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Threats to occupational health, labor productivity and the economy from increasing heat during climate change:

..... an emerging global health risk and a challenge to sustainable development and social equity

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Abstract

Excessive heat while working, generally above 30ºC, creates health risks and reduces work capacity and labor productivity. Maintaining a core body temperature close to 37 ºC is essential for health and human performance, and large amounts of sweating as a result of high heat exposure while working creates a risk of dehydration. Excessive body temperature and/or dehydration causes "heat exhaustion", slower work, more mistakes while working, clinical heat effects (heat syncope, heat stroke, and even death) and increased risk of accidental injuries. Either of these health effects lessens labor productivity, whether the worker is in paid work, in traditional subsistence agriculture or in other daily life activities, and the risks of serious heat stroke increases. Daily non-work activities, such as caring for children or the elderly, are also affected, and increasing heat levels due to global and local climate change will make the situation worse for millions of people.

The economic impact of these labor productivity losses has until now received little attention, but it may be a major economic effect of climate change, particularly in already hot parts of the world. These economic losses occur at family level, enterprise level, community level, national level and global level, and are likely to undermine efforts for poverty reduction and economic development in line with the United Nations Millennium Development Goals, the Sustainable Development Goals, and other global policies. The estimated health risks and economic losses are an additional reason for global agreements to take additional mitigation and adaptation actions against effects of climate change without delay.

Key questions

What is potentially the greatest health related economic impact of global climate change by 2030?

A recent report published the first analysis of the economic impact of workplace heat on physiological health and the linked labour productivity (see DARA website below). Out of an estimated total economic cost of US$ PPP 4.3 trillion due to climate change in 2030, US$ 2.4 trillion (56%) is due to workplace heat, reducing work capacity and productivity (the projected global GDP in 2030 is US$ 140 trillion). This negative impact will be particularly large in tropical low and middle income countries (billions of US$), and it will undermine efforts to protect health, reduce poverty and achieve the Millennium Development Goals. See:http://daraint.org/climate-vulnerability-monitor/climate-vulnerability-monitor-2012/. A recent analysis for the USA using different methods (Kopp et al., 2014) produced similar results as the DARA report (US$50 billion loss in 2030).

What lies behind this impact?

It is well known in human physiology (Parsons, 2014) that all people have the same normal level of body core temperature (close to 37 ºC). When this body temperature is exceeded by just 1-3ºC, serious heat stroke may happen with the possibility of death. Muscular work creates surplus heat inside the body, making working people vulnerable to hot environments. Basic laws of physics tell us that when the air temperature is higher than 37 ºC the only way body temperature can be maintained is via evaporation of sweat. When air humidity is high, sweat evaporation is slow and insufficient. In order to maintain a healthy body temperature a working person then needs to take breaks or slow work down (= "self-pacing"). This is already a problem for millions of people during the hot season in tropical and sub-tropical countries, where the vast majority of the worlds' population lives.

Why is this effect of a hotter climate overlooked?

Many people think that the human body can acclimatize to increasing heat. This is true to some extent, but there is a limit, and acclimatization mainly involves more efficient sweating which is still insufficient for people working in very hot humid environments. There is also a common belief that indoor workers are protected by air conditioning, but this is not true for millions of workers producing the cheap consumer products sold in high income countries. Some people think of high heat exposure as an issue that is only relevant during "heat waves", but from a physiological viewpoint excessive heat can continue every day for months in tropical areas.

How does climate change create this threat to working people?

All models of future climate indicate that much of the world will experience a hotter environment in the next few decades, and the longer it takes before effective climate change mitigation is implemented, the higher will be the heating of the air. Millions, if not billions, of people will be affected, particularly in tropical and sub-tropical countries, and poor people in any country will be the most vulnerable. Depending on the type of work and the trends of local heat exposure, varying percentages of work capacity loss (up to 100%) may occur. If people cannot work or carry out other daily activities as required, incomes will fall and many families and communities will suffer. The negative effects include lack of money for food, housing, and other daily needs, which will create further health risks, particularly for the children and the elderly. This will add to the already existing health inequity between and within countries.

What can we do to reduce the impact?

Building local resilience in low income communities to the health effects of climate change is a high priority. This includes investing now in water and sanitation, systems for nutritious food access, electricity supply, and basic public health services for all communities in low and middle income countries. In addition, available methods of reducing the impact of current climate conditions should be applied. Such methods include architectural and urban design that minimizes heat stress inside new factory and office buildings, as well as in family housing. Cooling systems need to be applied (including air conditioning in many buildings) during long hot seasons each year, and the energy for such cooling systems should ideally be provided from renewable energy sources, such as solar photovoltaic cells, wind power or hydropower. However, not all work situations can be protected via "adaptation". Therefore, "mitigation" of climate change is a key method of protecting future generations from the health and economic effects of increasing workplace heat due to climate change. There are also other serious effects of climate change that can only be prevented by "mitigation" without delay.

The conflict between workplace heat and workers health and productivity

It is well known that physical work creates heat inside the body (main reference Parsons, 2014, which reviews many hundred research reports). Combined with excessive workplace heat (as in the jobs shown in the pictures of figure 1) the worker's health and productivity is at risk. Millions of workers in low income jobs around the tropical and sub-tropical zones of the world are currently exposed to this type of hazard, and climate change will make the situation worse for them and for the local economy.

Figure 1. Typical workplaces with excessive heat exposures during several months each year.
Source: T Kjellstrom photos

Sugar cane cutting by hand in Nicaragua, 2003 …

This work and other agricultural activities in many tropical areas have to be carried out during the hottest season each year. Solar heat radiation adds substantially to the ambient air heat.

Heat stress and heavy work, as well as high exposures to agricultural chemicals, create clinical health risks and daily productivity losses….. many of these workers are paid by production output, so heat causes longer workdays or reduced daily income……

Shoe manufacture in Haiphong, Viet Nam, 2002 ...

Factories in low and middle income countries producing consumer goods for high income countries seldom have air conditioning or other effective cooling and ventilation systems. High chemical exposures may create health risks.

Heat stress and the same daily production targets in all parts of the year means that the workers have to work longer each day in the hot season than in cool season ..... but the salary is the same.....

The physiological foundation of the work-heat challenges

The core body temperature of every human being needs to be kept close to 37 ºC in order to avoid serious health risks (Parsons, 2014). When the external temperature is higher than 37 ºC, the only way for the body to stay at normal temperature is heat loss via sweat evaporation. However, high external air humidity, and the clothes worn in some jobs, limit sweat evaporation and core body temperature goes up. In hot environments, the internal heat from muscle work and the heat from outside the body combine to threaten health. In many situations the only way to avoid clinical "heat stroke" is to slow down work, take more rest, and stop to drink water frequently.

There are few reports available showing the quantitative impacts of high workplace heat exposures (the only recent example is: Sahu et al., 2013), but a number of interview studies of workers in hot countries have indicated that heat impacts on daily work productivity are already a common feature of work in such countries (for references, see "Hothaps Program Update, June 2014" on website: www.ClimateCHIP.org). The estimated work capacity loss starts at an hourly heat exposure index (WBGT) at 26 ºC for people in physically demanding jobs, and is reduced by 30-40% at WBGT >31ºC. The reduction follows a continuous trend and this can be used to calculate losses as climate change progresses in a location. (The heat stress index WBGT is lower than the air temperature by 0-10 degrees, depending on the air humidity; see: Kjellstrom et al., 2009).

Extent of ongoing climate change and estimates of future change

The report by the Intergovernmental Panel on Climate Change (IPCC, 2013) and a number of other reports have shown how the global climate is already changing towards higher temperatures. Much of the analysis by climatologists and the comments in mass media have focussed on the average temperature of the planet, and it has gone up by an average of 0.74 °C per century (or 0.074 °C per decade) in the period 1906-2005. The changes are not the same everywhere in the world and according to routine recordings at weather stations in Asia and Africa the increase of annual mean temperature from 1980 to 2012 is often 0.2-0.8 °C per decade (and even > 1°C per decade), much faster than the global average. Using existing climate data for 60,000 geographic grid cells over land around the world (0.5 x 0.5 degrees), we can show the levels of specific heat stress indexes. Figure 2 shows the current heat situation for WBGT in the hottest months in each part of the world. All the areas in colours other than green will experience workplace heat challenges described in this report, often during several months.

Figure 2. The hottest month average level of the occupational heat stress index WBGT in each part of the world, afternoon values in shade or indoors, 30-year averages 1980-2009.

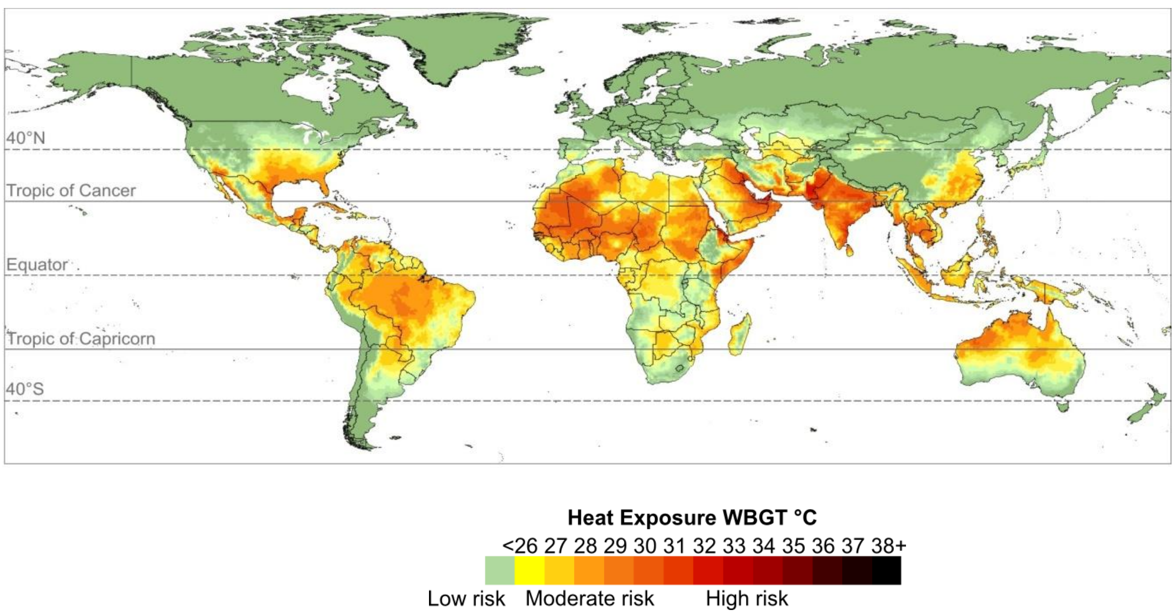
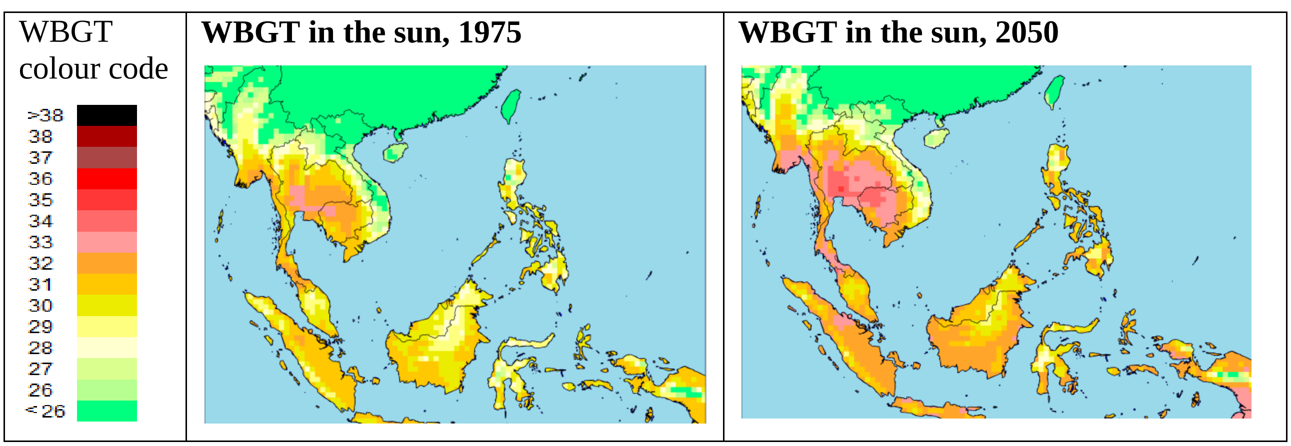


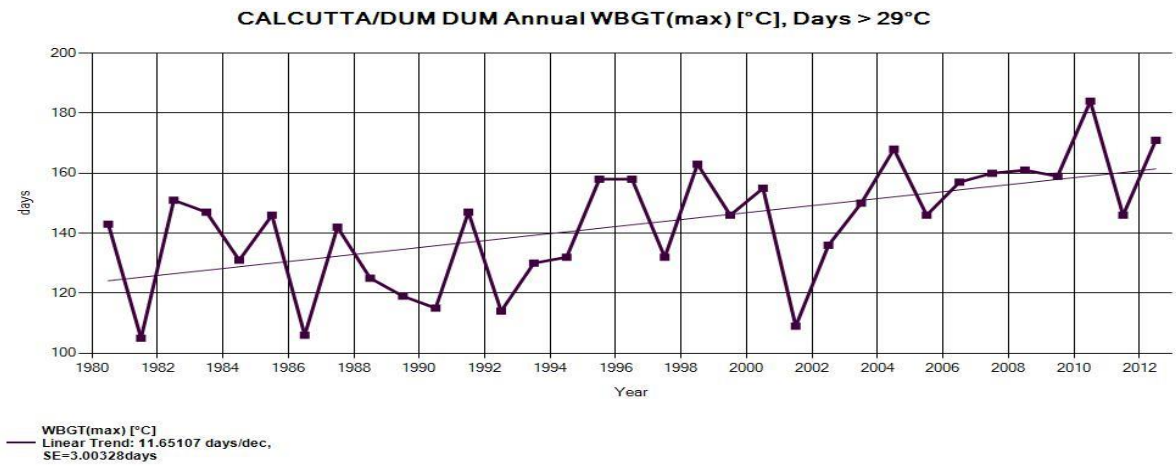
Figure 3. Average monthly WBGTmax values (afternoon) in March for people working outdoors in the full sun in 1975 and 2050 in South-East Asia. Source: Kjellstrom et al., 2013.



Using internationally accepted models for future climate conditions we calculated WBGT values to indicate heat stress risks. During the hottest months the impacts of climate change can be displayed, for example as is done in Figure 3. The increasing heat problems for working people in South-East Asia in March will be significant.

The Hothaps-Soft software and database (which includes daily data from thousands of weather stations around the world; see: www.ClimateCHIP.org) make it possible to analyse trends of seven climate variables on a monthly or annual basis at local level, and it produces estimated values for the heat stress indexes WBGT (Wet Bulb Globe Temperature) and UTCI (Universal Thermal Climate Index; see: www.utci.org) indoors or in the full shade. The software also calculates trends of averages or of the number of extreme days (Figure 4). It should be pointed out that the tropical and sub-tropical part of the world, with very hot seasons already now and with rapid climate change, is where most of the world population lives and works (appr. 4 billion people).

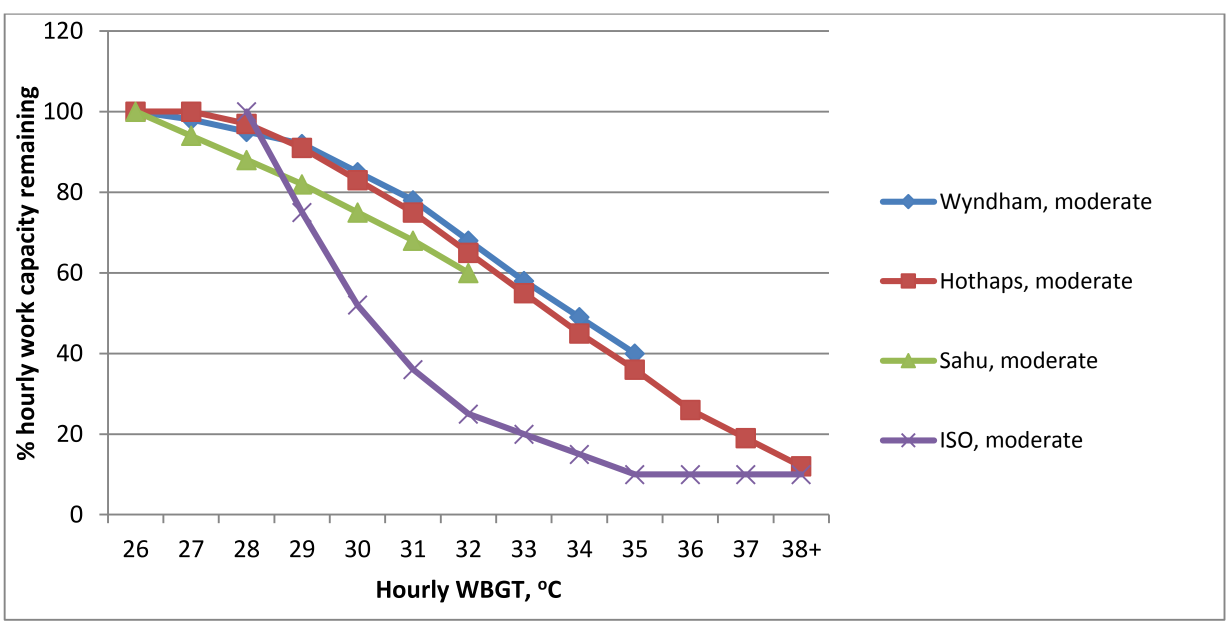
Figure 4. Annual number of days when the heat stress index WBGT indoors or in full shade in the afternoons (=WBGTmax) exceeded 29 ºC in Calcutta (Kolkata), a level that seriously reduces work capacity (> 30 more days in 2012 than in 1980). Source: Hothaps-Soft with data from US NOAA website



Estimated work capacity loss in different parts of the world

In order to calculate the work capacity loss in specific locations with weather stations or in areas defined by geographic grid cells we need the exposure-response or risk functions for different heat exposure levels. Figure 5 shows two epidemiological studies (Wyndham and Sahu), a best fit function (Hothaps), and the ISO international standard values (Nr 7243, 1989) for increased need to rest during hot work hours. Enforcing the standard would reduce the work output more than recorded outcomes; the standard protects heat sensitive workers.

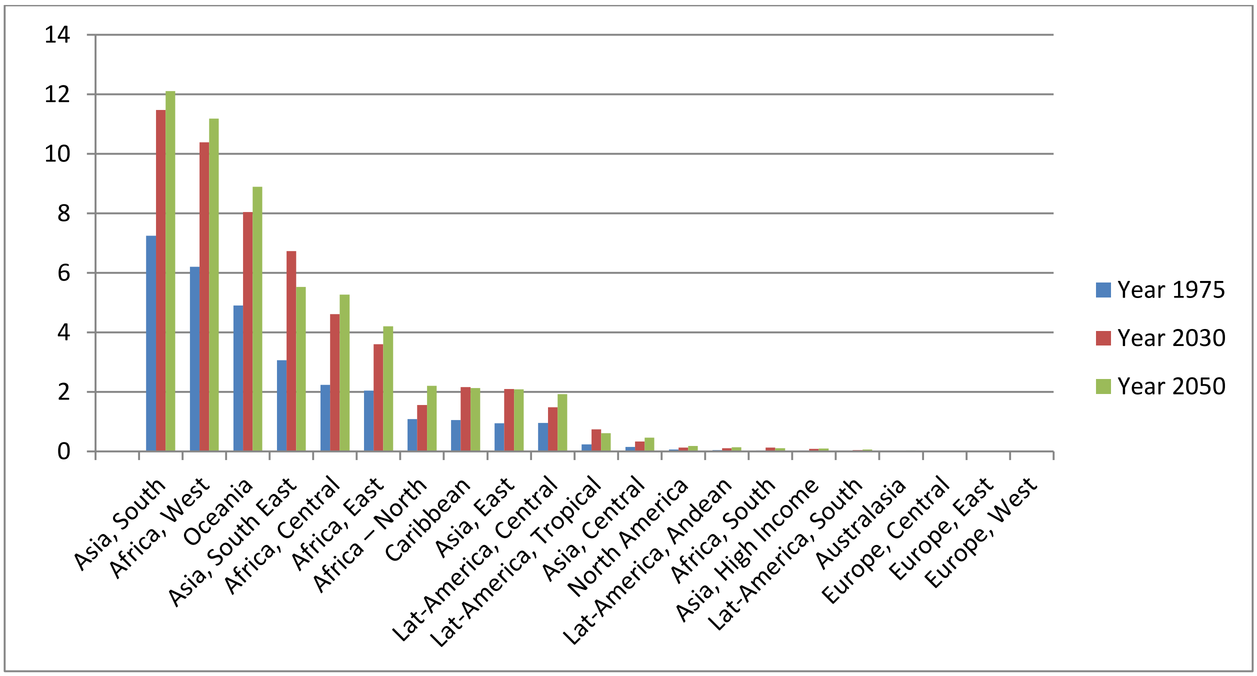
Figure 5. Exposure-response or risk functions for hourly workplace heat levels and percent of remaining work capacity for people in moderate intensity work (300W) (from Kjellstrom et al., 2014). Hothaps = our estimated risk function fitted to the published data.



The high heat exposure levels for in-sun work environments in South-East Asia (Figure 3) can now be interpreted with the risk functions in Figure 5. WBGTmax as high as 32-33 °C in the afternoons already occurred in 1975 and by 2050 parts of Thailand and Cambodia will reach WBGT at 34-35 °C. The in shade values are approximately 2-3°C lower. During moderate work in shade the “work capacity loss” due to heat in the countries shown can still be as high as 40-50%. In full sun the number increases to 60-70%. Morning and evening hours are somewhat cooler, but the daily variation of heat stress in this part of the world is limited, which means that daily work capacity is substantially reduced by climate change.

An analysis of the annual losses of daylight work hours due to excessive heat exposure using the fitted Hothaps risk function (Figure 5) shows the substantial losses in many regions of the world (Figure 6). The losses in the 1980-2009 period (1975 in the figure) are already substantial for several regions, up to 5-7%. In 2050 the worst affected regions are South Asia and West Africa, and ten regions have more than 2% work hour lost. If these losses lead to equivalent losses in national GDP for specific countries, the economic losses will be many billions of US dollars. The estimates in Figure 6 take likely changes in workforce distribution of agriculture, industry and services into account, as each has different work intensity and heat exposure (see Kjellstrom et al., 2014).

Figure 6. Climate modelling estimates of the percentage of annual daylight work hours that are lost due to excessive heat in 21 global regions in 30-year periods around 1975, 2030 and 2050 (ranked by losses in 2050). Adjusted for estimated population and workforce distribution changes.



Economic consequences of work capacity loss

A number of estimates of the economic costs of climate change in different parts of the world have been published. Some show the impact of climate change on GDP per capita, but the only one that specifically estimated the impact of heat stress on working people was the Climate Vulnerability Monitor, 2012 (DARA, 2012). A recent analysis for the USA only (Kopp et al., 2014) uses quite different methods, but produces similar impact levels for that country. The losses at global level already in 2030 are very large (Table 1): more than 2% of the annual GDP/capita will be lost by 2030 due to the increasing workplace heat. For specific countries, as much as 6% of the annual GDP/capita is lost. The accumulated impact is of the greatest importance; 2% loss/year over 30 years means that gain in GDP/capita could be less than half as much as if the heat loss had not occurred.

For instance, if an economy is booming at 8% GDP increase per year, after 30 years the GDP/capita would be 10 times increased. If 2% of this increase is lost each year after 30 years the resulting increase will only be 5.7 times, and at 4% loss per year the resulting increase will only be 3.2 times the starting value. Thus, if a country in 2010 had a GDP/capita at USD 2,000, the GDP/capita after 30 years of 8% increase would be USD 20,000, while with 2% loss due to heat each year the endpoint would be at USD 11,400, and at 4% loss at USD 6,400. These are average numbers, and without serious attention to the situation for the poorest people, the inequalities will increase and poverty reduction will be seriously reduced by climate change.

Table 1 shows that the estimated annual cost of labor productivity loss in developed countries (48 billion USD) is much less than in the developing countries (1,035 billion USD for low GHG emitter countries, and 1,364 billion USD for high emitters, including China). The political group of 20 developing countries with low emissions and potentially high climate change impacts have produced a detailed national analysis of the impacts: the Climate Vulnerability Monitor 2012 (DARA, 2012). The results for the more populated countries (Table 2) show very substantial losses already in 2030: 85 billion USD annual losses for Vietnam and the Philippines, 30 billion in Bangladesh and 15 billion in Ghana. China and India would lose 450 billion USD each, and USA 50 billion USD and Japan and South Korea 1 billion USD each (DARA, 2012). These initial estimates by DARA are approximate, and further analysis work is urgently needed. The only specific similar estimate for a country is the recent USA analysis (Kopp et al., 2014): medians at 10 billion USD in 2030, 30 billion in 2050 and 100 billion in 2090. The analysis methods were quite different, but it is noteworthy that the results are within a similar range.

Table 1. Economic impacts of climate change and the carbon economy in 2010 and 2030; millions of USD PPP. Source: DARA, 2012

Currency = millions of USD PPP	**Total global net cost, % of total climate cost ( )**		**Net cost in 2030 in specific country types**		
Impact component	**2010**	**2030**	**Developing, low emitters**	**Developing, high emitters**	**Developed**
Climate change					
Biodiversity	78199	389383	55544	199966	80241
Desertification	4594	20500	4597	3739	6202
Heating and cooling	-33046	-76819	30136	7179	-64855
Labor Productivity	**310909(51%)**	**2436112(56%)**	**1035241(60%)**	**1364130(60%)**	**48464 (27%)**
Permafrost	31266	153337	5434	67838	5092
Sea level rise	85282	526289	165698	309481	29332
Water	13558	12585	-20802	-44777	39026
Health impacts	22610(3.7%)	105976(2.4%)	84293(4.9%)	20726(0.9%)	2(0.001%)
Industry stress	66233	564576	329317	223116	7511
Environmental disasters	28983	212836	40142	141097	27840
TOTAL CLIMATE CHANGE COSTS	**608878 (100%)**	**4344777 (100%)**	**1729599 (100%)**	**2292494 (100%)**	**178856 (100%)**
TOTAL CARBON ECONOMY COSTS	538733	2422596	428950	1400966	437522

Conclusions

1. Working people are at particular risk of health effects of excessive heat exposure in the current climate, and future climate change will make the situation worse.
2. Lack of cooling systems means that workers need to reduce work intensity or take frequent breaks in order to avoid heat exhaustion and heat stroke; such actions reduce hourly productivity and economic output.
3. These economic effects on the worker, her/his family, the enterprise, the community and the country have until now been overlooked in the discussion and analysis of climate change impacts and prevention, but these effects can be very large and should be analysed further in order to present the full impact of climate change on communities.
4. Building resilience against excessive heat exposure and other climate extremes via improved health infrastructure and local health programs in poor communities in low and middle income countries is a key approach to protect vulnerable people from climate change impacts.
5. Also in higher income communities and occupation groups, including office workers, the protection against excessive workplace heat exposure is a key issue for the economic performance.

6. Adaptation methods in hot workplaces are important as a way to reduce health and productivity risks, but these methods may not achieve full protection and mitigation of climate change will be necessary to achieve the best possible economic results
7. Further analysis of the potential labor productivity losses and economic impacts is needed to understand the full impacts of current and future climate. This should be linked to economic benefits of specific heat protection methods (such as solar driven air conditioning) and national and global mitigation approaches.

Table 2. Heat and economic data for some of the 20 member countries of the Climate Vulnerable Forum.

Country	GNP/cap 2011	Heat loss 2010, % of GDP	Heat loss 2030, % of GDP	Heat loss 2030, millions USD	Total CC loss 2030, % of GDP	WBGTmax trend, °C/ decade	Serious heat days, decade trend	Serious heat days/year
Bangladesh	1529	1.5	3.0	30000	6.8	0.09	NA	NA
Costa Rica	10497	2.3	4.5	9000	6.3	0.1	NA	3
Ethiopia	971	1.3	2.4	6000	3.7	0.24		0
Ghana	1584	3.2	6.5	15000	8.9	0.16	12	280
Kenya	1492	1.2	2.3	4750	3.7	0.17	0	0
Nepal	1160	1.5	2.8	3750	4.1	0.44	NA	0
Philippines	3478	2.9	5.9	85000	7.1	-0.12	19	320
Rwanda	1133	1.4	2.4	850	4.5	0.47	NA	NA
Tanzania	1328	1.3	2.2	4000	4.8	0.16	26	260
Vietnam	2805	2.9	5.7	85000	10.7	0.02	0	170

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