Supplementary Information

1. Datasets used for the climate impact modelling

Table S1: Datasets used for the climate impact modelling.

	Mortality	Labour Productivity
Hazard	CH2018 climate scenarios data [1] (T_{max})	CH2018 climate scenarios data [1] (T_{min}; T_{max})
Exposure	Population statistics (STATPOP 2018 [2])	Companies' structure statistics (STATNET 2017 [3])
Vulnerability	RR functions from Ragettli *et al* (2017) [4]	Empirical studies (see Table 1 in paper)

2. Infer hourly temperature values

We find the function to transform daily gridded minimum and maximum temperature data in hourly mean temperature values by studying observational data for a few stations in Switzerland for the summer of 2018 (Bern, Geneva, Sion, and Lugano). We test different models to approximate the hourly temperature from the minimum and maximum. We then calculate the root mean squared error (RMSE) for each station for the model versus the observed hourly temperature, considering only the hours between 6:00 and 22:00. We find the "linked days" equation from Chow and Levermore (2007) [5] to have the smallest RMSE and we chose it for computing the hourly temperature. In Figure S1, the observed values, as well as the fit used to approximate the hourly temperature are shown as an example for the station of Bern.

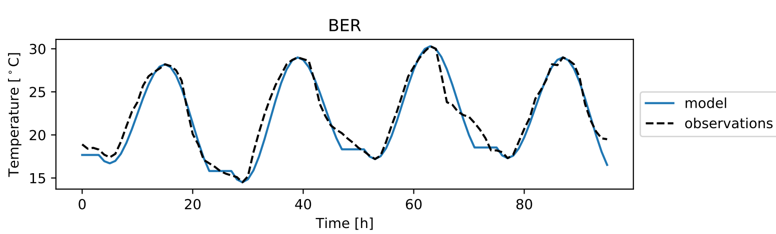


Figure S1: Example of a few days fitted with the hourly temperature model (blue line) and observed hourly temperature (black dashed line) for a meteorological station in Bern.

3. Infer indoor temperature values

To compute indoor temperature values, we use a dynamic thermal model. To be able to retrieve the operating temperature inside the building, we have to perform the energy analysis. The model represents a simplified office building with the typical thermal transmittance (see Table S2) located in the city area of Zurich. The extent of the area and the thermal properties of the building used in the model correspond to averages computed on the basis of the building stock constructed between 2001 and 2005 in Zurich. These are assumed to be valid also for the rest of Switzerland. The analysis period includes three hot days between 4-6 August 2018 in Zurich. We then compute the best estimate for the relationship between indoor and outdoor temperature, expressed as the relative change in percentage for the temperature inside compared to that outside (see Equation (1)).

zélie

Table S2: Assumptions at the basis of the dynamic thermal model.

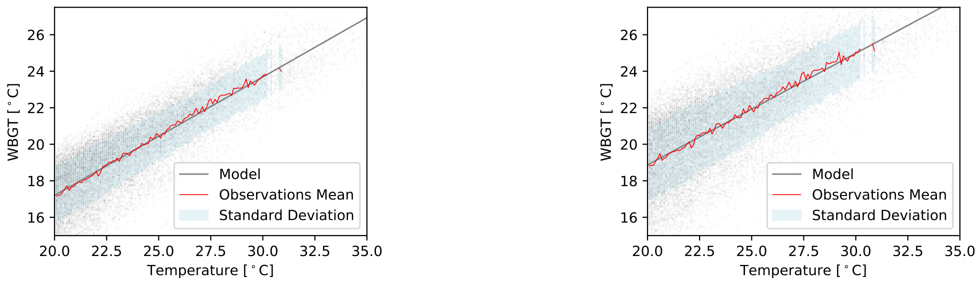
	Surface area	206 m^2
	Windows area	109 m^2
Thermal properties	U-value wall	0.3 W/m^2K
	U-value window	1.4 W/m^2K
	U-value ground	0.4 W/m^2K
	U-value roof	0.3 W/m^2K

The percentage difference between outside and inside temperature is given by:

$$percentage\,difference = (0.27614082 * \sin(0.27614082 T_{out} + 0.67076506) - 0.04965493) * 100 \quad (1)$$

4. Infer WBGT values from temperature

We study the relationship between temperature and WBGT for past observations at different stations. To calculate the WBGT, we use the R package *HeatStress* [6]. This package provides tools to calculate the WBGT from meteorological variables. Two functions are available in this package to get the WBGT: one to calculate the WBGT in the shadow (taking into account temperature, humidity, and a constant wind speed) and one in the sun (additionally taking into account the sun radiation). We plot the temperature against the calculated WBGT both in the sun and in the shadow as shown in Figure S2, and we chose linear relationships with normal distributions (see Equations (2) and (3)).



(a) (b)

Figure S2: Temperature and WBGT relationship for temperatures over 20 °C from 2015 to 2018 with the points being observations from stations in Chur, Zurich, Geneva, Lugano, and Basel in the shadow (a) or in the sun (b). The black line is the model which is taken to compute the hazards. An average from the standard deviations of the observations at each temperature is taken as standard deviation of the model in the Monte Carlo simulation.

The equations to transform the temperature in WBGT in the shadow and in the sun are given by:

$$WBGT_{shadow}(T) = 4.22085354 + 0.64879697T \tag{2}$$

$$WBGT_{sun}(T) = 4.664870352 + 0.611111305T \tag{3}$$

5. Categorisation of the activity classes

The category *low physical activity* consists primarily of knowledge workers, such as accounting and servicing, which do not require to perform any major physical effort during the working day (metabolic rate of $200W$). The jobs of the category *moderate physical activity* are for example industry activities, which demand a moderate physical effort (metabolic rate of $300W$). The category *high physical activity* refers to occupations that are particularly demanding on a physical level (metabolic rate of $400W$), with agriculture and construction being the predominant sectors.

Table S3: Subdivision of the activity classes in the three occupation categories: low (L), moderate (M), and high (H) physical activity. In the third column of the table it is specified whether the tasks of each activity class are mostly carried out indoor (I) or outdoor (O). Swiss average hourly salaries are indicated in the last column, expressed in CHF/h. We calculate these from mean monthly gross salaries of 2018 for Switzerland [7].

Activity class	Occupation category	Work setting	Average hourly salary [CHF/h]
Agriculture, hunting, and related activities	H	O	26.50
Forestry and timber harvesting	H	O	45.02
Fishing and aquaculture	H	O	NaN

Coal mining	H	O	41.50
Extraction of oil and gas	H	O	41.50
Ore mining	H	O	41.50
Extraction of stone and soil, other mining activities	H	O	41.50
Supply of services to the mining and quarrying industry	H	O	NaN
Manufacture of food and feed products	M	I	36.57
Beverage production	M	I	43.39
Tobacco processing	M	I	74.94
Manufacture of textiles	M	I	37.03
Manufacture of clothing	M	I	33.21
Manufacture of leather and related products	M	I	32.52
Manufacture of wood, plaiting, wicker, and cork products (without furniture)	M	I	38.98
Manufacture of paper and paperboard and articles thereof	M	I	41.64
Manufacture of printed matter; Duplication of recorded sound, image, and data carriers	M	I	40.51
Coke and mineral oil processing	M	I	49.33
Manufacture of chemical products	M	I	54.37
Manufacture of pharmaceutical products	M	I	71.06
Manufacture of rubber and plastic products	M	I	40.04
Production of glass and glassware, ceramics, processing of stones and soils	M	I	41.98
Metal production and processing	M	I	40.57
Manufacture of metal products	M	I	40.22
Manufacture of data processing equipment, electronic and optical products	M	I	47.84
Manufacture of electrical equipment	M	I	46.31
Machinery manufacture	M	I	46.57
Manufacture of automobiles and automobile parts	M	I	39.66
Other vehicle manufacture	M	I	46.96
Furniture manufacture	M	I	39.86
Manufacture of other goods	M	I	43.36
Repair and installation of machinery and equipment	M	I	43.65
Energy supply	M	O	55.69
Water supply	M	O	46.43
Wastewater disposal	M	O	41.61
Collection, treatment and disposal of waste; Recovery	M	O	40.46
Pollution abatement and other disposal	M	O	NaN
Building construction	H	O	42.79
Civil engineering	H	O	43.91

Preparatory construction site work, building installation and other finishing trades	H	O	39.89
Trade, maintenance, and repair of motor vehicles	M	I	39.87
Wholesale trade (except of trade of motor vehicles)	M	I	53.26
Retail trade (except of trade of motor vehicles)	M	I	33.57
Land transport and transport by pipeline	M	O	42.14
Shipping	M	I	40.29
Aviation	M	I	46.86
Warehousing and support activities for transportation	M	I	45.46
Postal, courier and express services	M	O	39.14
Accommodation	M	I	29.41
Gastronomy	M	I	28.85
Publishing industry	L	I	50.16
Production, distribution and sale of films and television programs; Cinemas; Sound studios and music publishing	L	I	42.46
Broadcasters	L	I	53.73
Telecommunications	L	I	59.39
Supply of information technology services	L	I	60.02
Information services	L	I	86.68
Supply of financial services	L	I	73.12
Insurance, reinsurance, and pension funding (excluding social insurance)	L	I	64.12
Activities auxiliary to financial and insurance services	L	I	67.61
Real estate and housing	L	I	47.35
Legal and tax advice, auditing	L	I	56.62
Administration and management of companies and enterprises; Management consultancy	L	I	75.01
Architecture and engineering offices; Technical, physical, and chemical analysis	L	I	49.20
Research and development	L	I	70.32
Advertising and market research	L	I	48.89
Other freelance, scientific, and technical activities	L	I	50.11
Veterinary services	L	I	41.73
Rental of movable goods	L	I	42.19
Placement and transfer of workers	L	I	37.77
Travel agencies, tour operators, and other reservation services	L	I	39.99
Guard and security services, detective agencies	L	I	35.81
Building management; Gardening and landscaping	H	O	35.38
Supply of economic services to enterprises and individuals n.e.c.	L	I	42.77
Public administration and defence; Social insurance	L	I	53.67
Education and teaching	L	I	55.25

Healthcare	L	I	46.47
Homes (excluding recreational and holiday homes)	L	I	38.69
Social services (without homes)	L	I	41.63
Creative, artistic and entertainment activities	L	I	41.96
Libraries, archives, museums, botanical and zoological gardens	L	I	46.66
Gaming, betting, and lottery	L	I	36.41
Supply of sports, entertainment, and recreational services	L	I	42.64
Interest groups, church and other religious associations (excluding social services and sport)	L	I	49.03
Repair of data processing equipment and consumer goods	L	I	37.56
Supply of other predominant personal services	L	I	28.79

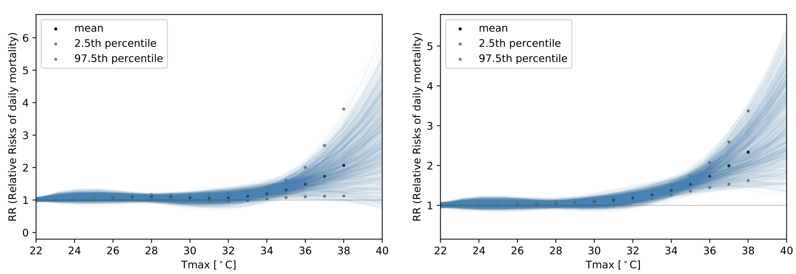
6. Sampling of the impact functions for mortality

6.1. Polynomial function

We assume the impact functions for mortality (RR functions) to be polynomial functions of the third order, with equation:

$$f(x) = ax^3 + bx^2 + cx + d \tag{4}$$

6.2. Sample distribution of probable impact functions for mortality



(a) (b)

Figure S3: Distribution of functions describing the relationship between daily maximum temperature and relative risk of daily mortality for (a) the people below the age of 75 and (b) with or above the age of 75. The mean curve and the confidence interval are taken from the study of Ragettli *et al* (2017) [4].

7. Sampling of the impact functions for labour productivity

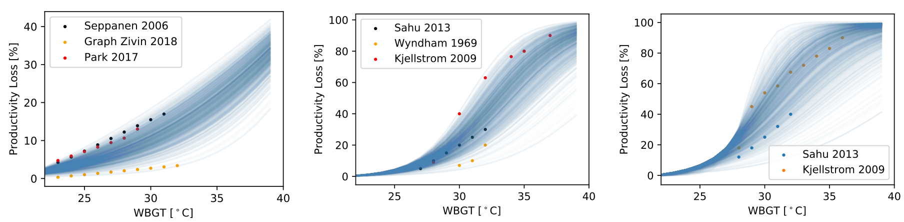
7.1. Sigmoid function

We assume the impact functions for labour productivity to be sigmoid functions, as for example some of the ones used in CLIMADA [8]. Also in other studies assessing the impact of heat on labour productivity sigmoid functions are used [9, 10]. The functions developed for the present study are logistic functions, with equation:

$$f(x) = \frac{L}{1 + e^{-k(x-x_0)}} \tag{5}$$

where x stands for the WBGT values and $f(x)$ is the percentage of labour productivity that get lost due to heat. L indicates the curve's maximum value (i.e. the maximum percent of labour productivity loss), k stands for the logistic growth rate (i.e. the steepness of the curve), and x_0 refers to the x-value of the sigmoid's midpoint.

7.2. Sample distribution of probable impact functions for labour productivity



(a) (b) (c)

Figure S4: Distribution of impact functions describing the relationship between WBGT and percentage of labour productivity loss for people working at a (a) low physical activity, (b) moderate physical activity, and (c) high physical activity.

8. Attributable Fraction (AF) of deaths to heat per degree of temperature

Based on Pérez (2009) [16]:

$$AF(T) = \frac{p_{ex}(RR(T) - 1)}{p_{ex}(RR(T) - 1) + 1} \tag{6}$$

where p_{ex} refers to the fraction of the population exposed to heat and $RR(T)$ to the RR of daily mortality for the respective temperature (i.e. impact functions).

9. Modelling equations

Modelling equation for mortality:

$$I_{Mortality} = \sum^{cells} \sum^{T} N_{deaths,cell} AF(T) N_{days,cell}(T) \tag{7}$$

where $N_{deaths,cell}$ stands for the average number of daily deaths per cell and $AF(T)$ is the fraction of deaths attributable to heat at the respective temperature. $N_{days,cell}(T)$ refers to the number of days per cell reaching the respective temperature as maximum.

Modelling equation for labour productivity:

$$I_{LabourProductivity} = \sum^{cells} \sum^{days} \sum^{hours} E_{cell} Loss(WBGT_{hour}) \quad (8)$$

where E_{cell} indicates exposed salary value at each cell and $Loss(WBGT_{hour})$ the hourly predicted loss in labour productivity for the respective WBGT (i.e. impact functions).

10. Sources of uncertainties and shape of their distributions

10.1. Distribution of the transformation to infer hourly temperature values

$$T(t) = T_{predicted}(t) + N(RMSE; \mu, \sigma) \quad (9)$$

10.2. Distribution of the transformation to indoor temperature values

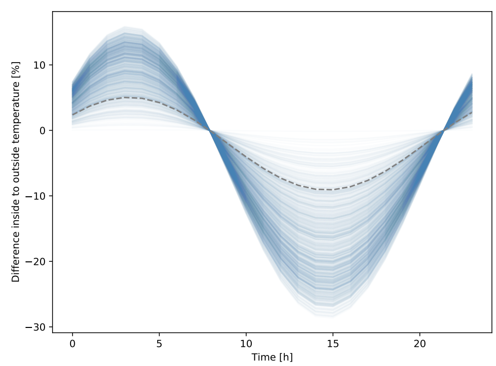


Figure S5: Percentage difference of the inside temperature to the outside temperature depending on the hour of the day. The dashed grey line corresponds to the simulation for a typical building in Zurich, while the blue lines shows a sample distribution of this transformation considering uncertainties.

10.3. Overview table

Table S4: Summary of the sources of uncertainties in both model and shapes of their distributions. The first group of uncertainties shows those which are common to both models, while the second shows the additional uncertainties which are embedded in the labour productivity model.

	Source of Uncertainty	Distribution
Common Uncertainties	Climate Model	Uniform
	Natural Variability	Uniform
	Impact Functions	Normal
Labour Productivity Uncertainties	Hourly temperature values	Normal
	Indoor temperature values	Triangular
	WBGT values	Normal
	Sun Exposition	Uniform

11. Sensitivity Analysis

The sensitivity analysis is performed for the labour productivity model, as shown in Figure S6. In the variables common to both models, the uncertainties stemming from the climate data (climate simulations and natural variability) play the most important role. In the example in Figure S6, the influence of the climate simulations can be up to 59% below and 77% above the median costs (95% confidence interval). The impact functions have a smaller contribution, with the impact being up to 28% below and 8% above the median costs. In the variables that exist only in the labour productivity model, the transformation from outside to inside temperature contributes most to the overall uncertainty (from 31% below to 74% above the median costs), followed by the transformation from temperature to WBGT values (from 48% below to 51% above).

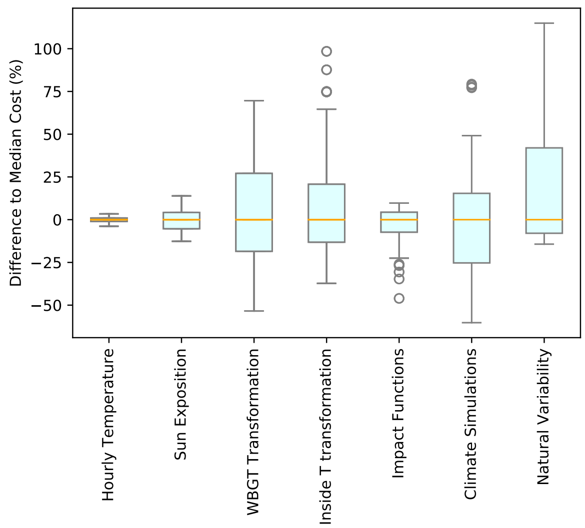


Figure S6: Sensitivity analysis for the labour productivity model. Results for the category *high physical activity* in the year 2050 and under the RCP8.5 scenario. The median is indicated by the orange line. The rectangles contain values from the 25th to the 75th percentile. The vertical lines span throughout the 95% confidence interval.

12. Spatially explicit results for mortality

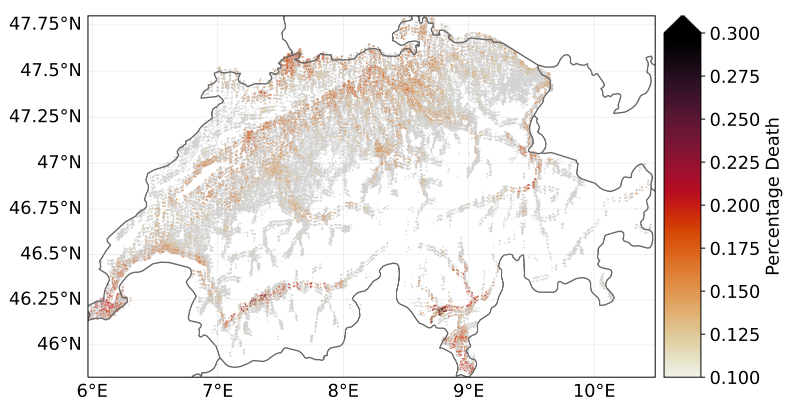
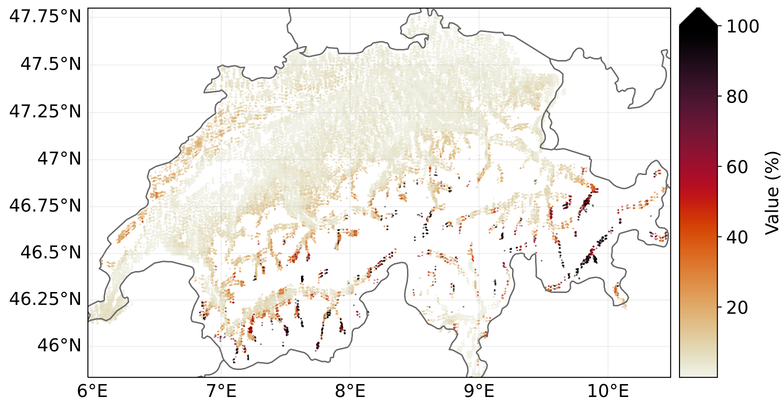
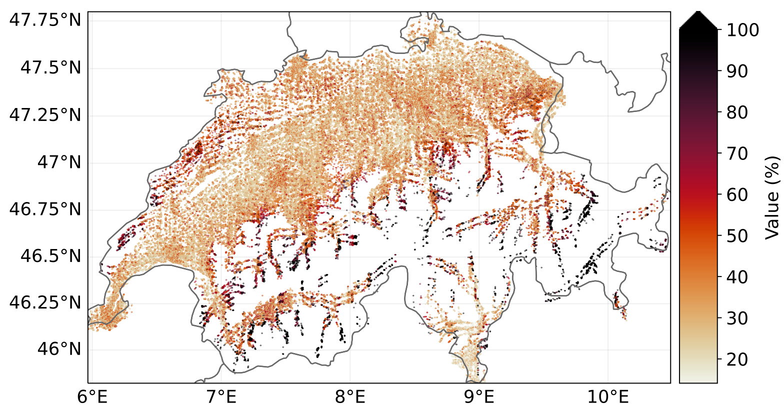


Figure S7: Map showing the spatial impact for mortality in percentage compared to the total exposure value for the year 2050, the RCP8.5 scenario, and the category of elderly people.



(a)



(b)

Figure S8: Maps showing the relative changes in number of heat-related deaths compared to the baseline for the year 2050 under an RCP2.6 (a) and an RCP8.5 scenario (b) for the category of elderly people.

13. Results at cantonal level

	Baseline (2020)	RCP2.6		RCP8.5	
	2050	2080	2050	2080	
canton					
Aargau	65	67	69	85	131
Appenzell Ausserrhoden	2	3	3	4	6
Appenzell Innerrhoden	0	0	0	1	2
Basel-Landschaft	32	33	34	42	64
Basel-Stadt	19	19	19	24	36
Bern	96	100	102	127	194
Fribourg	24	25	26	32	50
Genève	45	47	47	59	95
Glarus	2	2	3	3	6
Graubünden	13	15	15	20	34
Jura	7	8	8	10	16
Luzern	32	34	34	43	67
Neuchâtel	12	13	13	16	25
Nidwalden	3	3	3	4	7
Obwalden	2	2	2	3	6
Schaffhausen	8	9	9	11	17
Schwyz	10	10	11	13	21
Solothurn	30	31	31	38	58
St. Gallen	38	39	41	51	79
Thurgau	23	24	24	30	47
Ticino	51	52	51	62	90
Uri	2	2	2	3	5
Valais	33	35	35	46	73
Vaud	64	65	67	83	123
Zug	8	8	8	10	16
Zürich	121	124	127	156	241
Total	756	783	798	991	1519

Table S5: Median estimate for the number of heat-related deaths for each canton for the baseline (2020, RCP8.5), and the years 2050 and 2080 under the climate scenarios RCP2.6 and RCP8.5.

	Baseline (2020)	RCP2.6		RCP8.5	
	2050	2080	2050	2080	
canton					
Aargau	26.99	31.89	31.07	42.70	77.15
Appenzell Ausserrhoden	1.06	1.23	1.28	1.75	3.21
Appenzell Innerrhoden	0.30	0.35	0.36	0.50	0.96
Basel-Landschaft	13.35	15.80	15.36	21.17	38.24
Basel-Stadt	18.01	21.05	20.66	27.69	48.03
Bern	43.92	51.39	49.90	68.93	122.76
Fribourg	10.47	12.32	11.91	16.72	30.24
Genève	41.64	49.14	47.33	65.89	118.29
Glarus	1.02	1.21	1.19	1.73	3.33
Graubünden	6.49	8.02	7.90	11.67	23.64
Jura	2.44	2.88	2.80	3.90	7.04
Luzern	17.27	20.13	19.59	27.26	49.42
Neuchâtel	6.01	7.09	6.90	9.47	16.73
Nidwalden	1.45	1.71	1.67	2.33	4.28
Obwalden	1.16	1.40	1.36	1.95	3.73
Schaffhausen	3.24	3.81	3.71	5.13	9.25
Schwyz	5.25	6.16	6.07	8.48	15.54
Solothurn	10.90	12.84	12.47	17.15	30.98
St. Gallen	16.33	18.93	19.03	26.20	47.94
Thurgau	8.85	10.20	10.07	13.90	25.15
Ticino	24.79	28.32	27.74	38.68	69.33
Uri	0.88	1.08	1.04	1.51	2.97
Valais	13.46	16.54	15.81	22.91	44.48
Vaud	38.89	45.10	43.77	60.41	106.63
Zug	7.96	9.21	9.13	12.43	22.01
Zürich	91.83	106.47	104.37	140.30	245.99
Total	413.96	484.30	472.49	650.76	1167.32

Table S6: Median estimate of the losses in labour productivity (in million CHF) for each canton for the baseline (2020, RCP8.5), and for the years 2050 and 2080 under the climate scenarios RCP2.6 and RCP8.5.

References

[1] NCCS 2018 *CH2018 – Climate Scenarios for Switzerland* National Centre for Climate Services, Zurich https://naturalsciences.ch/service/publications/107868-ch2018---climate-scenarios-for-switzerland

[2] Bundesamt für Statistik BFS 2019a *Statistik der Bevölkerung und Haushalte (STATPOP), Geodaten 2018* https://www.bfs.admin.ch/bfs/de/home/dienstleistungen/geostat/geodaten-bundesstatistik/gebaeude-wohnungen-haushalte-personen/bevoelkerung-haushalte-ab-2010.assetdetail.9947069.html

[3] Bundesamt für Statistik BFS 2019b *Statistik der Unternehmensstruktur (STATENT), Beschäftigte und Arbeitsstätten: Geodaten 2017* https://www.bfs.admin.ch/bfs/de/home/dienstleistungen/geostat/geodaten-bundesstatistik/arbeitsstaetten-beschaeftigung/statistik-unternehmensstruktur-statent-ab-2011.assetdetail.9526894.html

[4] Ragettli M S, Vicedo-Cabrera A M, Schindler C and Röösli M 2017 Exploring the association between heat and mortality in Switzerland between 1995 and 2013 *Environmental Research* **158** pp 703–709 https://doi.org/10.1016/j.envres.2017.07.021

[5] Chow D H C and Levermore G J 2007 New algorithm for generating hourly temperature values using daily maximum, minimum and average values from climate models *Building Services Engineering Research and Technology* **28** pp 237–248 https://doi.org/10.1177/0143624407078642

[6] Casanueva A 2019 HeatStress: Calculate heat stress indices *R package version 1.0.7.* https://github.com/anacv/HeatStress

[7] Bundesamt für Statistik BFS 2020 *Swiss Earnings Structure Survey in 2018: initial findings* https://www.bfs.admin.ch/bfs/en/home/statistics/work-income/wages-income-employment-labour-costs.gnpdetail.2019-0502.html

[8] Aznar-Siguan G and Bresch D N 2019 CLIMADA v1: a global weather and climate risk assessment platform *Geoscientific Model Development* **12** pp 3085–3097 https://doi.org/10.5194/gmd-12-3085-2019

[9] Kjellstrom T, Freyberg C, Lemke B, Otto M and Briggs D 2018 Estimating population heat exposure and impacts on working people in conjunction with climate change *International Journal of Biometeorology* **62** pp 291–306 https://doi.org/10.1007/s00484-017-1407-0

[10] Kjellstrom T, Holmer I and Lemke B 2009 Workplace heat stress, health and productivity - an increasing challenge for low and middle-income countries during climate change *Global Health Action* **2** https://doi.org/10.3402/gha.v2i0.2047

[11] Seppänen O, Fisk W and Lei Q 2006 Effect of Temperature on Task Performance in Office Environment *Lawrence Berkeley National Laboratory* https://indoor.lbl.gov/sites/all/files/lbnl-60946.pdf

[12] Graff Zivin J, Song Y, Zhang P and Tang Q 2018 Temperature and high-stakes cognitive performance: Evidence from the national college entrance examination in China *Journal of Environmental Economics and Management* **104** https://doi.org/10.1016/j.jeem.2020.102365

[13] Park J 2017 Hot Temperature, Human Capital and Adaptation to Climate Change *Harvard University Economics Department* https://scholar.harvard.edu/files/jisungpark/files/paper_nyc_aer.pdf

[14] Sahu S, Sett M and Kjellstrom T 2013 Heat Exposure, Cardiovascular Stress and Work Productivity in Rice Harvesters in India: Implications for a Climate Change Future *Industrial Health* **51** pp 424–431 https://doi.org/10.2486/indhealth.2013-0006

[15] Wyndham C H 1969 Adaptation to heat and cold *Environmental research* **5** pp 442–469 https://doi.org/10.1016/0013-9351(69)90015-2

[16] Pérez L and Künzli N 2009 From measures of effects to measures of potential impact *International journal of public health* **54** pp 45–48 https://doi.org/10.1007/s00038-008-8025-x