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Kiel Working Paper No. 1321

Costs of Climate Change

The Effects of Rising Temperatures on Health and Productivity in Germany

by

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September 2007

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Abstract:

The aim of the study is to quantify climate induced health risks for Germany. Based on high resolution climate scenarios for the period 2071 to 2100 we forecast the number of days with heat load and cold stress. The heat frequency and intensity rise overall but more in the south. Referring to empirical studies on heat induced health effects we estimate an average increase in the number of heat induced casualties by a factor of more than 3. Heat related hospitalization costs increase 6-fold not including the cost of ambulant treatment. Heat also reduces the work performance resulting in an estimated output loss of between 0.1 % and 0.5 % of GDP.

Keywords: Costs of climate change, health effects, heat waves, mortality, hospitalization costs, labor productivity

JEL classification: I10, Q51, Q54

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1 Introduction

Climate change will probably lead to a number of detrimental health impacts such as vector-borne and food-borne diseases and allergies. In general future health effects are hard to quantify because the reaction of nature and human beings to climatic changes has not yet sufficiently been investigated. In this study we concentrate on the effects of high and low temperatures, especially of heat waves, on human well-being, since temperature related health impacts are substantial and better predictable than other health risks.

In the summer of 2003 thousands of people died in Germany and in other European countries due to long periods of intensive heat. Yet, fatal outcomes are just the peak of a variety of heat related health risks and negative effects for human well-being and performance. Table 1 summarizes existing estimates of the tremendous health impacts during the heat wave 2003 – in terms of increased mortality and increased emergency hospital admissions for different European States.

There is no mono-causal relationship between temperature and detrimental health effects, though. The most important variables influencing the risk of detrimental health effects are low as well as high temperatures, humidity and wind. Furthermore, different risk factors of affected people such as age, existing diseases (high blood pressure, heart, kidney, liver or metabolic diseases etc.), general low physical strength or fitness and adaptation possibilities have a large influence on the effects of high temperatures. Adaptation possibilities are also related to people’s social status, because poverty reduces the possibilities for heat protection through technical and structural measures, care and services. Single older people miss support and surveillance, and restricted mobility reduces the possibilities to “escape” from high temperatures (see BASU and SAMET 2002). Concerning the role of gender, the findings are indecisive. While European data have shown that a larger share of heat victims are women, US data find a higher risk for men. Finally, people can influence the heat risk via their own behaviour. Exhausting activities as well as alcohol and drugs increase the risk, while adequate clothing has the opposite effect. The main individual risk, however, is *age*. Older people (as well as young children) are most susceptible to heat. For these reasons fatalities due to heat mostly occur in hospitals and nursing homes, but partly also at home.[1] Diseases and weakness occur increasingly with growing age, so that age and diseases reinforce each other in their risk potential.

Generally, humans are able to *adapt* to changing climatic conditions via more efficient sweating and improved blood- and fluid-circulation. We call this *natural* adaptation. High temperatures in the first half of the years, when the affected people have not yet adapted are thus especially dangerous.[2] Furthermore, people can adapt their *behaviour* to climate change, generally speaking by living healthier. Action plans can be prepared in hospitals and old people’s homes to organize the adaptation measures during heat waves. In this context, heat

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[1] CALADO et al. (2005).

[2] KALKSTEIN and DAVIS (1989).

warning systems can help to adapt behaviour on time. They lead to the category of *technical* solutions (financed by public or private investment). A typical technical solution is air-conditioning in buildings.

This paper wants to collect scientific information about the dangers of heat addressing scientists, the public and decision makers, so that appropriate mitigation and adaptation measures can be applied, since waiting and ignoring the challenge of climate change will acerbate the costs and dangers for human health.

Place	Number of cases of heat mortality	Number of hospital emergency admissions	Source
Europe	25 000 - 35 000		Cited in KOPPE et al. (2003)
Germany	7 000		ZEBISCH et al. (2005)
Baden-Württemberg	1 100; 16 - 24 % increase		Cited in KOPPE et al. (2003)
England	2 091; 17 % increase, 23 % increase among people aged 75 years or older, 85 % of victims older than 75 years	1 % increase among people up to 64 years, 6 % increase among people aged 75 years or older	JOHNSON et al. (2005)
London	616; 42 % increase, 59 % increase among people aged 75 or older	4 % increase among people up to 64 years, 16 % increase among people aged 75 or older	JOHNSON et al. (2005)
France	14 800; 16 % increase, 80 % of victims older than 75 years		EEA (2004), S. 73
Netherlands	650		WHO EUROPE (2005)
Switzerland	975; 6.9 % increase		WHO EUROPE (2005)
Italy	9 704, 92 % of victims older than 75 years		WHO EUROPE (2005), CONTI et al. (2005)
Portugal	1 854; 40 % increase, 58 % up to 96.6 % of victims older than 75 years	11.6 % increase; 27.2 % increase among people aged 75 or older	CALADO et al. (2005), KOVATS and JENDRITZKY (2006)

Table 1: Estimated impacts of the European heat wave in 2003[3]

Against this background, the aim of this study is to quantify climate induced health risks for Germany. Since there are many uncertainties in parameter values observed in the past and unknown future development paths, the study is only a first step in this direction. Also, *adaptation*, which can significantly reduce the negative effects, is *not* included in the

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[3] For further literature reviews on heat related mortality see BASU and SAMET (2002) and KOVATS and JENDRITZKY (2006).

calculations. Yet, this interdisciplinary study combining scientific knowledge from the meteorological, geographical, medical and economic field is probably one of the first attempts to systematically quantify specific negative health effects of climate change in Germany. The focus is on such effects for which there are at least some quantitative information. For this reason we estimate heat induced mortality as well as hospitalization costs and losses in labor productivity. For mortality we also consider the effects of more extreme cold in winter. The results show a regionally different increase in heat stress for Germany in

the future and consequently substantially higher negative health impacts and production losses. The mortality rise during the summer dominates the possible mortality decrease during the winter. For more detailed results than presented in this study, see HÜBLER and KLEPPER (2007).

The study proceeds as follows. Before we can use any economic methods or models to assess the different effects, we need information on how important climate variables will change in the future. For this purpose we use forecasts of the climate model REMO that provides climate data for Germany in the period 2071-2100 in a high resolution in time and space. Based on these climate data we can compute additional days p. a. (per annum) with heat load accounting already for the most important variables temperature, humidity and wind. The employed model, the underlying climate scenarios and the resulting temperature scenarios for Germany are described in section 2. In section 3 we derive approximations of the resulting increases in mortality. Since estimating the economic costs of fatalities are surrounded with many methodological and also ethical questions and since we believe that the numbers speak for themselves we do not translate the fatalities into economic costs. In section 4 though, we try to estimate the economic costs of non fatal heat risks focussing on the costs of hospitalization and the reduction in labor output. In both sections 3 and 4 we use parameter values from existing empirical studies for our estimations. Section 5 concludes.

2 Heat scenarios for Germany

Climate change causes worldwide higher temperatures with different regional patterns. To generate heat and coldness scenarios for Germany in the necessary high spatial resolution we use the Regional Climate Model REMO. The model, the underlying emission scenarios and the resulting forecasts are described in the following subsections.

2.1 Employed climate models and climate scenarios

The Regional Climate Model REMO[4] computes climate scenarios with a high spatial resolution (10 km times 10 km, 121 squares in the horizontal, 103 in the vertical axis) for Germany and the surroundings.

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[4] JACOB (2001); REMO is run by the Max Planck Institute (MPI) for Meteorology in cooperation with Deutsches Klimarechenzentrum (DKRZ), both located in Hamburg.

Future emissions paths cannot be determined exactly because there is uncertainty about the availability of and demand for fossil energy, about the development of the world's civilization, about economic globalization, land use and future climate policies; and the phenomena climate and weather are complex and only partly deterministic. We thus use the emission scenarios of the IPCC (Intergovernmental Panel on Climate Change, IPCC 2001) that are based on different plausible assumptions on important determinants for emissions. Scenario A2 is the business as usual case where anthropogenic carbon dioxide emissions increase from 7 $GtCO_2$ in the year 2000 to 17 $GtCO_2$ in 2050 and 30 $GtCO_2$ in 2100. In scenario B1 emissions rise to 9 $GtCO_2$ in 2050 and then fall to 6 $GtCO_2$ in 2100, which implies rigorous changes in the world economy towards climate protection. This study mainly refers to scenario A1B with a medium emissions increase under plausible assumptions. In A1B, after an increase to 16 $GtCO_2$ in 2050, CO_2 emissions decrease to 13 $GtCO_2$ in the year 2100.

The climate data computed by REMO are then used as inputs for the so called climate "Michel" model developed by the German Weather Service.[5] This complete human temperature exchange model combines data on temperature, humidity, wind speed, sun radiation, clothing and physical activity of affected persons to calculate the so-called perceived temperature for a typical reference person. Perceived temperature can be seen as a measure of how temperature affects human well-being.

The most important variables influencing the risk of detrimental health effects are low as well as high temperatures, humidity and wind. Besides, the duration of heat or cold stress, daily temperature maxima and nightly minimal temperatures, which provide a chance for cooling, are important. Wind influences the temperature exchange directly as well as indirectly via transpiration. Under low temperatures wind further cools down the body, while in a hot and humid surrounding wind further heats it up. In the case of heat and dry air, wind has only small effects.[6] Humidity can exaggerate heat impacts. For instance, the heat wave in 2003 had such severe effects in France because humidity was higher compared to other countries like Germany. Yet, high temperatures often occur together with other factors that can intensify negative health effects such as high ozone stress, air pollution or summer smog.

The heat island effect is a well known meteorological phenomenon. In densely populated urban areas temperatures reach even higher values and the problems mentioned above can occur more frequently. Humans living in badly ventilated rooms without air conditioning bear an additional risk. In the high resolution scenarios for Germany (figures 1a and 1b) we can clearly see the heat island effect in Hamburg, Berlin and the Ruhr basin.

For practical applications it is useful to convert the perceived temperature into classes of thermal perception or classes of thermo-physiological stress as shown in table 2.

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[5] FANGER (1972), GAGGE et al. (1986), VDI (1994 and 1998), STAIGER et al. (1997), JENDRITZKY et al. (1990), JENDRITZKY et al. (2000).

[6] Risk factors based on HAVENITH (2005).

The 6 am and 12 am values of perceived temperatures are smoothed by applying half a Gaussian filter over 41 days. The longer go a value, the lower its weight. The smoothed values are then used to define dynamic limits for the classes of perceived temperature composed of fixed (2/3 weight) and variable (1/3 weight) limits.[7] This method imitates the human ability to adapt to climatic changes in the short-run. This procedure is also used in the heat warning system of the German Weather Service.[8]

Perceived temperature in °C	Thermal perception	Thermo-physiological stress
PT <= - 39	very cold	extreme cold stress
-39 < PT <= -26	cold	strong cold stress
-26 < PT <= -13	cool	moderate cold stress
-13 < PT <= 0	slightly cool	light cold stress
0 < PT < 20	comfortable	comfort possible
20 <= PT < 26	slightly warm	light heat stress
26 <= PT < 32	warm	moderate heat stress
32 <= PT < 38	hot	strong heat stress
38 <= PT	very hot	extreme heat stress

Table 2: Perceived temperature PT, classes of thermal perception and thermo-physiological stress according to JENDRITZKY et al. (2000)

2.2 Heat scenarios

To generate heat scenarios for the period 2071-2100 we calculate the average number of days p. a. with heat stress from the temperature data sorted in classes of perceived temperature. In this case, heat stress encompasses the classes of strong and extreme heat stress. In contrast to analysing time series data of numerous climate variables this approach results in a compact and meaningful description of future temperatures.

The numbers of additional days with heat stress for the period 2071-2100 and for the different IPCC scenarios are given by the difference to a reference run for 1971-2000 (CTL = control). The reference run uses actually measured greenhouse gas concentrations as inputs. The total number of future hot days results from adding the expected additional number of hot days to the actually observed number of hot days in the reference period 1971-2100. The following map (figure 1a) shows the number of days with (strong and extreme) heat stress for the REMO experiment A1B (2071-2100) minus the number of hot days in the control run CTL (1971-2000) in Germany and the surroundings in 10 km times 10 km resolution.

All climate experiments (B1, A1B and A2) forecast a significant increase in the frequency of days with strong or extreme heat at the end of the 21st century (2071-2100) compared to the

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[7] KOPPE (2005).

[8] http://www.dwd.de/de/WundK/Warnungen/Hitzewarnung/Kriterien.htm.

end of the 20th century (1971-2000) and result in two to five times as many hot days. In general, the number of hot days per year rises from north to south Germany. Scenario B1 yields one additional hot day at the coast in the north and around 18 near the Lake Constance in the south (figure 1b). Experiment A1B predicts one additional day with strong or extreme heat at the coast, seven to 15 in the middle of Germany and 26 near the Lake Constance and in Munich (figure 1a).

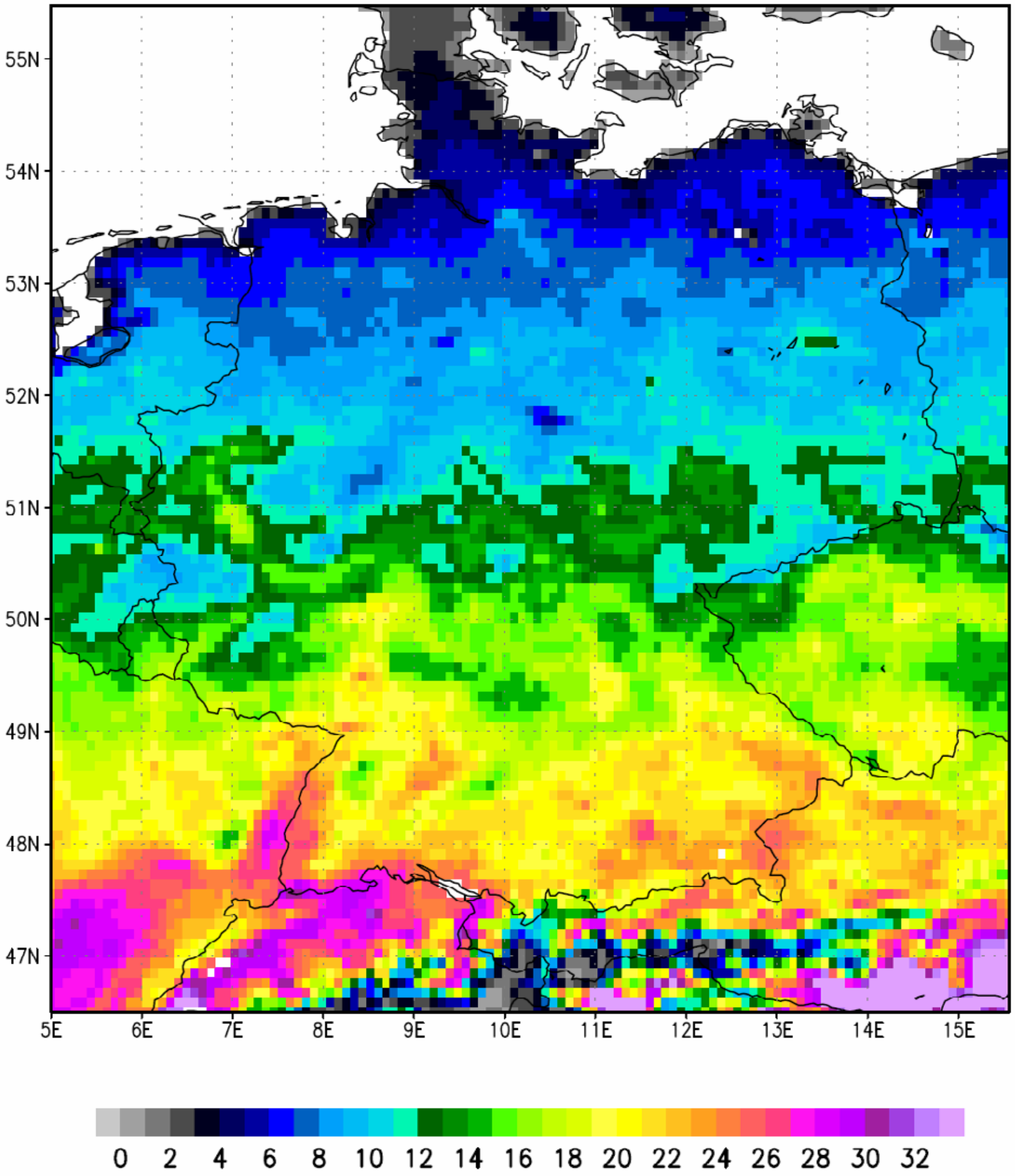

Figure 1a: Additional number of days with (strong and extreme) heat stress, REMO experiment A1B (2071-2100) minus control run CTL (1971-2000) in Germany

The results of scenario A2 are very similar to A1B (not shown). Accordingly, the regional climatic differences will increase in Germany. Figures 1a and 1b also reveal the heat island effect in cities like Hamburg, Berlin and Munich in contrast to the surrounding areas.

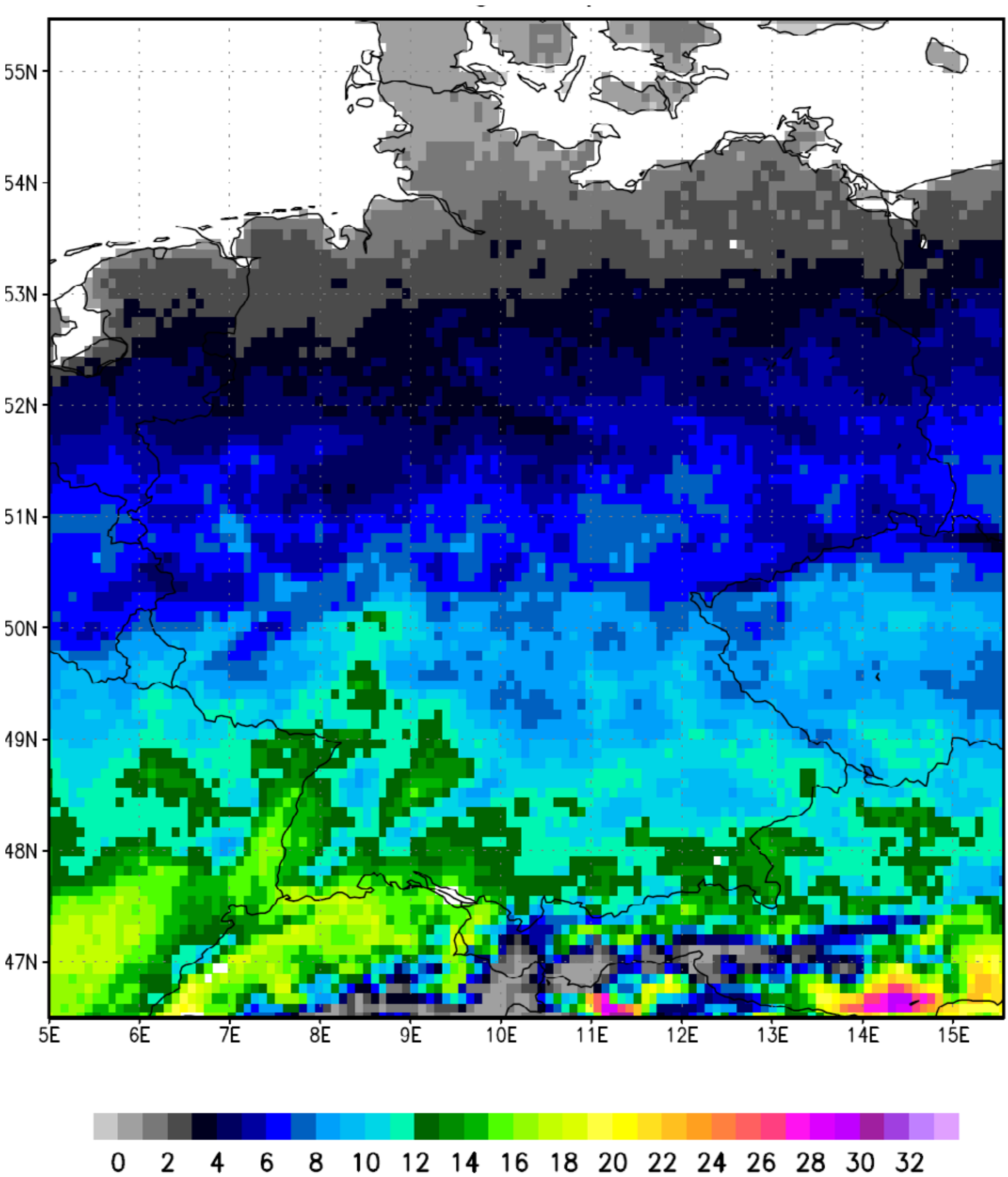

Figure 1b: Additional number of days with (strong and extreme) heat stress, REMO experiment B1 (2071-2100) minus control run CTL (1971-2000) in Germany

The comparison of figure 1a with 1b clearly shows that a successful mitigation of greenhouse gas emissions (assumed in scenario B1) can significantly reduce future heat load.

Additionally, we use temperature time series data for the German federal states, forecasted for one city in each state like Frankfurt/Main for Hessen (appendix, table 3). Figure 2 shows for Frankfurt/Main the rising trends of heat days p. a. for B1, A1B and A2 for the base run CTL.[9] It is again obvious, that a successful emissions mitigation policy, represented by scenario B1, reduces the occurrence of heat and consequently the related health risks .

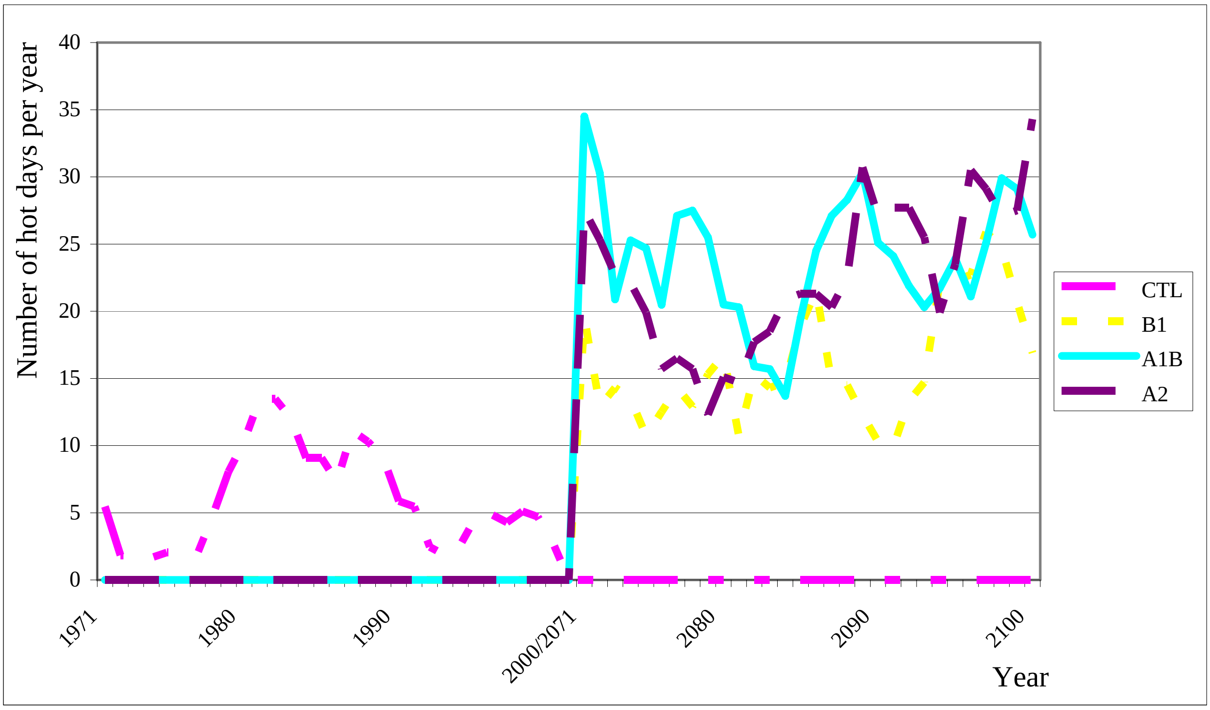

Figure 2: Additional number of days per year with strong or extreme heat stress in Frankfurt/Main (Hessen), moving averages over 5 years

2.3 Coldness scenarios

Climate change will not only increase summer temperatures and the likelihood of heat waves, but will also lead to higher average temperatures during the winter and increase the frequency of extreme weather events like storms and cold spells during the cold period of the year.

Analogously to the heat forecast we estimate future coldness as the average number of days per year with cold stress according to the IPCC scenarios B1, A1B and A2 for 2071-2100 and compare the results with the control run CTL for 1971-2000. We aggregate the number of days with light, modest, strong and extreme cold stress, since we observed no days with strong and extreme coldness and only few days with moderate coldness in the past (CTL).

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[9] Note that the moderate emission scenario A1B leads in some years to a higher heat frequency than the high emissions scenario A2. This can be explained by natural climate changes that superimpose the temperature increase due to anthropogenic greenhouse gas emissions.

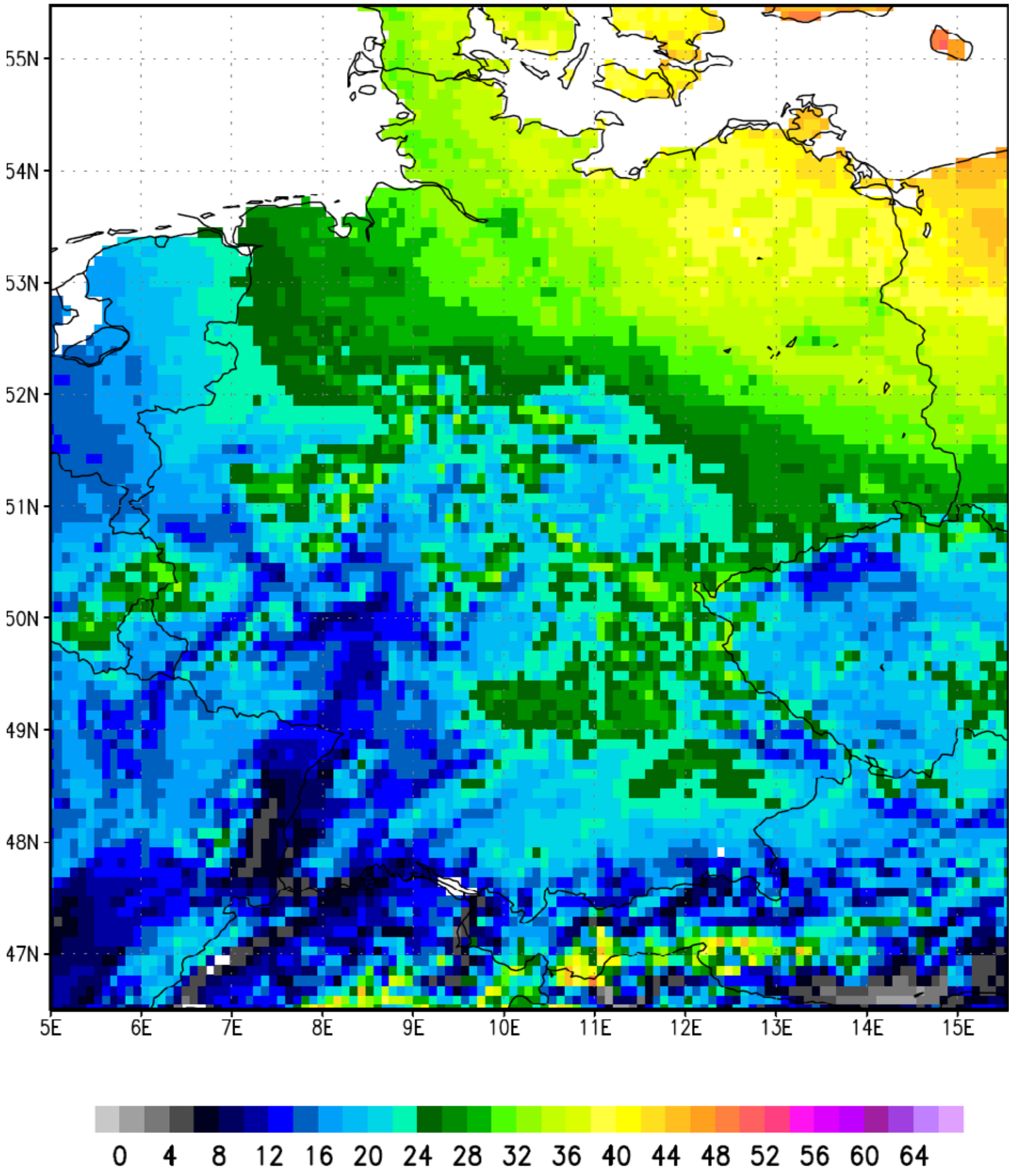

Figure 3: Reduction in the number of days per year with cold stress (light, moderate, strong and extreme), control run CTL (1971-2000) minus REMO experiment A1B (2071-2100) in Germany

Obviously, the reduction of cold stress is highest in the north-east of Germany reaching a decrease of 30 days in scenario B1 and 44 days in A1B (only scenario A1B is shown, see figure 3) and A2. The reduction in cold days amounts to 10 to 20 days in the middle of Germany in B1 and up to 25 days in A1B and A2. In all scenarios the lowest decrease of on average two days per year is found at the upper Rhine rift in the south-west. Moreover, the reduction of average coldness rises with altitude, which is obvious in the higher German regions and in the Alps.

Since we include light coldness, the reported total decrease of cold days becomes relatively high resulting on the one hand in an overestimation of the reduction of cold stress. On the other hand days with moderate cold stress down to –26 °C are treated in the same way as days with light coldness below 0 °C leading to an underestimation of the positive effects from reduced strong cold stress.

3 Temperature induced fatalities

The heat wave of 2003 has shown that extreme heat not only reduces well-being but can also cause a large number of fatalities. In this section we use the existing information on the relationship of temperature and mortality and combine it with the heat and coldness scenarios described before as well as with statistical population data in order to estimate climate change induced changes in mortality. While section 3.1 refers to high temperatures, section 3.2 deals with low temperatures.

3.1 Heat induced mortality

Our estimation model refers to McMichael et al. (2002) and relates heat induced mortality to the predicted additional number of hot days: [10]

$$D = \sum_{k}^{K} \sum_{w}^{W} (T_{w,k} + T_{0,w,k}) \cdot \frac{M_w}{365} \cdot d_k \cdot d_{season} \cdot p \qquad (3.2\text{-}1)$$

D	average total number of heat induced deaths p. a. in Germany 2071-2100 for IPCC scenario A1B
$T_{w,k}$	average number of additional days p. a. in 2071-2100 in perceived temperature class k in location w
$T_{0,w,k}$	actually measured average number of days p. a. in 1971-2000 in perceived temperature class k in location w
M_w	absolute mortality over the whole base year 2005 in federal state w
d_k	average relative mortality increase in perceived temperature class k
d_{season}	seasonal mortality adjustment
p	demographic change (age structure and population size) 2050 relative to 2005 in Germany

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[10] Absolute numbers are written in capital letters, relative numbers in small letters.

In two different runs w represents first one location for each federal state ($W = 16$, appendix, table 3) and second the 121 times 103 fields, each with a size of 10 km times 10 km. The temperature classes k ($K = 3$) are “strong” and “extreme” as well as “moderate heat stress”, all causing increased mortality.

$T_{w,k}$ is the average number of additional days p. a. in the prediction period (A1B, 2071-2100) compared to the reference period (CTL, 1971-2000) when the threshold of perceived temperature class k is reached in location w. $T_{w,k}$ is given by the climate forecast explained in section 2.2 and can be expressed as follows, where j ($J = 30$) is the time index for years in the prediction or reference period:

$$T_{w,k} = \left[\sum_{j=1}^{J} (T_{j,w,k}) / J \right]_{2071-2100} - \left[\sum_{j=1}^{J} (T_{j,w,k}) / J \right]_{1971-2000} \qquad (3.2\text{-}2)$$

In order to calculate the total number of heat related future fatalities in the first run, we add $T_{0,w,k}$, the actually measured average number of days p. a. in the reference period 1971-2000, to the estimated number of hot days. Since past observations are not available in 10 km times 10 km resolution, we cannot add $T_{0,w,k}$, in the second run.

M_w is the absolute number of general deaths in the base year 2005 in federal state w.[11] In case of 10 km times 10 km squares, M_w is the mean mortality rate in Germany multiplied by the population size in the square.[12] Dividing by 365 yields the number of deaths per day.

d_k denotes the percentage increase in general mortality M_w due to heat stress of class k. We use parameter values from LASCHEWSKI and JENDRITZKY (2002) for the period 1968-1997 in the federal state of Baden-Württemberg and observations during the heat wave 2003 in Baden-Württemberg reported by KOPPE et al. (2003) that refer to classes of perceived temperature. Based on LASCHEWSKI and JENDRITZKY (2002) we compute the mortality increase for moderate heat stress amounting to approximately 6.6 %; according to KOPPE et al. (2003) the mortality increase for strong heat stress is about 9.3 %. For extreme heat stress no suitable information is available. Extrapolation yields an increase of 12.0 % (linear extrapolation) and 14.8 % (exponential extrapolation), respectively. Neither the mortality statistics nor our model take into account that some deaths might occur anyway but happen (for instance one month) earlier due to heat.

Furthermore, we take into account the seasonal adjustment of general mortality, d_{season}, because general winter mortality is circa 8 % higher than the yearly average mortality while summer mortality is about 8 % lower.[13] To control for this seasonal fluctuation, the mortality change is multiplied by the factor 0.92.

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[11] STATISTISCHES BUNDESAMT (2006a).

[12] Data from LANDSCAN (2001).

[13] Calculation based on LASCHEWSKI and JENDRITZKY (2002).

p is the demographic adjustment coefficient. The number of people below the age of 75 will decrease by 18 % (*p(74-)* = 0.82), and the number of people aged 75 years and more will increase by 95 % (*p(75+)* = 1.95) resulting in a decrease of total German population by 9.3 %.[14] In accordance with the experiences of the heat wave 2003 we assume that 80 % of all heat stress victims are people aged 75 years and more (*m(75+)* = 0.8) and carry out sensitivity analyses to control for different assumptions.[15] The following formula captures this demographic change:

$$p = m(75+) \cdot p(75+) + (1 - m(75+)) \cdot p(74-) \qquad (3.2\text{-}3)$$

m(75+)	share of people of age 75 and more among heat fatalities during the heat wave 2003
p(75+)	number of people of age 75 and more in 2050 relative to 2005
p(74-)	number of people of age 74 and less in 2050 relative to 2005

Since there is a lack of more disaggregated information, we assume that the demographic development is the same across all federal states and 10 km times 10 km squares. Moreover, we neglect population movements within Germany (that will mainly take place from the east to the west and to the south of Germany) as well as international migration.

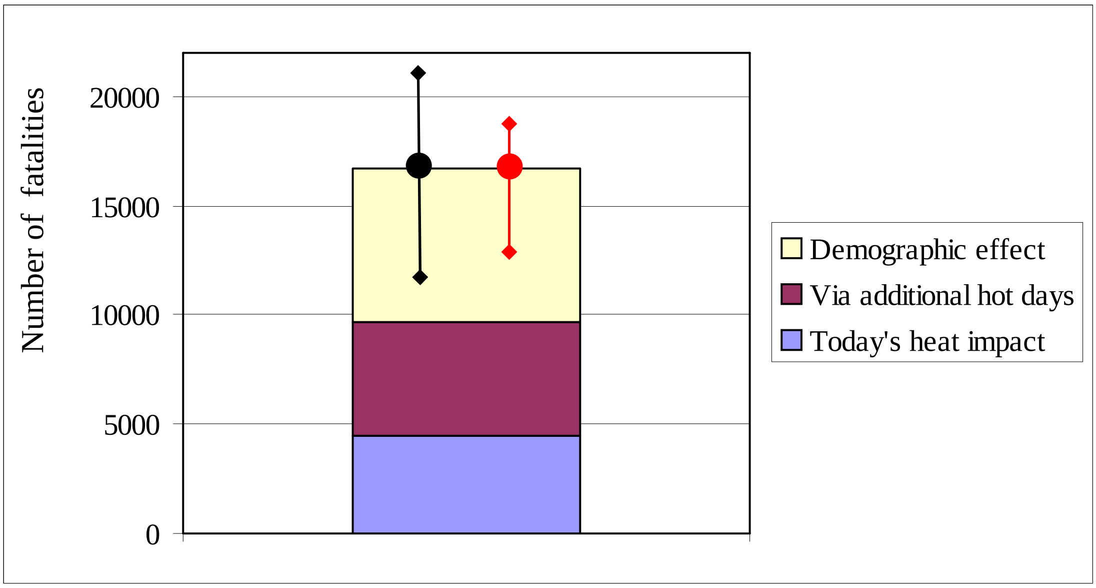

Figure 4: Number of heat induced deaths p. a. in Germany, 2071-2100 (exponential extrapolation for extreme heat stress)

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[14] Calculation with data by STATISTISCHES BUNDESAMT (2006a). We use population forecasts for 2050 since the forecasts by STATISTISCHES BUNDESAMT do not include the period 2051-2100.

[15] Shares of affected elderly people reported in the literature vary between 44 % (in the USA) and 96.6 % (in Portugal); overview in table 1; EEA (2004), p. 74; MORBIDITY AND MORTALITY WEEKLY REPORT for the USA cited in UPHOFF and HAURI (2005).

The calculations result in a substantially increased heat related mortality at the end of the 21st century. The first run on federal state level yields on average ca. 16 700 heat induced deaths p. a. in the period 2071 to 2100 (using exponential extrapolation for the class of extreme heat stress). This number can be disaggregated in the following way: Today's number of deaths statistically amounts to ca. 4 500 (bottom part in figure 4). This value was not measured in the past but is generated by the model as a reference. Without demographic change the prediction yields about 5 200 additional heat induced deaths (middle part in figure 4). The joint effect of a decrease in total population and an almost doubling number of elderly people creates ca. 7 000 additional potential heat victims, since the latter effect dominates (upper part in figure 4). This means, the total number of heat induced fatalities rises by the factor 3.7. Excluding today's number of heat related deaths from the calculation leads to a number of ca. 9 000 additional future deaths.

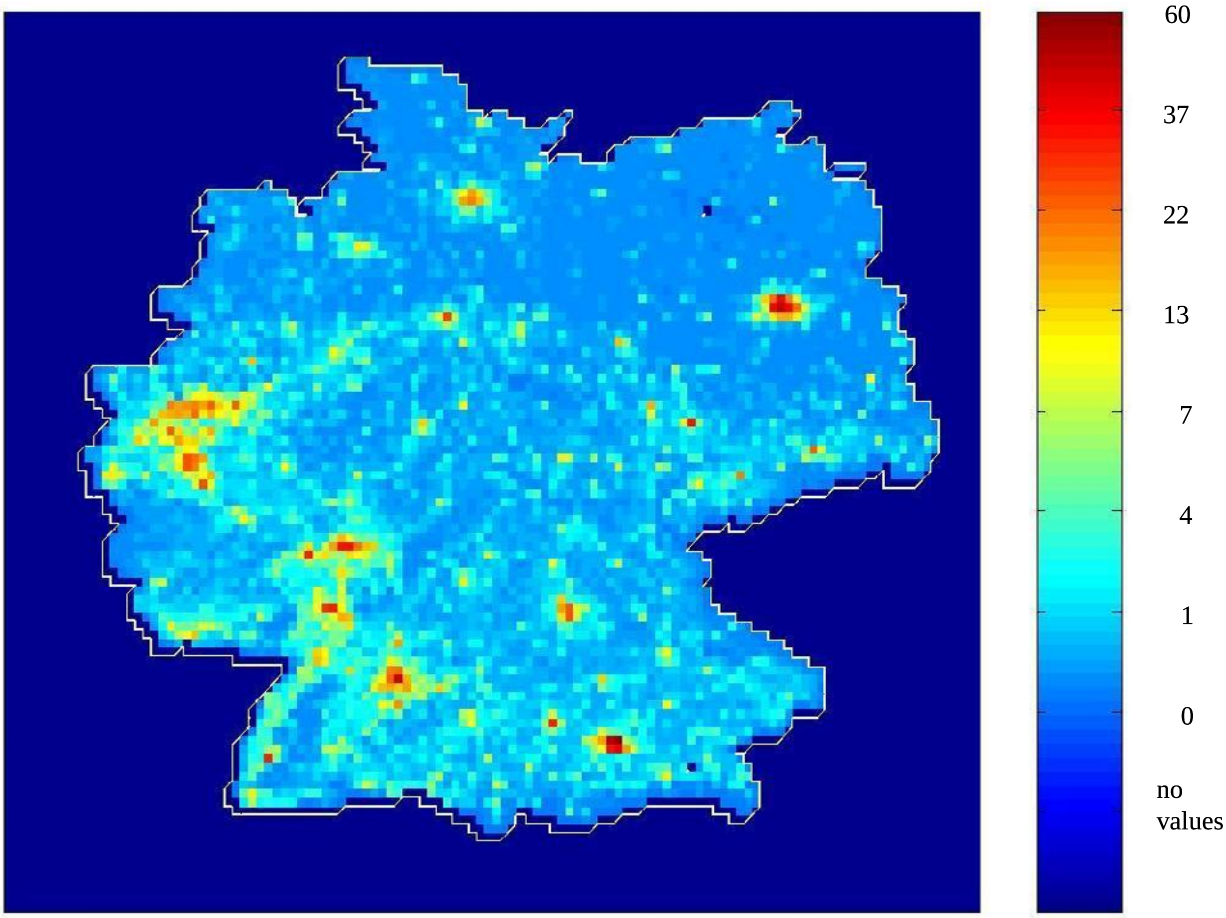

Figure 5: Distribution of additional heat induced deaths p. a. per 10 km times 10 km sectors in Germany, 2071-2100, A1B (exponential extrapolation for extreme heat stress)

Accordingly, the future health risk increases substantially without appropriate mitigation and adaptation efforts. It is important to note that these estimations do *not* include any adaptation to climate change (especially concerning elderly people) and hence overestimate the real effects. Furthermore, we do not take into account the so-called "harvesting effect", meaning that a certain number of sick and elderly people might have died even without heat in the near future. As a consequence the mortality ratio can slightly decrease under its average level after the heat event. Subtracting these casualties will in the short-run probably result in a less than 25 % reduction of the mortality numbers for Germany.[16]

Furthermore, we carry out sensitivity analyses for the parameters “heat related mortality increase d_k” and “share of elderly people among heat victims *m(75+)*”. Both vary with time and region and depend on the adaptation status and adaptation ability of the affected population and can thus not be determined exactly. The vertical sensitivity bar on the left hand side shows the range of total outcomes from about 11 500 to about 21 500 when d_k varies by ±30 % in accordance with the range of findings in the literature. The vertical sensitivity bar on the right hand side of figure 4 shows the range of total mortality from ca. 13 500 to ca. 19 000 when *m(75+)* is changed between 50 % and 100 %, again referring to the findings in the literature (see table 1). In the second run we compute heat induced mortality in 10 km times 10 km resolution visualized in figure 5. Obviously, the most heat victims will be in the regions with the highest population densities, i. e. in the cities. However, a comparison of Hamburg and Munich reveals a higher number of heat related fatalities in the south (in accordance with figure 1a).

Adding up the heat victims numbers of all 10 km times 10 km sectors yields the average additional number of heat related deaths in Germany p. a. amounting to 8 500 (compared to almost 9 000 in the first run ignoring the base value of today’s observations).[17]

These results have a similar order of magnitude as studies for the UK, Portugal and Australia.[18] A test run using the number of hot days in the year 2003 as an input indeed reproduces the estimated ca. 7 000 heat victims in Germany.

3.2 Coldness induced mortality

While we expect dangerous health impacts in summer, there might be positive effects in winter due to less coldness. There are much less empirical studies on the relationship of health and coldness and the role of age as a risk factor than for heat. It is also not clear, whether the health risk steadily increases with lower temperatures or whether there is a maximal risk at moderately low temperatures in combination with humidity. Nevertheless, we try to compare the effects in winter with those in summer, noticing that the medical causality is different in winter compared with the summer. The time lags of low temperature events and health effects are much longer than in summer, and the correlation is statistically weaker. Thus, the uncertainties of the winter mortality estimation are higher than those of the summer mortality

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[16] We thank GERD JENDRITZKY for this comment.

[17] Same demographic adjustment as in the first run. Ignoring the base value means excluding the lower part in figure 6 as well as part of the upper (demographic) part in figure 6, because today’s base value is expanded by the demographic factor, which is included in the upper part.

[18] Overview of heat victims prognoses in KOVATS and JENDRITZKY (2006), p. 87.

calculation. We apply again model equation (3.2-1), this time in high resolution only (w refers to 10 km times 10 km sectors) with the following new parameter values:

$T_{w,k}$ is now the average reduction of the number of days p. a. with cold stress in the prediction period (A1B, 2071-2100) compared to the reference period (CTL, 1971-2000). k encompasses the classes of perceived temperature with light and moderate cold stress.

$T_{0,w,k}$, the actually measured average number of days p. a. in the reference period 1971-2000, is not available in the high resolution and therefore not included here.

M_w is the mean mortality rate of Germany multiplied by the population size in a 10 km times 10 km square as before.[19] Dividing by 365 in the formula yields the number of deaths per day.

d_k is the relative increase in general mortality M_w due to cold stress of class k. Since we expect less days with cold stress in the future, this mortality increase will occur less frequently. We use again parameter values from LASCHEWSKI and JENDRITZKY (2002) that refer to classes of perceived temperature. The value for moderate cold stress is ca. 9.3 %. The value for light cold stress is computed as the average of mortality from 0 to -12 °C amounting to approximately 5.7 %. [20]

General mortality in winter is about 8 % higher than the yearly average. Hence, the adjustment coefficient d_{season} is 1.08.

According to HASSI (2005) elderly people are very susceptible to cold stress. Thus, it appears plausible to apply the same demographic adjustment factor p as for heat load making both results comparable.[21] (80 % of the affected people are at least 75 years old.)

The resulting map (figure 6) shows the highest expected reduction in winter mortality in areas with the highest population densities, i. e. in the cities. Comparing Hamburg, Berlin and Munich reveals higher mortality risk reductions in the north and north east compared to the south of Germany (in accordance with figure 3).

Adding up the numbers of all 10 km times 10 km sectors yields the average reduction in heat related deaths in Germany p. a. amounting to ca. 5 200 compared with 8 500 p. a. due to heat in summer assuming the same demographic adjustment (age effect). Hence, on average, the dangers of heat dominate some possible health advantages of milder winters by far, and the uncertainties of the estimations for the winter are higher than those of the summer estimations.[22] Figure 7 visualizes these results. A calculation without age effect leads to ca. 3 000 p. a.

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[19] Data from LANDSCAN (2001).

[20] LASCHEWSKI and JENDRITZKY (2002) eliminate the impact of influenza epidemics by smoothing outliers in the mortality data.

[21] Data on England show a higher coldness risk for people aged more than 75 years.

[22] We thank GERD JENDRITZKY for his comment.

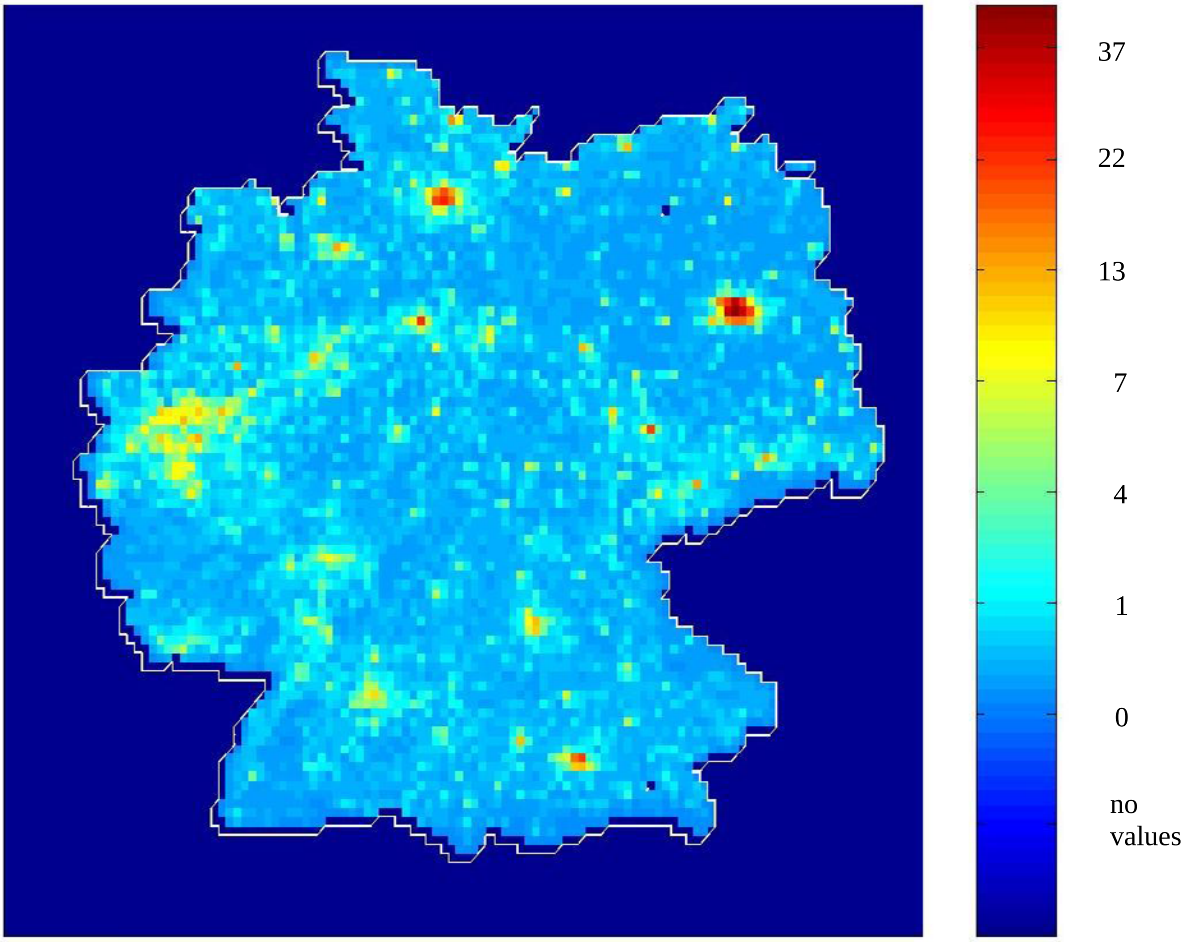

Figure 6: Distribution of the reduction in coldness induced deaths p. a. per 10 km times 10 km sectors in Germany, 2071-2100, A1B

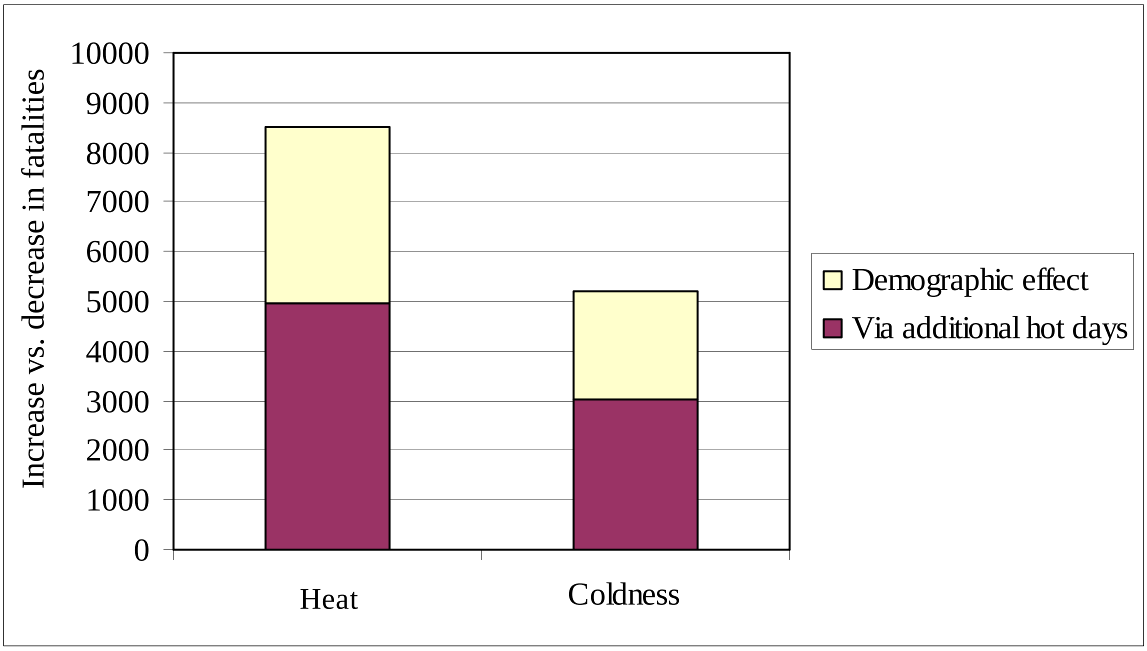

Figure 7: Comparison of the increase in heat related deaths and the reduction in coldness related deaths p. a. in Germany, 2071-2100, A1B, both computed in 10 km times 10 km resolution without base observations from the past

Figure 8 shows the mortality increase in summer minus the mortality decrease in winter in spatial distribution. In most parts of Germany the positive and negative thermal effects roughly balance each other. While only the north-eastern region with its mild maritime climate can benefit from a positive net effect, dangerous heat impacts dominate in the south and south-west. This outcome has to be interpreted with caution though: A zero or slightly positive net effect in some regions does not mean that there is no need to react. Even though there might be advantages in winter, the harmful impacts in summer can be avoided via natural adaptation and feasible adaptation activities.

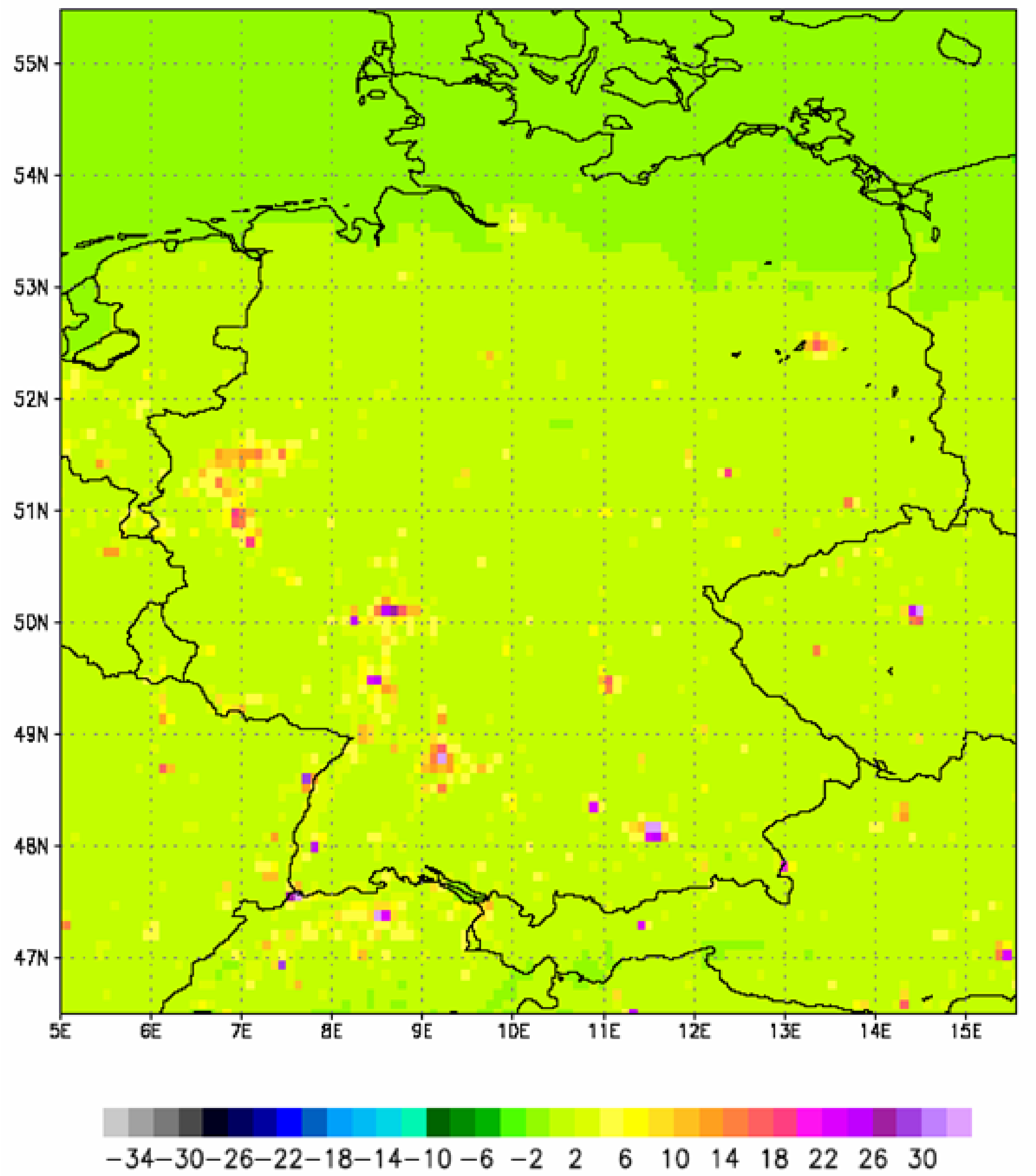

Figure 8: Distribution of additional heat induced deaths minus reduced coldness induced deaths p. a. per 10 km times 10 km sectors in Germany, 2071-2100

4 Economic costs of heat

Casualties represent the most extreme danger of heat. However, heat entails further serious non fatal health impacts. As described in table 1, the European heat wave in 2003 not only caused numerous deaths, but also a significant increase in hospital emergency admissions. This fact is confirmed by a study for the USA: SEMENZA et al. (1999) find 11 % more hospital emergency admissions during the heat wave 1995 in Chicago in general and 35 % more admissions in the age group 65 years and more. The next step would be to consider the number of visits in medical practises, but there is a lack of data.

Thus, as a first attempt, we estimate the expected increase in hospital emergency admissions under emissions scenario A1B and parameter assumptions explained in detail in section 4.1.

Today there are approximately 17 million hospital treatments p. a. in Germany. According to our model calculation this number includes about 24 500 heat related cases. At the end of the 21st century this number might increase to 150 000, which is a multiplication by the factor 6. This calculation ignores adaptation to climate change, but includes demographic change.

Although there are empirical studies on health related diseases, evidence is much weaker than for heat related mortality. Especially in Germany further research could enlighten today's and future thermal health risks.

So far we considered the most serious thermal human health risks. Moreover, heat can negatively affect well-being. It makes us feel uncomfortable and exhausted and entails transpiration and difficulties to concentrate. These aspects are hard to quantify in general and especially concerning leisure time, but become evident when doing physical or mental work. A number of studies investigate work performance or mental and mechanical abilities under different thermal environments and find evidence for strong negative effects of temperatures above the most comfortable level of slightly more than 20 °C. The studies describe human performance reductions in a range of 3 % to 50 % for temperatures higher than the comfortable level, reaching up to 75 % at temperatures of 35 to 37 °C.[23] For instance, office staff reached the maximal performance at 23 °C and only 70 % of the maximum at 30 °C.

Despite the empirical uncertainties, section 4.2 tries to quantify the value of the production loss due to heat from a macroeconomic point of view.

Estimating the economic costs of the different effects of heat entails a number of methodological problems. The main problem is that our temperature scenarios are for the time period 2071 to 2100, while it is not possible to obtain resilient forecasts of the development of the German society and economy over the next 100 years. We thus assess the costs of heat relative to the current gross national income and current prices. Methodologically it is also very difficult to evaluate well-being related to *perceived* temperature. In section 4.1 we use the quantitative indicator "hospital emergency admissions" that can be related to heat waves

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[23] WYON (1986), KAMPMANN (2000), PARSONS (2003), BUX (2006).

to obtain an estimate of the order of the costs associated with serious illnesses. The costs of non-serious illnesses and of the loss in the quality of life are thus not captured in this approach. Calculating the effects of heat on labor productivity in section 4.2, again, the relationship between productivity and heat is very complex and it is only possible to obtain a rough estimate. Adaptation and economic feedback processes are not captured in this study. We abstain from a valuation of fatalities estimated in section 3.1 believing that the results speak for themselves.

4.1 Heat induced hospitalization costs

Our calculation is a first attempt to identify heat induced health costs. Since there is no suitable information on medical treatment in practises and the related costs of treatment and medication, our estimation refers to statistics on the influence of heat on hospital emergency admissions and hospitalization costs. Moreover, it is difficult to identify the quantitative influence of temperature on specific diseases and the costs directly related to those diseases. Hence, we compute the heat induced rise in general hospitalization costs referring to today's costs. A definite forecast of absolute future health care costs is impossible, because we cannot predict the future progress in medical care technology.

The projection of hospital costs is based on the estimation of additional heat days for the 16 reference places in different federal states for the IPCC scenario A1B in 2071 to 2100. The estimation model[24] is similar to formula (3.2-1):[25]

$$H = \sum_{k}^{K} \sum_{w}^{W} (T_{w,k} + T_{0,w,k}) \cdot \frac{S_W}{365} \cdot K_w \cdot h_k^p \qquad (4.2\text{-}1)$$

H	average total hospitalization costs p. a. in Germany in the prediction period 2071-2100 for IPCC scenario A1B
$T_{w,k}$	average number of additional days p. a. in the prediction period in perceived temperature class *k* in location (federal state) *w*
$T_{0,w,k}$	actually measured average number of days p. a. in the reference period 1971-2000 in perceived temperature class *k* in location *w*
S_w	absolute number of new patients over the whole base year 2004 in federal state *w*
K_w	general hospitalization costs per case in federal state *w*
h_k^p	average relative increase in the number of hospital emergency admissions in perceived temperature class *k*, the demographic change *p* (age structure and population size) 2050 relative to 2005 in Germany is included

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[24] Similar McMICHAEL et al. (2002) predicting mortality increases.

[25] Absolute numbers are written in capital letters, relative numbers in small letters.

$T_{w,k}$ and $T_{0,w,k}$ are given by the climate data as before.

S_w denotes the base number of new patients over the whole base year 2004 in federal state w and K_w the related average medical treatment costs per case of medical treatment.[26]

h_k^p is the average relative increase in the number of hospital emergency admissions in the classes of moderate, strong and extreme heat load including the demographic development. There is no information available on the relationship of perceived temperature and emergency cases in Germany. Thus, we apply parameter values in absolute temperatures from a study for England during the heat wave 2003. In this statistical analysis JOHNSON et al. (2005) find a 1 % rise in hospital emergency admissions in the age group up to 64 years and a 6 % increase for people aged 75 years and more at maximal temperatures in the range of about 25 to 31 °C. According to JOHNSON et al. (2005) hospital admissions decrease by 4 % in the age group 65 to 74 years. These values are applied to the class of moderate heat load referring to the temperature range during the heat wave 2003 in England. In London maximum temperatures during the heat wave 2003 were in the range of 35 to 38 °C. So, we apply the following numbers to the class of strong heat stress: A 4 % increase of hospital admissions in the age class up to 64 years, a 5 % decrease in the age group 65 to 74 years and a 16 % rise among people aged 75 and older. Due to a lack of information on extreme heat stress we compute the related hospital admission changes via (linear and exponential) extrapolation.

The relative mean change h_k^p can then be expressed in the following way:

$$\begin{aligned} h_k^p &= share(64-)\cdot p(64-)\cdot h_k(64-) + share(65-74)\cdot p(65-74)\cdot h_k(65-74) \\ &+ share(75+)\cdot p(75+)\cdot h_k(75+) \end{aligned} \tag{4.2-2}$$

Where *share(.)* is the share of people in the age group in parentheses among the people who left hospital in the reference year 2004.[27]

p(.) denotes the size of the age group in parentheses in 2050 relative to 2004.[28] (This includes the change of the whole population size.) We assume that the demographic development is the same across all federal states.

$h_k(.)$ are the parameter values for the classes k of moderate, strong and extreme heat stress and the age groups in parentheses derived from England and London as described above.

A methodologically precise calculation requires the following consideration: Hospitalization costs in the reference year 2004 already include heat induced costs. So, before calculating the future heat related cost increase, today's heat induced costs need to be subtracted:[29]

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[26] STATISTISCHES BUNDESAMT (2004a), STATISTISCHES BUNDESAMT (2004b).

[27] STATISTISCHES BUNDESAMT (2006b).

[28] STATISTISCHES BUNDESAMT (2006a).

[29] The same method is applied when calculating a price net of taxes from a consumer price.

$$H_0 = h_k^p \cdot (S_w \cdot K_w - H_0) \Leftrightarrow H_0 = \frac{h_k^p}{1 + h_k^p} \cdot S_w \cdot K_w \qquad (4.2\text{-}3)$$

H_0 denotes heat related hospitalization costs in the reference year. Thus, total reference year hospitalization costs net of heat effects become slightly smaller than before, because we diminish base costs $S_w \cdot K_w$ by H_0:

$$H = \sum_k^K \sum_w^W (T_{w,k} + T_{0,w,k}) \cdot \frac{S_W \cdot K_w - H_0}{365} \cdot h_k^p \qquad (4.2\text{-}4)$$

The result shown in figure 9 indicates average hospitalization costs of about 495 million € per year in the period 2071 to 2100. This is equal to a multiplication by the factor 6 compared to the climatic reference period 1971 to 2000. On the other hand, this number represents only 0.88 % of total German hospitalization costs (for all kinds of diseases) and 0.27 % of German health care expenses. Figure 9 shows that more frequently and more intensive heat directly causes costs of ca. 222 million € (middle part), while the demographic change (age effect) contributes 191 million € (upper part). The base value of 82 million € (lower part) was not measured in the past but is generated by the model.

This estimation gives an idea of the magnitude of health costs due to dangerous climate change related health risks like serious cardiovascular and respiratory disorders. However, the calculation includes uncertain and changing parameter values, and heat related hospitalization costs cannot be identified exactly. Especially, the reaction of emergency cases to heat h_k^p is a crucial parameter. Hence, we carry out a sensitivity analysis varying the impact of heat on emergency cases by ±30 % according to the magnitudes found in the literature. This yields total hospitalization costs in the range of 300 to 700 million € p. a., represented by the vertical bar in figure 9.

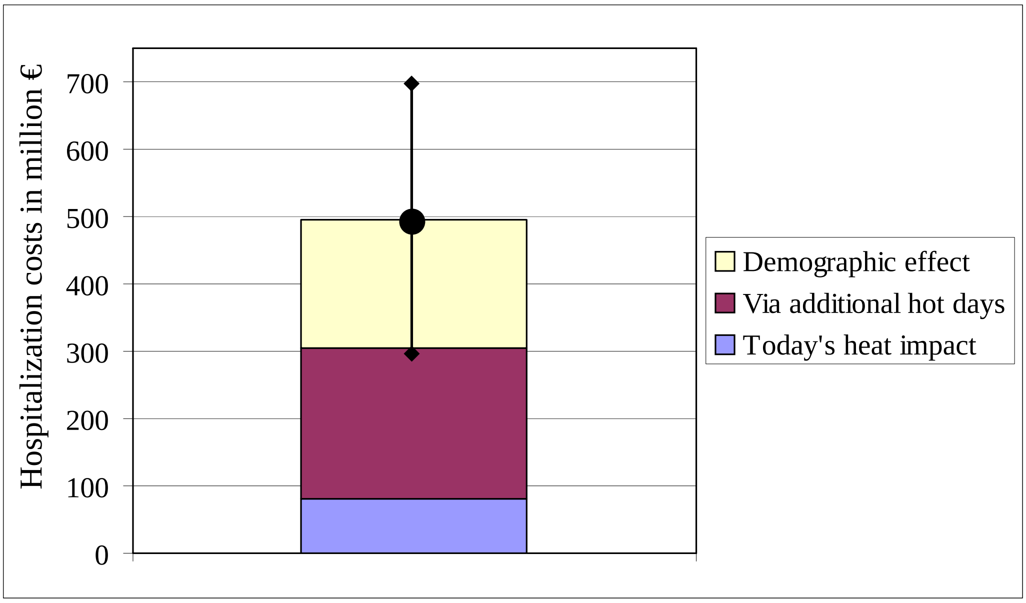

Figure 9: Hospitalization costs p.a. in Germany, 2071-2100 (exponential extrapolation for extreme heat stress)

4.2 Heat induced production loss

Scientific studies on the influence of temperature on work performance find a large range of results.[30] Accordingly, a detailed forecast needs to distinguish between indoor and outdoor work as well as mental and physical work. These aspects have not been implemented in this first attempt and leave room for further research. Of course, taking into account today's sectoral economic structure would still not cover future changes in the sectoral pattern of the economy that one cannot predict. Like in our estimations described before, we neglect any kind of adaptation to climate change. In this calculation we do not take into account any effects of coldness, rain or storms on production, either.

Assuming that heat directly reduces labor output, from a macroeconomic point of view the estimation model has the following form:[31]

$$L = \sum_{k}^{K} \sum_{w}^{W} T_{w,k} \cdot \frac{GDP_w + L_0}{365} \cdot q \cdot g_k \tag{4.3-1}$$

$$L_0 = g_k \cdot (L_0 + GDP_w) \Leftrightarrow L_0 = \frac{g_k}{1 - g_k} \cdot GDP_w \tag{4.3-2}$$

L	average GDP loss p. a. in Germany in the prediction period 2071-2100 for IPCC scenario A1B
L_0	heat related GDP loss in Germany in the reference year 2004 (generated by the model)
$T_{w,k}$	average number of additional days p. a. in the prediction period in perceived temperature class *k* in location (federal state) *w*
GDP_w	gross domestic product in the reference year 2004 in federal state *w*
q	wage share in Germany in the reference year 2004
g_k	mean relative productivity reduction when the threshold of perceived temperature class *k* is reached

GDP_w is the gross domestic product on German federal state level in 2004. This implies that the forecast refers to the GDP in the reference year 2004, because the development of GDP cannot be predicted till the end of the 21st century. Demographic change is neglected as well as technological progress, since both aspects cannot properly be implemented in a simple model. A possible interpretation is that the output expansion via technological progress just compensates the output loss due to a shrinking and ageing society.

As in the calculation of hospital costs we account for *today's* negative heat effects. German GDP would be higher, if temperatures were in the range of slightly more than 20 °C, that is

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[30] WYON (1986), KAMPMANN (2000), PARSONS (2003), BUX (2006).

[31] Absolute numbers are written in capital letters, relative numbers in small letters.

most comfortable for human beings, during the whole year. Equations (4.3-2) describe how to compute today's heat impact on production L_0.

The wage share q is defined as labor income relative to total income in the economy, which is 68.4 % in Germany in the reference year 2004. We assume the same wage share in all federal states.[32] It is unclear to what extent the productivity of machines, controlled by people who suffer from heat, also decreases. Thus, production losses focus on the production factor labor only. Again, changes of q due to the demographic and technological progress cannot be predicted in this simple model.

Since the quantitative impact of heat on work performance is unclear in the literature, we make the conservative assumption that there is no negative effect of moderate heat load and apply the range of scientific results cited by BUX (2006) for g_k: a productivity reduction of 3 % to 12 %.

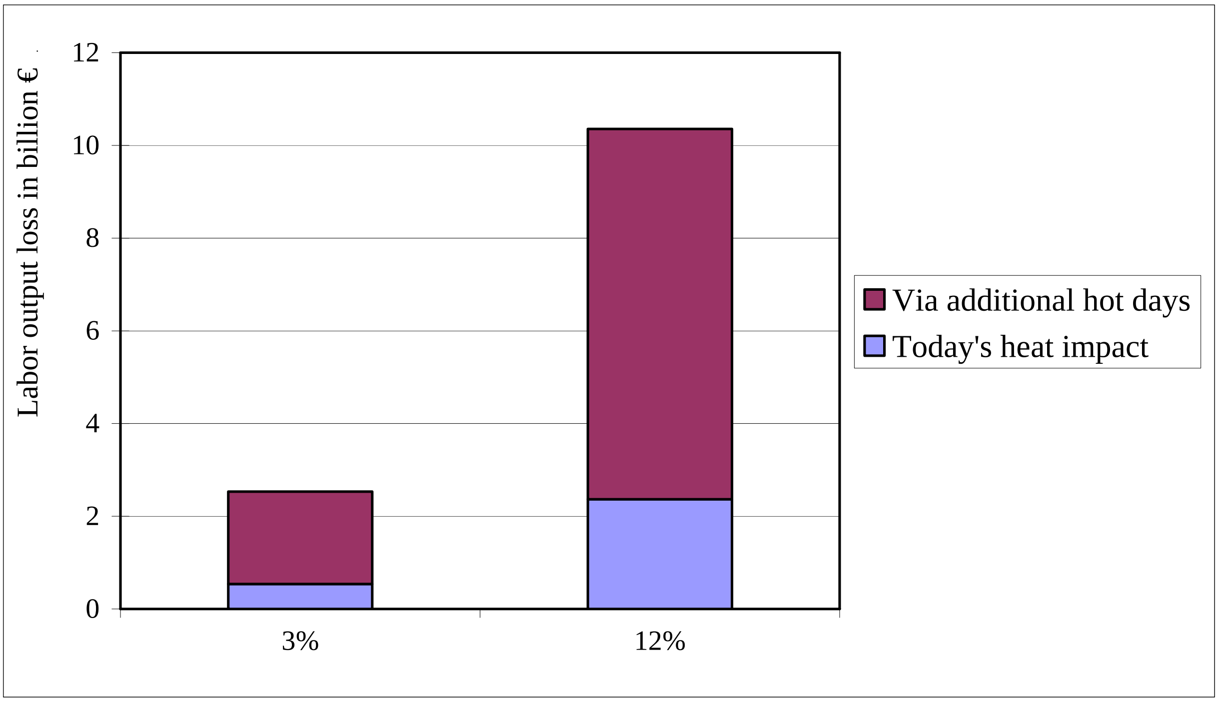

Figure 10: Heat related production loss in Germany p. a., 2071-2100 under two different impact assumptions

Figure 10 shows the economic loss due to a heat induced labor productivity decrease under two different impact assumptions. In the first case labor productivity is assumed to fall by 3 % on days with strong or extreme heat stress. Today's reference heat loss generated by the model amounts to approximately 540 million € (lower part), equal to 0.03 % of today's GDP; the estimated future loss is almost 2 billion € (upper part), together ca. 2.5 billion € or 0.12 % of today's GDP.

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[32] STATISTISCHES BUNDESAMT (2006c), Volkswirtschaftliche Gesamtrechnung, 24.4, referring to 2004.

Assuming g_k equal to 12 % for strong and extreme heat, the estimation results in a base value of about 2.4 billion € or 11 % of today's GDP and in an additional future heat loss of almost 8 billion €, in total ca. 10.4 billion € or 0.48 % of today's GDP.

If strong heat stress causes a productivity loss of 3 % and extreme heat a loss of 12 %, the resulting total economic loss is 6 billion €, which is between the results described above.

Using numbers of 30 % to 50 % mentioned in the literature for g_k leads to much higher heat related losses today (2.7 % of today's GDP) and in the future (5 % of today's GDP). These outcomes need to be treated with caution though, since this first attempt does not differentiate between different kinds of work. Certain activities like hard physical outdoor work are indeed affected drastically by heat, while office work in air conditioned rooms is not affected at all.

The calculations in this study are based on IPCC scenario A1B. Using IPCC scenario B1 (low emissions) and a 12 % heat impact on labor productivity yields an additional loss of ca. 4.2 billion €, which is significantly lower than in the A1B scenario (almost 8 billion €, representing the expected emissions development). Consequently, a successful reduction of greenhouse gas emissions clearly lowers the economic loss.

Figure 11 illustrates the different magnitudes of average per capita income losses across the German federal states.[33] The southern states Bavaria (Bayern) and Baden-Württemberg not only face the most severe heat load, but also have the highest total GDPs and high per capita incomes. Consequently, the per capita income losses reach around 50 € per person and year in Bavaria and Baden-Württemberg, while the mean income reductions in Schleswig-Holstein and Mecklenburg Western Pomerania (Mecklenburg-Vorpommern) amount to ca. 5 € p. a. and person only. Although the heat load is rather low in the northern cities Hamburg and Bremen, their estimated per capita income losses rise to values around the German average loss of ca. 24 € p. a., because the per capita incomes in these northern cities are relatively high.

These results have a similar magnitude as cost estimates of around 10 billion € for Europe for the heat summer 2003.[34] So far the economic impacts of heat waves are not evident in countries' growth rates.[35] According to our results, heat already has a high negative influence on the German economy which will substantially sharpen in the future. The main caveat is that we do not take into account who is affected by heat to what extent and who is not, and that such a disaggregated view is hard to predict for the end of the 21st century. Maybe most people will work in air conditioned environments, and machines will do any physical work, so that heat will have little influence on labor output.

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[33] Population data for 2004 from STATISTISCHES BUNDESAMT (2005), Bevölkerungsfortschreibung; graphic based on a map of Germany from UNIVERSITÄT TRIER (2007).

[34] MICHAEL HEISE, chief economist of the Allianz Group, cited in WELT AM SONNTAG (23.07.2006), this number includes other economic effects of heat besides health impacts.

[35] MICHAEL HEISE and CLAUDIA KEMFERT, cited in WELT AM SONNTAG (23.07.2006).

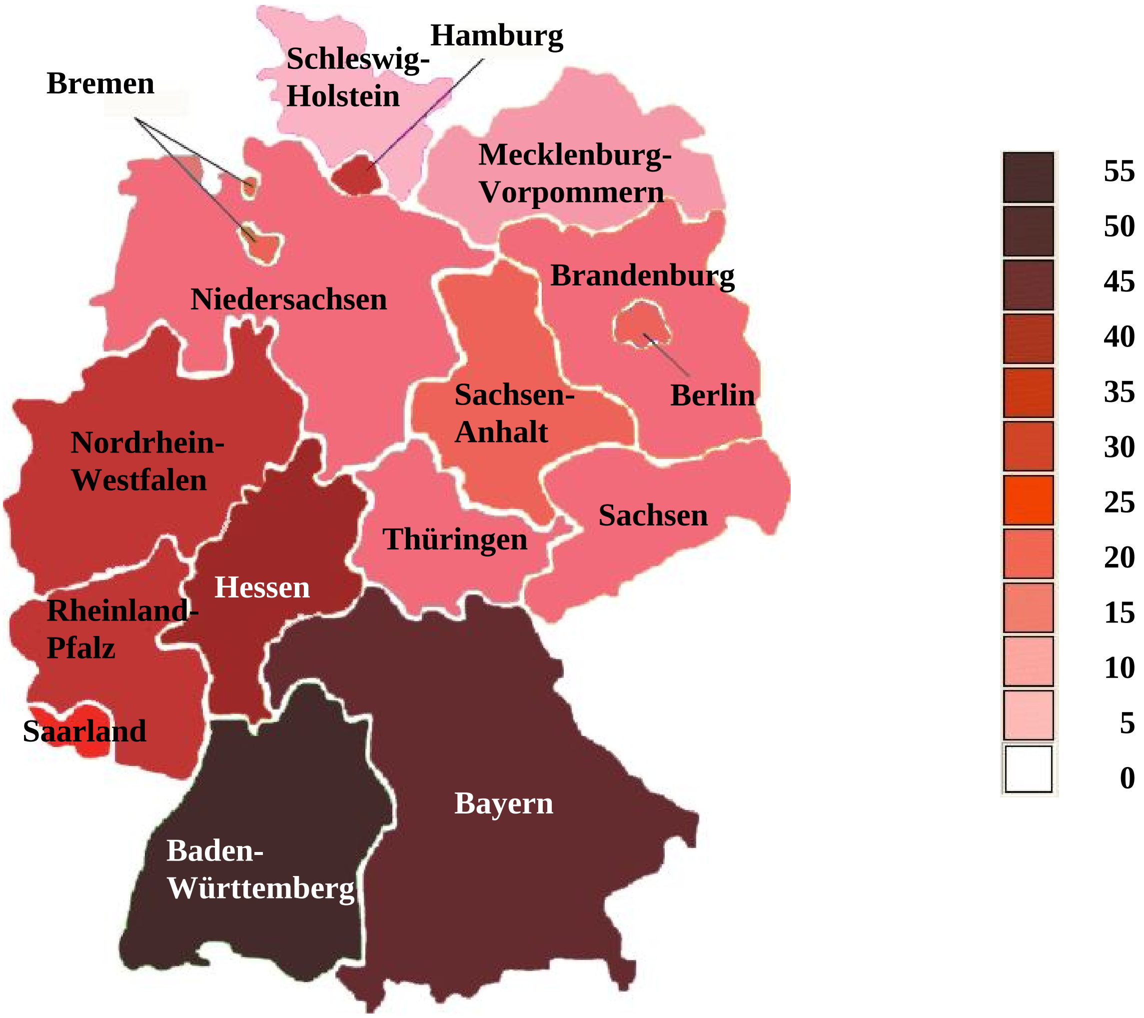

Figure 11: Heat related income losses p. a. and per capita, 2071-2100 in German federal states in 2004-€

5 Conclusion

Climate change is a complex phenomenon that alters the whole environment in which humans live. Assessing the potential impacts of climate change on human health provides already a challenging task. Evaluating these effects in terms of the economic cost that these health effects may impose on the German economy is even more challenging. The range of potential health effects from climate change is quite large encompassing direct effects such as the impact of changing temperatures on human well-being but also indirect effects such as the impacts of climate induced storms and floods, tick-borne and food-borne diseases and allergies causing plants. Many of these indirect impacts are not well understood so far. Therefore, the focus of this study is concentrated upon the effects of rising temperatures on health and well-being.

The study relies on high resolution computations of climate scenarios for the period 2071 to 2100 in Germany which are used to calculate the change in thermal stress in terms of the number of days with high or low temperatures. Instead of using absolute temperatures an index similar to a wind chill factor is used which better describes the subjectively felt heat than the often used absolute temperatures since it incorporates humidity, the length of the heat spell and other factors related to weather induced well-being. Different IPCC emission scenarios are run with the climate model in order to compute the heat and cold stress for the end of the century.

These scenarios are then used to derive rough estimates of different health problems starting with the potential changes in mortality, the potential costs for treating heat related health effects, and the economic costs of a reduced productivity of people while working under increased temperatures. These estimates are all performed without considering adaptation strategies. This is done for two reasons: First of all, the estimate without adaptation illustrates the size of the problem that one can expect in the future if no measures are taken. Secondly, an analysis of adaptation options and their costs is so far very difficult if not impossible since these issues have not been subject to research efforts.

The events of the heat summer 2003 with estimated 25 to 35 thousand heat related deaths in Europe provide the empirical basis for computing the additional heat related casualties in Germany for the period 2070 to 2100. Based on the 2003 data and an analysis of observations during the years 1968-1997 in Baden-Württemberg we expect 5 to 15 thousand additional heat related casualties per year by the end of the century (multiplication by 3.7 compared with today). This mortality increase is partly due to the rising share of elderly people who are known to suffer most from heat waves. Partly it is due to the strong increase in days with extreme heat. The negative effects of heat waves, mainly in the south of Germany, dominate the reduction in the number of deaths from milder winter periods by far. We do not take into account that a certain number of sick and elderly people might have died even without heat in the near future. Subtracting these casualties can possibly reduce the mortality numbers by less than 25 % (in the short-run).

The majority of negative health effects will not lead to deaths but may still require medical assistance. Because evidence on the number of heat related health problems is not clear and the costs of ambulant treatment are not known we concentrate on heat induced hospital admissions. The climate scenarios result in hospitalization costs of 300 to 700 million € p. a. at today’s prices in Germany (multiplication by 6 compared with today). However, these results are not well supported by the medical evidence about heat related hospital admissions. Studies on this issue come to conclusions showing a large variance of results.

Finally, we look at the achievement potential of people under high temperatures which may affect their productivity in production processes. Medical studies on the relation of heat and work performance come to quite diverse results. A first calculation results in a reduction of German GDP by 0.1 to 0.5 percent (multiplication by 4 compared with today). These costs are significantly higher than the estimated hospitalization costs.

In summary, this study represents a first attempt to quantify the effects of climate change on health in Germany. The focus on direct temperature related effects was determined both by the size of the project and by the lack of conclusive results from the different disciplines concerned with the assessment of the quantitative effects such as the spread of tick-borne and food-borne diseases, the spread and risk of other extreme events, or plants that cause allergies. Even in the case of heat waves and cold spells we had to rely on a number of ad hoc assumptions and to a large extent on literature reviews. The results could become more robust within a larger research effort that is supported by further expert knowledge from many disciplines.

One of the challenging tasks would be to look at the different adaptation options. Adaptation encompasses natural changes (human beings blood circulation etc.), behavioural changes (changes in lifestyles, emergency plans) and suitable measures (air-conditioning, other working hours). While natural and behavioural adaptation is hard to quantify in economic terms, the cost of private and public adaptation measures could be estimated. This could lead to an assessment of optimal adaptation strategies to health related climate change effects.

The productivity effects of heat seem to impose the highest monetary cost of health related climate impacts. A thorough analysis of the working conditions and the impact of temperature on human productivity would greatly enhance the quality of the estimates. This would need to be accompanied by a high resolution representation of economic activity in order to better identify the hotspots of impact. Also adaptation strategies will become an important aspect for alleviating the negative productivity effects.

The simulation results on the basis of the different IPCC scenarios also show that the health impacts can differ substantially depending on the emission path of greenhouse gases, thus indicating the benefits of mitigating climate change can be substantial. An analysis of the benefits of mitigation and the cost of adaptation would constitute a further fruitful extension of the research that is presented here.

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7 Appendix

City	Federal state	Latitude	Longitude	CTL	OBS	B1 - CTL	A1B - CTL	A2 - CTL
		Degree		Number of hot days				
Schleswig	Schleswig-Holstein	54.5	9.6	1.6	0.7	0.7	3.2	2.4
Hamburg	Hamburg	53.6	10.0	11.0	1.9	2.6	9.2	6.4
Schwerin	Mecklenburg-Vorpommern	53.6	11.4	3.1	2.2	1.9	5.6	4.1
Bremen	Bremen	53.0	8.8	8.3	2.3	2.9	8.3	7.0
Hannover	Niedersachsen	52.5	9.7	9.3	2.5	4.8	9.6	9.2
Magdeburg	Sachsen-Anhalt	52.1	11.6	14.7	5	5.7	12.2	11.1
Potsdam	Berlin, Brandenburg	52.4	13.1	7.6	3.9	5.1	9.6	8.8
Düsseldorf	Nordrhein-Westfahlen	51.3	6.8	13.7	3	7.3	15.8	13.1
Leipzig	Sachsen	51.4	12.2	13.1	3.5	6.8	12.4	11.8
Erfurt	Thüringen	51.0	11.0	13.5	2.4	7.5	14.2	11.9
Trier	Rheinland-Pfalz	49.8	6.7	12.4	4.6	10.1	16.2	15.6
Frankfurt/M.	Hessen	50.0	8.6	18.9	4	12.0	19.2	19.5
Saarbrücken	Saarland	49.2	7.1	13.2	2.2	10.7	16.8	17.4
Stuttgart	Baden-Württemberg	48.7	9.2	23.1	3.3	13.8	22.9	22.4
Regensburg	Bayern	49.0	12.1	21.2	5.1	11.8	21.9	19.9

Table 3: Number of hot days according to the control run CTL (simulation 1971-2000), actual observations OBS (1971-2000), and estimated additional number of hot days for different IPCC scenarios (each expressed as forecast 2071-2100 minus control run 1971-2000) in cities in the German federal states

We thank the Umweltbundesamt for the REMO data, Deutscher Wetterdienst for providing the climate "Michel" model and Prof. Dr. Wolfram Mauser for contributing geographical population data. Special thanks to Dr. Birger Tinz for computing and documenting the climate forecasts and for helpful comments. We also thank Prof. Dr. Gerd Jendritzky for further comments.