5, and 2. This has been done for each of the 13 regions in the AD-WITCH model:

1. USA
2. WEU: Western Europe (excluding the EEU)
3. European Economic Union (EEU)
4. KOSAU: South Korea, South Africa, Australia
5. CAJAZ: Canada, Japan, New Zealand
6. TE: Transition Economies
7. MENA: Middle East and North Africa
8. SSA: Sub-Saharan Africa
9. SASIA: South Asia (excluding India)
10. CHINA
11. EASIA: East Asia (excluding China)
12. LACA: Latin America and the Caribbean
13. INDIA.

The results are given in Annex II for values of η equal to 1, 1.5, and 2. Figure 5 shows the damage curves with and without the risk premium for a value of η equal to 2 for 4 of the 13 regions.

Figure 5: Damages With and Without the Risk Premium for η = 2



The calculations show that the risk premium is significant. It adds around 90-110% to the damage estimate, irrespective of the temperature increase. These are the increases for a value of η of 2. For a value of η equal to 1 the increase is much lower, around 1-10% depending on the region considered. For a value of η equal to 1.5 the increase in damage due to the risk premium ranges between 1 and 19%. Thus the choice of the coefficient of risk aversion is critical.

1.6 Applying the Damage Functions with the Risk Premium in AD-WITCH

The core structure of the AD-WITCH model has been described in the Deliverable 3.3. Here we recall the most relevant features for the uncertainty analysis described in this paper. AD-WITCH uses reduced-form regional damage functions of the global average temperature increase, as shown in Eq. (14):

$$\Omega(t,n) = 1 + \frac{\left[\omega_{1,neg(n)}T(t) + \omega_{2,neg(n)}T(t)^{\omega_{3,neg(n)}}\right]}{1+Q(ADA,t,n)^{\varepsilon(n)}} + \omega_{1,pos(n)}T(t) + \omega_{2,pos(n)}T(t)^{\omega_{3,pos(n)}} + \omega_{4,neg(n)} + \omega_{4,pos(n)} \tag{14}$$

The damage reduced final output as in Eq. (15):

$$Y(t,n) = \frac{tfp0\left[\alpha(n)\left(\left(tfp_y(t,n)K_C(t,n)^{\beta}L(t,n)^{1-\beta}\right)^{\rho} + \left(1-\alpha(n)\right)ES(t,n)^{\rho}\right)^{\frac{1}{\rho}}\right]}{\Omega(t,n)} \tag{15}$$

where:

Y(t,n): Net Output (2005 USD Trillion)

tfp0: Initial level of TFP (index)

tfpy (t,n): Total factor productivity (index)

L(t,n): Population (million people)

ES(t,n): Energy services (2005 USD Trillion)

KC (t,n): Capital in final good (2005 USD Trillion)

Q(ADA,t,n): Adaption nest (2005 USD Trillion)

The parameters ω are used to calibrate the regional damages on the impact estimates data gathered by the literature (Bosello and De Cian 2014). Table 1 reports the parameter values for the AD-WITCH default damages, which in this setting correspond to the expected, or average damages. The baseline used for the present analysis is the Shared Socioeconomic Pathways SSP5 which is consistent with the Representative Concentration Pathway scenario (RCP) 8.5. This RCP-SSP combination is one of the scenarios that have been identified as common framework to the various analyses in the BASE project (see Deliverable 3.1).

Table 1: Parameter values of the AD-WITCH regional damage functions

	ω1,neg(n)	ω2,neg(n)	ω3,neg(n)	ω4,neg(n)	ω1,posg(n)	ω2,pos(n)	ω3,pos(n)	ω4,pos(n)
USA	0.0025	0.0006	2.0000	0.0068	-0.0010	0.0002	2.0000	0.0007
WEU	0.0028	0.0011	2.0000	0.0072	-0.0036	0.0008	2.0000	0.0022
EEU	0.0052	0.0008	2.0000	0.0000	0.0000	0.0000	2.0000	0.0000
KOSAU	0.0069	0.0000	2.0000	0.0004	-0.0077	0.0014	2.0000	0.0049
CAJAZ	0.0020	0.0008	2.0000	0.0076	-0.0003	0.0001	2.0000	0.0002
TE	0.0045	0.0009	2.0000	0.0000	-0.0041	0.0009	2.0000	0.0025
MENA	0.0043	0.0026	2.0000	0.0000	0.0000	0.0000	2.0000	0.0000
SSA	0.0102	0.0034	2.0000	0.0000	0.0000	0.0000	2.0000	0.0000
SASIA	0.0037	0.0095	2.0000	0.0000	-0.0009	0.0000	2.0000	-0.0002
CHINA	0.0043	0.0006	2.0000	0.0000	-0.0067	0.0012	2.0000	0.0041
EASIA	0.0034	0.0081	2.0000	0.0000	-0.0001	0.0000	2.0000	0.0000
LACA	0.0069	0.0010	2.0000	0.0000	0.0000	0.0000	2.0000	0.0000
INDIA	0.0051	0.0096	2.0000	0.0000	-0.0009	0.0000	2.0000	-0.0002

In this study we modify the parameters in Table 1 to calibrate risk-adjusted regional damages using the estimates computed in Section 4 and summarized in Annex II. The risk premium increases the negative part of the damage function. Therefore, we modify only the parameters $\omega_{1,\mathrm{neg(n)}}, \omega_{2,\mathrm{neg(n)}}, \ \omega_{4,\mathrm{neg(n)}}$. We do not modify the exponent, $\omega_{3,\mathrm{neg(n)}}$, which is left equal to 2. Table 2 summarizes the parameter values obtained to calibrate risk-adjusted damage functions for different risk premium levels.

Table 2: Parameter values that calibrate the regional damage functions to reflect different risk premium (Rp) levels of 1, 1.5 and 2. The case Rp=0 is the default AD-WITCH damage function (average damage).

Rp=0

	ω1,neg(n)	ω2,neg(n)	ω3,neg(n)	ω4,neg(n)
USA	0.0025	0.0006	2.0000	0.0068
WEU	0.0028	0.0011	2.0000	0.0072
EEU	0.0052	0.0008	2.0000	0.0000
KOSAU	0.0069	0.0000	2.0000	0.0004
CAJAZ	0.0020	0.0008	2.0000	0.0076
TE	0.0045	0.0009	2.0000	0.0000
MENA	0.0043	0.0026	2.0000	0.0000
SSA	0.0102	0.0034	2.0000	0.0000
SASIA	0.0037	0.0095	2.0000	0.0000
CHINA	0.0043	0.0006	2.0000	0.0000
EASIA	0.0034	0.0081	2.0000	0.0000
LACA	0.0069	0.0010	2.0000	0.0000
INDIA	0.0051	0.0096	2.0000	0.0000

Rp=1

	ω1,neg(n)	ω2,neg(n)	ω3,neg(n)	ω4,neg(n)
USA	0.0014	0.0009	2.0000	0.0083
WEU	0.0013	0.0017	2.0000	0.0086
EEU	0.0056	0.0009	2.0000	0.0000
KOSAU	0.0062	0.0004	2.0000	0.0009
CAJAZ	0.0009	0.0011	2.0000	0.0091
TE	0.0044	0.0013	2.0000	0.0000
MENA	0.0047	0.0031	2.0000	0.0000
SSA	0.0110	0.0040	2.0000	0.0000
SASIA	0.0048	0.0113	2.0000	0.0000
CHINA	0.0036	0.0012	2.0000	0.0000
EASIA	0.0043	0.0096	2.0000	0.0000
LACA	0.0074	0.0011	2.0000	0.0000
INDIA	0.0062	0.0114	2.0000	0.0000

Rp=1.5

	ω1,neg(n)	ω2,neg(n)	ω3,neg(n)	ω4,neg(n)
USA	0.0014	0.0010	2.0000	0.0083
WEU	0.0012	0.0018	2.0000	0.0084
EEU	0.0058	0.0010	2.0000	0.0000
KOSAU	0.0062	0.0005	2.0000	0.0007
CAJAZ	0.0009	0.0012	2.0000	0.0090
TE	0.0045	0.0014	2.0000	0.0000
MENA	0.0050	0.0032	2.0000	0.0000
SSA	0.0115	0.0042	2.0000	0.0000
SASIA	0.0057	0.0119	2.0000	0.0000
CHINA	0.0037	0.0012	2.0000	0.0000
EASIA	0.0051	0.0101	2.0000	0.0000
LACA	0.0076	0.0012	2.0000	0.0000
INDIA	0.0072	0.0120	2.0000	0.0000

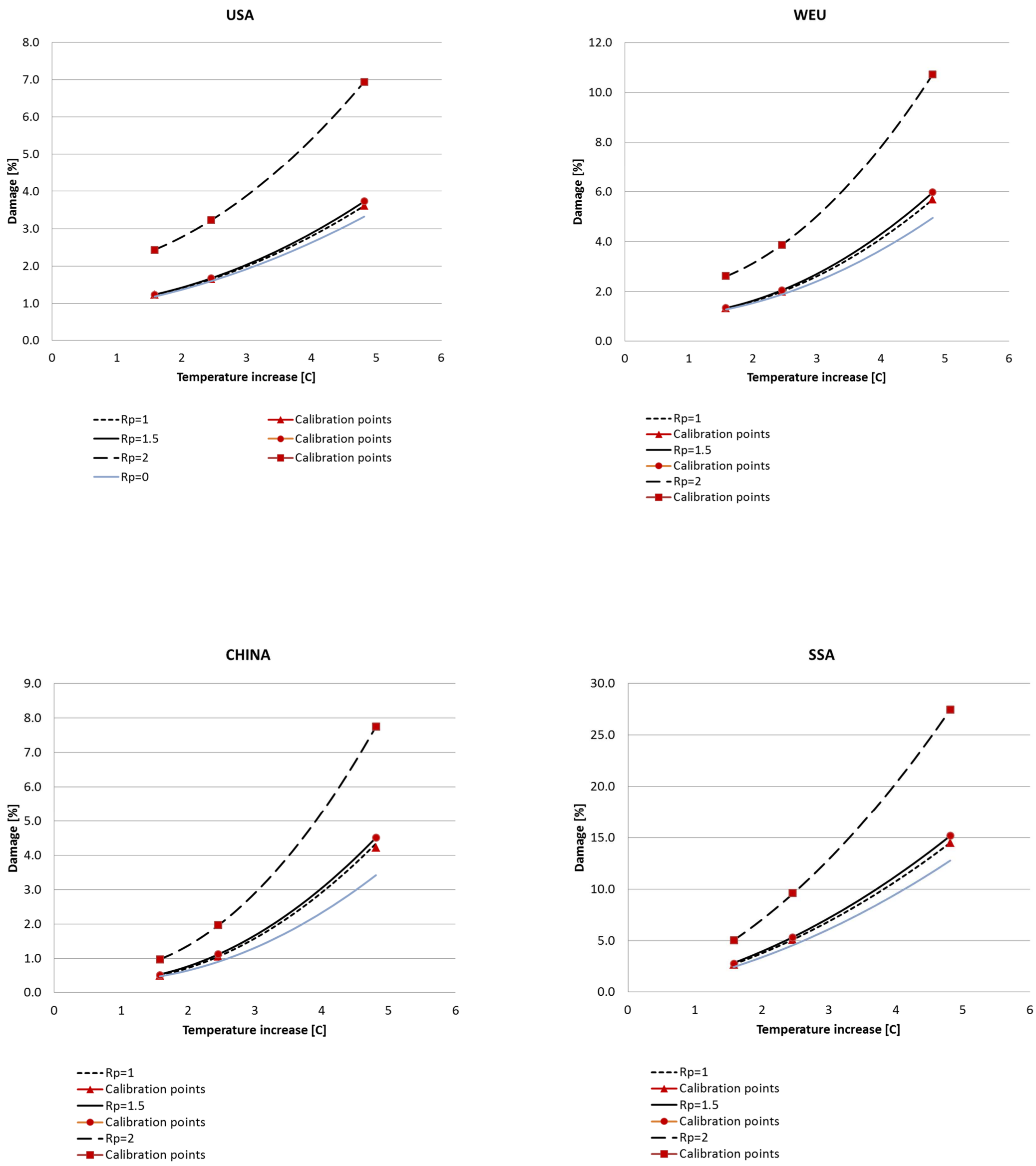
Rp=2

	ω1,neg(n)	ω2,neg(n)	ω3,neg(n)	ω4,neg(n)
USA	0.0017	0.0019	2.0000	0.0173
WEU	0.0000	0.0037	2.0000	0.0183
EEU	0.0104	0.0018	2.0000	0.0000
KOSAU	0.0048	0.0019	2.0000	0.0068
CAJAZ	0.0014	0.0022	2.0000	0.0185
TE	0.0054	0.0031	2.0000	0.0011
MENA	0.0079	0.0060	2.0000	0.0000
SSA	0.0198	0.0077	2.0000	0.0000
SASIA	0.0035	0.0219	2.0000	0.0000
CHINA	0.0015	0.0029	2.0000	0.0037
EASIA	0.0043	0.0186	2.0000	0.0000
LACA	0.0141	0.0022	2.0000	0.0000
INDIA	0.0093	0.0215	2.0000	0.0000

Figure 6 illustrates the calibration procedure, which is based on three points corresponding to three temperature increases of 1.58, 2.45, and 4.81 relative to preindustrial levels, which occur in 2030, 2050, 2100, and shows the resulting risk-adjusted damage functions for four selected regions7. The same methodology is applied to all 13 regions of the model. The Figure clearly highlights the highly non-linear increase in damages when increasing the risk premium from 1.5 to 2. It also shows the nonlinearity with the temperature increase.

[7] Since the temperature increases for which the risk premium has been calculated slightly deviates from the temperature increase that is observed in the model, with risk premium was adjusted accordingly to the temperature levels obtained in the model. Consider for example SSA, with η = 1.5. WITCH temperature profile, which is an endogenous output of the models reaches 2.45 in 2050 and 2.70 in 2055. We have scaled the risk-adjusted damage estimated at 2.5°C temperature increases as follows: $Rp_{t=2.45C}$ = $Rp_{t=2.5C}$*2.45/2.5. In the case of SSA this gives a risk premium of 5.332 for a temperature increase of 2.45C (while the corresponding risk premium at 2.5C is 5.432).

Figure 6: Calibration of the risk premium in the AD-WITCH model in four selected regions. Damage measured as loss in % regional Gross Domestic Product (GDP)



The AD-WITCH is an Integrated Assessment model and the economic module is an optimal Ramsey optimal growth model. The utility function of the representative region takes the form of a constant relative risk aversion coefficient utility function (CRRA) of the consumption per capita, as described in Eq. (16):

$$U(t,n) = \sum_t L(t,n) \frac{\frac{C(t,n)}{L(t,n)}^{1-\eta}}{1-\eta} r(t) \qquad (16)$$

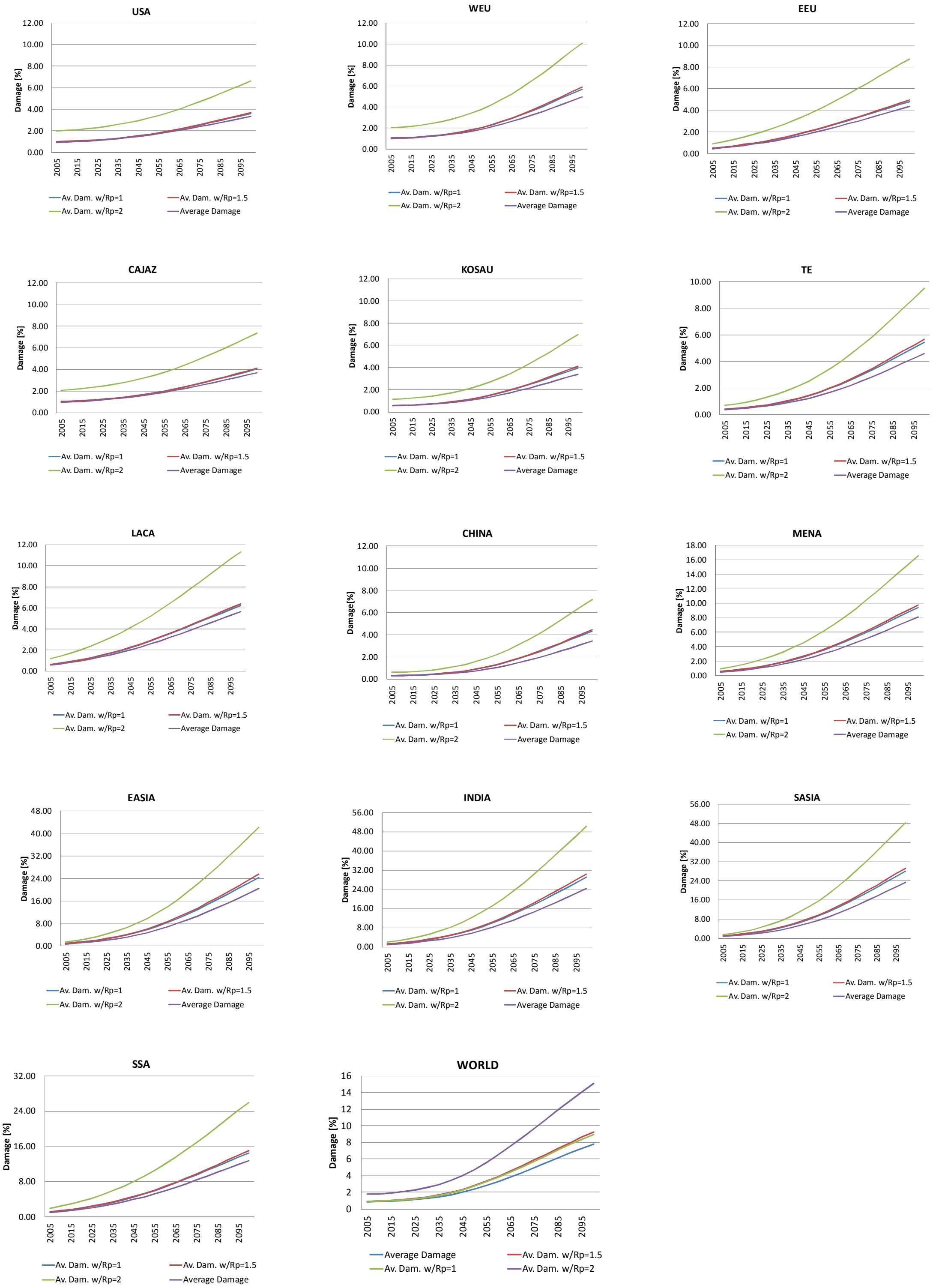
where $r(t)$ is the utility discount factor that related to the pure time preference discount factor as follows:

$$r(t) = \prod_{t'=0}^{t} (1+\rho(t'))^5 \qquad (17)$$

The default value of the inverse of the inter-temporal elasticity of substitution (IES) η is 1.5 and the pure rate of time preference ρ is 1%. When implementing the risk-adjusted damage functions that use a risk premium calculated with a value of the η equal to 1 or 2, we have modified the value of the same parameter (IES) in the AD-WITCH model accordingly. The case η=2 give some infeasibilities for high-damage regions, such as SSA, unless the pure rate of time preference is adjusted downward, from 1% to 0.001%. The intuition is the following. The case η=2 corresponds to a situation of high relative risk aversion and of low willingness to substitute consumption inter-temporally. In this case future damages are high, as they incorporate a large premium for the risk, and representative agents in the model would have a stronger preference to consume everything today. From the Ramsey equation, an increase in η reduces the growth rate of consumption. The resulting lower sensitivity of consumption growth to the gap between the interest rate and the pure rate of time preference can be compensated by reducing the pure rate of time preference. A very high risk premium for future climate change impacts causes the representative agents of the model to save more in the present as a precautionary response to the future reduction in output due to damages. Gollier (2002) shows how uncertainty in future consumption modifies the Ramsey equation in a similar way. The pure rate of time preference would be lower in order to induce precautionary savings. In the context of the debate on climate change discounting, Gollier (2008) and Dasgupta (2008) have also suggested a parameter combination of η=2 and ρ=0.

Figure 7 compares the risk-adjusted regional damage functions with the average damages without risk in the baseline scenario SSP5. With moderate risk aversion (η=1 and 1.5) the regional damages increase only marginally, especially in the short-run. Consider for example SSA. In SSA climate change damages increase from 2.46 to 2.74 with η=1, and to 2.85 with η =1.5. With higher risk aversion, the damages can increase from 2.46 to 5.02 already in 2030 (see Annex III for regional damage estimates over time, for various risk premium levels).

Figure 7: AD-WITCH model risk-adjusted regional damage functions. Damage measured as loss in % regional Gross Domestic Product (GDP)



1.7 Conclusions

This deliverable has described a methodology that makes use of a risk premium to account for risk aversion to climate change damages in the affected population. It uses the notion of risk aversion in the framework of expected utility theory to compute the risk premium, namely the amount the representative agent would be willing to pay in order to reduce the riskiness of future damages. We have used the resulting risk premium to calibrate a new set of regional damage functions in the AD-WITCH models, which we refer to as risk-adjusted damage functions. Risk-adjusted damage functions are higher than the expected damages because they take into account the premium the representative agent would be willing to pay to avoid to be exposed to a risky situation. We have calibrated three sets of risk-adjusted regional damage functions for three different levels of risk aversion, low (risk aversion parameter in the constant relative risk aversion utility function equal to 1), medium (1.5), and high (2). With low and medium coefficients of relative risk aversion equal to 1 and 1.5 the additional damage component is quite small. The damage addition due to risk aversion is highly nonlinear and it increases significantly under high risk-aversion (2). It is also interesting to note that the risk premium varies from region to region, implying that not only, as well known, the degree of both mitigation and adaptation response will be region-specific, but also the response to risk of the strategic interaction between the two policy options.

Having set the investigation modelling framework, in the next step, as part of the research to be developed in WP6, the “risk augmented” AD-WITCH model will be used to perform a cost effectiveness analysis of mitigation and adaptation strategies jointly. The aim is to get insights on the “optimal” policy mix and to highlight under which conditions mitigation and adaptation can be complement or substitute in the different scenarios of climate change (RCP 4.5 and 8.5) and of social economic development (SSP2 and SSP5) chosen as reference by the BASE consortium, as well as under different assumption of risk and risk aversion.

It is worth stressing that this line of research will be integrated in WP6 with the work described in the section 2 of this deliverable. More specifically, the macroeconomic investigation on the strategic complementarity between mitigation and adaptation conducted with the AD-WITCH model, will also incorporate information provided by all the sectorial analyses developed within BASE, thus including also those performed with the SARA framework (see below). In particular, AD-WITCH will include in the calibration of its impact-adaptation functions related to agriculture, cost and effectiveness information provided by the SARA modelling exercise.

2 Part 2: Framework for analysis of adaptation priorities accounting for spatial heterogeneity: Application to agriculture

2.1 Introduction

This section of the deliverable focuses on the spatial variability of climate damage costs assessments and the related issues of adaptation capacity and costs, taking the case of European agriculture (EU28). Climate change impacts are predominantly geographically localized. Also, effectiveness and efficiency of adaptation measures will depend on the local climatic and socioeconomic context. Together, this can have large implications for evaluating the costs of inaction and for prioritizing adaptation measures and instruments.

This section develops a framework for i) investigating the influence of climatic variation and related water availability on agricultural land use patterns across EU28 under the RCP4.5 and RCP8.5 scenarios for 2050 and 2100 and ii) exploring the impacts of autonomous and planned adaptation to climate change in the agricultural sector in the SARA framework. The analyses under this framework will be applied in Task 6.3 where it will also be compared with estimates from the AD-WITCH model, the integrated assessment model, in order to ascertain the policy implications of accounting for spatial heterogeneity of climate effects and adaptation options.

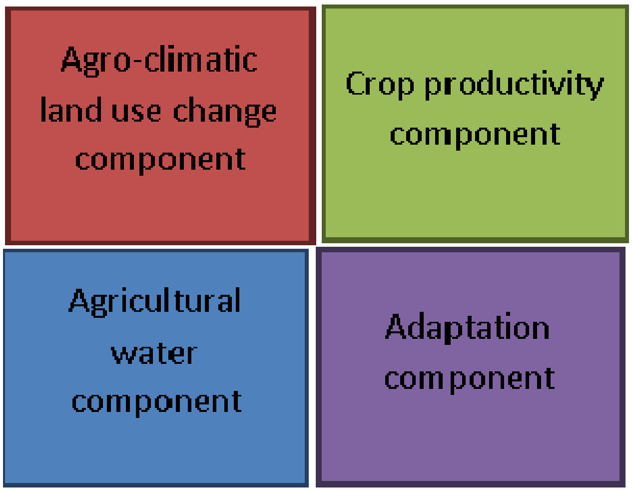
The framework for the analysis is the Supporting Agricultural Regional Adaptation (SARA) modelling framework introduced in the BASE deliverable on the model developments in the sectoral assessment, D3.2, Chapter 5.3. This sub-task feeds into the SARA framework by developing the agro-climatic land use change component. Together with the three other components: land productivity, agricultural water and adaptation pathways, the SARA framework aims at assessing the land productivity choices resulting from different climate scenarios and multiple adaptation pathways.

This section of the deliverable reports first on *i*) the activities to generate the high spatial resolution data sets on land use, climate and farm management and *ii*) the development and validation of the land use model. Second, this section outlines how the land use model component will be used together with the other agricultural components in WP6, Task 6.3. Third, the report includes a summary of the scale issues addressed by the agricultural modelling task.

2.2 SARA (Supporting Agricultural Regional Adaptation) modelling framework

To understand adaptation to climate change on the agricultural sector and the potential economic and environmental impacts several components need to be considered; impacts on crop productivity, changes in water requirements, land use change and other adaptation choices, both planned and autonomous. SARA (Supporting Agricultural Regional Adaptation) is the modelling framework developed in BASE to support adaptation choices in the agricultural sector. This framework emphasises the need to model the different aspects of climate change adaptation jointly and allows us to explore the interactions between the different components. The main components of the SARA modelling framework are outlined in Figure 8.

Figure 8: Components of the SARA (Supporting Agricultural Regional Adaptation) modelling framework (Source: BASE deliverable 3.2)



Accounting for land use change is crucial for understanding the overall economic and environmental impacts of climate change and the costs and benefits associated with alternative adaptation pathways. If land use change in response to climate changes is ignored the direct economic estimates of impacts are likely to be too pessimistic (Mendelsohn, 2009). This is because the opportunities from climate warming and expansion of productive agriculture are not captured, and the reductions in costs in disadvantaged areas from shifts to more resistant crops are not included. However, adaptation to climate changes is also likely to incur indirect costs and benefits. In particular, climate change is likely to increase water scarcity in many regions and the competition for water is likely to reduce environmental water flows, with implications for fresh water ecosystems (Vorosmarty et al., 2010). Furthermore, land use change in itself has implications for multiple environmental services (e.g. Bateman et al, 2013). Incorporating land use change into adaptation modelling frameworks is therefore essential for understanding the full impacts of climate change related to agriculture.

2.3 Modelling relationship between land use and climate

Modelling adaptation in the agricultural sector in D3.4 is approached using land use share model framework. The choice of the framework is inspired by previous studies (Lichtenberg, 1989; Wu and Segerson, 1995; Plantinga, 1996). In the implementation of the model, employed a fractional logit model (Papke and Wooldridge, 1996). The model is spatially explicit and can in principle be developed at the resolution of the 1km x 1km. The model is estimated for the reference situation of 2004, the latest year for which land use data exist. On the basis of the estimation results, projection of agricultural land use share under future changing climate is subsequently undertaken. This future projection provides a basis for developing the SARA framework for modelling climate change adaptation in the agricultural sector within EU.

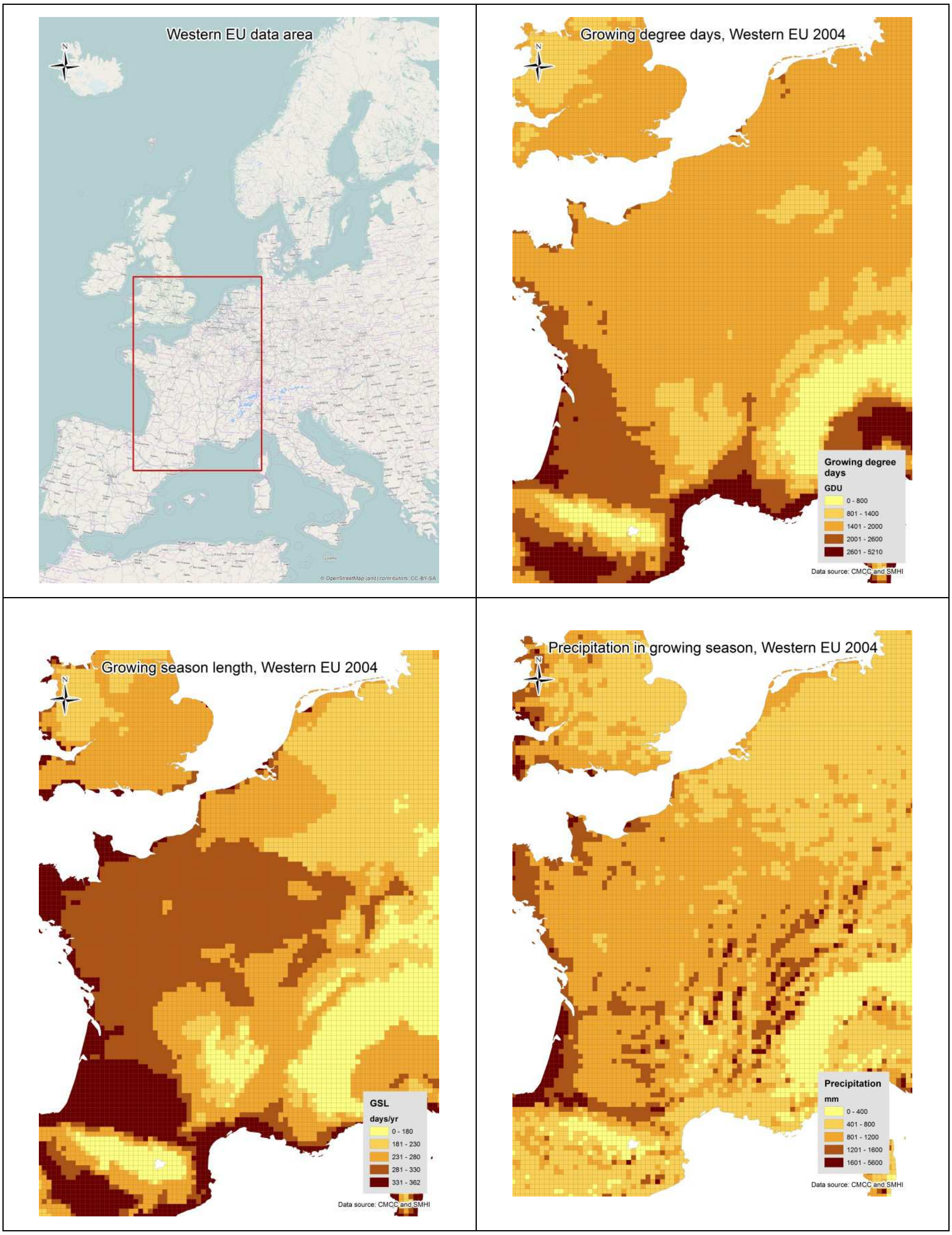
2.4 Data description

Data for the analysis consists of climate data, land use data and farm management data.

We use the climate data, at a 14km x 14km grid scale provided by CMCC, reported in D5.1. The data is based on the outputs of the latest version of the high resolution Regional Climate Model (RCM) developed at the Rossby Centre, the climate modelling research unit of the Swedish Meteorological and Hydrological Institute (SMHI).As part of BASE D3.4, we have processed the climate datasets, as the data sets delivered in D5.1 are not directly applicable for agricultural land use model. This has generated the following set of climate variables for the current climate and the scenarios used in BASE. The variables have been chosen based on (Huntley, 1995; Pearson et al., 2002), and are now available at the EU scale (Pls. see Figure 9).

- Growing Season Length (GSL). Defined as the annual number of days bounded by daily mean temperature >5 °C for 5 days and daily mean temperature <5 °C for 5 consecutive days.
- Growing Degree Days (GDD). Calculated as GDD = $\sum T_d - T_t$; for all days in a given year when averaged daily temperature > 5 °C. T_d = averaged daily temperature, T_t = threshold temperature (5 °C).
- Annual minimum temperature.
- Annual maximum temperature.
- Total annual precipitation.
- Total precipitation over growing season.
- Total annual evapotranspiration.
- Total evapotranspiration over growing season.
- Soil moisture over growing season (minimum, maximum, and average).

Figure 9: Selected climate data variables: growing degree days, growing season length and precipitation in growing season. Data source: CMCC (D5.1) and SMHI (2004), own calculations.

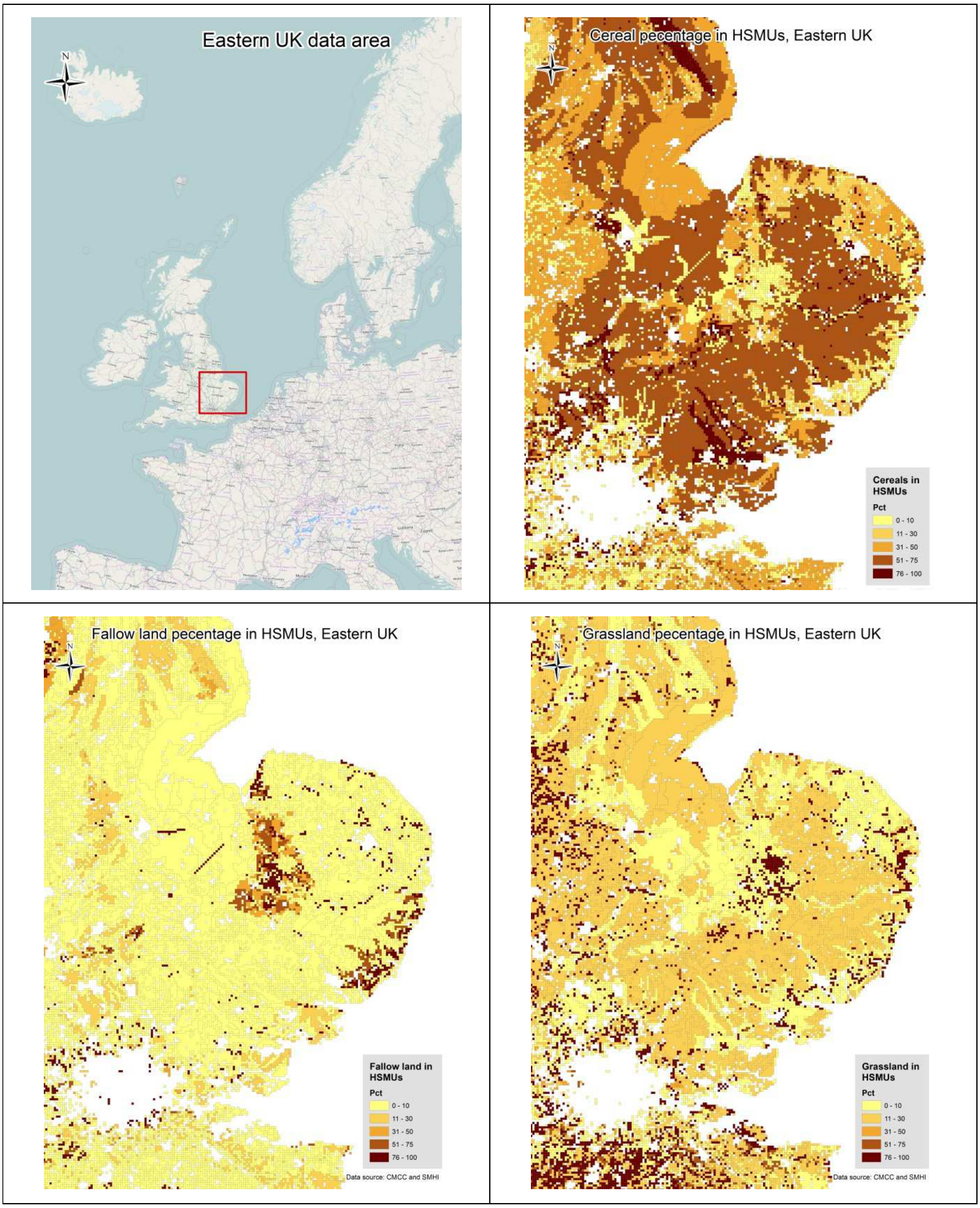


Land use data obtained at a 1km x 1km grid scale considers a list of the most abundant crop types within the EU28 area. These data have been made available from JRC (CAPRI2004 Crop Datasets) and is based on the CAPRI (Common Agricultural Policy Regionalised Impact) modelling system. This modelling system produces land cover information based on a supply module comprising 53 crop and animal activities. These data have been disaggregated from NUTS2 level to HSMU (homogeneous soil mapping unit) level following the procedure described by Leip et al. (2007). Each HSMU may consist of several polygons not necessarily connected, and may feature an area between an individual 1x1 km cell to several thousand square kilometres, depending on the spatial variability of the delineation factors described in Leip et al. (2007).

Within all HSMUs, the obtained dataset contain area data on the following crop categories: Wheat, Durum wheat, Rye and Meslin, Barley, Oats, Grain Maize, Rapeseed, Sun flower, Flowers, Fodder Maize, Extensive grass, Intensive grass, Paddy rice, Olives for oil, Pulses. Potatoes, Sugar beet, Flax and Hemp, Tobacco, Tomatoes, Apples, Pear and Peaches, Citrus fruits, Table olives, Tables grapes, Tables wine, and Fallow land.

For the purpose of modelling the relationship between land use and climate in BASE we have categorized these crops into the following categories; Cereal, Oil seed, Vegetables, Grass, Fruits, Olives, Fallow, Other arable and not categorized. For an example of the generated dataset see Figure 10 overleaf.

Figure 10: Cereals, fallow land and grassland as a percentage at HSMU level, example from the Eastern part of UK. Data source: JRC, own calculations.



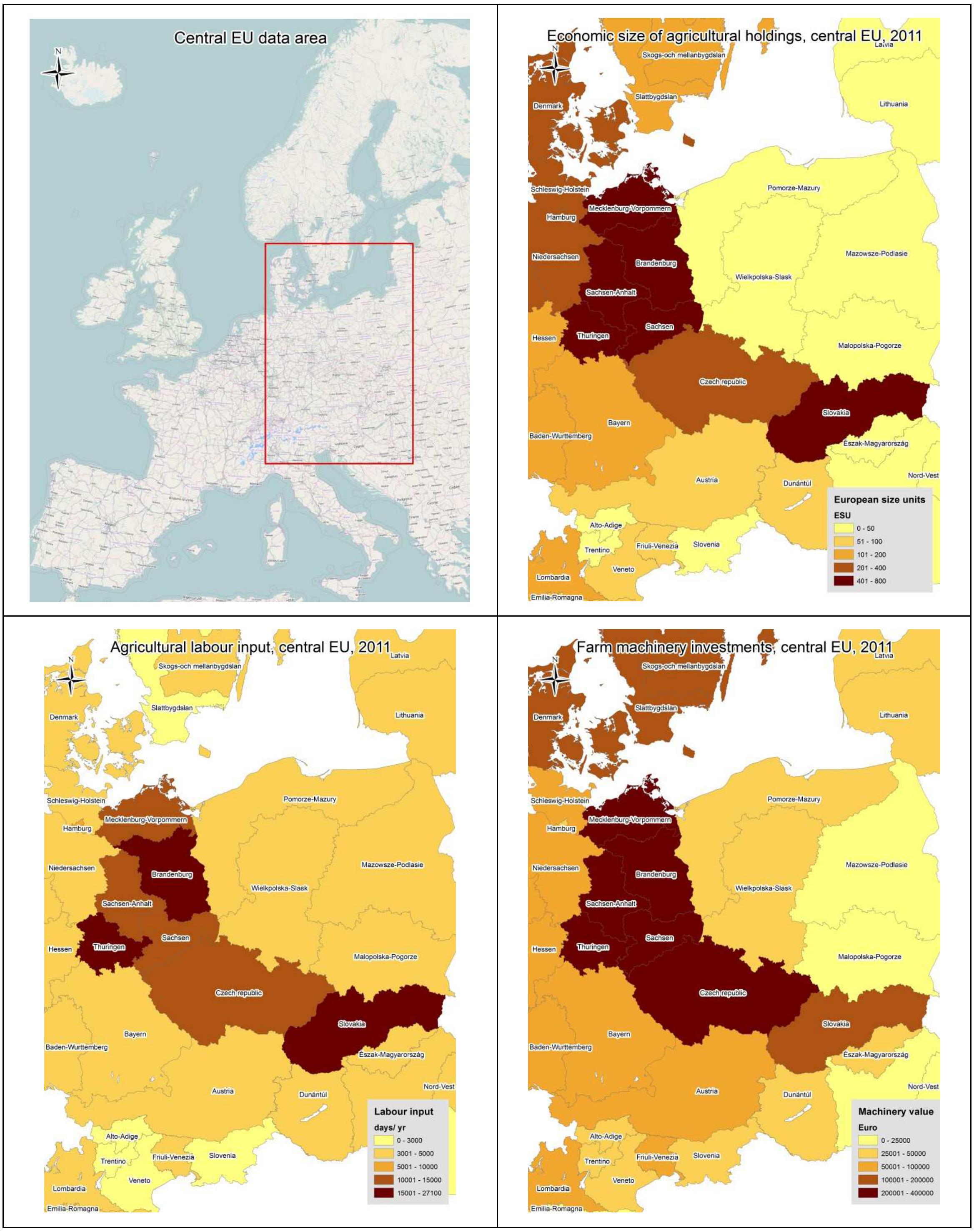
Farm management data is based on the FADN (Farm accountancy data network) data base. FADN information is aggregated into a Standard Results database available for the following dimensions: Time (year), geographic (Country, Region), Typology (Type of Farming) and economic size (ES).

The standard results are a set of statistics, computed from the Farm Returns, which are periodically produced and published by the Commission. These are available in a Public Database. They describe in considerable detail the economic situation of farmers by different groups throughout the European Union.

The FADN data is observed data but represents a weighted average of farms within each FADN region.

For the modelling for this section of the deliverable the following variables are considered: standard economic output, labour input, total utilized agricultural area, rented Utilised Agricultural Area (UAA), woodland area, total livestock units, dairy cows, other cattle, sheep and goats, total output of crops, livestock and other products, wages paid, gross farm income, farm net income, total assets, total fixed assets, buildings, machinery, average farm capital, gross investment, net investment, total subsidies excluding on investments, set aside premiums, other crops subsidies, total subsidies on livestock, other livestock subsidies, environmental subsidies, total support for rural development, other rural development payments, decoupled payments, and single farm payments (Pls. see Figure 11 for an illustration of the spatial distribution of a selection of farm management characteristics based on the FADN data).

Figure 11: Selected farm management variables for FADN areas: Economic size, labour input, machinery investments. Data source: FADN and Eurostat.



2.5 Results

The land use share model confirms that climate plays a significant role in driving agricultural land use patterns in Europe. Table 3 summarizes the direction of climatic influence on the share of agricultural land uses across the EU27 based on 2004 data. Several key findings are worth highlighting:

- Climate appears to have the same directional effect on cereals and oil seed cultivation. For these two land use types, evapotranspiration and soil moisture exert favorable influence, relative to the other crops, while growing season length, growing degree days and precipitation have the opposite effect;
- Climatic factors also seem to shape the patterns of the cultivation of vegetables, fruits, and olives in the same direction. In this case, growing season length, growing degree days and precipitation are found to have positive influence on the share of these crops. On the contrary, evapotranspiration and soil moisture show negative effects;
- For other arable crops, cultivation appears to demand longer growing season and more soil moisture. In the case of vine cultivation, all climatic variables except precipitation show positive effect; and
- Agricultural areas under a climate regime characterized by longer growing season and increased evaporation and soil moisture are unlikely to be taken out of production (fallow).

Table 3: Marginal effects of climatic variables on agricultural land use share in EU27

	Cereals	Oil seed	Other arable	Vegetable	Grass	Fruits	Olives	Vine	No class	Fallow
Growing season length	-	-	+	+	-	+	+	+	-	-
Growing degree days	-	-	-	+	-	+	+	+	+	+
Precipitation (annual total)	-	-	-	+	+	+	+	-	-	+
Evapotranspiration (annual total)	+	+	-	-	+	-	-	+	-	-
Average soil moisture over growing season	+	+	+	-	-	-	-	+	+	-

We tested and validated how well the estimated model actually performs using a random selection of half the data points to assess the model's capability to predict the remaining set of observations. Examples of the prediction outcomes are presented in Figure 12 overleaf.

The predicted model output shows that olives production only takes place in Southern Europe, which is in concordance with what one would expect. This also supports the reliability of the model predictions. For cereals, the prediction shows that in the larger parts of EU cereals production occupy more than 20% of the agricultural area, this emphasizes the importance of cereal production within the EU. Another very important land use is grassland. In large parts across the EU, grasslands occupy up to 50% of the agricultural areas, despite large regional differences in the intensity of livestock and grazing systems. A somewhat less extensive, though still important and highly debated land use, is fallow land. Fallow land and grassland do not reach high abundances in the same areas, which can be explained by the fact that fallow land is a part of a crop rotation production system, whereas grass land is a different land use type and is not part of a crop rotation scheme.

Figure 13 further highlights the validation of the land use change model illustrated for three selected land use types: cereals, fallow land and grass land. Figure 13 shows the differences between the actual observations and the model predictions. In areas with negative differences, the model over-predicts and in areas with positive differences the model under-predicts, resulting in optimistic and conservative estimates respectively.

For cereals we find that in large part of central EU the model predicts within a +/- 10% span (light green). If considering a +/- 30% expanding (yellow and dark green) almost the entire area shown in the map is covered; only leaving out an area in mid-Sweden and some few spots in Denmark, Germany and Poland, where the model seemingly under-predicts more than 30%. Considering fallow land, the model fit is within +/- 10% for almost the entire area shown, only raising concern in the same region in Sweden as for the cereals. The general picture is the same for grassland, though adding larger model deviations in some parts of the shown area. The model validation generally shows a good fit as shown by the high degree of agreement between the actual observations and the model predictions. It is important to note nonetheless that the present land use share model only factors in climatic variables. Recognizing that land use change is a process driven by multiple factors, in the next stage, we will develop the current model further by incorporating other variables (i.e. farm management related factors). It is expected that such effort will further improve the fit of the model.

Figure 12: Predicted land use share of selected crops: cereals, grass lands, fallow lands. Data source: own calculations based on land use share modelling

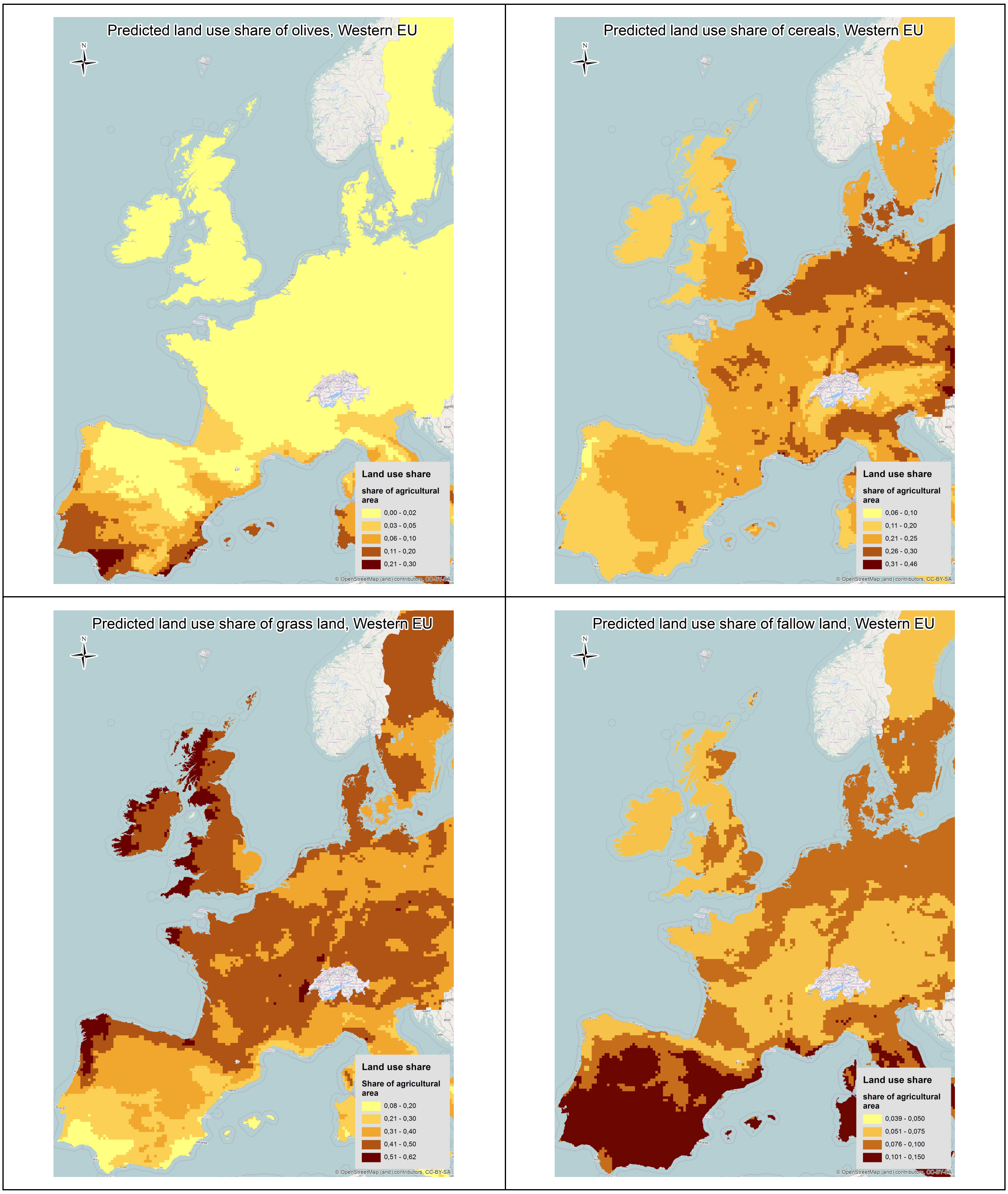
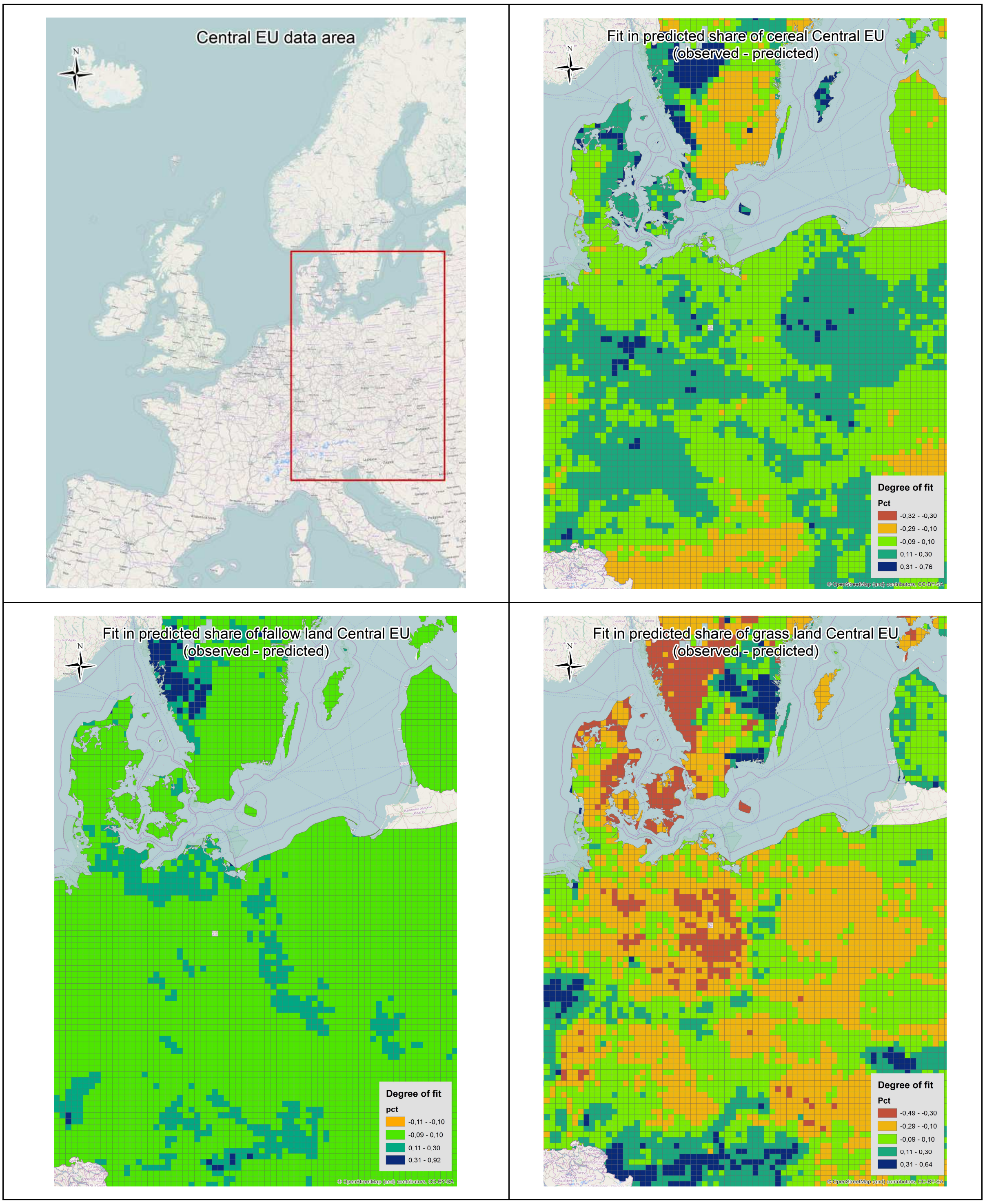


Figure 13: Results of the fit in land use share prediction model concerning cereals and fallow land. The results have been aggregated to a 14x14km grid scale for visualization. Data source: own calculations.



2.6 Application of the SARA framework in WP6

The integrated analysis of agricultural adaptation in SARA will require consistent development of the agro-climatic land use change, the crop productivity and the water allocation models used in BASE. The crop productivity component will be adapted to match the crop classification used for the land use change component and apply the same high-resolution spatial climate variables developed in this deliverable.

The land use share results from the agro-climatic land use change model will be used in the crop productivity model to increase the accuracy and reliability of the spatial distribution of the crop productivity changes. For instance, the current crop productivity models may project an improved productivity but will omit the possibility that the change in climate may offer the opportunity to introduce new crops (Iglesias et al., 2012; Trnka et al., 2011; Ciscar et al., 2011). The introduction of new crops or changes in the crop share would in this case increase land productivity far more than simply accounting for changes in productivity of the currently grown crops for the longer growing season of spring wheat. Figure 14 shows the sequential steps in the model analysis in the modelling framework and Figure 15 summarises the climate scenarios in the nine agro-climatic regions.

Figure 14: Modelling process.

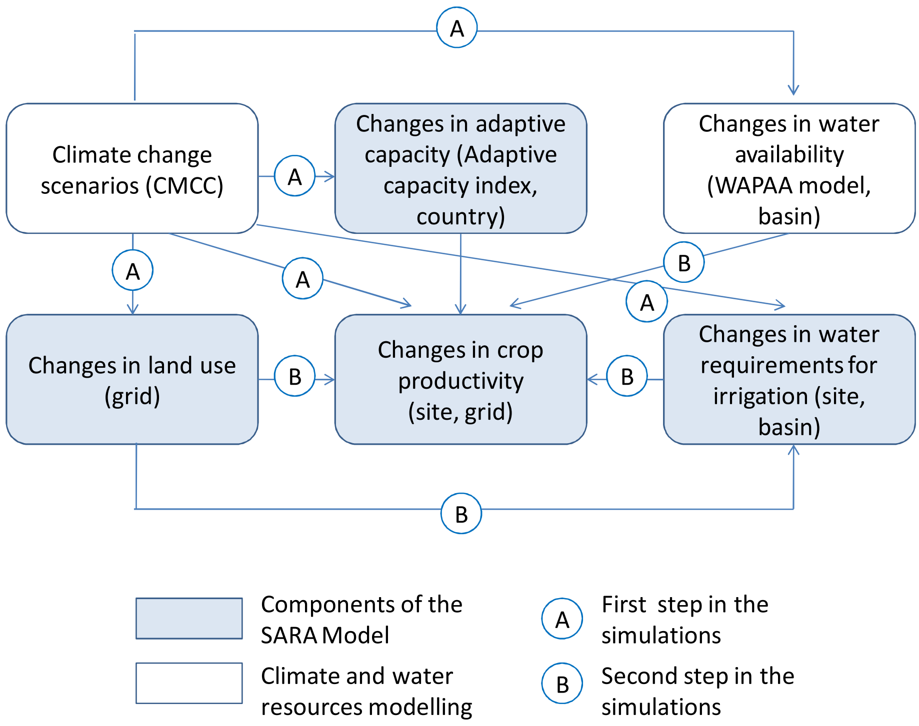
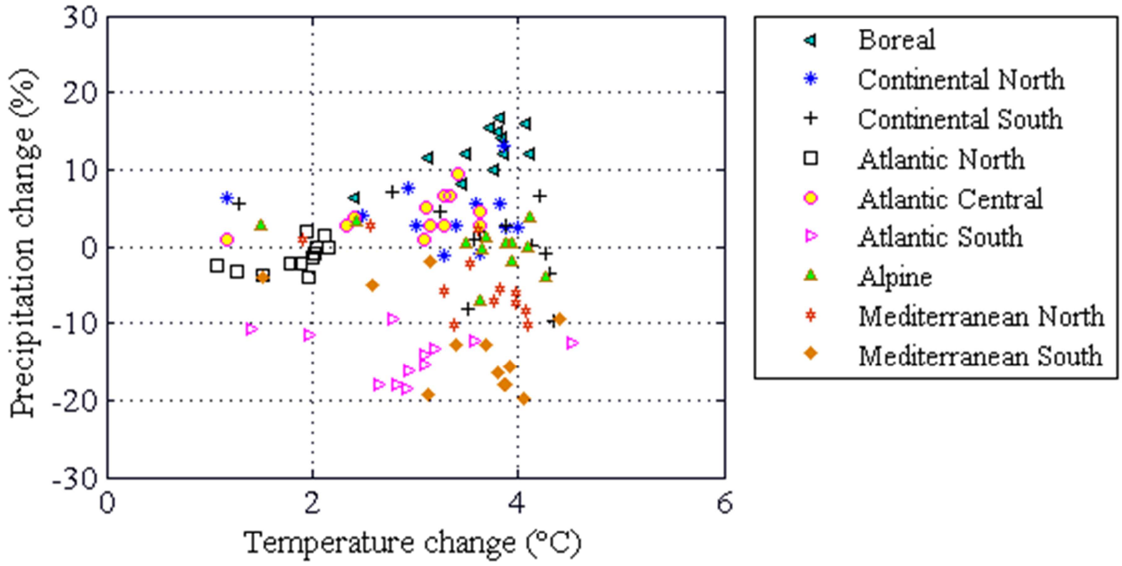


Figure 15: Changes in annual average temperatures and total annual precipitation in 2071-2100 relative to baseline simulations for 11 climate CORDEX models for the nine agro-climatic regions of Europe.



Overall, the SARA framework will enable BASE to assess the impacts of alternative climate adaptation pathways. The land use component will allow us to take into account the contribution that land use adaptation makes to climate changes impacts. The WAPAA model will allow us to assess the contribution that alternative water policies will have on agriculture. Table 4 below outlines the adaptation choices that can be modelled by using the SARA approach in response to the main determinants of agricultural changes under climate change. The table also outlines the policy linkages that will be further developed in WP6.

Table 4: Examples of adaptation responses addressing changes in the main determinants of agricultural changes driven by climate change in Europe.

Main determinants of agricultural changes driven by climate change in Europe	**Example of adaptation response simulated by SARA**	**Policy linkages**
Changes in land use	Change crops and cropping patterns	Linkages to rural planning policies
Changes in crop productivity	Changes in cultivation practices and agrochemicals (i.e., N fertiliser)	Linkages to mitigation
Changes in additional irrigation	Provide supplemental irrigation (if available, as defined by the WAPAA model) Shift to crops requiring less water	Linkages to adaptation of the water resources systems and ecosystem services
Changes in water availability (WAPAA model)	Changes in crops and cropping patterns	Linkages to adaptation of the water resources systems and ecosystem services
Changes in adaptive capacity	Assumptions of technological improvement Assumptions on improved management	Linkages to the assumptions in the AD-Witch top-down model

A fundamental assumption, given the European Water Framework Directive, is that agriculture in future will not be allowed a larger share of 'blue' water (from rivers and dams) without an absolute reduction in water demand in other sectors. The policy scenarios include i) increases in water efficiency in urban areas allows for increased usage in the agricultural sector; ii) conjunct use of hydroelectric power and irrigation; iii) integrated management at the sub-basin scale allowing to improve supply management choices; and iv) revision of environmental flow requirements The policy scenarios will be further developed in WP6.

2.7 Integration across scales

Our modelling approach considers that the main determinants of crop changes include: changes in agro-climatic regions and land use, crop productivity, water requirements, and adaptation management (autonomous and deliberate adjustments). The spatial scales of each model component are outlined in Table 5 below.

Figure 16 shows the areas where the most detailed land use change analysis will take place. These areas include five of the nine agroclimatic regions of Europe and represent the areas with the largest potential of land use transitions under climate change. Southern regions not included in the analysis will expect major changes derived from the intensification of water needs in the already intensive irrigated systems (Figure 17); these aspects are considered in the water availability component.

Table 5: Model components, spatial scale analysis and model outputs.

Component of the SARA model	Spatial scale of analysis	Model outputs
Land use	Grid Nuts 2 regions	Changes in land suitability for 7 major crop types
Crop productivity modelling	Site (1300 sites) Spatially interpolated to the land use analysis grid Aggregated at the country level	Changes in crop productivity (cereals, pasture and horticulture) and N fertiliser input
Water requirements modelling	Site (1300 sites) Spatially interpolated to the land use analysis grid Aggregated at the country level	Changes in irrigation requirements
Adaptive capacity modelling	Country (28 countries)	Adaptive capacity index
Water requirements modelling	EU sub-basins (430 sub-basins)	Output of the WAPAA model
Summary results input for the AD-Witch model	Agroclimatic regions and selected countries (9 regions)	Changes in productivity by 2050s defined by climate, land use and water availability

Figure 16: Agroclimatic regions in Europe under current climate. The red rectangles indicate the regions with detailed land use analysis.

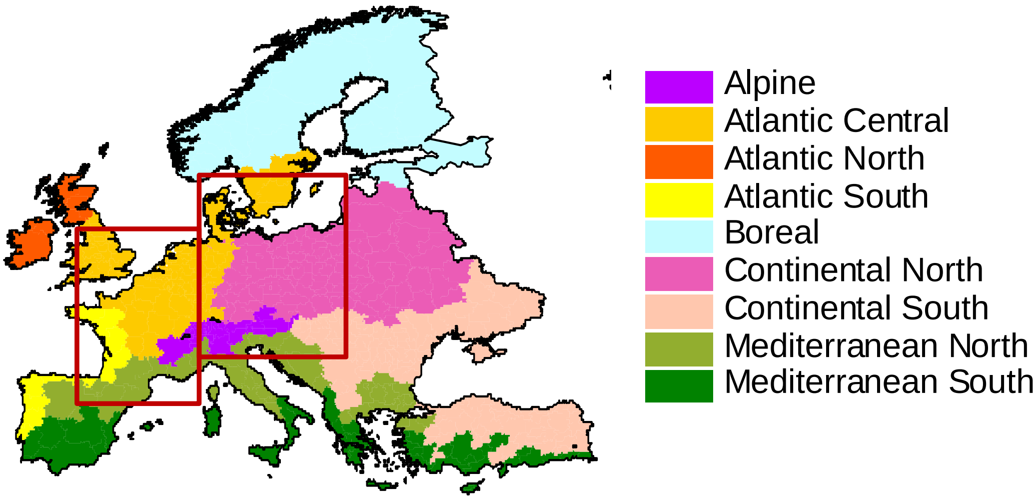
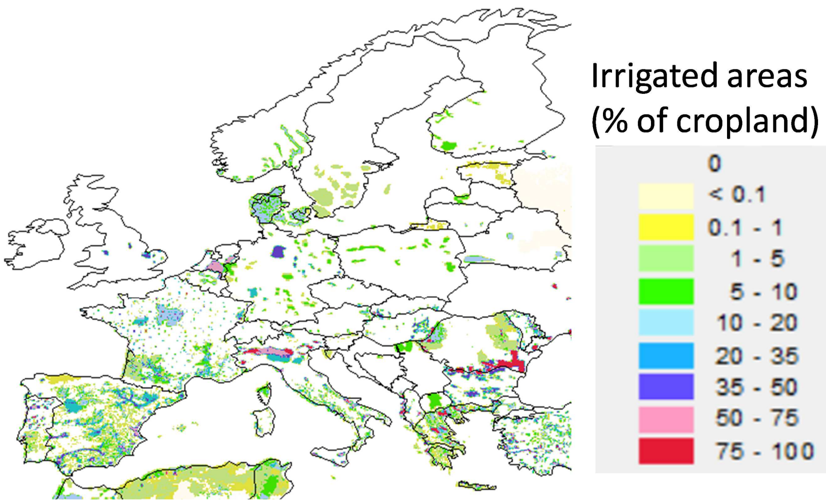


Figure 17: Spatial analysis: Irrigated areas of Europe and intensity of irrigation.



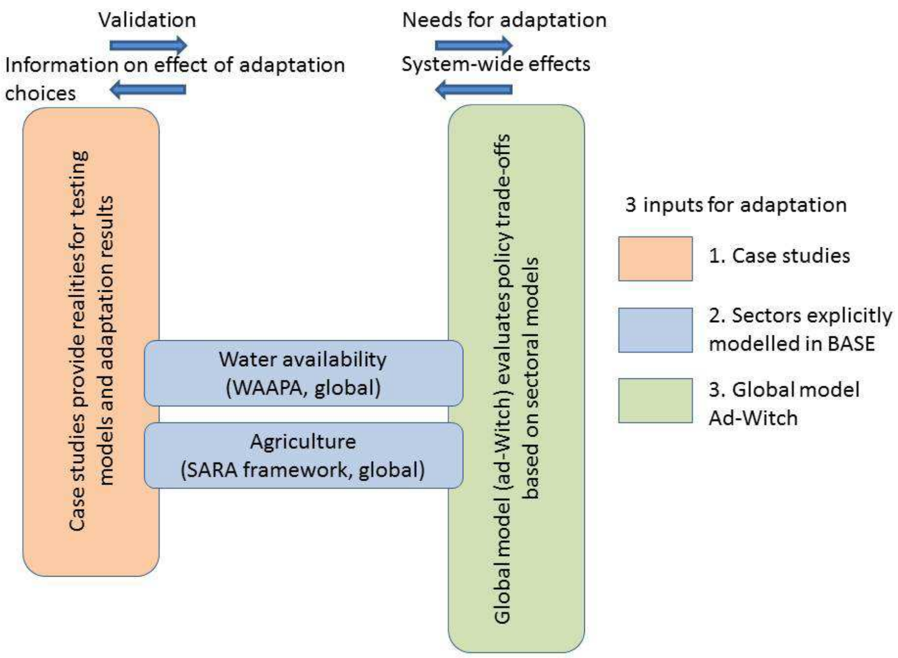
2.8 Conclusion

This Part 2 of the deliverable has proposed, applied and tested a method to investigate spatial differences in climate change impacts on agriculture in terms of land use changes. This land use change model feeds into the SARA framework which will allow for an integrated analysis of adaptation pathways in the agricultural sector at EU level.

First, we derived annual climate indicators suitable for agricultural modelling under climate change scenarios based on climate scenarios data, which come originally in daily simulations (BASE D5.1, based on D3.1). This results in a spatially explicit EU-wide climate data layer including changes in season length, growing degree days which are the variables that are likely to be important drivers of land use (crop) change in the agricultural sector. Next, we developed, tested and applied a land use change model based on climatic drivers to the EU scale. Results suggest that climate has a strong predictive power over land use across EU. The validation of the model demonstrates a high degree of agreement between the model predictions and the actual observations.

The land use change model will subsequently be integrated with the other components in the SARA framework to allow for an integrated analysis of adaptation pathways in the sectoral models in BASE in D6.3. Furthermore, the spatially explicit SARA framework will be used to explore the links with the Ad-Witch model, taking an aggregated adaptation modelling approach. Case studies will provide an opportunity for validating results of the sectoral models and in return the models provide information on the effect of adaptation choices. Figure 18 below illustrates the links between case studies, the agricultural sectoral models and the top-down ad-WITCH model.

Figure 18: Conceptual framework of adaptation in agriculture in BASE



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4 Annex I: Data on Damage Distribution as a Function of Temperature Change

Expected temperature	Region	dist_meanlog	dist_sdlog	Expected damage	Damage (75th quantile)	Damage (90th quantile)
1.50	USA	-4.46	0.11	1.16	1.25	1.33
1.50	WEU	-4.38	0.12	1.25	1.36	1.46
1.50	EEU	-4.65	0.28	0.96	1.16	1.38
1.50	KOSAU	-4.93	0.15	0.73	0.80	0.88
1.50	CAJAZ	-4.39	0.12	1.24	1.34	1.44
1.50	TE	-4.94	0.28	0.72	0.86	1.02
1.50	MENA	-4.40	0.35	1.23	1.56	1.93
1.50	SSA	-3.77	0.32	2.30	2.84	3.45
1.50	SASIA	-3.67	0.44	2.54	3.40	4.44
1.50	CHINA	-5.39	0.21	0.46	0.52	0.60
1.50	EASIA	-3.76	0.43	2.32	3.09	4.00
1.50	LACA	-4.37	0.28	1.26	1.52	1.80
1.50	INDIA	-3.59	0.42	2.77	3.69	4.77
2.00	USA	-4.29	0.15	1.37	1.52	1.67
2.00	WEU	-4.17	0.19	1.54	1.75	1.97
2.00	EEU	-4.30	0.29	1.36	1.65	1.97
2.00	KOSAU	-4.68	0.22	0.93	1.08	1.24
2.00	CAJAZ	-4.21	0.16	1.48	1.65	1.82
2.00	TE	-4.56	0.33	1.05	1.31	1.60
2.00	MENA	-3.96	0.36	1.90	2.42	3.01
2.00	SSA	-3.38	0.33	3.40	4.24	5.16
2.00	SASIA	-3.14	0.44	4.34	5.83	7.59
2.00	CHINA	-5.04	0.32	0.65	0.80	0.97
2.00	EASIA	-3.24	0.43	3.90	5.20	6.73
2.00	LACA	-4.03	0.29	1.78	2.16	2.57
2.00	INDIA	-3.07	0.43	4.66	6.21	8.04
2.50	USA	-4.12	0.18	1.63	1.84	2.06
2.50	WEU	-3.95	0.24	1.93	2.27	2.62
2.50	EEU	-4.02	0.29	1.80	2.19	2.61
2.50	KOSAU	-4.42	0.28	1.21	1.45	1.72
2.50	CAJAZ	-4.04	0.19	1.77	2.01	2.26
2.50	TE	-4.22	0.35	1.48	1.87	2.32
2.50	MENA	-3.61	0.36	2.70	3.44	4.28
2.50	SSA	-3.06	0.33	4.68	5.83	7.11
2.50	SASIA	-2.72	0.43	6.62	8.83	11.44
2.50	CHINA	-4.67	0.38	0.94	1.21	1.52
2.50	EASIA	-2.83	0.42	5.89	7.80	10.06
2.50	LACA	-3.75	0.29	2.35	2.85	3.39
2.50	INDIA	-2.65	0.42	7.03	9.31	12.00
3.00	USA	-3.95	0.20	1.92	2.20	2.50
3.00	WEU	-3.73	0.27	2.41	2.90	3.41
3.00	EEU	-3.78	0.28	2.28	2.76	3.27
3.00	KOSAU	-4.17	0.30	1.55	1.90	2.29
3.00	CAJAZ	-3.86	0.21	2.10	2.42	2.75
3.00	TE	-3.92	0.36	1.99	2.53	3.15
3.00	MENA	-3.32	0.35	3.63	4.60	5.69
3.00	SSA	-2.79	0.32	6.12	7.59	9.22
3.00	SASIA	-2.37	0.41	9.37	12.34	15.80
3.00	CHINA	-4.34	0.40	1.31	1.72	2.20
3.00	EASIA	-2.49	0.40	8.28	10.85	13.84
3.00	LACA	-3.52	0.28	2.97	3.58	4.24
3.00	INDIA	-2.31	0.40	9.88	12.94	16.49

Expected temperature	Region	dist_meanlog	dist_sdlog	Expected damage	Damage (75th quantile)	Damage (90th quantile)
3.50	USA	-3.79	0.22	2.26	2.61	2.98
3.50	WEU	-3.51	0.29	2.99	3.63	4.33
3.50	EEU	-3.58	0.27	2.80	3.37	3.98
3.50	KOSAU	-3.93	0.32	1.97	2.44	2.95
3.50	CAJAZ	-3.70	0.22	2.48	2.88	3.30
3.50	TE	-3.65	0.35	2.60	3.29	4.08
3.50	MENA	-3.06	0.34	4.69	5.90	7.25
3.50	SSA	-2.56	0.31	7.74	9.55	11.53
3.50	SASIA	-2.07	0.39	12.60	16.39	20.77
3.50	CHINA	-4.03	0.40	1.78	2.33	2.98
3.50	EASIA	-2.20	0.38	11.08	14.35	18.13
3.50	LACA	-3.31	0.27	3.64	4.37	5.15
3.50	INDIA	-2.02	0.38	13.21	17.10	21.58
4.00	USA	-3.64	0.23	2.63	3.08	3.55
4.00	WEU	-3.31	0.31	3.66	4.50	5.42
4.00	EEU	-3.39	0.27	3.36	4.04	4.77
4.00	KOSAU	-3.71	0.33	2.45	3.07	3.75
4.00	CAJAZ	-3.54	0.24	2.90	3.41	3.94
4.00	TE	-3.41	0.36	3.29	4.18	5.19
4.00	MENA	-2.83	0.34	5.88	7.39	9.07
4.00	SSA	-2.35	0.31	9.52	11.74	14.19
4.00	SASIA	-1.81	0.38	16.30	21.11	26.63
4.00	CHINA	-3.76	0.41	2.33	3.07	3.92
4.00	EASIA	-1.95	0.38	14.28	18.43	23.18
4.00	LACA	-3.13	0.27	4.36	5.24	6.17
4.00	INDIA	-1.77	0.38	17.02	21.95	27.59
4.50	USA	-3.49	0.25	3.05	3.61	4.20
4.50	WEU	-3.12	0.32	4.43	5.51	6.70
4.50	EEU	-3.23	0.28	3.96	4.78	5.67
4.50	KOSAU	-3.50	0.35	3.01	3.80	4.68
4.50	CAJAZ	-3.39	0.26	3.37	4.00	4.67
4.50	TE	-3.20	0.36	4.08	5.20	6.48
4.50	MENA	-2.63	0.34	7.20	9.07	11.17
4.50	SSA	-2.16	0.32	11.48	14.20	17.21
4.50	SASIA	-1.59	0.38	20.48	26.52	33.48
4.50	CHINA	-3.51	0.41	2.98	3.93	5.05
4.50	EASIA	-1.72	0.38	17.89	23.10	29.08
4.50	LACA	-2.97	0.28	5.13	6.18	7.31
4.50	INDIA	-1.55	0.38	21.31	27.50	34.60
5.00	USA	-3.35	0.27	3.50	4.19	4.93
5.00	WEU	-2.94	0.34	5.29	6.64	8.16
5.00	EEU	-3.08	0.29	4.60	5.59	6.66
5.00	KOSAU	-3.32	0.36	3.63	4.62	5.74
5.00	CAJAZ	-3.25	0.27	3.88	4.66	5.49
5.00	TE	-3.01	0.37	4.95	6.35	7.94
5.00	MENA	-2.45	0.35	8.65	10.96	13.56
5.00	SSA	-2.00	0.32	13.60	16.93	20.62
5.00	SASIA	-1.38	0.39	25.13	32.66	41.34
5.00	CHINA	-3.29	0.42	3.71	4.91	6.32
5.00	EASIA	-1.52	0.38	21.90	28.39	35.86
5.00	LACA	-2.82	0.28	5.95	7.21	8.57
5.00	INDIA	-1.34	0.38	26.08	33.79	42.65

5 Annex II: Risk-premium adjusted damages

Risk-premium adjusted damages for η = 1

Expected temperature	Region	Expected Damage	Risk Premium	Damage With Risk
1.50	USA	1.16	0.01	1.17
1.50	WEU	1.25	0.01	1.27
1.50	EEU	0.96	0.04	1.04
1.50	KOSAU	0.73	0.01	0.74
1.50	CAJAZ	1.24	0.01	1.26
1.50	TE	0.72	0.03	0.77
1.50	MENA	1.23	0.08	1.39
1.50	SSA	2.30	0.12	2.53
1.50	SASIA	2.54	0.25	3.04
1.50	CHINA	0.46	0.01	0.48
1.50	EASIA	2.32	0.22	2.76
1.50	LACA	1.26	0.05	1.36
1.50	INDIA	2.77	0.26	3.29
2.00	USA	1.37	0.02	1.40
2.00	WEU	1.54	0.03	1.60
2.00	EEU	1.36	0.06	1.48
2.00	KOSAU	0.93	0.02	0.98
2.00	CAJAZ	1.48	0.02	1.52
2.00	TE	1.05	0.06	1.17
2.00	MENA	1.90	0.13	2.15
2.00	SSA	3.40	0.19	3.77
2.00	SASIA	4.34	0.43	5.21
2.00	CHINA	0.65	0.03	0.72
2.00	EASIA	3.90	0.37	4.64
2.00	LACA	1.78	0.07	1.93
2.00	INDIA	4.66	0.44	5.54
2.50	USA	1.63	0.03	1.68
2.50	WEU	1.93	0.06	2.04
2.50	EEU	1.80	0.08	1.95
2.50	KOSAU	1.21	0.05	1.30
2.50	CAJAZ	1.77	0.03	1.83
2.50	TE	1.48	0.10	1.67
2.50	MENA	2.70	0.18	3.06
2.50	SSA	4.68	0.26	5.19
2.50	SASIA	6.62	0.63	7.88
2.50	CHINA	0.94	0.07	1.08
2.50	EASIA	5.89	0.54	6.96
2.50	LACA	2.35	0.10	2.55
2.50	INDIA	7.03	0.64	8.31
3.00	USA	1.92	0.04	2.00
3.00	WEU	2.41	0.09	2.59
3.00	EEU	2.28	0.09	2.46
3.00	KOSAU	1.55	0.07	1.70
3.00	CAJAZ	2.10	0.05	2.19
3.00	TE	1.99	0.13	2.25
3.00	MENA	3.63	0.23	4.09
3.00	SSA	6.12	0.32	6.76
3.00	SASIA	9.37	0.81	11.00
3.00	CHINA	1.31	0.11	1.53
3.00	EASIA	8.28	0.69	9.66
3.00	LACA	2.97	0.12	3.20
3.00	INDIA	9.88	0.82	11.52

Expected temperature	Region	Expected Damage	Risk Premium	Damage With Risk
4.00	USA	2.63	0.07	2.78
4.00	WEU	3.66	0.18	4.01
4.00	EEU	3.36	0.13	3.62
4.00	KOSAU	2.45	0.14	2.73
4.00	CAJAZ	2.90	0.08	3.07
4.00	TE	3.29	0.21	3.72
4.00	MENA	5.88	0.35	6.57
4.00	SSA	9.52	0.47	10.47
4.00	SASIA	16.30	1.24	18.78
4.00	CHINA	2.33	0.20	2.73
4.00	EASIA	14.28	1.06	16.40
4.00	LACA	4.36	0.16	4.69
4.00	INDIA	17.02	1.25	19.53
4.50	USA	3.05	0.10	3.24
4.50	WEU	4.43	0.24	4.90
4.50	EEU	3.96	0.16	4.28
4.50	KOSAU	3.01	0.19	3.38
4.50	CAJAZ	3.37	0.11	3.59
4.50	TE	4.08	0.28	4.63
4.50	MENA	7.20	0.44	8.07
4.50	SSA	11.48	0.59	12.65
4.50	SASIA	20.48	1.56	23.61
4.50	CHINA	2.98	0.26	3.50
4.50	EASIA	17.89	1.33	20.55
4.50	LACA	5.13	0.20	5.53
4.50	INDIA	21.31	1.58	24.47
5.00	USA	3.50	0.13	3.75
5.00	WEU	5.29	0.31	5.91
5.00	EEU	4.60	0.20	4.99
5.00	KOSAU	3.63	0.24	4.11
5.00	CAJAZ	3.88	0.14	4.17
5.00	TE	4.95	0.35	5.65
5.00	MENA	8.65	0.55	9.75
5.00	SSA	13.60	0.74	15.07
5.00	SASIA	25.13	1.97	29.07
5.00	CHINA	3.71	0.34	4.38
5.00	EASIA	21.90	1.68	25.27
5.00	LACA	5.95	0.25	6.44
5.00	INDIA	26.08	1.99	30.07

Risk-premium adjusted damages for η = 1.5

Expected temperature	Region	Expected Damage	Risk Premium	Damage With Risk
1.50	USA	1.16	0.01	1.18
1.50	WEU	1.25	0.02	1.28
1.50	EEU	0.96	0.08	1.07
1.50	KOSAU	0.73	0.02	0.75
1.50	CAJAZ	1.24	0.02	1.26
1.50	TE	0.72	0.06	0.80
1.50	MENA	1.23	0.15	1.46
1.50	SSA	2.30	0.23	2.64
1.50	SASIA	2.54	0.48	3.27
1.50	CHINA	0.46	0.02	0.49
1.50	EASIA	2.32	0.42	2.96
1.50	LACA	1.26	0.10	1.41
1.50	INDIA	2.77	0.50	3.53
2.00	USA	1.37	0.03	1.42
2.00	WEU	1.54	0.06	1.62
2.00	EEU	1.36	0.11	1.53
2.00	KOSAU	0.93	0.05	1.00
2.00	CAJAZ	1.48	0.04	1.54
2.00	TE	1.05	0.11	1.22
2.00	MENA	1.90	0.25	2.27
2.00	SSA	3.40	0.36	3.95
2.00	SASIA	4.34	0.83	5.60
2.00	CHINA	0.65	0.07	0.75
2.00	EASIA	3.90	0.71	4.98
2.00	LACA	1.78	0.15	2.00
2.00	INDIA	4.66	0.84	5.94
2.50	USA	1.63	0.06	1.71
2.50	WEU	1.93	0.11	2.10
2.50	EEU	1.80	0.15	2.03
2.50	KOSAU	1.21	0.09	1.34
2.50	CAJAZ	1.77	0.06	1.86
2.50	TE	1.48	0.19	1.76
2.50	MENA	2.70	0.35	3.23
2.50	SSA	4.68	0.50	5.43
2.50	SASIA	6.62	1.21	8.46
2.50	CHINA	0.94	0.14	1.14
2.50	EASIA	5.89	1.03	7.45
2.50	LACA	2.35	0.19	2.64
2.50	INDIA	7.03	1.23	8.89
3.00	USA	1.92	0.08	2.04
3.00	WEU	2.41	0.18	2.68
3.00	EEU	2.28	0.18	2.55
3.00	KOSAU	1.55	0.14	1.77
3.00	CAJAZ	2.10	0.09	2.24
3.00	TE	1.99	0.25	2.38
3.00	MENA	3.63	0.45	4.31
3.00	SSA	6.12	0.63	7.07
3.00	SASIA	9.37	1.56	11.74
3.00	CHINA	1.31	0.21	1.63
3.00	EASIA	8.28	1.33	10.30
3.00	LACA	2.97	0.23	3.32
3.00	INDIA	9.88	1.58	12.28
3.50	USA	2.26	0.11	2.42
3.50	WEU	2.99	0.25	3.37
3.50	EEU	2.80	0.21	3.12
3.50	KOSAU	1.97	0.20	2.27
3.50	CAJAZ	2.48	0.12	2.67
3.50	TE	2.60	0.32	3.09
3.50	MENA	4.69	0.54	5.51
3.50	SSA	7.74	0.75	8.87
3.50	SASIA	12.60	1.92	15.51
3.50	CHINA	1.78	0.29	2.21
3.50	EASIA	11.08	1.64	13.56
3.50	LACA	3.64	0.27	4.04
3.50	INDIA	13.21	1.94	16.16

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Expected temperature	Region	Expected Damage	Risk Premium	Damage With Risk
4.00	USA	2.63	0.14	2.85
4.00	WEU	3.66	0.34	4.18
4.00	EEU	3.36	0.25	3.74
4.00	KOSAU	2.45	0.27	2.86
4.00	CAJAZ	2.90	0.17	3.15
4.00	TE	3.29	0.42	3.92
4.00	MENA	5.88	0.67	6.90
4.00	SSA	9.52	0.92	10.92
4.00	SASIA	16.30	2.39	19.94
4.00	CHINA	2.33	0.39	2.92
4.00	EASIA	14.28	2.04	17.38
4.00	LACA	4.36	0.32	4.85
4.00	INDIA	17.02	2.42	20.69
4.50	USA	3.05	0.19	3.33
4.50	WEU	4.43	0.46	5.13
4.50	EEU	3.96	0.31	4.43
4.50	KOSAU	3.01	0.36	3.55
4.50	CAJAZ	3.37	0.22	3.70
4.50	TE	4.08	0.53	4.88
4.50	MENA	7.20	0.85	8.48
4.50	SSA	11.48	1.15	13.21
4.50	SASIA	20.48	3.02	25.06
4.50	CHINA	2.98	0.51	3.74
4.50	EASIA	17.89	2.57	21.79
4.50	LACA	5.13	0.39	5.72
4.50	INDIA	21.31	3.05	25.94
5.00	USA	3.50	0.25	3.88
5.00	WEU	5.29	0.60	6.21
5.00	EEU	4.60	0.38	5.18
5.00	KOSAU	3.63	0.47	4.34
5.00	CAJAZ	3.88	0.28	4.31
5.00	TE	4.95	0.67	5.97
5.00	MENA	8.65	1.07	10.27
5.00	SSA	13.60	1.43	15.77
5.00	SASIA	25.13	3.80	30.90
5.00	CHINA	3.71	0.64	4.69
5.00	EASIA	21.90	3.25	26.83
5.00	LACA	5.95	0.48	6.68
5.00	INDIA	26.08	3.85	31.92

Risk-premium adjusted damages for η = 2

Expected temperature	Region	Expected Damage	Risk Premium	Damage With Risk
1.50	USA	1.16	1.15	2.31
1.50	WEU	1.25	1.24	2.50
1.50	EEU	0.96	0.99	1.99
1.50	KOSAU	0.73	0.73	1.46
1.50	CAJAZ	1.24	1.23	2.48
1.50	TE	0.72	0.74	1.48
1.50	MENA	1.23	1.30	2.60
1.50	SSA	2.30	2.39	4.80
1.50	SASIA	2.54	2.76	5.55
1.50	CHINA	0.46	0.46	0.93
1.50	EASIA	2.32	2.51	5.05
1.50	LACA	1.26	1.30	2.61
1.50	INDIA	2.77	3.00	6.03
2.00	USA	1.37	1.37	2.76
2.00	WEU	1.54	1.55	3.12
2.00	EEU	1.36	1.40	2.82
2.00	KOSAU	0.93	0.94	1.90
2.00	CAJAZ	1.48	1.48	2.98
2.00	TE	1.05	1.10	2.21
2.00	MENA	1.90	2.01	4.03
2.00	SSA	3.40	3.55	7.14
2.00	SASIA	4.34	4.73	9.50
2.00	CHINA	0.65	0.68	1.36
2.00	EASIA	3.90	4.23	8.50
2.00	LACA	1.78	1.84	3.69
2.00	INDIA	4.66	5.05	10.15
2.50	USA	1.63	1.64	3.29
2.50	WEU	1.93	1.96	3.95
2.50	EEU	1.80	1.86	3.73
2.50	KOSAU	1.21	1.24	2.49
2.50	CAJAZ	1.77	1.78	3.58
2.50	TE	1.48	1.56	3.13
2.50	MENA	2.70	2.85	5.73
2.50	SSA	4.68	4.88	9.82
2.50	SASIA	6.62	7.18	14.43
2.50	CHINA	0.94	1.00	2.00
2.50	EASIA	5.89	6.36	12.79
2.50	LACA	2.35	2.42	4.87
2.50	INDIA	7.03	7.60	15.26
3.00	USA	1.92	1.94	3.90
3.00	WEU	2.41	2.48	4.98
3.00	EEU	2.28	2.35	4.72
3.00	KOSAU	1.55	1.61	3.23
3.00	CAJAZ	2.10	2.13	4.27
3.00	TE	1.99	2.10	4.22
3.00	MENA	3.63	3.82	7.68
3.00	SSA	6.12	6.38	12.82
3.00	SASIA	9.37	10.08	20.27
3.00	CHINA	1.31	1.41	2.83
3.00	EASIA	8.28	8.89	17.86
3.00	LACA	2.97	3.06	6.14
3.00	INDIA	9.88	10.60	21.30
3.50	USA	2.26	2.29	4.60
3.50	WEU	2.99	3.08	6.20
3.50	EEU	2.80	2.88	5.79
3.50	KOSAU	1.97	2.05	4.11
3.50	CAJAZ	2.48	2.52	5.06
3.50	TE	2.60	2.74	5.50
3.50	MENA	4.69	4.92	9.89
3.50	SSA	7.74	8.04	16.16
3.50	SASIA	12.60	13.46	27.05
3.50	CHINA	1.78	1.91	3.83
3.50	EASIA	11.08	11.81	23.74
3.50	LACA	3.64	3.74	7.52
3.50	INDIA	13.21	14.08	28.29

Expected temperature	Region	Expected Damage	Risk Premium	Damage With Risk
4.00	USA	2.63	2.68	5.38
4.00	WEU	3.66	3.80	7.64
4.00	EEU	3.36	3.45	6.94
4.00	KOSAU	2.45	2.56	5.15
4.00	CAJAZ	2.90	2.95	5.94
4.00	TE	3.29	3.47	6.97
4.00	MENA	5.88	6.17	12.39
4.00	SSA	9.52	9.89	19.89
4.00	SASIA	16.30	17.37	34.91
4.00	CHINA	2.33	2.51	5.04
4.00	EASIA	14.28	15.19	30.53
4.00	LACA	4.36	4.48	9.00
4.00	INDIA	17.02	18.10	36.37
4.50	USA	3.05	3.11	6.25
4.50	WEU	4.43	4.62	9.29
4.50	EEU	3.96	4.08	8.20
4.50	KOSAU	3.01	3.16	6.35
4.50	CAJAZ	3.37	3.44	6.92
4.50	TE	4.08	4.31	8.66
4.50	MENA	7.20	7.56	15.20
4.50	SSA	11.48	11.95	24.01
4.50	SASIA	20.48	21.83	43.87
4.50	CHINA	2.98	3.21	6.45
4.50	EASIA	17.89	19.03	38.25
4.50	LACA	5.13	5.28	10.61
4.50	INDIA	21.31	22.67	45.56
5.00	USA	3.50	3.59	7.22
5.00	WEU	5.29	5.55	11.15
5.00	EEU	4.60	4.75	9.54
5.00	KOSAU	3.63	3.83	7.70
5.00	CAJAZ	3.88	3.99	8.01
5.00	TE	4.95	5.25	10.55
5.00	MENA	8.65	9.11	18.31
5.00	SSA	13.60	14.20	28.53
5.00	SASIA	25.13	26.84	53.94
5.00	CHINA	3.71	4.01	8.05
5.00	EASIA	21.90	23.36	46.94
5.00	LACA	5.95	6.13	12.33
5.00	INDIA	26.08	27.80	55.88

6 Annex III: Risk-premium adjusted damages. Results from the AD-WITCH model in % of regional GDP

		2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100
cajaz	Av. Dam. w/Rp=1	1.04	1.08	1.12	1.18	1.24	1.32	1.42	1.53	1.67	1.82	1.99	2.17	2.37	2.58	2.81	3.05	3.29	3.53	3.78	4.02
cajaz	Av. Dam. w/Rp=1.5	1.04	1.08	1.12	1.18	1.25	1.33	1.43	1.54	1.68	1.83	2.00	2.19	2.39	2.61	2.85	3.09	3.34	3.60	3.86	4.12
cajaz	Av. Dam. w/Rp=2	2.08	2.15	2.23	2.33	2.46	2.60	2.78	2.97	3.20	3.45	3.74	4.06	4.40	4.77	5.17	5.58	6.01	6.45	6.90	7.33
cajaz	Average Damage	0.96	1.01	1.06	1.12	1.19	1.27	1.37	1.48	1.60	1.74	1.89	2.06	2.24	2.43	2.63	2.83	3.04	3.26	3.47	3.68
china	Av. Dam. w/Rp=1	0.31	0.32	0.34	0.37	0.43	0.50	0.60	0.73	0.89	1.08	1.30	1.55	1.83	2.14	2.48	2.83	3.20	3.58	3.96	4.34
china	Av. Dam. w/Rp=1.5	0.32	0.34	0.36	0.40	0.46	0.53	0.64	0.77	0.92	1.11	1.33	1.59	1.87	2.18	2.52	2.88	3.26	3.65	4.05	4.44
china	Av. Dam. w/Rp=2	0.62	0.64	0.68	0.75	0.84	0.97	1.13	1.34	1.59	1.89	2.24	2.63	3.08	3.58	4.11	4.69	5.29	5.92	6.56	7.19
china	Average Damage	0.33	0.34	0.36	0.38	0.42	0.48	0.55	0.65	0.76	0.91	1.07	1.26	1.47	1.71	1.97	2.24	2.52	2.82	3.12	3.42
easia	Av. Dam. w/Rp=1	0.88	1.16	1.49	1.92	2.45	3.09	3.85	4.74	5.79	6.98	8.31	9.77	11.34	13.02	14.80	16.65	18.56	20.49	22.43	24.34
easia	Av. Dam. w/Rp=1.5	0.96	1.27	1.63	2.09	2.65	3.31	4.10	5.01	6.07	7.28	8.64	10.15	11.78	13.53	15.39	17.33	19.34	21.39	23.45	25.49
easia	Av. Dam. w/Rp=2	1.40	1.89	2.48	3.24	4.17	5.27	6.57	8.07	9.80	11.77	13.99	16.45	19.13	22.04	25.14	28.39	31.76	35.23	38.72	42.13
easia	Average Damage	0.72	0.95	1.23	1.59	2.02	2.54	3.16	3.88	4.72	5.69	6.77	7.98	9.29	10.70	12.19	13.76	15.38	17.03	18.69	20.33
india	Av. Dam. w/Rp=1	1.04	1.38	1.79	2.30	2.93	3.69	4.60	5.67	6.91	8.33	9.91	11.64	13.51	15.51	17.62	19.83	22.09	24.39	26.69	28.96
india	Av. Dam. w/Rp=1.5	1.15	1.51	1.95	2.49	3.16	3.95	4.89	5.98	7.24	8.69	10.31	12.09	14.03	16.12	18.33	20.64	23.02	25.45	27.91	30.32
india	Av. Dam. w/Rp=2	1.86	2.47	3.21	4.14	5.27	6.60	8.17	9.98	12.04	14.40	17.03	19.96	23.14	26.57	30.23	34.07	38.03	42.11	46.20	50.22
india	Average Damage	0.85	1.13	1.47	1.89	2.42	3.04	3.78	4.64	5.64	6.79	8.09	9.52	11.08	12.76	14.54	16.40	18.32	20.29	22.27	24.21
kosau	Av. Dam. w/Rp=1	0.56	0.58	0.61	0.65	0.71	0.78	0.87	0.99	1.13	1.29	1.48	1.69	1.92	2.18	2.45	2.73	3.03	3.34	3.64	3.95
kosau	Av. Dam. w/Rp=1.5	0.55	0.57	0.61	0.65	0.71	0.79	0.88	1.00	1.14	1.31	1.50	1.72	1.97	2.23	2.51	2.82	3.13	3.45	3.78	4.11
kosau	Av. Dam. w/Rp=2	1.14	1.18	1.23	1.30	1.40	1.53	1.69	1.88	2.11	2.38	2.69	3.04	3.43	3.86	4.33	4.82	5.33	5.87	6.41	6.95
kosau	Average Damage	0.55	0.57	0.60	0.64	0.69	0.75	0.83	0.93	1.04	1.18	1.33	1.51	1.70	1.91	2.13	2.37	2.62	2.87	3.13	3.38
laca	Av. Dam. w/Rp=1	0.63	0.76	0.90	1.06	1.25	1.46	1.69	1.95	2.23	2.54	2.86	3.21	3.56	3.93	4.31	4.70	5.08	5.47	5.84	6.21
laca	Av. Dam. w/Rp=1.5	0.65	0.78	0.93	1.10	1.29	1.50	1.74	1.99	2.28	2.58	2.91	3.26	3.62	4.00	4.39	4.79	5.19	5.59	5.98	6.37
laca	Av. Dam. w/Rp=2	1.20	1.45	1.71	2.03	2.38	2.76	3.18	3.63	4.12	4.65	5.22	5.83	6.46	7.12	7.81	8.50	9.21	9.92	10.61	11.28
laca	Average Damage	0.58	0.70	0.83	0.98	1.15	1.34	1.55	1.77	2.02	2.30	2.59	2.89	3.22	3.55	3.90	4.25	4.60	4.95	5.30	5.63
mena	Av. Dam. w/Rp=1	0.53	0.67	0.83	1.02	1.25	1.52	1.83	2.19	2.60	3.06	3.57	4.12	4.70	5.32	5.97	6.64	7.33	8.02	8.71	9.39
mena	Av. Dam. w/Rp=1.5	0.57	0.71	0.88	1.08	1.32	1.59	1.91	2.28	2.69	3.16	3.67	4.23	4.84	5.48	6.16	6.86	7.58	8.31	9.04	9.76
mena	Av. Dam. w/Rp=2	0.95	1.20	1.48	1.83	2.25	2.72	3.27	3.88	4.57	5.35	6.21	7.15	8.16	9.24	10.39	11.58	12.81	14.06	15.32	16.54
mena	Average Damage	0.48	0.60	0.73	0.90	1.10	1.33	1.59	1.89	2.23	2.62	3.05	3.51	4.01	4.55	5.11	5.69	6.28	6.89	7.49	8.08
neweuro	Av. Dam. w/Rp=1	0.47	0.57	0.68	0.81	0.95	1.11	1.29	1.49	1.71	1.94	2.20	2.46	2.74	3.03	3.32	3.62	3.92	4.22	4.52	4.80
neweuro	Av. Dam. w/Rp=1.5	0.49	0.60	0.71	0.84	0.99	1.15	1.33	1.53	1.75	1.99	2.24	2.51	2.79	3.09	3.40	3.71	4.02	4.33	4.64	4.94
neweuro	Av. Dam. w/Rp=2	0.89	1.08	1.29	1.52	1.79	2.08	2.40	2.75	3.13	3.54	3.98	4.45	4.95	5.46	6.00	6.55	7.10	7.65	8.20	8.73
neweuro	Average Damage	0.44	0.53	0.63	0.75	0.88	1.02	1.18	1.36	1.55	1.76	1.98	2.22	2.47	2.73	3.00	3.27	3.55	3.82	4.09	4.35
oldeuro	Av. Dam. w/Rp=1	1.05	1.07	1.11	1.16	1.24	1.34	1.46	1.62	1.81	2.03	2.29	2.58	2.90	3.25	3.63	4.02	4.43	4.85	5.28	5.70
oldeuro	Av. Dam. w/Rp=1.5	1.04	1.06	1.10	1.16	1.24	1.34	1.47	1.63	1.82	2.05	2.31	2.61	2.94	3.31	3.70	4.11	4.54	4.99	5.45	5.89
oldeuro	Av. Dam. w/Rp=2	2.04	2.09	2.17	2.28	2.42	2.60	2.82	3.09	3.41	3.78	4.22	4.70	5.24	5.84	6.48	7.16	7.87	8.60	9.35	10.08
oldeuro	Average Damage	0.99	1.02	1.06	1.12	1.20	1.29	1.40	1.54	1.70	1.89	2.10	2.35	2.62	2.91	3.22	3.55	3.89	4.24	4.60	4.95
sasia	Av. Dam. w/Rp=1	0.93	1.25	1.62	2.11	2.71	3.43	4.31	5.33	6.53	7.90	9.43	11.11	12.93	14.88	16.93	19.08	21.29	23.53	25.78	27.99
sasia	Av. Dam. w/Rp=1.5	1.03	1.37	1.78	2.30	2.94	3.69	4.60	5.64	6.86	8.26	9.83	11.56	13.44	15.47	17.62	19.88	22.20	24.58	26.98	29.33
sasia	Av. Dam. w/Rp=2	1.44	1.98	2.65	3.49	4.55	5.79	7.28	8.99	10.97	13.24	15.79	18.63	21.73	25.09	28.67	32.45	36.35	40.38	44.42	48.39
sasia	Average Damage	0.74	1.00	1.31	1.71	2.20	2.79	3.50	4.32	5.28	6.39	7.64	9.02	10.53	12.16	13.88	15.70	17.57	19.48	21.41	23.31
ssa	Av. Dam. w/Rp=1	1.06	1.31	1.58	1.91	2.30	2.74	3.25	3.82	4.46	5.18	5.95	6.78	7.66	8.58	9.54	10.53	11.53	12.53	13.53	14.50
ssa	Av. Dam. w/Rp=1.5	1.12	1.37	1.66	2.00	2.40	2.85	3.37	3.94	4.59	5.31	6.09	6.94	7.84	8.79	9.79	10.81	11.86	12.91	13.97	15.00
ssa	Av. Dam. w/Rp=2	1.95	2.41	2.92	3.53	4.23	5.02	5.92	6.91	8.01	9.23	10.55	12.00	13.53	15.17	16.87	18.64	20.45	22.29	24.12	25.90
ssa	Average Damage	0.97	1.19	1.44	1.73	2.07	2.46	2.90	3.39	3.94	4.55	5.22	5.94	6.71	7.52	8.36	9.23	10.12	11.01	11.91	12.77
te	Av. Dam. w/Rp=1	0.40	0.45	0.52	0.61	0.71	0.85	1.01	1.19	1.42	1.67	1.95	2.27	2.61	2.97	3.36	3.77	4.18	4.60	5.03	5.45
te	Av. Dam. w/Rp=1.5	0.41	0.47	0.54	0.63	0.74	0.88	1.04	1.23	1.46	1.72	2.01	2.33	2.68	3.06	3.46	3.89	4.33	4.77	5.23	5.67
te	Av. Dam. w/Rp=2	0.69	0.80	0.93	1.10	1.31	1.55	1.83	2.16	2.53	2.96	3.44	3.97	4.55	5.18	5.84	6.54	7.27	8.01	8.76	9.49
te	Average Damage	0.38	0.43	0.49	0.56	0.65	0.76	0.89	1.05	1.23	1.43	1.67	1.92	2.21	2.51	2.84	3.18	3.53	3.89	4.25	4.61
usa	Av. Dam. w/Rp=1	0.99	1.02	1.06	1.10	1.16	1.23	1.32	1.42	1.53	1.66	1.81	1.97	2.15	2.34	2.53	2.74	2.96	3.17	3.39	3.60
usa	Av. Dam. w/Rp=1.5	0.99	1.02	1.06	1.11	1.17	1.24	1.32	1.42	1.54	1.67	1.82	1.99	2.17	2.36	2.57	2.79	3.01	3.24	3.47	3.69
usa	Av. Dam. w/Rp=2	1.98	2.04	2.11	2.19	2.30	2.43	2.58	2.75	2.95	3.17	3.43	3.71	4.01	4.34	4.69	5.06	5.44	5.83	6.22	6.61
usa	Average Damage	0.91	0.95	0.99	1.05	1.11	1.19	1.27	1.37	1.48	1.60	1.74	1.88	2.04	2.21	2.39	2.57	2.76	2.95	3.14	3.32