Heat related respiratory hospital admissions in Europe in a changing climate: A health impact assessment

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Heat related respiratory hospital admissions in Europe in a changing climate

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ABSTRACT

Objectives: Respiratory diseases are ranked second in Europe in terms of mortality, prevalence and costs. Studies have shown that extreme heat has a large impact on mortality and morbidity, with a large relative increase for respiratory diseases. Expected increases in mean temperature and the number of extreme heat events over the coming decades due to climate change raise questions about the possible health impacts. Here we aim to assess the number of heat related respiratory hospital admissions in a future with a different climate.

Design: A European wide health impact assessment.

Setting: An assessment for each of the EU27 countries.

Methods: Heat-related hospital admissions under a changing climate are projected using multi-city epidemiologic exposure-response relationships applied to gridded population data and country-specific baseline respiratory hospital admission rates. Times-series of temperatures are simulated with a regional climate model based on four global climate models, under two greenhouse gas emission scenarios.

Results: Between a reference period (1981–2010) and a future period (2021–2050), the total number of respiratory hospital admissions attributed to heat is projected to be larger in Southern Europe, with three-times more heat attributed respiratory hospital admissions in the future period. The smallest change was estimated in Eastern Europe with about a two-fold increase. For all of Europe, the number of heat-related respiratory hospital admissions is projected to be 26,000 annually in the future period compared with 11,000 in the reference period.

Conclusions: The results suggest that projected effects of climate change on temperature and the number of extreme heat events could substantially influence respiratory morbidity across Europe.

ARTICLE SUMMARY

Article focus

To assess how heat related respiratory hospital admissions in Europe are expected to change with the global warming in the near future.

With a range of climate change projections explore the range of the different impact estimates.

Key messages

The 30 year annual mean increase in respiratory hospital admissions related to heat can be counted in 10's of thousands.

The increase will be different in different parts of Europe with the largest relative increase in Southern Europe.

Strengths and limitations

The study takes the spatial variation in both climate and population density into account in the impact calculations. This makes the estimates valid for countries with large national differences in population densities and climate.

The study results exemplifies some the variation of the impacts depending on different climate change scenarios as well as the variations within one climate scenario depending on the underlying climate model.

The use of real spatial population data has limited the study to explore the change in all age respiratory hospital admissions without demographic trends. The fact that the elderly is a well-known risk group when studying heat related illness combined with the future rise of the proportion of elderly people in the population may suggest that the estimated impacts are rather conservative.

INTRODUCTION

Respiratory diseases are ranked second in Europe in terms of mortality, prevalence and costs.[1] This burden is expected to increase, partly due to a changing climate.[2] An environmental factor with a large impact on mortality and morbidity in Europe is extreme heat, with large effects on respiratory diseases. [3-5] Physiological effects of exposure to heat can be directly heat related (heat stroke, heat fatigue and dehydration) or can contribute to worsening of respiratory and cardiovascular diseases, electrolyte disorders, and kidney problems.[4-7] A review found that heatwaves have a stronger relative impact on mortality than on emergency room visits and hospital admissions, suggesting that many individuals die before they can get to the hospital.[8] However, several studies confirm that heat also affects health care utilisation.[3 9] During the heatwave of 2003 in France, the Assistance Public Hôpitaux de Paris recorded 2,400 additional visits to the emergency care units and 1,900 additional hospital admissions.[10] During the heatwave in California in 2006 there were almost 1,200 hospital admissions together with more than 16,000 visits to the emergency departments.[6]

It is possible that hospital admissions could increase in the future due to temperature changes projected with climate change, assuming no additional acclimatisation. Projected changes include an increase in global mean temperature of 1.8°C to 4.0°C by the end of this century, with larger increases over land areas at high latitudes, changing seasonal temperatures, and increases in the frequency, intensity, duration, and spatial extent of heatwaves.[11] Recent projections for 2070–2100 suggest that maximum temperatures experienced once every 20 years during the period 1961–1990 could be expected as often as every year in southern Europe and every 3rd-5th year in northern Europe.[12] This means that Europe should expect an increase in both mean temperatures and the number of extreme heat events. Recent heatwaves are consistent with projections. For example, the heatwave that occurred in Europe 2003 could be expected to return every 46,000 years, based on the temperature distribution for the years 1864–2000.[13] However, such extreme hot conditions may become normal in the end of this century due to anthropogenic climate changes.[14] The uncertainty in this estimated return time is quite high, with a lower bound of the 90% confidence interval of 9,000 years. Even so, another heatwave occurred in 2006 with the most anomalous July temperature ever measured in Europe.[15] In 2010, Eastern Europe experienced a heatwave with summer temperatures higher than the last 140 years, resulting in roughly 55,000 excess deaths in Russia.[16]

The possible impacts of these changes in morbidity, particularly respiratory health, are relatively unexplored.

Aim

The aim of this study is to assess the extent to which climate change could affect heat related respiratory hospital admissions (RHAs) in Europe. Using a range of climate projections, we estimate the change in hospital admissions between a reference period and a future period.

METHODS

Climate change and temperature modelling

The Rossby Centre regional atmospheric climate model RCA3[17] was developed by SMHI (Swedish meteorological and hydrological institute) to dynamically downscale results from the global climate models CCSM3[18], ECHAM5[19], HadleyCM3[20] and ECHAM4[21] to a higher resolution over Europe. RCA3 is run on a horizontal grid spacing of 0.44° (corresponding to approximately 50 km) and a time step of 30 minutes. Projections are based on the global greenhouse gas emission scenarios A1B and A2 (scenarios are described in detail in the SRES[22]). Both have been used in climate change health impact assessments (HIA).[23-26] A1B is a “middle of the road” scenario and A2 is considered a high emission scenario, although recent greenhouse gas emissions have been higher. Data from one climate model, under one climate change scenario, is referred to as one climate change projection.

We use aggregated daily projections of maximum temperature and relative humidity data to estimate exposure for the periods 1981–2021 (reference period) and 2021–2050 (future period).

Population and morbidity rates

The annual country specific rate of respiratory hospital admissions between 2005 and 2010 were extracted from the WHO's European Health for All Database (http://data.euro.who.int/hfadb) for the EU27 countries. The mean value over the six years was used as a baseline morbidity rate. Official population data were from the HYDE theme within the Netherlands Environmental Assessment Agency.[27] These data are gridded on a 0.0833° resolution (approximately 9,45km) and matched with the climatic data by summing the population within each climatic grid cell.

Exposure-response assumption

The impact calculations were based on the heat morbidity relationship estimated within the European PHEWE project.[3] This relationship was based on analyses of 12 European cities over the 1990s, using the daily maximum of apparent temperature (AT), where AT is a combination of the measured temperature and the dew point temperature:

$$AT = -2.653 + 0.944*T + 0.0153 * (DT)^2$$

where T is the air temperature and DP the dew point temperature, which can be derived from temperature and relative humidity.[28] The AT accounts for heat stress related not only to the absolute temperature but also to the saturation of the surrounding air that makes it harder to regulate body temperature by sweating, the most important mechanism to maintain a healthy body temperature.[29 30] The PHEWE study used a 0–3 day lag of the maximum AT and concluded that the 90th percentile of this exposure variable for the summer months, April to September, is the appropriate threshold value for the heat morbidity function.[3] We calculated the 90th percentile for the summer months for each grid cell from the climate data for the 1990s yielding individual thresholds for each grid cell for each climate projection.

The PHEWE study calculated the relative risk (RR) coefficients for each of the 12 cities and then combined into two meta-coefficients for North-Continental cities 1.012 (95% CI 1.001–1.022) and

Mediterranean cities 1.021 (95% CI 1.006–1.036), associated with a 1-degree increase above the temperature threshold. Meta-coefficients were more suitable as they allowed calculation of the change in RHAs for countries with and without a city in the PHEWE Study. We assigned the Mediterranean coefficient to Portugal and the Mediterranean countries. The rest of Europe was assigned the RR for the North continental cities. Because the population data were not stratified by age, we used the PHEWE study coefficients for all ages.

Projections

The final data used in the impact calculations were based on the climate data grid with a resolution of 0.44° resulting in 8,075 grid cells over Europe. The population data, RR coefficients and baseline morbidity rates were projected for each grid cell. In addition, the countries within EU27 were grouped into four regions, Northern, Western, Eastern and Southern Europe, according to the United Nations classification scheme (http://unstats.un.org/unsd/methods/m49/m49regin.htm#europe).

Thus, each grid cell includes (1) a daily time-series of 0–3 day lag maximum AT for each climate change projection; (2) a grid cell specific temperature morbidity threshold and a location-based RR coefficient; and (3) population. For each grid cell, the AT was compared to the specific threshold for each day in the two time periods and risk estimates were calculated for each day. The expected number of daily RHAs in each cell was calculated using the population and the expected daily number of RHAs per capita, based on the national average of the grid cell.

$$RHA_{i,t} = RR_i\text{^}(AT_{i,t} - Thres_i)_+ * Pop_i * RHApc_i$$

where $RHA_{i,t}$ is the number of RHAs attributable to heat in grid cell i at time t, RR_i the RR coefficient in grid cell i, $(AT_{i,t} - Thres_i)_+$ the positive difference between the 0–3 lag AT and the threshold for grid cell i at time t, Pop_i and $RHApc_i$ the population and expected number RHAs per capita in grid cell i.

For each country, the estimated number of RHAs attributed to heat was calculated for each climate change projection, for both the reference and the future period. The estimated number of RHAs attributed to heat was then transformed into the proportion of the expected annual number RHAs for each country (data available from the authors). Mean estimates were calculated for each region for each climate change projection.

Sensitivity analysis

Because the study results could heavily depend on the RR coefficients and thresholds used, we assess whether the estimates appeared sensitive to the region-specific meta-coefficients. We investigated the grids that contained the cities in the PHEWE study using both the location (Mediterranean or North-Continental) and city specific RR coefficients.[3] We then compared the results with respect to the attributed proportion of RHAs and the proportional change in heat related RHAs.

RESULTS

The periods of warm days will increase in the future. For the cities included in the sensitivity analysis, the temperature threshold was exceeded by 20 days in the baseline period and 40 days in the future period, on average each year.

In the future period approximately 0.4% of the annual numbers of RHAs in Europe was estimated to be due to heat (Table 1), based on the mean estimates over the climate change projections. In absolute terms, assuming all else equal, this represents about 26,000 cases annually in Europe. This should be compared to the reference period where approximately 0.18% of all RHAs were attributed to heat or about 11,000 cases annually. Thus, the results suggest more than a relative doubling of the RHAs attributed to heat in Europe.

Table 1. The estimated proportion of RHAs attributed to heat for each region. Intervals describe the highest and lowest estimate in each region

Region	1981–2010	2021–2050	Change
Eastern Europe	0.17% (0.16% – 0.19%)	0.31% (0.29% –0.35%)	0.14% (0.11% – 0.17%)
Northern Europe	0.13% (0.10% – 0.15%)	0.27% (0.19% – 0.32%)	0.14% (0.07% – 0.17%)
Southern Europe	0.23% (0.18% – 0.26%)	0.64% (0.42% – 0.68%)	0.41% (0.23% – 0.44%)
Western Europe	0.18% (0.16% – 0.20%)	0.39% (0.34% – 0.45%)	0.21% (0.17% – 0.26%)
EU27	0.18% (0.10% – 0.26%)	0.40% (0.19% – 0.68%)	0.21% (0.07% – 0.44%)

On the regional level, the five projections estimate increases in the number of heat related RHAs for Europe (Table 2). However, in one climate change projection, The Czech Republic, Hungary, Poland and Slovakia were estimated to have a decrease in heat related RHAs (Fig 1). The countries with the highest estimated increase also show the largest range between the highest and lowest estimate. The Scandinavian and Baltic countries show the smallest range between the highest and lowest estimates along with small increases of the mean estimates.

Table 2. Future increase in heat related RHAs based on the four climate models, under two emission scenarios, as the proportion of the annual expected number of RHAs in each region

Global climate model	**CCSM3**	**ECHAM5**	**HadCM3**	**ECHAM4**	**ECHAM5**
Greenhouse gas scenario		***A1B***		***A2***	
Eastern Europe	0.32%	0.08%	0.18%	0.12%	0.01%
Northern Europe	0.17%	0.09%	0.14%	0.20%	0.08%
Southern Europe	0.51%	0.29%	0.64%	0.45%	0.14%
Western Europe	0.30%	0.11%	0.26%	0.29%	0.06%
EU27	0.32%	0.13%	0.29%	0.26%	0.07%

There is variation among countries, with the largest increases in the Southern European countries and the smallest increase in Eastern Europe (Table 2). The relative change in the burden of RHA´s in relation to the climate change scenarios investigated indicate a larger relative increase in

Mediterranean countries (approximately three times) compared to Northern European countries (approximately two times).

Sensitivity analysis

The calculations using the city specific RR coefficients yielded a different proportion and number of estimated RHAs than the ones using the two meta-coefficients, as expected. The relative changes in the number of hospital admissions attributed to heat between the two time-periods were not affected by the change of the RR coefficients.

DISCUSSION

The analysis estimates that the number of RHAs will increase in a warmer climate with more hot days. Heat related RHAs were projected to increase two- to three-fold in the future due to climate change. However, the proportion of respiratory admissions attributed to heat would remain rather small. As most heat related health outcomes occur during the warmest period of the year, presenting the increase as a change in the proportion of the total number of annual RHAs can underestimate the additional burden on the health care system during summer. As the threshold was exceeded for approximately 40 days in one year, an annual increase of 0.21% would result in a 1.9% increase on average during these 40 days. The annual numbers are used because the available baseline rates of RHAs are expressed as an annual average. Applying results to sub-national scales could be inappropriate because national averages summarize over considerable heterogeneity.

The results suggest a larger impact from heat in Southern Europe in the future period, centred on year 2035, than in the eastern and northern parts. This is in line with many climate change projections showing a larger relative increase in the number of extremely hot days in southern Europe compared with northern Europe.[12] However, to some extent this might also be explained by model bias for northern Europe introduced by the RCA3 model, where the model appears to underestimate temperature for the warmest days.[17] This temperature bias is present in the reference period, future period, and threshold values; therefore, the estimated numbers of RHAs from the two periods within each scenario are comparable, but comparisons within the same time-period, across scenarios may be inaccurate.

As the estimates are based on the population size in each grid cell, the added burden will be larger in countries with larger increases in temperatures in densely populated areas. Because the population of a city is considered a good predictor of the size of the urban heat island,[31] an increase in the population living in urban will increase the numbers exposed and the temperature to which they are exposed. Heat islands increase temperatures in urbanized areas compared to surrounding areas, also reducing cooling during the night time.[32] These factors combined are likely to magnify the health burden during a heatwave.[33] The coarse spatial scale of the climate models makes them unable to take the urban heat island effect into account. Together with the urbanization of Europe, this could potentially result in underestimation of actual consequences/RHAs in the future period because the same population size and composition were assumed in both periods. In addition, climate change is likely to increase ozone concentrations that would add an additional health burden to people at risk of respiratory diseases. The number of deaths and RHAs, due to a change in ozone, is expected to change in the future.[34]

We used the same thresholds for the reference and future period to isolate the effect of climate change. This would tend to overestimate the increased impact because there will undoubtedly be biological and/or social adaptations that will reduce future health temperature-related burdens. However, given the uncertainty of such adaptation effects, we choose to not incorporate such effects in the projections. Studies from the U.S show that the heat related health burdens decreased over the last 50 years,[35] indicating that some adaptation is taking place. An opposite trend appears to be occurring in Stockholm, with an increase of the risk of mortality associated with heat during the 1990s.[36] The magnitude and the extent of future adaptation is, of course, highly uncertain, and will vary between and within countries. Nevertheless, cities with higher thresholds seem to have higher risk ratio coefficients.[3 37] In an effort to estimate future and presumably higher thresholds, one must also adjust the risk ratio coefficients. This would result in fewer days of elevated risk, but the risk increase on each occasion could be higher due to the higher RRs.

Table 1 shows how the results vary by global climate models and greenhouse gas scenarios. This study exemplifies the magnitude of the difference between projections made by a model with different initial conditions and between different models with the same initial conditions. The results indicate the range of these estimates is large. The mean increase over the five projections however, provides confidence that the number of RHAs will increase over Europe as the climate continues to change.

To improve the estimates of the impacts of heat of RHAs, detailed data on emergency room visits and admissions during summer are needed, such as the proportion of emergency department cases admitted to hospital, and the fatality rate. A better understanding of vulnerable groups is needed, including how these groups could change over time. For example, the portion of the population aged over 65 will increase from 17 to 29%[38] by 2050, significantly increasing the size of this vulnerable group.

Normal weather patterns in the future will be different than those of today, both for average temperature and extreme weather events. As the number of heat related RHAs are expected to increase on the sub-continental scale, additional national or regional projections of the future health burden from heat are needed, taking into account possible changes in exposure and vulnerability.

CONCLUSIONS

Projected changes in temperature and the number of extreme heat events with climate change could substantially influence respiratory morbidity across Europe. Analyses projected that both the future proportion of annual RHAs attributed to heat and the relative change in heat related RHAs will be largest in Southern Europe, where they are expected to nearly triple. Eastern Europe can expect the smallest increase in heat related RHAs, where they are estimated to approximately double. For all of Europe, the number of respiratory heat-related hospital admissions is projected to be 26,000 annually in the future period (2021–2050) compared with 11,000 in the reference period (1981–2010).

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Contribution statement: CÅ, BF, HO has planned and designed the study. GS represented SMHI and provided climate data. CÅ ran the analyses, drafted the first manuscript and is guarantor. All authors have participated in the interpretation of results and revised the manuscript.

The specific estimates for each of the EU27 countries, for each of the climate projections is available after contact with corresponding author.

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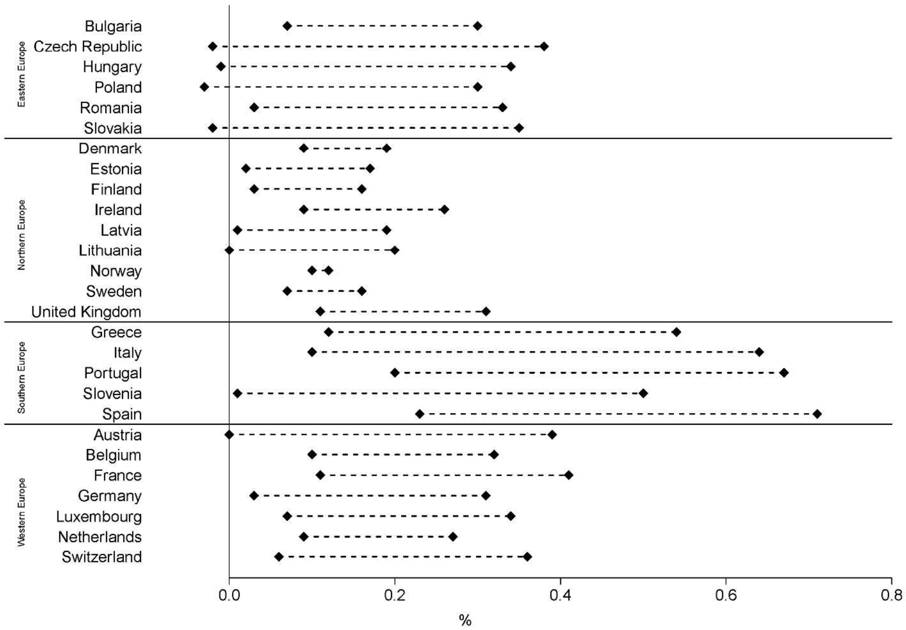
Figure 1. The range of the absolute increase in RHAs attributed to heat between the two periods (1981-2010, 2021-2050) as proportion the annual expected number of RHAs for each of the 27 countries. The points show the highest and lowest estimate from four climate models under two emission scenarios.



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The 30 year mean annual increase in respiratory hospital admissions related to heat between the periods 1981-2010 and 2021-2050 can be counted in 10's of thousands.

The increase will be different in different parts of Europe with the largest relative increase in Southern Europe.

Strengths and limitations

The study takes the spatial variation in both climate and population density into account in the impact calculations. This makes the estimates valid for countries with large national differences in population densities and climate.

The study results exemplifies some the variation of the impacts depending on different climate change scenarios as well as the variations within one climate scenario depending on the underlying climate model.

The use of real spatial population data has limited the study to explore the change in all age respiratory hospital admissions without demographic trends. The fact that the elderly is a well-known risk group when studying heat related illness combined with the future rise of the proportion of elderly people in the population may suggest that the estimated impacts are rather conservative

ABSTRACT

Respiratory diseases are ranked second in Europe in terms of mortality, prevalence and costs. Studies have shown that extreme heat has a large impact on mortality and morbidity, with a large relative increase for respiratory diseases. Expected increases in mean temperature and the number of extreme heat events over the coming decades due to climate change raise questions about the possible health impacts.

Heat-related respiratory hospital admissions under a changing climate are projected using multi-city epidemiologic exposure-response relationships applied to gridded population data and country-specific baseline respiratory hospital admission rates. Times-series of temperatures are simulated with a regional climate model based on four global climate models, under two greenhouse gas emission scenarios (A1B & A2).

Between a reference period (1981–2010) and a future period (2021–2050), the total number of respiratory hospital admissions attributed to heat is projected to be larger in Southern Europe, with three-times more heat attributed respiratory hospital admissions in the future period. The smallest change was estimated in Eastern Europe with about a two-fold increase. For all of Europe, the number of respiratory heat-related hospital admissions is projected to be 26,000 annually in the future period compared with 11,000 in the reference period.

The results suggest that projected effects of climate change on temperature and the number of extreme heat events could substantially influence respiratory morbidity across Europe.

INTRODUCTION

Respiratory diseases are ranked second in Europe in terms of mortality, prevalence and costs.[1] This burden is expected to increase, partly due to a changing climate.[2] An environmental factor with a large impact on mortality and morbidity in Europe is extreme heat, with large effects on respiratory diseases.[3-5] Physiological effects of exposure to heat can be directly heat related (heat stroke, heat fatigue and dehydration) or can contribute to worsening of respiratory and cardiovascular diseases, electrolyte disorders, and kidney problems.[4-7] The reasons for an increase in respiratory admissions may be several. Elderly with respiratory diseases such as COPD are less fit and suffer often from circulatory problems. Heat influenced admissions due to chronic airway obstruction and asthma increased more than admissions due to chronic bronchitis in a study from New York City,[8] but the daily number of admissions seldom allow a study of specific diagnoses. In a recent expert elicitation amongst European researchers engaged in environmental medicine or respiratory health, extreme heat stood out as most important climate related pathway to adverse impacts on respiratory health, more important than changes in air pollutants and allergens.[9] A review found that heatwaves have a stronger relative impact on mortality than on emergency room visits and hospital admissions, suggesting that many individuals die before they can get to the hospital.[10] However, several studies confirm that heat also affects health care utilisation.[3 11] During the heatwave of 2003 in France, the Assistance Public Hôpitaux de Paris recorded 2,400 additional visits to the emergency care units and 1,900 additional hospital admissions.[12] During the heatwave in California in 2006 there were almost 1,200 hospital admissions together with more than 16,000 visits to the emergency departments.[6]

It is possible that hospital admissions could increase in the future due to temperature changes projected with climate change, assuming no additional acclimatisation. Projected changes include an increase in global mean temperature of 1.8°C to 4.0°C by the end of this century, with larger increases over land areas at high latitudes, changing seasonal temperatures, and increases in the frequency, intensity, duration, and spatial extent of heatwaves.[13] Recent projections for 2070–2100

suggest that maximum temperatures experienced once every 20 years during the period 1961–1990 could be expected as often as every year in southern Europe and every 3rd-5th year in northern Europe.[14] This means that Europe should expect an increase in both mean temperatures and the number of extreme heat events. Recent heatwaves are consistent with projections. For example, the heatwave that occurred in Europe 2003 could be expected to return every 46,000 years, based on the temperature distribution for the years 1864–2000.[15] However, such extreme hot conditions may become much more common in the end of this century due to anthropogenic climate changes.[16] The uncertainty in this estimated return time is quite high, with a lower bound of the 90% confidence interval of 9,000 years. Even so, another heatwave occurred in 2006 with the most anomalous July temperature ever measured in Europe.[17] In 2010, Eastern Europe experienced a heatwave with summer temperatures higher than the last 140 years, resulting in roughly 55,000 excess deaths in Russia.[18]

The possible impacts of these changes on morbidity, particularly respiratory health, are relatively unexplored.

Aim

The aim of this study is to assess the extent to which changes in the frequency of hot days due to climate change over the next 40 years could affect heat related respiratory hospital admissions (RHAs) in Europe. Using a range of climate projections, we estimate the change in hospital admissions between a reference period and a future period.

METHODS

Climate change and temperature modelling

The Rossby Centre regional atmospheric climate model RCA3[19] was developed by SMHI (Swedish meteorological and hydrological institute) to dynamically downscale results from the global climate models CCSM3[20], ECHAM5[21], HadleyCM3[22] and ECHAM4[23] to a higher resolution over Europe. RCA3 is

run on a horizontal grid spacing of 0.44° (corresponding to approximately 50 km) and a time step of 30 minutes. Projections are based on the global greenhouse gas emission scenarios A1B and A2 (scenarios are described in detail in the SRES[24]). Both have been used in climate change health impact assessments (HIA).[25-28] A1B is a "middle of the road" scenario and A2 is considered a high emission scenario, although recent greenhouse gas emissions have been higher. Data from one climate model, under one climate change scenario, is referred to as one climate change projection.

We use aggregated daily projections of maximum temperature and relative humidity data to estimate exposure for the periods 1981–2020 (reference period) and 2021–2050 (future period).

Population and morbidity rates

The annual country specific rate of respiratory hospital admissions between 2005 and 2010 were extracted from the WHO's European Health for All Database (http://data.euro.who.int/hfadb) for the EU27 countries. The mean value over the six years was used as a baseline morbidity rate. Official population data were from the HYDE theme within the Netherlands Environmental Assessment Agency.[29] These data are gridded on a 0.0833° resolution (approximately 9,45km) and matched with the climatic data by summing the population within each climatic grid cell.

Exposure-response assumption

The impact calculations were based on the relationship between heat and RHAs (ICD-9:460–519) estimated within the European PHEWE (Assessment and Prevention of Acute Health Effects of Weather Conditions in Europe) project.[3] This relationship was based on analyses of 12 European cities over the 1990s, using the daily maximum of apparent temperature (AT), where AT is a combination of the measured temperature and the dew point temperature:

$$AT = -2.653 + 0.944*T + 0.0153 * (DT)^2$$

where T is the air temperature and DP the dew point temperature, which can be derived from temperature and relative humidity.[30] The AT accounts for heat stress related not only to the absolute temperature but also to the saturation of the surrounding air that makes it harder to regulate body temperature by sweating, the most important mechanism to maintain a healthy body temperature.[31 32] The PHEWE model also included potential confounders such as air pollution, holidays, week days etc. The study used a 0–3 day lag of the maximum AT and concluded that the 90th percentile of this exposure variable for the summer months, April to September, is the appropriate threshold value for the heat-morbidity function.[3] We calculated the 90th percentile for the summer months for each grid cell from the climate data for the 1990s, yielding individual thresholds for each grid cell for each climate projection.

The PHEWE study calculated the relative risk (RR) coefficients for each of the 12 cities and then combined these into two meta-coefficients, for North-Continental cities 1.012 (95% CI 1.001–1.022) and Mediterranean cities 1.021 (95% CI 1.006–1.036), associated with a 1-degree increase above the temperature threshold. Meta-coefficients were more suitable as they allowed calculation of the change in RHAs for countries with and without a city in the PHEWE Study. We assigned the Mediterranean coefficient to Portugal and the Mediterranean countries. The rest of Europe was assigned the RR for the North continental cities. Statistically significant coefficients were found for all ages and age 75+ in the PHEWE study. Because the population data were not stratified by age, we used the PHEWE study coefficients for all ages.

Projections

The final data used in the impact calculations were based on the climate data grid with a resolution of 0.44° resulting in 8,075 grid cells over Europe. The population data, RR coefficients and baseline morbidity rates were projected for each grid cell. The countries within EU27 were grouped into four regions, Northern, Western, Eastern and Southern Europe, according to the United Nations classification scheme (http://unstats.un.org/unsd/methods/m49/m49regin.htm#europe).

Thus, each grid cell includes (1) a daily time-series of 0–3 day lag maximum AT for each climate change projection; (2) a grid cell specific temperature morbidity threshold and a location-based RR coefficient; and (3) population. For each grid cell, the AT was compared to the specific threshold for each day in the two time periods and risk estimates were calculated for each day. The expected number of daily RHAs in each cell was calculated using the population and the expected daily number of RHAs per capita, based on the national average of the grid cell.

$$RHA_{i,t} = RR_i\hat{}(AT_{i,t} - Thres_i)_+ * Pop_i * RHApc_i$$

where $RHA_{i,t}$ is the number of RHAs attributable to heat in grid cell *i* at time *t*, RR_i the RR coefficient in grid cell *i*, $(AT_{i,t} - Thres_i)_+$ the difference between the 0–3 lag AT and the threshold for grid cell *i* at time *t* if $AT_{i,t}$ were greater than the threshold and 0 otherwise, Pop_i and $RHApc_i$ the population and expected number RHAs per capita in grid cell *i*.

For each country, the estimated number of RHAs attributed to heat was calculated for each climate change projection, for both the reference and the future period. The estimated number of RHAs attributed to heat was then transformed into the proportion of the expected annual number RHAs for each country (data available from the authors). Mean estimates were calculated for each region for each climate change projection.

Sensitivity analysis

Because the study results could heavily depend on the RR coefficients and thresholds used, we assess whether the estimates appeared sensitive to the region-specific meta-coefficients. We investigated the grids that contained the cities in the PHEWE study using both the location (Mediterranean or North-Continental) and city specific RR coefficients.[3] We then compared the results with respect to the attributed proportion of RHAs and the proportional change in heat related RHAs.

RESULTS

The periods of warm days will increase in the future. For the cities included in the sensitivity analysis, the temperature threshold was exceeded by 20 days in the baseline period and 40 days in the future period, on average each year.

In the future period approximately 0.4% of the annual numbers of RHAs in Europe was estimated to be due to heat (Table 1), based on the mean estimates over the climate change projections. In absolute terms, assuming all else equal, this represents about 26,000 cases annually in Europe. This should be compared to the reference period where approximately 0.18% of all RHAs were attributed to heat or about 11,000 cases annually. Thus, the results suggest more than a relative doubling of the RHAs attributed to heat in Europe.

Table 1. The estimated proportion of RHAs attributed to heat for each region. Intervals describe the highest and lowest estimate in each region

Region	1981–2010	2021–2050	Change
Eastern Europe	0.17% (0.16% – 0.19%)	0.31% (0.29% –0.35%)	0.14% (0.11% – 0.17%)
Northern Europe	0.13% (0.10% – 0.15%)	0.27% (0.19% – 0.32%)	0.14% (0.07% – 0.17%)
Southern Europe	0.23% (0.18% – 0.26%)	0.64% (0.42% – 0.68%)	0.41% (0.23% – 0.44%)
Western Europe	0.18% (0.16% – 0.20%)	0.39% (0.34% – 0.45%)	0.21% (0.17% – 0.26%)
EU27	0.18% (0.10% – 0.26%)	0.40% (0.19% – 0.68%)	0.21% (0.07% – 0.44%)

On the regional level, the five projections estimate increases in the number of heat related RHAs for Europe (Table 2). However, in one climate change projection, The Czech Republic, Hungary, Poland and Slovakia were estimated to have a decrease in heat related RHAs (Fig 1). The countries with the highest estimated increase also show the largest range between the highest and lowest estimate. The Scandinavian and Baltic countries show the smallest range between the highest and lowest estimates along with small increases of the mean estimates.

Table 2. Future increase in heat related RHAs based on the four climate models, under two emission scenarios, as the percentage of the annual expected number of RHAs in each region

Climate model	CCSM3	ECHAM5	HadCM3	ECHAM4	ECHAM5
Greenhouse gas scenario		***A1B***		***A2***	
Eastern Europe	0.32%	0.08%	0.18%	0.12%	0.01%
Northern Europe	0.17%	0.09%	0.14%	0.20%	0.08%
Southern Europe	0.51%	0.29%	0.64%	0.45%	0.14%
Western Europe	0.30%	0.11%	0.26%	0.29%	0.06%
EU27	0.32%	0.13%	0.29%	0.26%	0.07%

There is variation among countries, with the largest increases in the Southern European countries and the smallest increase in Eastern Europe (Table 2). The relative change in the burden of RHA´s in relation to the climate change scenarios investigated indicate a larger relative increase in Mediterranean countries (approximately three times) compared to Northern European countries (approximately two times).

Sensitivity analysis

The calculations using the city specific RR coefficients yielded a different proportion and number of estimated RHAs than the ones using the two meta-coefficients, as expected. However, the relative changes in the number of hospital admissions attributed to heat between the two time-periods were not affected by the change of the RR coefficients.

DISCUSSION

The analysis estimates that the number of RHAs will increase in a warmer climate with more hot days. Heat related RHAs were projected to increase two- to three-fold in the future due to climate change. However, the proportion of respiratory admissions attributed to heat would remain rather small. This projection is in line with the results of a recent study which estimates that the respiratory admissions due to excessive heat in New York State will increase 2-6 times from the period 1991-2004 to the period 2080-2099.[33]

As most heat related health outcomes occur during the warmest period of the year, presenting the increase as a change in the proportion of the total number of annual RHAs can underestimate the additional burden on the health care system during summer. As the threshold was exceeded for approximately 40 days in one year, an annual increase of 0.21% would result in a 1.9% increase on average during these 40 days. The annual numbers are used because the available baseline rates of RHAs are expressed as an annual average. Applying results to sub-national scales could be inappropriate because national averages summarize over considerable heterogeneity.

The results suggest a larger impact from heat in Southern Europe in the future period, centred on year 2035, than in the eastern and northern parts. This is in line with many climate change projections showing a larger relative increase in the number of extremely hot days in southern Europe compared with northern Europe.[14] However, to some extent this might also be explained by model bias for northern Europe introduced by the RCA3 model, where the model appears to underestimate temperature for the warmest days.[19] This temperature bias is present in the reference period, future period, and threshold values; therefore, the estimated numbers of RHAs from the two periods within each scenario are comparable, but comparisons within the same time-period, across scenarios may be inaccurate.

As the estimates are based on the population size in each grid cell, the added burden will be larger in countries with larger increases in temperatures in densely populated areas. Because the population of a city is considered a good predictor of the size of the urban heat island,[34] an increase in the population living in urban areas will increase the numbers exposed and the temperature to which they are exposed. Heat islands increase temperatures in urbanized areas compared to surrounding areas, also reducing cooling during the night time.[35] These factors combined are likely to magnify the health burden during a heatwave.[36] The coarse spatial scale of the climate models makes them unable to take the urban heat island effect into account. Together with the urbanization of Europe, this could potentially result in underestimation of actual consequences/RHAs in the future period because the same population size and composition were assumed in both periods. In addition, climate change is likely to increase ozone concentrations that would add an additional health burden for people at risk of respiratory diseases. The number of deaths and RHAs, due to a change in ozone, is expected to change in the future.[37] A sensitivity analysis in the PHEWE study however showed that the exposure-response relationship for heat did not substantially differ between models taking ozone into account and models adjusting for NO_2 alone.[3]

We used the same thresholds for the reference and future period to isolate the effect of climate change. This would tend to overestimate the increased impact because there will undoubtedly be biological and/or social adaptations that will reduce future health temperature-related burdens. However, given the uncertainty of such adaptation effects, we choose to not incorporate such effects in the projections. Recent studies in the U.S indicate heat related health burdens have decreased,[38] indicating that some adaptation is taking place. An opposite trend appears to be occurring in Stockholm, with an increase of the risk of mortality associated with heat during the 1990s.[39] A study looking at the impact of heat on mortality, before and after the implementation of a heat warning system, in Italy shows that the effects of extreme heat can be reduced while the effects of moderate increased average temperatures remains similar.[40] The magnitude and the extent of future adaptation is, of course, highly uncertain, and will vary between and within countries. Nevertheless, cities with higher thresholds seem to have higher risk ratio coefficients.[3 41] In an effort to estimate future and presumably higher thresholds, one must also adjust the risk ratio coefficients. This would result in fewer days of elevated risk, but the risk increase on each occasion could be higher due to the higher RRs.

Table 1 shows how the results vary by global climate models and greenhouse gas scenarios. This study exemplifies the magnitude of the difference between projections made by a model with different initial conditions and between different models with the same initial conditions. The results indicate the range of these estimates is large. The mean increase over the five projections however, provides confidence that the number of RHAs will increase over Europe as the climate continues to change.

To improve the estimates of the impacts of heat on RHAs, detailed data on emergency room visits and admissions during summer are needed, such as the proportion of emergency department cases admitted to hospital, and the fatality rate. A better understanding of vulnerable groups is needed, including how these groups could change over time. For example, the portion of the population aged over 65 will increase from 17 to 29%[42] by 2050, significantly increasing the size of this vulnerable group. COPD is mainly a disease of the elderly. Persons suffering from COPD appear especially vulnerable to heat[43] and the incidence of COPD is likely to increase[44] with the consequence that the health impacts of heat may increase in future years. This study was limited to estimating the impacts on the total population because few age-specific relationship were reported and because age stratified data were only available on a coarser spatial scale than the climate data, which would reduce the benefits of having spatial climate data.

Normal weather patterns in the future will be different than those of today, both for average temperature and extreme weather events. As the number of heat related RHAs are expected to increase on the sub-continental scale, additional national or regional projections of the future health burden from heat are needed, taking into account possible changes in exposure and vulnerability.

CONCLUSIONS

Projected changes in temperature and the number of extreme heat events with climate change could substantially influence respiratory morbidity across Europe. Analyses projected that both the future proportion of annual RHAs attributed to heat and the relative change in heat related RHAs will be largest in Southern Europe, where they are expected to nearly triple. Eastern Europe can expect the smallest increase in heat related RHAs, where they are estimated to approximately double. For all of Europe, the number of respiratory heat-related hospital admissions is projected to be 26,000 annually in the future period (2021–2050) compared with 11,000 in the reference period (1981–2010). The estimates presented rely on the assumption that no additional adaptation occurs. Future studies should elaborate and quantify the possible effects of different adaptation assumptions applied to regional conditions.

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Contribution statement: CÅ, BF, HO has planned and designed the study. GS represented SMHI and provided climate data. CÅ ran the analyses, drafted the first manuscript and is guarantor. All authors have participated in the interpretation of results and revised the manuscript.

The specific estimates for each of the EU27 countries, for each of the climate projections is available after contact with corresponding author.

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Figure 1. The range of the absolute increase in RHAs attributed to heat between the two periods (1981-2010, 2021-2050) as proportion the annual expected number of RHAs for each of the 27 countries. The points show the highest and lowest estimate from four climate models under two emission scenarios.

Heat related respiratory hospital admissions in Europe in a changing climate

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ARTICLE SUMMARY

Article focus

To assess how heat related respiratory hospital admissions in Europe are expected to change with the global warming in the near future. With a range of climate change projections explore the range of the different impact estimates.

Key messages

The 30 year mean annual mean increase in respiratory hospital admissions related to heat between the periods 1981-2010 and 2021-2050 can be counted in 10's of thousands.

The increase will be different in different parts of Europe with the largest relative increase in Southern Europe.

Strengths and limitations

The study takes the spatial variation in both climate and population density into account in the impact calculations. This makes the estimates valid for countries with large national differences in population densities and climate.

The study results exemplifies some the variation of the impacts depending on different climate change scenarios as well as the variations within one climate scenario depending on the underlying climate model.

The use of real spatial population data has limited the study to explore the change in all age respiratory hospital admissions without demographic trends. The fact that the elderly is a wellknown well-known risk group when studying heat related illness combined with the future rise of the proportion of elderly people in the population may suggest that the estimated impacts are rather conservative.

ABSTRACT

Respiratory diseases are ranked second in Europe in terms of mortality, prevalence and costs. Studies have shown that extreme heat has a large impact on mortality and morbidity, with a large relative increase for respiratory diseases. Expected increases in mean temperature and the number of extreme heat events over the coming decades due to climate change raise questions about the possible health impacts.

Heat-related respiratory hospital admissions under a changing climate are projected using multi-city epidemiologic exposure-response relationships applied to gridded population data and country-specific baseline respiratory hospital admission rates. Times-series of temperatures are simulated with a regional climate model based on four global climate models, under two greenhouse gas emission scenarios. (A1B & A2).

Between a reference period (1981–2010) and a future period (2021–2050), the total number of respiratory hospital admissions attributed to heat is projected to be larger in Southern Europe, with three-times more heat attributed respiratory hospital admissions in the future period. The smallest change was estimated in Eastern Europe with about a two-fold increase. For all of Europe, the number of respiratory heat-related hospital admissions is projected to be 26,000 annually in the future period compared with 11,000 in the reference period.

The results suggest that projected effects of climate change on temperature and the number of extreme heat events could substantially influence respiratory morbidity across Europe.

INTRODUCTION

Respiratory diseases are ranked second in Europe in terms of mortality, prevalence and costs.[1] This burden is expected to increase, partly due to a changing climate.[2] An environmental factor with a large impact on mortality and morbidity in Europe is extreme heat, with large effects on respiratory diseases.[3-5] Physiological effects of exposure to heat can be directly heat related (heat stroke, heat fatigue and dehydration) or can contribute to worsening of respiratory and cardiovascular diseases, electrolyte disorders, and kidney problems.[4-7] The reasons for an increase in respiratory admissions may be several. Elderly with respiratory diseases such as COPD are less fit and suffer often from circulatory problems. Heat influenced admissions due to chronic airway obstruction and asthma increased more than admissions due to chronic bronchitis in a study from New York City,[8] but the daily number of admissions seldom allow a study of specific diagnoses. In a recent expert elicitation amongst European researchers engaged in environmental medicine or respiratory health, extreme heat stood out as most important climate related pathway to adverse impacts on respiratory health, more important than changes in air pollutants and allergens.[9] A review found that heatwaves have a stronger relative impact on mortality than on emergency room visits and hospital admissions, suggesting that many individuals die before they can get to the hospital.[8 10] However, several studies confirm that heat also affects health care utilisation.[3 9 11] During the heatwave of 2003 in France, the Assistance Public Hôpitaux de Paris recorded 2,400 additional visits to the emergency care units and 1,900 additional hospital admissions.[10 12] During the heatwave in California in 2006 there were almost 1,200 hospital admissions together with more than 16,000 visits to the emergency departments.[6]

It is possible that hospital admissions could increase in the future due to temperature changes projected with climate change, assuming no additional acclimatisation. Projected changes include an increase in global mean temperature of 1.8°C to 4.0°C by the end of this century, with larger increases over land areas at high latitudes, changing seasonal temperatures, and increases in the frequency, intensity, duration, and spatial extent of heatwaves.[11 13] Recent projections for 2070–2100 suggest that maximum temperatures experienced once every 20 years during the period 1961–1990 could be expected as often as every year in southern Europe and every 3rd-5th year in northern Europe.~~[12]~~[14] This means that Europe should expect an increase in both mean temperatures and the number of extreme heat events. Recent heatwaves are consistent with projections. For example, the heatwave that occurred in Europe 2003 could be expected to return every 46,000 years, based on the temperature distribution for the years 1864–2000.~~[13]~~[15] However, such extreme hot conditions may become ~~normal~~much more common in the end of this century due to anthropogenic climate changes.~~[14]~~[16] The uncertainty in this estimated return time is quite high, with a lower bound of the 90% confidence interval of 9,000 years. Even so, another heatwave occurred in 2006 with the most anomalous July temperature ever measured in Europe.~~[15]~~[17] In 2010, Eastern Europe experienced a heatwave with summer temperatures higher than the last 140 years, resulting in roughly 55,000 excess deaths in Russia.~~[16]~~[18]

The possible impacts of these changes ~~in~~on morbidity, particularly respiratory health, are relatively unexplored.

Aim

The aim of this study is to assess the extent to which changes in the frequency of hot days due to climate change over the next 40 years could affect heat related respiratory hospital admissions (RHAs) in Europe. Using a range of climate projections, we estimate the change in hospital admissions between a reference period and a future period.

METHODS

Climate change and temperature modelling

The Rossby Centre regional atmospheric climate model ~~RCA3[17]~~RCA3[19] was developed by SMHI (Swedish meteorological and hydrological institute) to dynamically downscale results from the global climate models ~~CCSM3[18], ECHAM5[19], HadleyCM3[20] and ECHAM4[21]~~CCSM3[20], ECHAM5[21], HadleyCM3[22] and ECHAM4[23] to a higher resolution over Europe. RCA3 is run on a horizontal grid spacing of 0.44° (corresponding to approximately 50 km) and a time step of 30 minutes. Projections are based on the global greenhouse gas emission scenarios A1B and A2 (scenarios are described in detail in the SRES[22]SRES[24]). Both have been used in climate change health impact assessments (HIA).[23-26][25-28] A1B is a "middle of the road" scenario and A2 is considered a high emission scenario, although recent greenhouse gas emissions have been higher. Data from one climate model, under one climate change scenario, is referred to as one climate change projection.

We use aggregated daily projections of maximum temperature and relative humidity data to estimate exposure for the periods 1981–20212020 (reference period) and 2021–2050 (future period).

Population and morbidity rates

The annual country specific rate of respiratory hospital admissions between 2005 and 2010 were extracted from the WHO's European Health for All Database (http://data.euro.who.int/hfadb) for the EU27 countries. The mean value over the six years was used as a baseline morbidity rate. Official population data were from the HYDE theme within the Netherlands Environmental Assessment Agency.[27][29] These data are gridded on a 0.0833° resolution (approximately 9,45km) and matched with the climatic data by summing the population within each climatic grid cell.

Exposure-response assumption

The impact calculations were based on the heat morbidity relationship between heat and RHAs (ICD-9:460–519) estimated within the European PHEWE (Assessment and Prevention of Acute Health Effects of Weather Conditions in Europe) project.[3] This relationship was based on analyses of 12 European cities over the 1990s, using the daily maximum of apparent temperature (AT), where AT is a combination of the measured temperature and the dew point temperature:

$$AT = -2.653 + 0.944*T + 0.0153 * (DT)^2$$

where T is the air temperature and DP the dew point temperature, which can be derived from temperature and relative humidity.[28][30] The AT accounts for heat stress related not only to the absolute temperature but also to the saturation of the surrounding air that makes it harder to regulate body temperature by sweating, the most important mechanism to maintain a healthy body temperature.[29 30] The PHEWE[31 32] The PHEWE model also included potential confounders such as air pollution, holidays, week days etc. The study used a 0–3 day lag of the maximum AT and concluded that the 90th percentile of this exposure variable for the summer months, April to September, is the appropriate threshold value for the heat-morbidity function.[3] We calculated the 90th percentile for the summer months for each grid cell from the climate data for the 1990s, yielding individual thresholds for each grid cell for each climate projection.

The PHEWE study calculated the relative risk (RR) coefficients for each of the 12 cities and then combined these into two meta-coefficients, for North-Continental cities 1.012 (95% CI 1.001–1.022) and Mediterranean cities 1.021 (95% CI 1.006–1.036), associated with a 1-degree increase above the temperature threshold. Meta-coefficients were more suitable as they allowed calculation of the change in RHAs for countries with and without a city in the PHEWE Study. We assigned the Mediterranean coefficient to Portugal and the Mediterranean countries. The rest of Europe was assigned the RR for the North continental cities. Statistically significant coefficients were found for all ages and age 75+ in the PHEWE study. Because the population data were not stratified by age, we used the PHEWE study coefficients for all ages.

Projections

The final data used in the impact calculations were based on the climate data grid with a resolution of 0.44° resulting in 8,075 grid cells over Europe. The population data, RR coefficients and baseline morbidity rates were projected for each grid cell. In addition, The countries within EU27 were grouped into four regions, Northern, Western, Eastern and Southern Europe, according to the United Nations classification scheme (http://unstats.un.org/unsd/methods/m49/m49regin.htm#europe).

Thus, each grid cell includes (1) a daily time-series of 0–3 day lag maximum AT for each climate change projection; (2) a grid cell specific temperature morbidity threshold and a location-based RR coefficient; and (3) population. For each grid cell, the AT was compared to the specific threshold for each day in the two time periods and risk estimates were calculated for each day. The expected number of daily RHAs in each cell was calculated using the population and the expected daily number of RHAs per capita, based on the national average of the grid cell.

$$RHA_{i,t} = RR_i\hat{}(AT_{i,t} - Thres_i)_+ * Pop_i * RHApc_i$$

where $RHA_{i,t}$ is the number of RHAs attributable to heat in grid cell *i* at time *t*, RR_i the RR coefficient in grid cell *i*, $(AT_{i,t} - Thres_i)_+$ the ~~positive~~ difference between the 0–3 lag AT and the threshold for grid cell *i* at time *t* if $AT_{i,t}$ were greater than the threshold and 0 otherwise, Pop_i and $RHApc_i$ the population and expected number RHAs per capita in grid cell *i*.

For each country, the estimated number of RHAs attributed to heat was calculated for each climate change projection, for both the reference and the future period. The estimated number of RHAs attributed to heat was then transformed into the proportion of the expected annual number RHAs for each country (data available from the authors). Mean estimates were calculated for each region for each climate change projection.

Sensitivity analysis

Because the study results could heavily depend on the RR coefficients and thresholds used, we assess whether the estimates appeared sensitive to the region-specific meta-coefficients. We investigated the grids that contained the cities in the PHEWE study using both the location (Mediterranean or North-Continental) and city specific RR coefficients.[3] We then compared the results with respect to the attributed proportion of RHAs and the proportional change in heat related RHAs.

RESULTS

The periods of warm days will increase in the future. For the cities included in the sensitivity analysis, the temperature threshold was exceeded by 20 days in the baseline period and 40 days in the future period, on average each year.

In the future period approximately 0.4% of the annual numbers of RHAs in Europe was estimated to be due to heat (Table 1), based on the mean estimates over the climate change projections. In absolute terms, assuming all else equal, this represents about 26,000 cases annually in Europe. This should be compared to the reference period where approximately 0.18% of all RHAs were attributed to heat or about 11,000 cases annually. Thus, the results suggest more than a relative doubling of the RHAs attributed to heat in Europe.

Table 1. The estimated proportion of RHAs attributed to heat for each region. Intervals describe the highest and lowest estimate in each region

Region	1981–2010	2021–2050	Change
Eastern Europe	0.17% (0.16% – 0.19%)	0.31% (0.29% –0.35%)	0.14% (0.11% – 0.17%)
Northern Europe	0.13% (0.10% – 0.15%)	0.27% (0.19% – 0.32%)	0.14% (0.07% – 0.17%)
Southern Europe	0.23% (0.18% – 0.26%)	0.64% (0.42% – 0.68%)	0.41% (0.23% – 0.44%)
Western Europe	0.18% (0.16% – 0.20%)	0.39% (0.34% – 0.45%)	0.21% (0.17% – 0.26%)
EU27	0.18% (0.10% – 0.26%)	0.40% (0.19% – 0.68%)	0.21% (0.07% – 0.44%)

On the regional level, the five projections estimate increases in the number of heat related RHAs for Europe (Table 2). However, in one climate change projection, The Czech Republic, Hungary, Poland and Slovakia were estimated to have a decrease in heat related RHAs (Fig 1). The countries with the highest estimated increase also show the largest range between the highest and lowest estimate. The Scandinavian and Baltic countries show the smallest range between the highest and lowest estimates along with small increases of the mean estimates.

Table 2. Future increase in heat related RHAs based on the four climate models, under two emission scenarios, as the ~~proportion~~percentage of the annual expected number of RHAs in each region

Climate model	CCSM3	ECHAM5	HadCM3	ECHAM4	ECHAM5
Greenhouse gas scenario		***A1B***		***A2***	
Eastern Europe	0.32%	0.08%	0.18%	0.12%	0.01%
Northern Europe	0.17%	0.09%	0.14%	0.20%	0.08%
Southern Europe	0.51%	0.29%	0.64%	0.45%	0.14%
Western Europe	0.30%	0.11%	0.26%	0.29%	0.06%
EU27	0.32%	0.13%	0.29%	0.26%	0.07%

There is variation among countries, with the largest increases in the Southern European countries and the smallest increase in Eastern Europe (Table 2). The relative change in the burden of RHA´s in relation to the climate change scenarios investigated indicate a larger relative increase in Mediterranean countries (approximately three times) compared to Northern European countries (approximately two times).

Sensitivity analysis

The calculations using the city specific RR coefficients yielded a different proportion and number of estimated RHAs than the ones using the two meta-coefficients, as expected. However, the relative changes in the number of hospital admissions attributed to heat between the two time-periods were not affected by the change of the RR coefficients.

DISCUSSION

The analysis estimates that the number of RHAs will increase in a warmer climate with more hot days. Heat related RHAs were projected to increase two- to three-fold in the future due to climate change. However, the proportion of respiratory admissions attributed to heat would remain rather small. This projection is in line with the results of a recent study which estimates that the respiratory admissions due to excessive heat in New York State will increase 2-6 times from the period 1991-2004 to the period 2080-2099.[33]

As most heat related health outcomes occur during the warmest period of the year, presenting the increase as a change in the proportion of the total number of annual RHAs can underestimate the additional burden on the health care system during summer. As the threshold was exceeded for approximately 40 days in one year, an annual increase of 0.21% would result in a 1.9% increase on average during these 40 days. The annual numbers are used because the available baseline rates of RHAs are expressed as an annual average. Applying results to sub-national scales could be inappropriate because national averages summarize over considerable heterogeneity.

The results suggest a larger impact from heat in Southern Europe in the future period, centred on year 2035, than in the eastern and northern parts. This is in line with many climate change projections showing a larger relative increase in the number of extremely hot days in southern Europe compared with northern Europe.[~~12~~14] However, to some extent this might also be explained by model bias for northern Europe introduced by the RCA3 model, where the model appears to underestimate temperature for the warmest days.[~~17~~19] This temperature bias is present in the reference period, future period, and threshold values; therefore, the estimated numbers of RHAs from the two periods within each scenario are comparable, but comparisons within the same time-period, across scenarios may be inaccurate.

As the estimates are based on the population size in each grid cell, the added burden will be larger in countries with larger increases in temperatures in densely populated areas. Because the population of a city is considered a good predictor of the size of the urban heat island,[~~31~~34] an increase in the population living in urban areas will increase the numbers exposed and the temperature to which they are exposed. Heat islands increase temperatures in urbanized areas compared to surrounding areas, also reducing cooling during the night time.[~~32~~35] These factors combined are likely to magnify the health burden during a heatwave.[~~33~~36] The coarse spatial scale of the climate models makes them unable to take the urban heat island effect into account. Together with the urbanization of Europe, this could potentially result in underestimation of actual consequences/RHAs in the future period because the same population size and composition were assumed in both periods. In addition, climate change is likely to increase ozone concentrations that would add an additional health burden tofor people at risk of respiratory diseases. The number of deaths and RHAs, due to a change in ozone, is expected to change in the future.[34][37] A sensitivity analysis in the PHEWE study however showed that the exposure-response relationship for heat did not substantially differ between models taking ozone into account and models adjusting for NO_2 alone.[3]

We used the same thresholds for the reference and future period to isolate the effect of climate change. This would tend to overestimate the increased impact because there will undoubtedly be biological and/or social adaptations that will reduce future health temperature-related burdens. However, given the uncertainty of such adaptation effects, we choose to not incorporate such effects in the projections. Studies fromRecent studies in the U.S show that theindicate heat related health burdens have decreased over the last 50 years,[35] ,[38] indicating that some adaptation is taking place. An opposite trend appears to be occurring in Stockholm, with an increase of the risk of mortality associated with heat during the 1990s.[36][39] A study looking at the impact of heat on mortality, before and after the implementation of a heat warning system, in Italy shows that the effects of extreme heat can be reduced while the effects of moderate increased average temperatures remains similar.[40] The magnitude and the extent of future adaptation is, of course, highly uncertain, and will vary between and within countries. Nevertheless, cities with higher thresholds seem to have higher risk ratio coefficients.[3] [37][41] In an effort to estimate future and presumably higher thresholds, one must also adjust the risk ratio coefficients. This would result in fewer days of elevated risk, but the risk increase on each occasion could be higher due to the higher RRs.

Table 1 shows how the results vary by global climate models and greenhouse gas scenarios. This study exemplifies the magnitude of the difference between projections made by a model with different initial conditions and between different models with the same initial conditions. The results indicate the range of these estimates is large. The mean increase over the five projections however, provides confidence that the number of RHAs will increase over Europe as the climate continues to change.

To improve the estimates of the impacts of heat ~~of~~on RHAs, detailed data on emergency room visits and admissions during summer are needed, such as the proportion of emergency department cases admitted to hospital, and the fatality rate. A better understanding of vulnerable groups is needed, including how these groups could change over time. For example, the portion of the population aged over 65 will increase from 17 to 29%[~~38~~42] by 2050, significantly increasing the size of this vulnerable group. COPD is mainly a disease of the elderly. Persons suffering from COPD appear especially vulnerable to heat[43] and the incidence of COPD is likely to increase[44] with the consequence that the health impacts of heat may increase in future years. This study was limited to estimating the impacts on the total population because few age-specific relationship were reported and because age stratified data were only available on a coarser spatial scale than the climate data, which would reduce the benefits of having spatial climate data.

Normal weather patterns in the future will be different than those of today, both for average temperature and extreme weather events. As the number of heat related RHAs are expected to increase on the sub-continental scale, additional national or regional projections of the future health burden from heat are needed, taking into account possible changes in exposure and vulnerability.

CONCLUSIONS

Projected changes in temperature and the number of extreme heat events with climate change could substantially influence respiratory morbidity across Europe. Analyses projected that both the future proportion of annual RHAs attributed to heat and the relative change in heat related RHAs will be largest in Southern Europe, where they are expected to nearly triple. Eastern Europe can expect the smallest increase in heat related RHAs, where they are estimated to approximately double. For all of Europe, the number of respiratory heat-related hospital admissions is projected to be 26,000 annually in the future period (2021–2050) compared with 11,000 in the reference period (1981–2010). The estimates presented rely on the assumption that no additional adaptation occurs. Future studies should elaborate and quantify the possible effects of different adaptation assumptions applied to regional conditions.

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Contribution statement: CÅ, BF, HO has planned and designed the study. GS represented SMHI and provided climate data. CÅ ran the analyses, drafted the first manuscript and is guarantor. All authors have participated in the interpretation of results and revised the manuscript.

The specific estimates for each of the EU27 countries, for each of the climate projections is available after contact with corresponding author.

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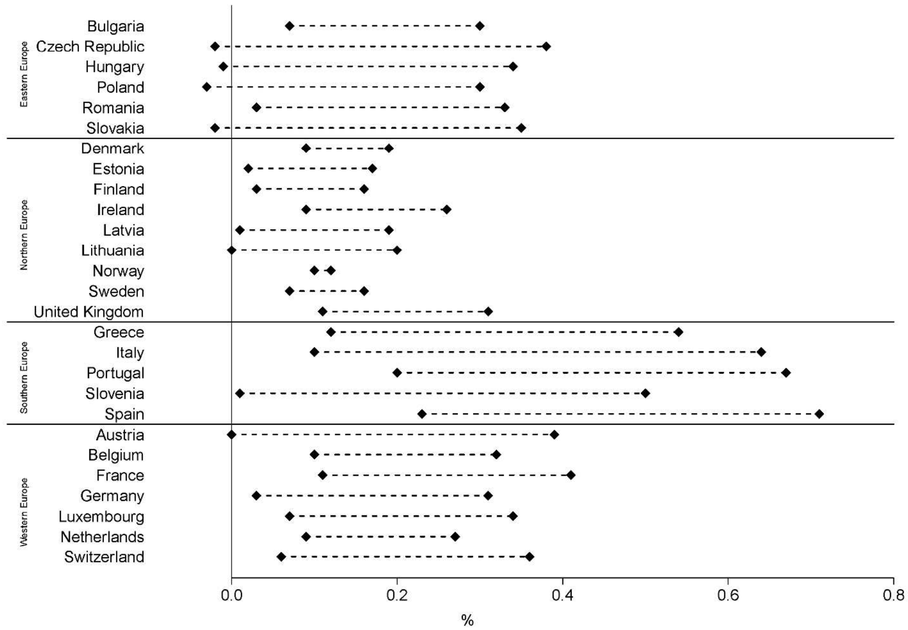
Figure 1. The range of the absolute increase in RHAs attributed to heat between the two periods (1981-2010, 2021-2050) as proportion the annual expected number of RHAs for each of the 27 countries. The points show the highest and lowest estimate from four climate models under two emission scenarios.



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Heat related respiratory hospital admissions in Europe in a changing climate: A health impact assessment

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Heat related respiratory hospital admissions in Europe in a changing climate

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ARTICLE SUMMARY

Article focus

To assess how heat-related respiratory hospital admissions in Europe could change with increasing temperatures in the near future. Within a range of climate change projections, explore different impact estimates.

Key messages

The 30-year mean annual increase in heat-related respiratory hospital admissions between the periods 1981-2010 and 2021-2050 can be counted in the 10's of thousands because of projected temperature increases. The increase will be different in different parts of Europe with the largest relative increase in Southern Europe.

Strengths and limitations

The study takes the spatial variation in climate and population density into account in impact calculations, making the estimates valid for countries with large national differences in these factors.

The study results exemplify some the variation of impacts under different climate change scenarios, as well as the variations within one scenario depending on the underlying climate model.

The use of spatial population data limited the study to exploring the change in all age respiratory hospital for studying heat-related illness, combined with the future increase in the proportion of elderly people, suggests the estimated impacts are likely to be conservative

ABSTRACT

Objectives: Respiratory diseases are ranked second in Europe in terms of mortality, prevalence and costs. Studies have shown that extreme heat has a large impact on mortality and morbidity, with a large relative increase for respiratory diseases. Expected increases in mean temperature and the number of extreme heat events over the coming decades due to climate change raise questions about the possible health impacts. Here we aim to assess the number of heat related respiratory hospital admissions in a future with a different climate.

Design: A European wide health impact assessment.

Setting: An assessment for each of the EU27 countries.

Methods: Heat-related hospital admissions under a changing climate are projected using multi-city epidemiologic exposure-response relationships applied to gridded population data and country-specific baseline respiratory hospital admission rates. Times-series of temperatures are simulated with a regional climate model based on four global climate models, under two greenhouse gas emission scenarios.

Results: Between a reference period (1981–2010) and a future period (2021–2050), the total number of respiratory hospital admissions attributed to heat is projected to be larger in Southern Europe, with three-times more heat attributed respiratory hospital admissions in the future period. The smallest change was estimated in Eastern Europe with about a two-fold increase. For all of Europe, the number of heat-related respiratory hospital admissions is projected to be 26,000 annually in the future period compared with 11,000 in the reference period.

Conclusions: The results suggest that projected effects of climate change on temperature and the number of extreme heat events could substantially influence respiratory morbidity across Europe.

INTRODUCTION

Respiratory diseases are ranked second in Europe in terms of mortality, prevalence, and costs.[1] This burden is expected to increase, partly due to a changing climate.[2] An environmental factor with a large impact on mortality and morbidity in Europe is extreme heat, with large effects on respiratory diseases.[3-5] Physiological effects of exposure to heat can be directly heat-related (heat stroke, heat fatigue and dehydration) or can contribute to worsening of respiratory and cardiovascular diseases, electrolyte disorders, and kidney problems.[4-7] The reasons for an increase in respiratory admissions may be several. Elderly with respiratory diseases such as COPD are less fit and suffer often from circulatory problems. Heat influenced admissions due to chronic airway obstruction and asthma increased more than admissions due to chronic bronchitis in a study from New York City,[8] but the daily number of admissions seldom allow a study of specific diagnoses. In a recent expert elicitation amongst European researchers engaged in environmental medicine or respiratory health, extreme heat stood out as most important climate-related pathway to adverse impacts on respiratory health, more important than changes in air pollutants and allergens.[9] A review found that heatwaves have a stronger relative impact on mortality than on emergency room visits and hospital admissions, suggesting that many individuals die before they can get to the hospital.[10] However, several studies confirm that heat also affects health care utilisation.[3 11] During the heatwave of 2003 in France, the Assistance Public Hôpitaux de Paris recorded 2,400 additional visits to the emergency care units and 1,900 additional hospital admissions.[12] During the heatwave in California in 2006 there were almost 1,200 hospital admissions together with more than 16,000 visits to the emergency departments.[6]

It is possible that hospital admissions could increase in the future due to temperature changes projected with climate change, assuming no additional acclimatisation. Projected changes include an increase in global mean temperature of 1.8°C to 4.0°C by the end of this century, with larger increases over land areas at high latitudes, changing seasonal temperatures, and increases in the frequency, intensity, duration, and spatial extent of heatwaves.[13] Recent projections for 2070–2100

suggest that maximum temperatures experienced once every 20 years during the period 1961–1990 could be expected as often as every year in southern Europe and every 3rd-5th year in northern Europe.[14] This means that Europe should expect an increase in both mean temperatures and the number of extreme heat events. Recent heatwaves are consistent with projections. For example, the heatwave that occurred in Europe 2003 could be expected to return every 46,000 years, based on the temperature distribution for the years 1864–2000.[15] However, such extreme hot conditions may become much more common in the end of this century due to anthropogenic climate changes.[16] The uncertainty in this estimated return time is quite high, with a lower bound of the 90% confidence interval of 9,000 years. Even so, another heatwave occurred in 2006 with the most anomalous July temperature ever measured in Europe.[17] In 2010, Eastern Europe experienced a heatwave with summer temperatures higher than the last 140 years, resulting in roughly 55,000 excess deaths in Russia.[18]

The possible impacts of these changes on morbidity, particularly respiratory health, are relatively unexplored.

Aim

The aim of this study is to assess the extent to which changes in the frequency of hot days due to climate change over the next 40 years could affect heat related respiratory hospital admissions (RHAs) in Europe. Using a range of climate projections, we estimate the change in hospital admissions between a reference period and a future period.

METHODS

Climate change and temperature modelling

The Rossby Centre regional atmospheric climate model RCA3[19] was developed by SMHI (Swedish meteorological and hydrological institute) to dynamically downscale results from the global climate models CCSM3[20], ECHAM5[21], HadleyCM3[22] and ECHAM4[23] to a higher resolution over Europe. RCA3 is

run on a horizontal grid spacing of 0.44° (corresponding to approximately 50 km) and a time step of 30 minutes. Projections are based on the global greenhouse gas emission scenarios A1B and A2 (scenarios are described in detail in the SRES[24]). Both have been used in climate change health impact assessments (HIA).[25-28] A1B is a "middle of the road" scenario and A2 is considered a high emission scenario, although recent greenhouse gas emissions have been higher. Data from one climate model, under one climate change scenario, is referred to as one climate change projection.

We use aggregated daily projections of maximum temperature and relative humidity data to estimate exposure for the periods 1981–2020 (reference period) and 2021–2050 (future period).

Population and morbidity rates

The annual country specific rate of RHAs (ICD-9:460–519) between 2005 and 2010 were extracted from the WHO's European Health for All Database (http://data.euro.who.int/hfadb) for the EU27 countries. In the dataset, national hospital admissions data are provided by national public health institutes, health ministries or corresponding functions. The ICD-9 codes were preferred because the epidemiological studies in the PHEWE study were based on ICD-9 RHAs. The mean value over the six years was used as a baseline morbidity rate. In order to have a fine spatial resolution, official population data were from the HYDE theme within the Netherlands Environmental Assessment Agency.[29] These data are gridded on a 0.0833° resolution (approximately 9,45km) and matched with the climatic data by summing the population within each climatic grid cell.

Exposure-response assumption

The impact calculations were based on the relationship between heat and RHAs (ICD-9:460–519) estimated within the European PHEWE (Assessment and Prevention of Acute Health Effects of Weather Conditions in Europe) project.[3] This relationship was based on analyses of 12 European cities over the 1990s, using the daily maximum of apparent temperature (AT), where AT is a combination of the measured temperature and the dew point temperature:

$$AT = -2.653 + 0.944*T + 0.0153 * (DT)^2$$

where T is the air temperature and DP the dew point temperature, which can be derived from temperature and relative humidity.[30] The AT accounts for heat stress related not only to the absolute temperature but also to the saturation of the surrounding air that makes it harder to regulate body temperature by sweating, the most important mechanism to maintain a healthy body temperature.[31] [32] The PHEWE model also included potential confounders such as air pollution, holidays, week days etc. The study used a 0–3 day lag of the maximum AT and concluded that the 90th percentile of this exposure variable for the summer months, April to September, is the appropriate threshold value for the heat-morbidity function.[3] We calculated the 90th percentile for the summer months for each grid cell from the climate data for the 1990s, yielding individual thresholds for each grid cell for each climate projection.

The PHEWE study calculated the relative risk (RR) coefficients for each of the 12 cities and then combined these into two meta-coefficients, for North-Continental cities 1.012 (95% CI 1.001–1.022) and Mediterranean cities 1.021 (95% CI 1.006–1.036), associated with a 1-degree increase above the temperature threshold. Meta-coefficients were more suitable as they allowed calculation of the change in RHAs for countries with and without a city in the PHEWE Study. We assigned the Mediterranean coefficient to Portugal and the Mediterranean countries. The rest of Europe was assigned the RR for the North continental cities. Statistically significant coefficients were found for all ages and ages 75+ in the PHEWE study. Because the population data were not stratified by age, we used the PHEWE study coefficients for all ages.

Projections

The final data used in the impact calculations were based on the climate data grid with a resolution of 0.44° resulting in 8,075 grid cells over Europe. The population data, RR coefficients and baseline morbidity rates were projected for each grid cell. The countries within EU27 were grouped into four regions, Northern, Western, Eastern and Southern Europe, according to the United Nations classification scheme (http://unstats.un.org/unsd/methods/m49/m49regin.htm#europe).

Thus, each grid cell includes (1) a daily time-series of 0–3 day lag maximum AT for each climate change projection; (2) a grid cell specific temperature-morbidity threshold and a location-based RR coefficient; and (3) population. For each grid cell, the AT was compared to the specific threshold for each day in the two time periods and risk estimates were calculated for each day. The expected number of daily RHAs in each cell was calculated using the population and the expected daily number of RHAs per capita, based on the national average of the grid cell.

$$RHA_{i,t} = RR_i\text{^}(AT_{i,t} - Thres_i)_+ * Pop_i * RHApc_i$$

where $RHA_{i,t}$ is the number of RHAs attributable to heat in grid cell *i* at time *t*, RR_i the RR coefficient in grid cell *i*, $(AT_{i,t} - Thres_i)_+$ the difference between the 0–3 lag AT and the threshold for grid cell *i* at time *t* if $AT_{i,t}$ were greater than the threshold and 0 otherwise, Pop_i and $RHApc_i$ the population and expected number RHAs per capita in grid cell *i*.

For each country, the estimated number of RHAs attributed to heat was calculated for each climate change projection, for both the reference and the future period. The estimated number of RHAs attributed to heat was then transformed into the proportion of the expected annual number RHAs for each country (data available from the authors). Mean estimates were calculated for each region for each climate change projection.

Sensitivity analysis

Because the study results could heavily depend on the RR coefficients and thresholds used, we assess whether the estimates appeared sensitive to the region-specific meta-coefficients. We investigated the grids that contained the cities in the PHEWE study using both the location (Mediterranean or North-Continental) and city specific RR coefficients.[3] We then compared the results with respect to the attributed proportion of RHAs and the proportional change in heat related RHAs.

RESULTS

The periods of warm days will increase in the future. For the cities included in the sensitivity analysis, the temperature threshold was exceeded annually, on average, by 20 days in the baseline period and 40 days in the future period.

In the future period, approximately 0.4% of the annual numbers of RHAs in Europe was estimated to be due to heat (Table 1), based on the mean estimates over the climate change projections. In absolute terms, assuming all else equal, this represents about 26,000 cases annually in Europe. This should be compared to the reference period where approximately 0.18% of all RHAs were attributed to heat or about 11,000 cases annually. Thus, the results suggest more than a relative doubling of the RHAs attributed to heat in Europe.

Table 1. The estimated proportion of RHAs attributed to heat for each region. Intervals describe the highest and lowest national estimate in each region

Region	1981–2010	2021–2050	Change
Eastern Europe	0.17% (0.16% – 0.19%)	0.31% (0.29% –0.35%)	0.14% (0.11% – 0.17%)
Northern Europe	0.13% (0.10% – 0.15%)	0.27% (0.19% – 0.32%)	0.14% (0.07% – 0.17%)
Southern Europe	0.23% (0.18% – 0.26%)	0.64% (0.42% – 0.68%)	0.41% (0.23% – 0.44%)
Western Europe	0.18% (0.16% – 0.20%)	0.39% (0.34% – 0.45%)	0.21% (0.17% – 0.26%)
EU27	0.18% (0.10% – 0.26%)	0.40% (0.19% – 0.68%)	0.21% (0.07% – 0.44%)

On the regional level, the five projections estimate increases in the number of heat-related RHAs for Europe (Table 2). However, in one climate change projection, The Czech Republic, Hungary, Poland and Slovakia were estimated to have a decrease in heat-related RHAs (Fig 1). The countries with the highest estimated increase also show the largest range between the highest and lowest estimate. The Scandinavian and Baltic countries show the smallest range between the highest and lowest estimates along with small increases of the mean estimates.

Table 2. Future increase in heat-related RHAs based on the four climate models, under two emission scenarios, as the percentage of the annual expected number of RHAs in each region

Climate model	**CCSM3**	**ECHAM5**	**HadCM3**	**ECHAM4**	**ECHAM5**
Greenhouse gas scenario		***A1B***		***A2***	
Eastern Europe	0.32%	0.08%	0.18%	0.12%	0.01%
Northern Europe	0.17%	0.09%	0.14%	0.20%	0.08%
Southern Europe	0.51%	0.29%	0.64%	0.45%	0.14%
Western Europe	0.30%	0.11%	0.26%	0.29%	0.06%
EU27	0.32%	0.13%	0.29%	0.26%	0.07%

There is variation among countries, with the largest increases in the Southern European countries and the smallest increase in Eastern Europe (Table 2). The relative change in the burden of RHA´s in relation to the climate change scenarios investigated indicate a larger relative increase in Mediterranean countries (approximately three times) compared to Northern European countries (approximately two times).

Sensitivity analysis

The calculations using the city specific RR coefficients yielded a different proportion and number of estimated RHAs than the ones using the two meta-coefficients, as expected. However, the relative changes in the number of hospital admissions attributed to heat between the two time-periods were not affected by the change of the RR coefficients.

DISCUSSION

The analysis estimates that the number of RHAs will increase in a warmer climate with more hot days. Heat-related RHAs were projected to increase two- to three-fold in the future due to climate change. However, the proportion of respiratory admissions attributed to heat would remain rather small. This projection is in line with the results of a recent study that estimates respiratory admissions due to excessive heat in New York State will increase 2-6 times from the period 1991-2004 to the period 2080-2099.[33]

As most heat-related health outcomes occur during the warmest period of the year, presenting the increase as a change in the proportion of the total number of annual RHAs can underestimate the additional burden on the health care system during summer. As the threshold was exceeded for approximately 40 days in one year, an annual increase of 0.21% would result in a 1.9% increase on average during these 40 days. The annual numbers are used because the available baseline rates of RHAs are expressed as an annual average. Applying results to sub-national scales could be inappropriate because national averages summarize over considerable heterogeneity.

The results suggest a larger impact from heat in Southern Europe in the future period, centred on year 2035, than in the eastern and northern parts. This is in line with many climate change projections showing a larger relative increase in the number of extremely hot days in southern Europe compared with northern Europe.[14] However, to some extent this might also be explained by model bias for northern Europe introduced by the RCA3 model, where the model appears to underestimate temperature for the warmest days.[19] This temperature bias is present in the reference period, future period, and threshold values; therefore, the estimated numbers of RHAs from the two periods within each scenario are comparable, but comparisons within the same time-period, across scenarios may be inaccurate.

As the estimates are based on the population size in each grid cell, the added burden will be larger in countries with larger increases in temperatures in densely populated areas. Because the population of a city is considered a good predictor of the size of the urban heat island,[34] an increase in the population living in urban areas will increase the numbers exposed and the temperature to which they are exposed. Heat islands increase temperatures in urbanized areas compared to surrounding areas, also reducing cooling during the night time.[35] These factors combined are likely to magnify the health burden during a heatwave.[36] The spatial scale of the climate models makes them unable to take the urban heat island effect into account. Together with the urbanization of Europe, this could potentially result in underestimation of actual consequences/RHAs in the future period because the same population size and composition were assumed in both periods. In addition, climate change is likely to increase ozone concentrations that would add an additional health burden for people at risk of respiratory diseases. The number of deaths and RHAs, due to a change in ozone, is expected to change in the future.[37] A sensitivity analysis in the PHEWE study however showed that the exposure-response relationship for heat did not substantially differ between models taking ozone into account and models adjusting for NO_2 alone.[3]

We used the same thresholds for the reference and future period to isolate the effect of climate change. This would tend to overestimate the increased impact because there will undoubtedly be biological and/or social adaptations that will reduce future health temperature-related burdens. However, given the uncertainty of such adaptation effects, we choose to not incorporate such effects in the projections. Recent studies in the U.S indicate heat-related health burdens have decreased,[38] indicating that some adaptation is taking place. An opposite trend appears to be occurring in Stockholm, with an increase of the risk of mortality associated with heat during the 1990s.[39] A study looking at the impact of heat on mortality, before and after the implementation of a heat warning system, in Italy shows that the effects of extreme heat can be reduced while the effects of moderate increased average temperatures remains similar.[40] The magnitude and the extent of future adaptation is, of course, highly uncertain, and will vary between and within countries. Nevertheless, cities with higher thresholds seem to have higher risk ratio coefficients.[3 41] In an effort to estimate future and presumably higher thresholds, one must also adjust the risk ratio coefficients. This would result in fewer days of elevated risk, but the risk increase on each occasion could be higher due to the higher RRs.

Table 2 shows how the results vary by global climate models and greenhouse gas scenarios. This study exemplifies the magnitude of the difference between projections made by a model with different initial conditions and between different models with the same initial conditions. The results indicate the range of these estimates is large. The mean increase over the five projections however, provides confidence that the number of RHAs will increase over Europe as the climate continues to change. The results from the different greenhouse gas emission scenarios are somewhat inconsistent with what is expected based on the characteristics of the scenarios. The scenario A2, which is considered a high emission scenario, shows lower estimates of the increase in RHAs than the A1B scenario, which is considered a middle of the road scenario. This result is from the different regional climate models rather than the emission scenarios themselves. Up until 2050, the estimated temperature increase is actually estimated to be higher in A1B than A2 according to IPCC.

To improve the estimates of the impacts of heat on RHAs, detailed data on emergency room visits and admissions during summer are needed, such as the proportion of emergency department cases admitted to hospital, and the fatality rate. A better understanding of vulnerable groups is needed, including how these groups could change over time. For example, the portion of the population aged over 65 will increase from 17 to 29%[42] by 2050, significantly increasing the size of this vulnerable group. COPD is mainly a disease of the elderly. Persons suffering from COPD appear especially vulnerable to heat[43] and the incidence of COPD is likely to increase[44] with the consequence that the health impacts of heat may increase in future years. This study was limited to estimating the impacts on the total population because few age-specific relationships were reported and because age-stratified data were only available on a coarser spatial scale than the climate data, which would reduce the benefits of having spatial climate data. When spatial population data, such as the Eurostat data, have a finer age-stratification, a more detailed assessment will be possible.

Normal weather patterns in the future will be different than those of today, both for average temperature and extreme weather events. As the number of heat related RHAs are expected to increase on the sub-continental scale, additional national or regional projections of the future health burden from heat are needed, taking into account possible changes in exposure and vulnerability.

CONCLUSIONS

Projected changes in temperature and the number of extreme heat events with climate change could substantially influence respiratory morbidity across Europe. Analyses projected that both the future proportion of annual RHAs attributed to heat and the relative change in heat related RHAs will be largest in Southern Europe, where they are expected to nearly triple. Eastern Europe can expect the smallest increase in heat-related RHAs, where they are estimated to approximately double. For all of Europe, the number of respiratory heat-related hospital admissions is projected to be 26,000 annually in the future period (2021–2050) compared with 11,000 in the reference period (1981–2010). The estimates presented rely on the assumption that no additional adaptation occurs. Future studies should elaborate and quantify the possible effects of different adaptation assumptions applied to regional conditions.

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Contribution statement: CÅ, BF, HO has planned and designed the study. GS represented SMHI and provided climate data. CÅ ran the analyses, drafted the first manuscript and is guarantor. All authors have participated in the interpretation of results and revised the manuscript.

The specific estimates for each of the EU27 countries, for each of the climate projections is available after contact with corresponding author.

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Figure 1. The range of the absolute increase in RHAs attributed to heat between the two periods (1981-2010, 2021-2050) as proportion the annual expected number of RHAs for each of the 27 countries. The points show the highest and lowest estimate from four climate models under two emission scenarios.

Heat related respiratory hospital admissions in Europe in a changing climate

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ARTICLE SUMMARY

Article focus

To assess how heat-related respiratory hospital admissions in Europe ~~are expected to~~could change with ~~the global warming~~increasing temperatures in the near future. ~~With~~Within a range of climate change projections, explore ~~the range of the~~ different impact estimates.

Key messages

The 30-year mean annual increase in heat-related respiratory hospital admissions ~~related to heat~~ between the periods 1981-2010 and 2021-2050 can be counted in the 10's of thousands~~.~~ because of projected temperature increases. The increase will be different in different parts of Europe with the largest relative increase in Southern Europe.

Strengths and limitations

The study takes the spatial variation in ~~both~~ climate and population density into account in ~~the~~ impact calculations~~. This makes~~, making the estimates valid for countries with large national differences in ~~population densities and climate~~these factors.

The study results ~~exemplifies~~exemplify some the variation of ~~the~~ impacts ~~depending on~~under different climate change scenarios, as well as the variations within one ~~climate~~ scenario depending on the underlying climate model.

The use of ~~real~~ spatial population data ~~has~~ limited the study to ~~explore~~exploring the change in all age respiratory hospital ~~admissions without demographic trends. The fact that the elderly is a well-known risk group when~~for studying heat-related illness, combined with the future ~~rise of~~increase in the proportion of elderly people ~~in the population may suggest that~~, suggests the estimated impacts are ~~rather~~likely to be conservative

ABSTRACT

Respiratory diseases are ranked second in Europe in terms of mortality, prevalence, and costs. Studies have shown that extreme heat has a large impact on mortality and morbidity, with a large relative increase for respiratory diseases. Expected increases in mean temperature and the number of extreme heat events over the coming decades due to climate change raise questions about the possible health impacts.

Heat-related respiratory hospital admissions under a changing climate are projected using multi-city epidemiologic exposure-response relationships applied to gridded population data and country-specific baseline respiratory hospital admission rates. Times-series of temperatures are simulated with a regional climate model based on four global climate models, under two greenhouse gas emission scenarios (A1B & A2).

Between a reference period (1981–2010) and a future period (2021–2050), the total number of respiratory hospital admissions attributed to heat is projected to be larger in Southern Europe, with three-times more heat attributed respiratory hospital admissions in the future period. The smallest change was estimated in Eastern Europe with about a two-fold increase. For all of Europe, the number of respiratory heat-related hospital admissions is projected to be 26,000 annually in the future period compared with 11,000 in the reference period.

The results suggest that projected effects of climate change on temperature and the number of extreme heat events could substantially influence respiratory morbidity across Europe.

INTRODUCTION

Respiratory diseases are ranked second in Europe in terms of mortality, prevalence, and costs.[1] This burden is expected to increase, partly due to a changing climate.[2] An environmental factor with a large impact on mortality and morbidity in Europe is extreme heat, with large effects on respiratory diseases.[3-5] Physiological effects of exposure to heat can be directly heat-related (heat stroke, heat fatigue and dehydration) or can contribute to worsening of respiratory and cardiovascular diseases, electrolyte disorders, and kidney problems.[4-7] The reasons for an increase in respiratory admissions may be several. Elderly with respiratory diseases such as COPD are less fit and suffer often from circulatory problems. Heat influenced admissions due to chronic airway obstruction and asthma increased more than admissions due to chronic bronchitis in a study from New York City,[8] but the daily number of admissions seldom allow a study of specific diagnoses. In a recent expert elicitation amongst European researchers engaged in environmental medicine or respiratory health, extreme heat stood out as most important climate-related pathway to adverse impacts on respiratory health, more important than changes in air pollutants and allergens.[9] A review found that heatwaves have a stronger relative impact on mortality than on emergency room visits and hospital admissions, suggesting that many individuals die before they can get to the hospital.[10] However, several studies confirm that heat also affects health care utilisation.[3 11] During the heatwave of 2003 in France, the Assistance Public Hôpitaux de Paris recorded 2,400 additional visits to the emergency care units and 1,900 additional hospital admissions.[12] During the heatwave in California in 2006 there were almost 1,200 hospital admissions together with more than 16,000 visits to the emergency departments.[6]

It is possible that hospital admissions could increase in the future due to temperature changes projected with climate change, assuming no additional acclimatisation. Projected changes include an increase in global mean temperature of 1.8°C to 4.0°C by the end of this century, with larger increases over land areas at high latitudes, changing seasonal temperatures, and increases in the frequency, intensity, duration, and spatial extent of heatwaves.[13] Recent projections for 2070–2100

suggest that maximum temperatures experienced once every 20 years during the period 1961–1990 could be expected as often as every year in southern Europe and every 3rd-5th year in northern Europe.[14] This means that Europe should expect an increase in both mean temperatures and the number of extreme heat events. Recent heatwaves are consistent with projections. For example, the heatwave that occurred in Europe 2003 could be expected to return every 46,000 years, based on the temperature distribution for the years 1864–2000.[15] However, such extreme hot conditions may become much more common in the end of this century due to anthropogenic climate changes.[16] The uncertainty in this estimated return time is quite high, with a lower bound of the 90% confidence interval of 9,000 years. Even so, another heatwave occurred in 2006 with the most anomalous July temperature ever measured in Europe.[17] In 2010, Eastern Europe experienced a heatwave with summer temperatures higher than the last 140 years, resulting in roughly 55,000 excess deaths in Russia.[18]

The possible impacts of these changes on morbidity, particularly respiratory health, are relatively unexplored.

Aim

The aim of this study is to assess the extent to which changes in the frequency of hot days due to climate change over the next 40 years could affect heat related respiratory hospital admissions (RHAs) in Europe. Using a range of climate projections, we estimate the change in hospital admissions between a reference period and a future period.

METHODS

Climate change and temperature modelling

The Rossby Centre regional atmospheric climate model RCA3[19] was developed by SMHI (Swedish meteorological and hydrological institute) to dynamically downscale results from the global climate models CCSM3[20], ECHAM5[21], HadleyCM3[22] and ECHAM4[23] to a higher resolution over Europe. RCA3 is

run on a horizontal grid spacing of 0.44° (corresponding to approximately 50 km) and a time step of 30 minutes. Projections are based on the global greenhouse gas emission scenarios A1B and A2 (scenarios are described in detail in the SRES[24]). Both have been used in climate change health impact assessments (HIA).[25-28] A1B is a "middle of the road" scenario and A2 is considered a high emission scenario, although recent greenhouse gas emissions have been higher. Data from one climate model, under one climate change scenario, is referred to as one climate change projection.

We use aggregated daily projections of maximum temperature and relative humidity data to estimate exposure for the periods 1981–2020 (reference period) and 2021–2050 (future period).

Population and morbidity rates

The annual country specific rate of ~~respiratory hospital admissions~~RHAs (ICD-9:460–519) between 2005 and 2010 were extracted from the WHO's European Health for All Database (http://data.euro.who.int/hfadb) for the EU27 countries. In the dataset, national hospital admissions data are provided by national public health institutes, health ministries or corresponding functions. The ICD-9 codes were preferred because the epidemiological studies in the PHEWE study were based on ICD-9 RHAs. The mean value over the six years was used as a baseline morbidity rate. In order to have a fine spatial resolution, official population data were from the HYDE theme within the Netherlands Environmental Assessment Agency.[29] These data are gridded on a 0.0833° resolution (approximately 9,45km) and matched with the climatic data by summing the population within each climatic grid cell.

Exposure-response assumption

The impact calculations were based on the relationship between heat and RHAs (ICD-9:460–519) estimated within the European PHEWE (Assessment and Prevention of Acute Health Effects of Weather Conditions in Europe) project.[3] This relationship was based on analyses of 12 European cities over the 1990s, using the daily maximum of apparent temperature (AT), where AT is a combination of the measured temperature and the dew point temperature:

$$AT = -2.653 + 0.944*T + 0.0153 * (DT)^2$$

where T is the air temperature and DP the dew point temperature, which can be derived from temperature and relative humidity.[30] The AT accounts for heat stress related not only to the absolute temperature but also to the saturation of the surrounding air that makes it harder to regulate body temperature by sweating, the most important mechanism to maintain a healthy body temperature.[31 32] The PHEWE model also included potential confounders such as air pollution, holidays, week days etc. The study used a 0–3 day lag of the maximum AT and concluded that the 90th percentile of this exposure variable for the summer months, April to September, is the appropriate threshold value for the heat-morbidity function.[3] We calculated the 90th percentile for the summer months for each grid cell from the climate data for the 1990s, yielding individual thresholds for each grid cell for each climate projection.

The PHEWE study calculated the relative risk (RR) coefficients for each of the 12 cities and then combined these into two meta-coefficients, for North-Continental cities 1.012 (95% CI 1.001–1.022) and Mediterranean cities 1.021 (95% CI 1.006–1.036), associated with a 1-degree increase above the temperature threshold. Meta-coefficients were more suitable as they allowed calculation of the change in RHAs for countries with and without a city in the PHEWE Study. We assigned the Mediterranean coefficient to Portugal and the Mediterranean countries. The rest of Europe was assigned the RR for the North continental cities. Statistically significant coefficients were found for all ages and ~~age~~ages 75+ in the PHEWE study. Because the population data were not stratified by age, we used the PHEWE study coefficients for all ages.

Projections

The final data used in the impact calculations were based on the climate data grid with a resolution of 0.44° resulting in 8,075 grid cells over Europe. The population data, RR coefficients and baseline morbidity rates were projected for each grid cell. The countries within EU27 were grouped into four regions, Northern, Western, Eastern and Southern Europe, according to the United Nations classification scheme (http://unstats.un.org/unsd/methods/m49/m49regin.htm#europe).

Thus, each grid cell includes (1) a daily time-series of 0–3 day lag maximum AT for each climate change projection; (2) a grid cell specific temperature-morbidity threshold and a location-based RR coefficient; and (3) population. For each grid cell, the AT was compared to the specific threshold for each day in the two time periods and risk estimates were calculated for each day. The expected number of daily RHAs in each cell was calculated using the population and the expected daily number of RHAs per capita, based on the national average of the grid cell.

$$RHA_{i,t} = RR_i\hat{}(AT_{i,t} - Thres_i)_+ * Pop_i * RHApc_i$$

where $RHA_{i,t}$ is the number of RHAs attributable to heat in grid cell *i* at time *t*, RR_i the RR coefficient in grid cell *i*, $(AT_{i,t} - Thres_i)_+$ the difference between the 0–3 lag AT and the threshold for grid cell *i* at time *t* if $AT_{i,t}$ were greater than the threshold and 0 otherwise, Pop_i and $RHApc_i$ the population and expected number RHAs per capita in grid cell *i*.

For each country, the estimated number of RHAs attributed to heat was calculated for each climate change projection, for both the reference and the future period. The estimated number of RHAs attributed to heat was then transformed into the proportion of the expected annual number RHAs for each country (data available from the authors). Mean estimates were calculated for each region for each climate change projection.

Sensitivity analysis

Because the study results could heavily depend on the RR coefficients and thresholds used, we assess whether the estimates appeared sensitive to the region-specific meta-coefficients. We investigated the grids that contained the cities in the PHEWE study using both the location (Mediterranean or North-Continental) and city specific RR coefficients.[3] We then compared the results with respect to the attributed proportion of RHAs and the proportional change in heat related RHAs.

RESULTS

The periods of warm days will increase in the future. For the cities included in the sensitivity analysis, the temperature threshold was exceeded annually, on average, by 20 days in the baseline period and 40 days in the future period~~, on average each year~~.

In the future period, approximately 0.4% of the annual numbers of RHAs in Europe was estimated to be due to heat (Table 1), based on the mean estimates over the climate change projections. In absolute terms, assuming all else equal, this represents about 26,000 cases annually in Europe. This should be compared to the reference period where approximately 0.18% of all RHAs were attributed to heat or about 11,000 cases annually. Thus, the results suggest more than a relative doubling of the RHAs attributed to heat in Europe.

Table 1. The estimated proportion of RHAs attributed to heat for each region. Intervals describe the highest and lowest national estimate in each region

Region	1981–2010	2021–2050	Change
Eastern Europe	0.17% (0.16% – 0.19%)	0.31% (0.29% –0.35%)	0.14% (0.11% – 0.17%)
Northern Europe	0.13% (0.10% – 0.15%)	0.27% (0.19% – 0.32%)	0.14% (0.07% – 0.17%)
Southern Europe	0.23% (0.18% – 0.26%)	0.64% (0.42% – 0.68%)	0.41% (0.23% – 0.44%)
Western Europe	0.18% (0.16% – 0.20%)	0.39% (0.34% – 0.45%)	0.21% (0.17% – 0.26%)
EU27	0.18% (0.10% – 0.26%)	0.40% (0.19% – 0.68%)	0.21% (0.07% – 0.44%)

On the regional level, the five projections estimate increases in the number of heat-related RHAs for Europe (Table 2). However, in one climate change projection, The Czech Republic, Hungary, Poland and Slovakia were estimated to have a decrease in heat-related RHAs (Fig 1). The countries with the highest estimated increase also show the largest range between the highest and lowest estimate. The Scandinavian and Baltic countries show the smallest range between the highest and lowest estimates along with small increases of the mean estimates.

Table 2. Future increase in heat-related RHAs based on the four climate models, under two emission scenarios, as the percentage of the annual expected number of RHAs in each region

Climate model	**CCSM3**	**ECHAM5**	**HadCM3**	**ECHAM4**	**ECHAM5**
Greenhouse gas scenario	***A1B***			***A2***	
Eastern Europe	0.32%	0.08%	0.18%	0.12%	0.01%
Northern Europe	0.17%	0.09%	0.14%	0.20%	0.08%
Southern Europe	0.51%	0.29%	0.64%	0.45%	0.14%
Western Europe	0.30%	0.11%	0.26%	0.29%	0.06%
EU27	0.32%	0.13%	0.29%	0.26%	0.07%

There is variation among countries, with the largest increases in the Southern European countries and the smallest increase in Eastern Europe (Table 2). The relative change in the burden of RHA´s in relation to the climate change scenarios investigated indicate a larger relative increase in Mediterranean countries (approximately three times) compared to Northern European countries (approximately two times).

Sensitivity analysis

The calculations using the city specific RR coefficients yielded a different proportion and number of estimated RHAs than the ones using the two meta-coefficients, as expected. However, the relative changes in the number of hospital admissions attributed to heat between the two time-periods were not affected by the change of the RR coefficients.

DISCUSSION

The analysis estimates that the number of RHAs will increase in a warmer climate with more hot days. Heat-related RHAs were projected to increase two- to three-fold in the future due to climate change. However, the proportion of respiratory admissions attributed to heat would remain rather small. This projection is in line with the results of a recent study ~~which~~that estimates ~~that the~~

respiratory admissions due to excessive heat in New York State will increase 2-6 times from the period 1991-2004 to the period 2080-2099.[33]

As most heat-related health outcomes occur during the warmest period of the year, presenting the increase as a change in the proportion of the total number of annual RHAs can underestimate the additional burden on the health care system during summer. As the threshold was exceeded for approximately 40 days in one year, an annual increase of 0.21% would result in a 1.9% increase on average during these 40 days. The annual numbers are used because the available baseline rates of RHAs are expressed as an annual average. Applying results to sub-national scales could be inappropriate because national averages summarize over considerable heterogeneity.

The results suggest a larger impact from heat in Southern Europe in the future period, centred on year 2035, than in the eastern and northern parts. This is in line with many climate change projections showing a larger relative increase in the number of extremely hot days in southern Europe compared with northern Europe.[14] However, to some extent this might also be explained by model bias for northern Europe introduced by the RCA3 model, where the model appears to underestimate temperature for the warmest days.[19] This temperature bias is present in the reference period, future period, and threshold values; therefore, the estimated numbers of RHAs from the two periods within each scenario are comparable, but comparisons within the same time-period, across scenarios may be inaccurate.

As the estimates are based on the population size in each grid cell, the added burden will be larger in countries with larger increases in temperatures in densely populated areas. Because the population of a city is considered a good predictor of the size of the urban heat island,[34] an increase in the population living in urban areas will increase the numbers exposed and the temperature to which they are exposed. Heat islands increase temperatures in urbanized areas compared to surrounding areas, also reducing cooling during the night time.[35] These factors combined are likely to magnify the health burden during a heatwave.[36] The ~~coarse~~ spatial scale of the climate models makes them unable to take the urban heat island effect into account. Together with the urbanization of Europe, this could potentially result in underestimation of actual consequences/RHAs in the future period because the same population size and composition were assumed in both periods. In addition, climate change is likely to increase ozone concentrations that would add an additional health burden for people at risk of respiratory diseases. The number of deaths and RHAs, due to a change in ozone, is expected to change in the future.[37] A sensitivity analysis in the PHEWE study however showed that the exposure-response relationship for heat did not substantially differ between models taking ozone into account and models adjusting for NO_2 alone.[3]

We used the same thresholds for the reference and future period to isolate the effect of climate change. This would tend to overestimate the increased impact because there will undoubtedly be biological and/or social adaptations that will reduce future health temperature-related burdens. However, given the uncertainty of such adaptation effects, we choose to not incorporate such effects in the projections. Recent studies in the U.S indicate heat-related health burdens have decreased,[38] indicating that some adaptation is taking place. An opposite trend appears to be occurring in Stockholm, with an increase of the risk of mortality associated with heat during the 1990s.[39] A study looking at the impact of heat on mortality, before and after the implementation of a heat warning system, in Italy shows that the effects of extreme heat can be reduced while the effects of moderate increased average temperatures remains similar.[40] The magnitude and the extent of future adaptation is, of course, highly uncertain, and will vary between and within countries. Nevertheless, cities with higher thresholds seem to have higher risk ratio coefficients.[3,41] In an effort to estimate future and presumably higher thresholds, one must also adjust the risk ratio coefficients. This would result in fewer days of elevated risk, but the risk increase on each occasion could be higher due to the higher RRs.

Table ~~1~~2 shows how the results vary by global climate models and greenhouse gas scenarios. This study exemplifies the magnitude of the difference between projections made by a model with different initial conditions and between different models with the same initial conditions. The results indicate the range of these estimates is large. The mean increase over the five projections however, provides confidence that the number of RHAs will increase over Europe as the climate continues to change. The results from the different greenhouse gas emission scenarios are somewhat inconsistent with what is expected based on the characteristics of the scenarios. The scenario A2, which is considered a high emission scenario, shows lower estimates of the increase in RHAs than the A1B scenario, which is considered a middle of the road scenario. This result is from the different regional climate models rather than the emission scenarios themselves. Up until 2050, the estimated temperature increase is actually estimated to be higher in A1B than A2 according to IPCC.

To improve the estimates of the impacts of heat on RHAs, detailed data on emergency room visits and admissions during summer are needed, such as the proportion of emergency department cases admitted to hospital, and the fatality rate. A better understanding of vulnerable groups is needed, including how these groups could change over time. For example, the portion of the population aged over 65 will increase from 17 to 29%[42] by 2050, significantly increasing the size of this vulnerable group. COPD is mainly a disease of the elderly. Persons suffering from COPD appear especially vulnerable to heat[43] and the incidence of COPD is likely to increase[44] with the consequence that the health impacts of heat may increase in future years. This study was limited to estimating the impacts on the total population because few age-specific ~~relationship~~relationships were reported and because age-stratified data were only available on a coarser spatial scale than the climate data, which would reduce the benefits of having spatial climate data. When spatial population data, such as the Eurostat data, have a finer age-stratification, a more detailed assessment will be possible.

Normal weather patterns in the future will be different than those of today, both for average temperature and extreme weather events. As the number of heat related RHAs are expected to increase on the sub-continental scale, additional national or regional projections of the future health burden from heat are needed, taking into account possible changes in exposure and vulnerability.

CONCLUSIONS

Projected changes in temperature and the number of extreme heat events with climate change could substantially influence respiratory morbidity across Europe. Analyses projected that both the future proportion of annual RHAs attributed to heat and the relative change in heat related RHAs will be largest in Southern Europe, where they are expected to nearly triple. Eastern Europe can expect the smallest increase in heat-related RHAs, where they are estimated to approximately double. For all of Europe, the number of respiratory heat-related hospital admissions is projected to be 26,000 annually in the future period (2021–2050) compared with 11,000 in the reference period (1981–2010). The estimates presented rely on the assumption that no additional adaptation occurs. Future studies should elaborate and quantify the possible effects of different adaptation assumptions applied to regional conditions.

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Contribution statement: CÅ, BF, HO has planned and designed the study. GS represented SMHI and provided climate data. CÅ ran the analyses, drafted the first manuscript and is guarantor. All authors have participated in the interpretation of results and revised the manuscript.

The specific estimates for each of the EU27 countries, for each of the climate projections is available after contact with corresponding author.

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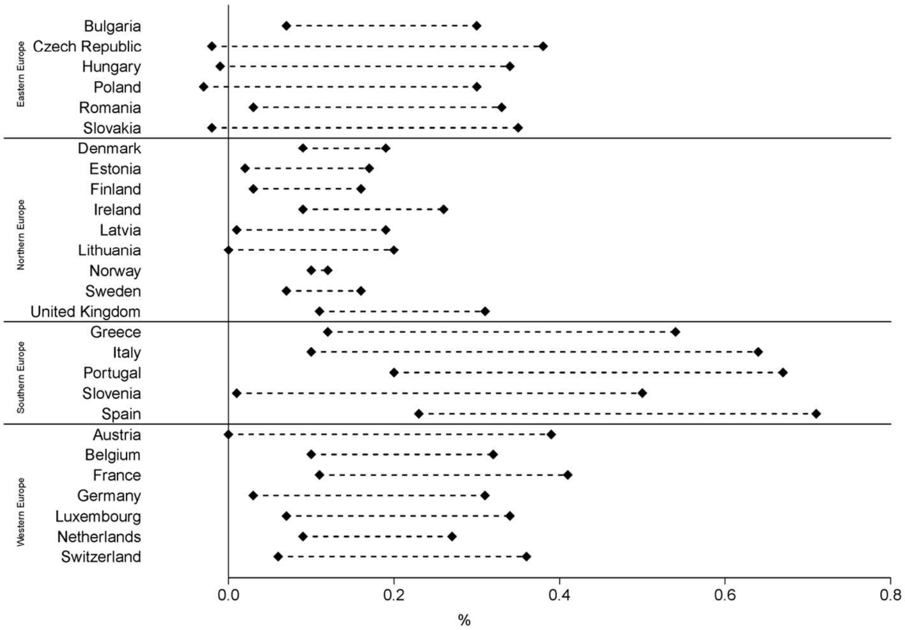
Figure 1. The range of the absolute increase in RHAs attributed to heat between the two periods (1981-2010, 2021-2050) as proportion the annual expected number of RHAs for each of the 27 countries. The points show the highest and lowest estimate from four climate models under two emission scenarios.



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