Costs of Climate Change

The Effects of Rising Temperatures

on Health and Productivity in Germany

Preprint Version for Ecological Economics

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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

1 Introduction

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 an 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 heat load on human health and well-being but also indirect effects that result from climate induced storms and floods, tick-borne and food-borne diseases and allergies causing plants. Since it is difficult to attribute future economic costs to these indirect impacts, this study concentrates on the direct effects of heat load.

In the summer of 2003 thousands of people died in Germany and 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 estimates of the tremendous health impacts of the heat wave 2003 – in terms of increased mortality and increased emergency hospital admissions for different European States.

Table 1

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, wind and short- and long-wave radiant fluxes. Furthermore, different risks such as adverse physical conditions (high blood pressure, heart, kidney, liver or metabolic diseases etc.) and low physical fitness influence the effect of heat load. The main individual risk, however, is age. Older people (as well as young children) are most susceptible to heat, because weakness and diseases occur increasingly with higher age while the human adaptation capacity decreases. Therefore it is not surprising that fatalities due to heat load mostly occur in hospitals and nursing homes.[1]

Generally, humans are able to adapt to changing climatic conditions via more efficient sweating and improved blood- and fluid-circulation. We call this physiological adaptation. High temperatures in the first half of a year, 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 warning systems can help to adapt behaviour on time. They lead to the category of technical solutions (financed by public or private investment). Climate related building design and air-conditioning in buildings are typical technical solutions. Adaptation possibilities are

[1] Calado et al. (2005).
[2] Kalkstein and Davis (1989).

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).

Against this background, the aim of this study is to quantify climate induced health risks for Germany. It addresses scientists, decision makers, medical care personnel and the public, providing findings on future health risks, so that appropriate mitigation and adaptation measures can be derived. This interdisciplinary work combining scientific knowledge from the meteorological, geographical, medical and economic field is probably one of the first attempts to systematically quantify future negative health effects of climate change in Germany. The focus is on such effects for which there is at least some quantitative information. For this reason we estimate heat induced mortality, hospitalization costs and *losses in labor productivity*. For mortality we also consider the effects of less coldness in winter. The estimates predict a regionally differentiated increase in heat load within Germany and consequently substantially higher negative health impacts and production losses in some regions. The mortality rise during the summer clearly dominates the possible mortality decrease during the winter. (For more detailed results than presented in this study, see Hübler and Klepper 2007). Since there are many uncertainties in past parameter values and unknown future development paths, the study is only a first step in this direction. And it has the drawbacks of a typical partial equilibrium model. The study does neither account for future changes in the sectoral pattern of the economy nor for changes of prices and quantities that are relevant for assessing future economic impact. Moreover, it does not include future adaptation, which can significantly reduce the negative effects. (The estimations are based on a population that is more or less adapted to the present climate.)

The paper proceeds as follows. In section 2 we explain forecasts of the climate model REMO[3] based on IPCC scenarios for Germany in the period 2071-2100. Using these climate data we compute additional days p. a. (per annum) with heat load. In section 3 we derive approximations of the resulting increase in mortality as an indicator for the future health risk. In section 4 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 apply 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.

[3] REMO has been criticized concerning the estimation of precipitation (the use of different time scales and deviations of the results depending on the spatial resolution). The problem has been explained and corrected (Max-Planck-Institut 2006), and precipitation is not the focus of our examination.

2.1 Employed climate models and climate scenarios

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

Future emissions paths depend on the uncertain development of the world economy. The forecasts therefore use the emission scenarios of the IPCC (2001) that are based on different plausible assumptions on important determinants for emissions such as economic activities and economic integration. Scenario A2 is the business as usual case. In scenarios A1B and B1 emissions rise till 2050 and then fall until 2100. While B1 implies rigorous climate protection measures, this study mainly refers to scenario A1B with a medium emissions increase.

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, radiation, clothing and physical activity of affected persons to calculate the so-called perceived temperature for a typical reference person. Perceived temperature is a measure of how temperature affects human well-being. For instance, the heat wave in 2003 had such severe effects in France because humidity was higher than in other countries like Germany.

For practical applications it is useful to convert the perceived temperature into classes of thermal perception or classes of thermo-physiological stress according to Jendritzky et al. (2000). The 6 am and 12 am values of perceived temperatures are smoothed by applying half a Gaussian filter over 41 days. The longer ago 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.[6] This method imitates the human ability to adapt to climatic changes in the short-run. The procedure is also used in the heat warning system of the German Weather Service.[7]

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 according to Jendritzky et al. (2000). In the illustrations heat stress encompasses the classes of strong and extreme heat stress, i. e. perceived temperatures of at least 32 °C .

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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.
[5] Fanger (1972), Gagge et al. (1986), VDI (1994 and 1998), Staiger et al. (1997), Jendritzky et al. (1990), Jendritzky et al. (2000). For a description of risk factors see Havenith (2005).
[6] Koppe and Jendritzky (2005), Koppe (2005).
[7] http://www.dwd.de/de/WundK/Warnungen/Hitzewarnung/Kriterien.htm.

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 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 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. (Note that acclimatisation will weaken the north-south gradient of heat stress.) Experiment A1B predicts one additional day with strong or extreme heat at the coast in the north, seven to 15 in the middle of Germany and 26 near the Lake Constance and in Munich (Figure 1a). Scenario B1 with lower emissions yields one additional hot day at the coast and around 18 near the Lake Constance in the south (Figure 1b). The results of scenario A2 (not shown) are very similar to those of A1B. 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, that means, higher temperatures in densely populated areas compared with the surrounding areas.

Figure 1a

Figure 1b

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. Figure 2 shows for Frankfurt/Main the rising trends of heat days p. a. for B1, A1B, A2 and for the base run CTL. 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

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.[8]

Analogously to the heat forecast we estimate future cold stress 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, i. e. perceived temperatures of 0 °C or lower, since there were no days with strong and extreme cold stress (perceived temperatures of -26 °C or lower) and only few days with moderate cold stress (from -13 °C to -26 °C) in the past (in CTL).

Figure 3

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 (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 ca. two days per year is found at the upper Rhine rift in the south-west.[9] Moreover, the reduction of average coldness rises with altitude, which is obvious in the higher German regions and in the Alps.

3 Temperature induced fatalities

In this section we use information on the relationship of temperature and mortality from the literature and combine it with the heat and coldness scenarios described before as well as with statistical population data in order to estimate future climate change induced changes in mortality. Section 3.1 refers to heat load and section 3.2 to cold stress.

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]

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

[8] It is not clear if events of strong cold stress will occur more often in the future.
[9] Since we include light cold stress, the reported total decrease of cold days becomes relatively high.
[10] Absolute numbers are written in capital letters, relative numbers in small letters.

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

In two different runs w represents first one location for each federal state (W = 16) 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 deaths in general (due to any reason for death) 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 temperatures. Based on Laschewski and Jendritzky (2002) we compute the mortality increase for moderate

[11] Statistisches Bundesamt (2006a).
[12] Data from Landscan (2001).

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.

Furthermore, we take the seasonal adjustment of the general mortality, denoted by d_{season}, into account, because winter mortality is circa 8 % higher than the yearly average mortality while summer mortality is about 8 % lower.[13] The mortality change referring to the summer is therefore multiplied by the factor 0.92.

p is the demographic adjustment coefficient. The number of people below the age of 75 will decrease by 18 % (*p(74-)* = 0.82) until 2050, 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 in 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 parameter assumptions.[15] The following formula captures the 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

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) which can be disaggregated as follows: Today's number of deaths amounts to ca. 4 500 (bottom part in Figure 4). This value is not measured 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

[13] Calculation based on Laschewski and Jendritzky (2002).

[14] Calculation with data from 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).

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 ca. 9 000 additional future deaths p. a.

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 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. The heat event shifts the date of death forward. As a consequence the mortality ratio can decrease under its average level after the heat event. Subtracting these casualties will in the short-run probably result in an up to 25 % reduction of the mortality numbers for Germany. However, Koppe (2005) finds (referring to Baden-Württemberg, 1968-2003) that the extent of the "harvesting effect" differs substantially, being much higher for people younger than 75 years (85.4 % for moderate heat load and 50.7 % for strong heat load) than for people in the age of at least 75 years (17.7 % for moderate heat load, only 2.1 % for strong heat load).

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, most heat fatalities will be in the regions with the highest population densities, i. e. in the cities, and the health risk increases from north-east to south-west (in accordance with Figure 1a).

Figure 5

Adding up the 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).[16]

These results have a similar order of magnitude as studies for the UK, Portugal and Australia.[17] 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.

[16] 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.

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. The time lags of low temperature events and health effects are much longer than in summer, and the correlation is statistically weaker. The medical causality is different, and it is not evident, whether the health risk steadily increases with lower temperatures. To get an idea of the effects in winter we nevertheless apply again model equation (3.2-1), this time in high spatial resolution only (w refers to 10 km times 10 km sectors) with the following new parameters:

$T_{w,k}$ 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. with cold stress in the reference period 1971-2000, is not available in the high resolution and therefore not included here.

M_w is the general mean mortality rate of Germany multiplied by the population size in a 10 km times 10 km square as before.[18] 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 %.[19]

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.[20] (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).

Figure 6

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[17] Overview of heat victims prognoses in Kovats and Jendritzky (2006, p. 87)
[18] Data from Landscan (2001).
[19] Laschewski and Jendritzky (2002) eliminate the impact of influenza epidemics by smoothing outliers in the mortality data.

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 the possible health advantages of milder winters by far, and the uncertainties of the estimations for the winter are higher than those of the summer. Figure 7 visualizes these results. A calculation without the age effect leads to only ca. 3 000 p. a.

Figure 7

A comparison of Figures 5 and 6 shows that 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.

4 Economic costs of heat

Casualties represent the most extreme danger of heat. As described in Table 1, the European heat wave in 2003 also caused a rise 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. Nevertheless, the empirical evidence is much weaker than for heat related mortality. Moreover, heat can negatively affect well-being making us feel uncomfortable and exhausted and entails difficulties to concentrate. These aspects are hard to quantify, but become evident when doing physical or mental work.

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 referring to the current gross national income, to the current sectoral structure, to current prices and to today’s (medical and general) technologies. There is also a lack of hospitalization data referring to perceived temperatures. Again, we neglect any kind of adaptation to climate change.

In section 4.1 we use the indicator “hospital emergency admissions” to get an idea of the costs associated with serious illnesses. In section 4.2 we obtain a rough estimate of the effects of

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

heat on labor productivity. (We abstain from a monetary valuation of the fatalities estimated in section 3.1.)

4.1 Heat induced hospitalization 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.

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[21] is similar to formula (3.2-1):[22]

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

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

$T_{w,k}$ 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.[23]

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

[21] Similar McMichael et al. (2002) predicting mortality increases.
[22] Absolute numbers are written in capital letters, relative numbers in small letters.
[23] Statistisches Bundesamt (2004a), Statistisches Bundesamt (2004b).

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 emergency 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:

$$h_k^p = share(64-) \cdot p(64-) \cdot h_k(64-) + share(65-74) \cdot p(65-74) \cdot h_k(65-74) \\ + share(75+) \cdot p(75+) \cdot h_k(75+) \qquad (4.2\text{-}2)$$

Where *share(.)* is the share of people in the age group in parentheses among the people who left hospital in the reference year 2004.[24]

p(.) denotes the size of the age group in parentheses in 2050 relative to 2004.[25] (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:

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

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:

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

[24] Statistisches Bundesamt (2006b).
[25] Statistisches Bundesamt (2006a).

The result shown in Figure 8 indicates average hospitalization costs of about 495 million € per year in the period 2071 to 2100. This corresponds to an increase by a 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 8 shows that more frequent 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.

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 8.

Figure 8

4.2 Heat induced production loss

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.[26] For instance, office staff reached the maximal performance at 23 °C and only 70 % of the maximum at 30 °C. However, the range of results is large, and the economic interactions are complex. A more detailed forecast would need 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. 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:[27]

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

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

[26] Wyon (1986), Kampmann (2000), Parsons (2003), Bux (2006).
[27] Absolute numbers are written in capital letters, relative numbers in small letters.

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 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.[28] 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, 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, i. e. a productivity reduction of 3 % to 12 %.

Figure 9 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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[28] 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 0.11 % 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.

Figure 9

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

Using numbers of 30 % to 50 % mentioned in the literature for g_k, the heat related losses today (2.7 % of today's GDP) and in the future (5 % of today's GDP) are much higher. These outcomes need to be treated with caution though, since this first attempt does not differentiate between different kinds of work.

The calculations 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 10 illustrates the different magnitudes of average per capita income losses across the German federal states.[29] 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 are about the German average loss of ca. 24 € p. a., because the per capita incomes in these northern cities are relatively high.

The results have a similar magnitude as cost estimates of around 10 billion € for Europe for the heat summer 2003.[30] Nevertheless, so far the economic impacts of heat waves have not been evident in countries' growth rates.[31] According to our results, heat already has a high negative influence on the German economy today 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.

Figure 10

[29] Population data for 2004 from Statistisches Bundesamt (2005), Bevölkerungsfortschreibung; graphic based on a map of Germany from Universität Trier (2007).
[30] 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.
[31] Michael Heise and Claudia Kemfert, cited in Welt am Sonntag (23.07.2006).

5 Conclusion

Climate change will lead to a number of detrimental health impacts. In this study we focus on the effect of heat load on human well-being. The study is based on high resolution computations of climate data for the period 2071 to 2100 in Germany referring to IPCC scenarios. We calculate the change in the number of days with thermal stress. For this purpose, we apply perceived temperatures including humidity, wind and radiation, which better describe the heat subjectively felt by human beings than normal absolute temperatures. The results are then used to derive rough estimates of heat related health problems: the potential change in mortality, the potential costs of hospital emergency admissions, and the macroeconomic costs of a reduced work performance.

Heat induced mortality is examined as an indicator for the future health risk, since in contrast to particular heat related diseases sufficient statistical information on mortality is available. We expect an increase of heat related casualties by a factor of 3.7 at the end of the century compared with today. This increase is partly due to the rising share of elderly people who are known to suffer most from heat waves. The negative effects of heat waves, mainly in the south of Germany, dominate the reduction in the number of casualties because of 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 up to 25 % (in the short-run).

The majority of negative health effects will not lead to deaths but may require medical assistance. Due to a lack of data we concentrate on heat induced hospital admissions. We find future hospitalization costs of 300 to 700 million € p. a. for Germany at today’s prices, i. e. a 6-fold cost increase.

Finally, we look at the labor productivity of people under future heat load. A rough calculation yields a reduction of German GDP by 0.1 to 0.5 percent, i. e. a loss 4 times larger than at today’s climate. These costs are significantly higher than the estimated hospitalization costs.

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 quantitative assessment of climate related health risks. The underlying empirical evidence of heat related hospital admissions and thermal impacts on work performance shows a large variance. The results could become more robust if a larger research project brought together further interdisciplinary expert knowledge. A more detailed analysis of the working conditions in different sectors would enhance the quality of the estimates. Furthermore, more research is necessary to quantify the influence of climate change on health and productivity during the cold period of the year.

These estimates are all performed without considering physiological adaptation of the population and without including adaptation strategies in order to illustrate the size of the problem and because we did lack information on adaptation costs. Taking adaptation into account would change the numerical results and the appearance of the presented figures. One of the challenging tasks would be to assess different adaptation options and the related costs. While physiological and behavioural adaptation are hard to quantify in monetary terms, the cost of private and public adaptation measures (such as building design and urban planning) could be estimated. The simulations based on 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 compared with the costs of adaptation would constitute a fruitful extension of the research that is presented here.

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Table 1: Estimated impacts of the European heat wave in 2003[32]

Place	Number of cases of heat mortality	Number of hospital emergency admissions	Source
Europe	25 000 - 35 000		Cited in Koppe et al. (2003), compare with Kosatsky (2005)
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, 70 % mortality increase among people aged 75 to 94 years, 120 % mortality increase for people older than 94		EEA (2004), Kosatsky (2005)
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)

[32] For further literature reviews on heat related mortality see Basu and Samet (2002) and Kovats and Jendritzky (2006).

Figures

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

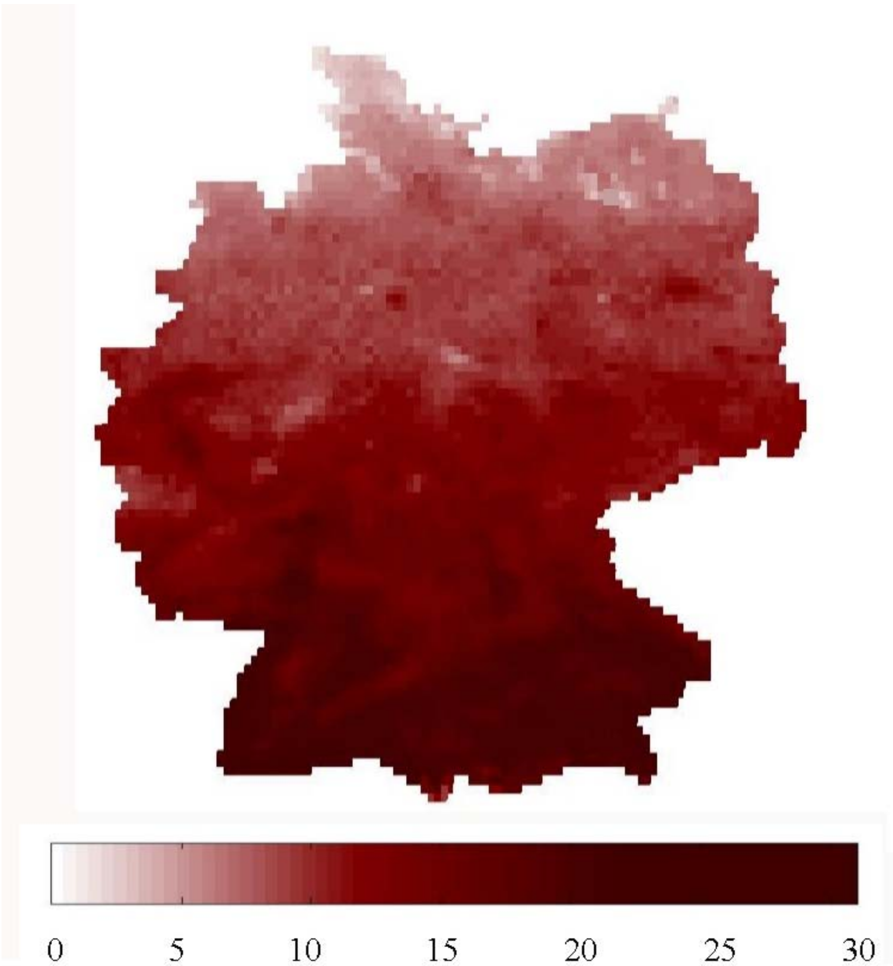

Figure 1b: Additional number of days with (strong or extreme) heat stress, REMO experiment B1 (2071-2100) minus control run CTL (1971-2000) in Germany

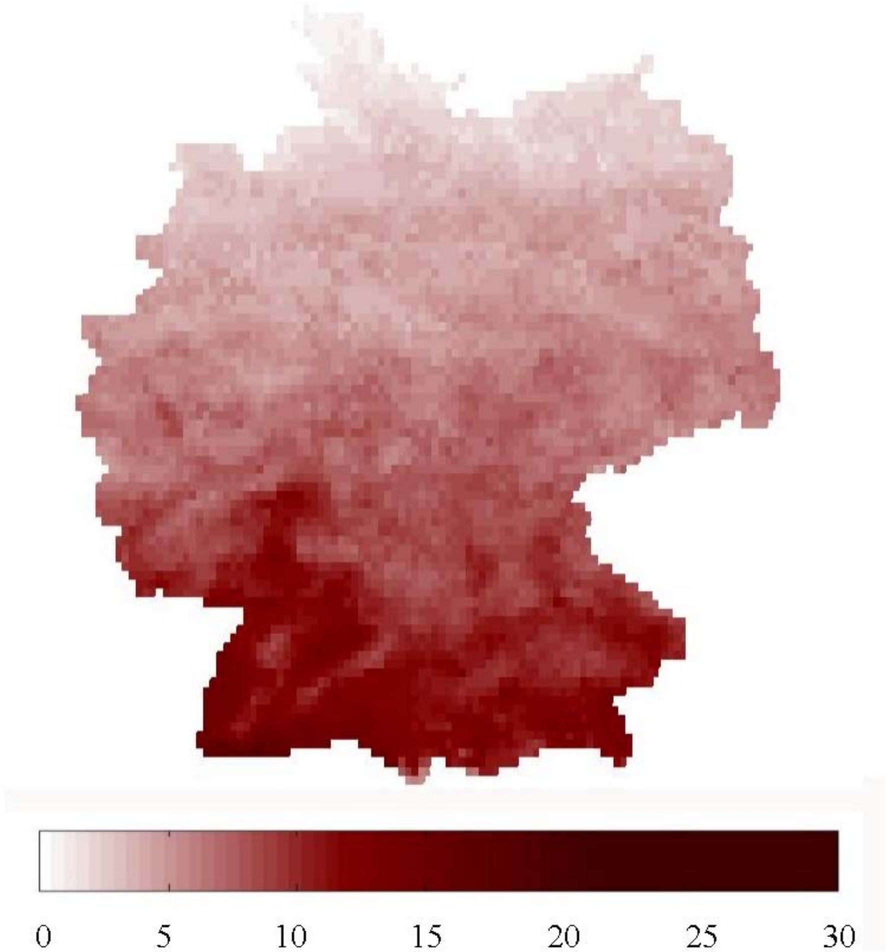

Figure 2: Additional number of days per year with strong or extreme heat stress in Frankfurt/Main (Hessen), moving averages over 5 years

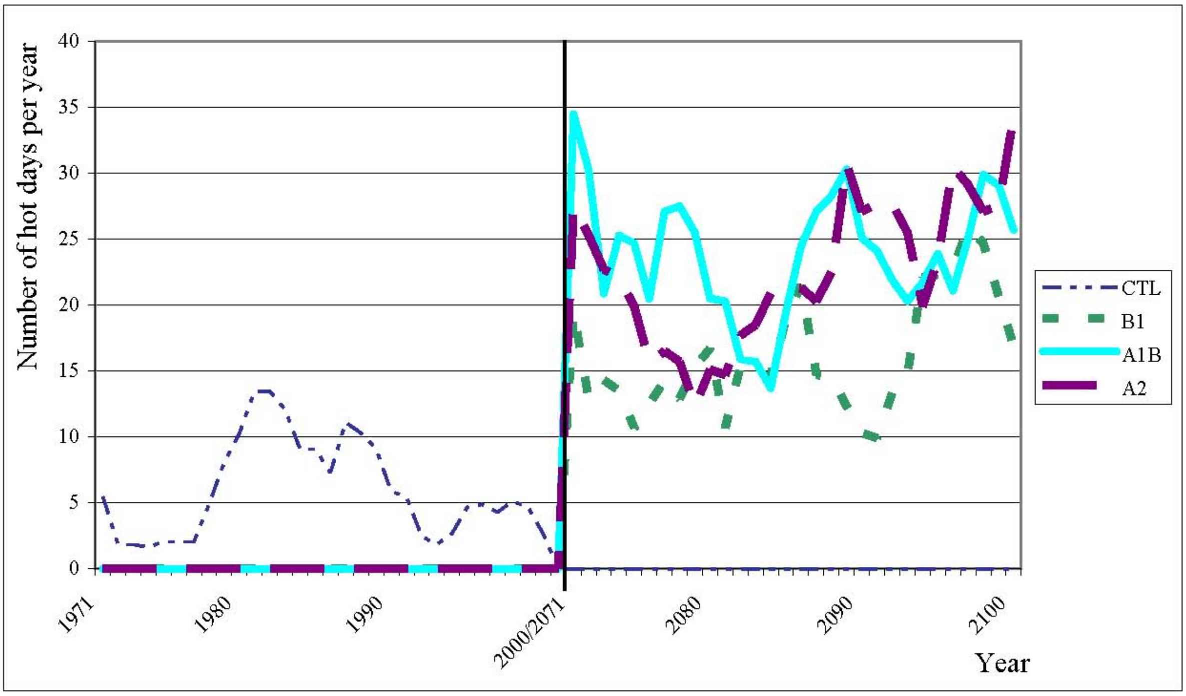

Figure 3: Reduction in the number of days per year with (light, moderate, strong or extreme) cold stress, control run CTL (1971-2000) minus REMO experiment A1B (2071-2100) in Germany

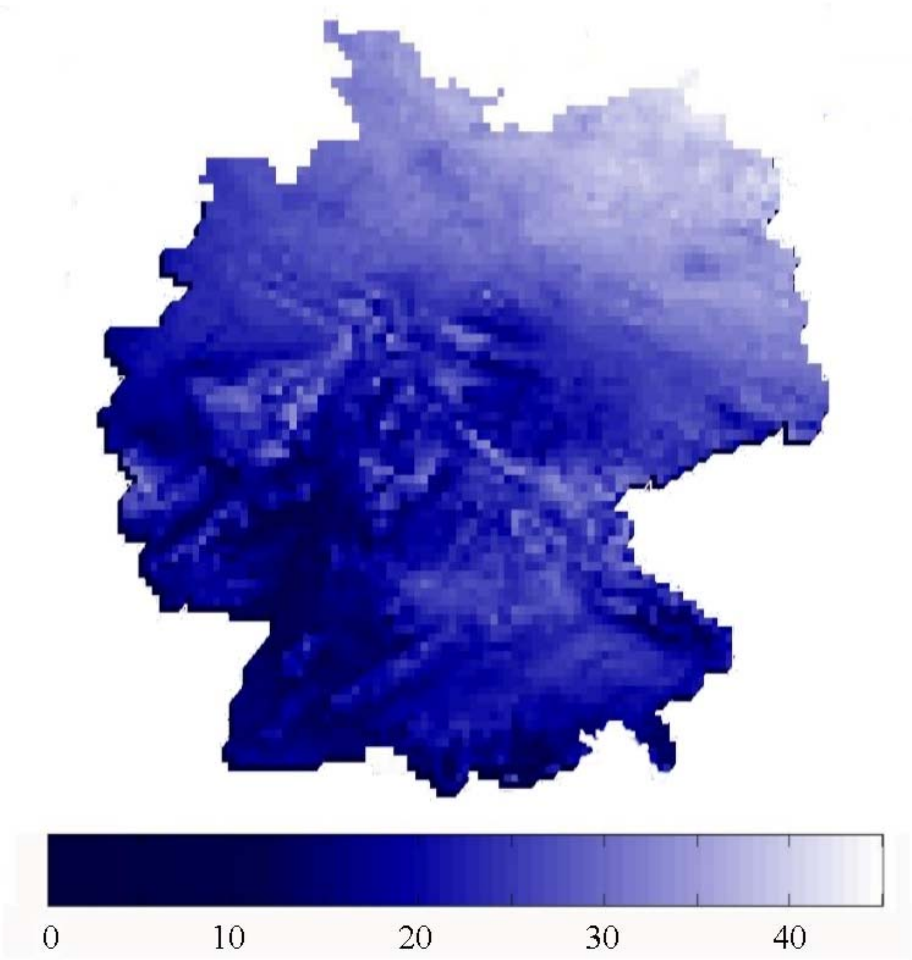

Figure 4: Number of heat induced deaths p. a. in Germany, 2071-2100
(exponential extrapolation for extreme heat stress)

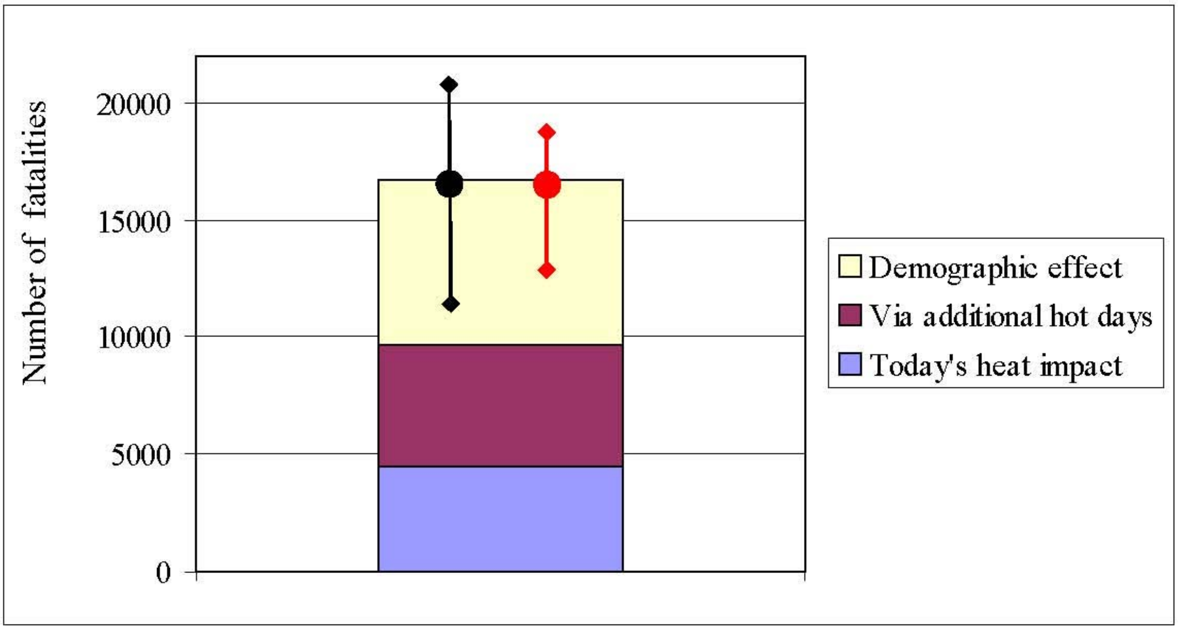

Figure 5: Distribution of additional heat induced deaths p. a. per 10 km times 10 km sectors in Germany, 2071-2100, A1B (exponential extrapolation for extreme heat stress)

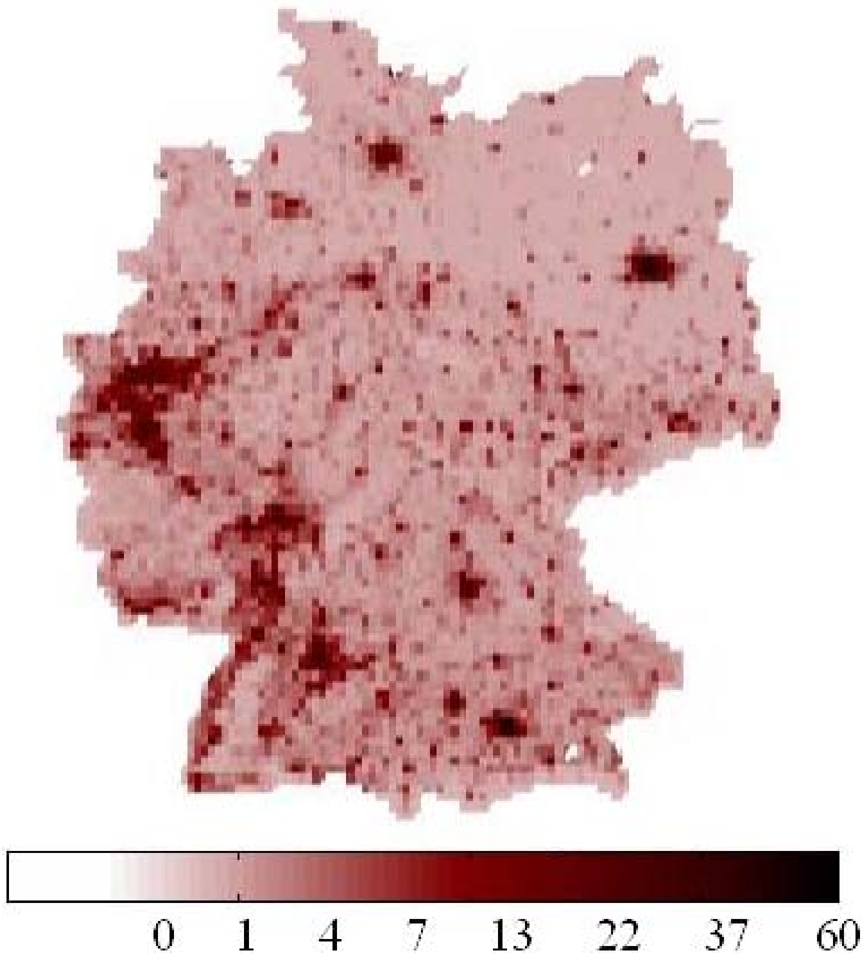

Figure 6: Distribution of the reduction in coldness induced deaths p. a. per 10 km times 10 km sectors in Germany, 2071-2100, A1B

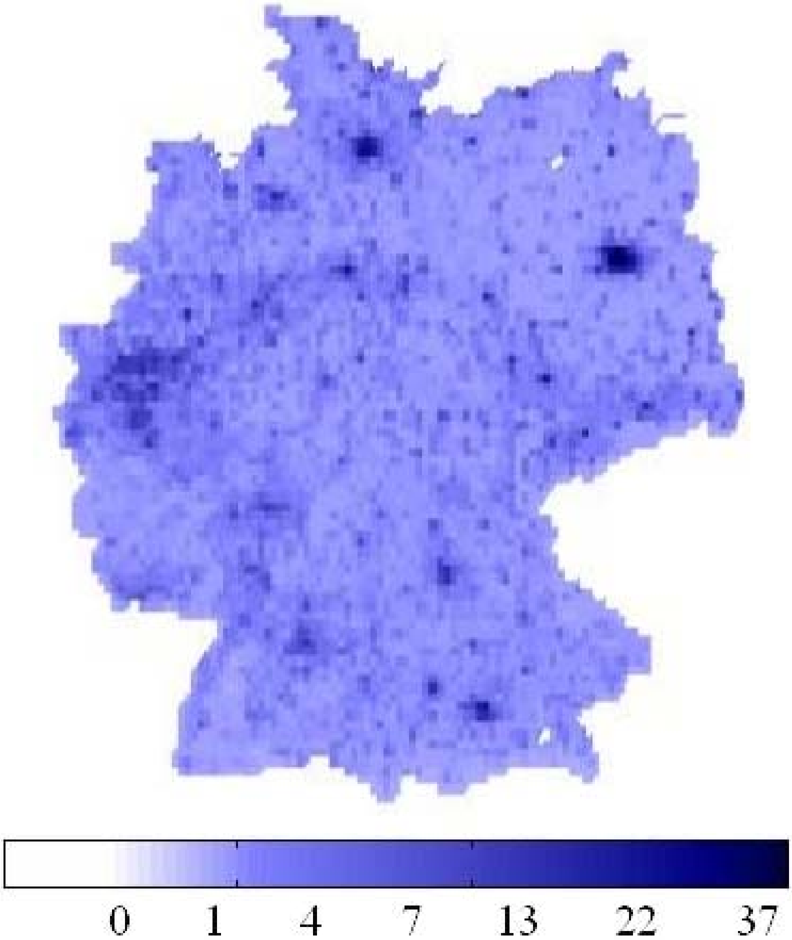

Figure 7: Comparison of the increase in heat related deaths and the reduction in coldness related deaths p. a. in Germany, 2071-2100, A1B, both computed in 10 km times 10 km resolution without base observations from the past

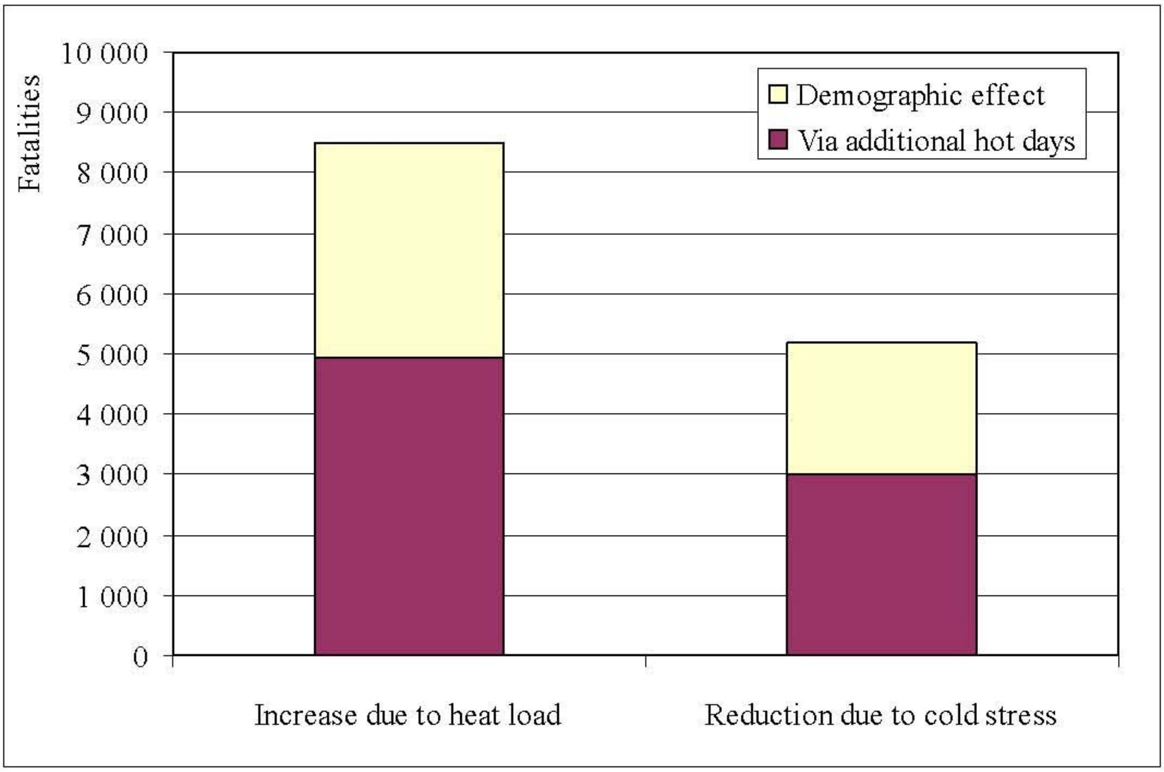

Figure 8: Hospitalization costs p.a. in Germany, 2071-2100 (exponential extrapolation for extreme heat stress)

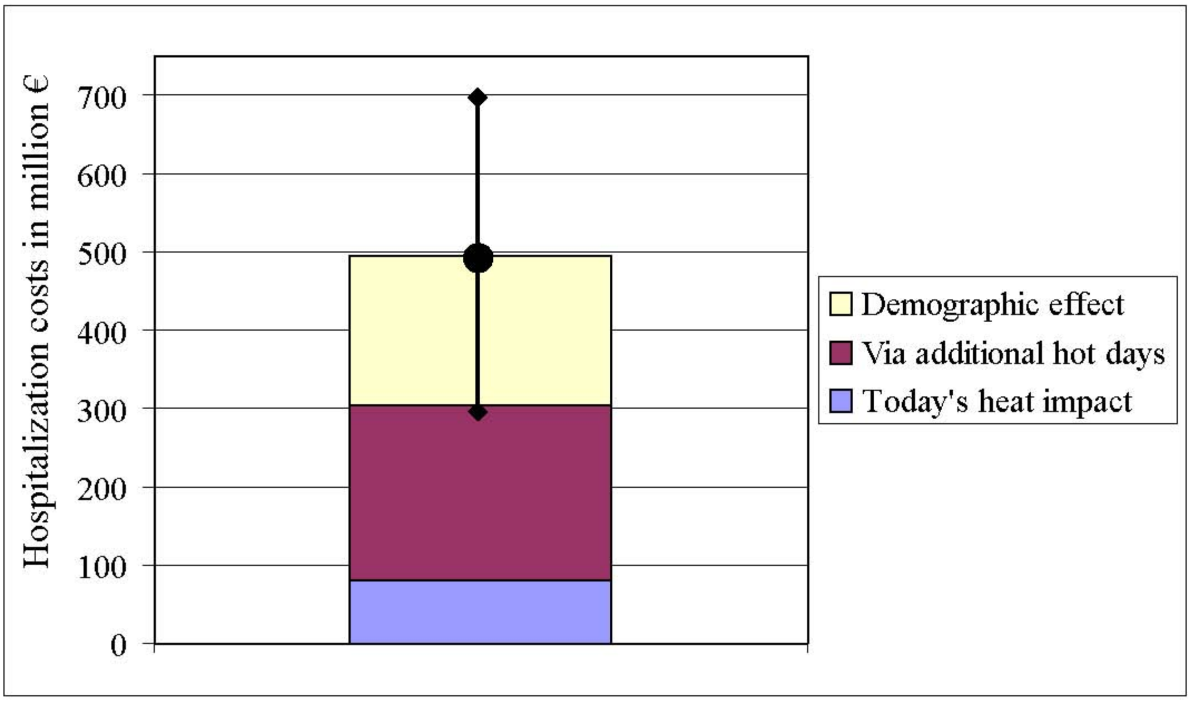

Figure 9: Heat related production loss in Germany p. a., 2071-2100 under two different impact assumptions

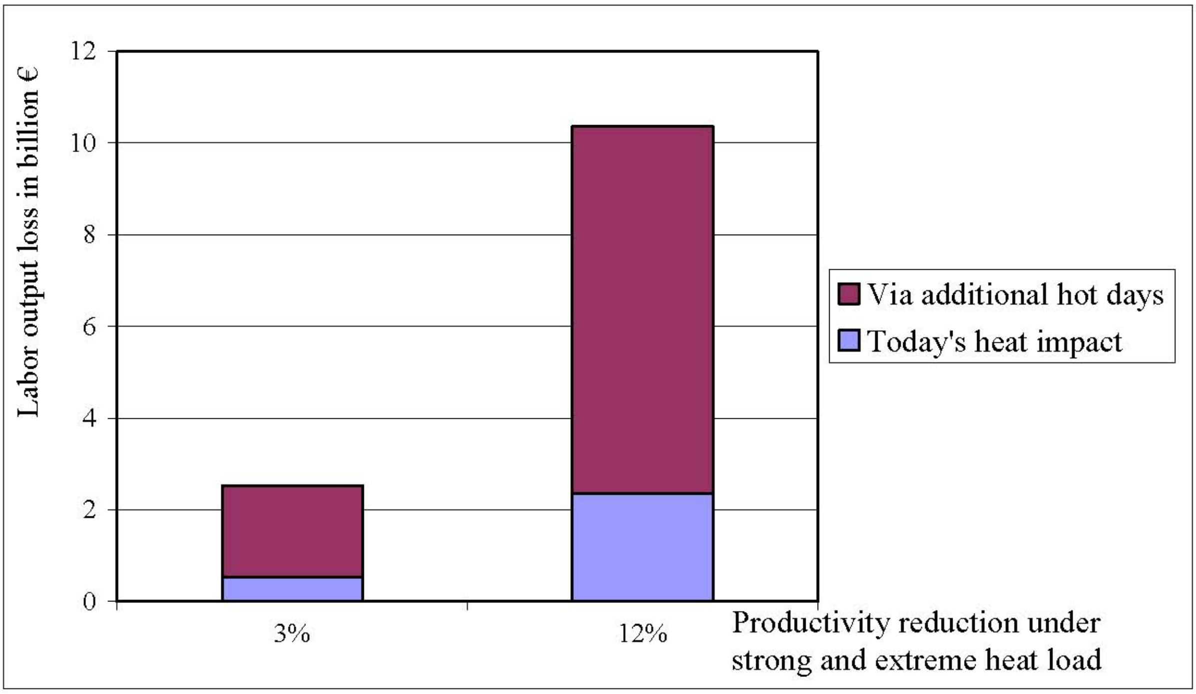

Figure 10: Heat related income losses p. a. and per capita, 2071-2100 across German federal states in 2004-€