

Kjellstrom, Tord; Kovats, R. Sari; Lloyd, Simon J.; Holt, Tom; Tol, Richard S. J.

**Working Paper**

## The direct impact of climate change on regional labour productivity

ESRI Working Paper, No. 260

**Provided in Cooperation with:**

The Economic and Social Research Institute (ESRI), Dublin

*Suggested Citation:* Kjellstrom, Tord; Kovats, R. Sari; Lloyd, Simon J.; Holt, Tom; Tol, Richard S. J. (2008) : The direct impact of climate change on regional labour productivity, ESRI Working Paper, No. 260, The Economic and Social Research Institute (ESRI), Dublin

This Version is available at:

<https://hdl.handle.net/10419/50035>

**Standard-Nutzungsbedingungen:**

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

**Terms of use:**

*Documents in EconStor may be saved and copied for your personal and scholarly purposes.*

*You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.*

*If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.*

## The Direct Impact of Climate Change on Regional Labour Productivity

**Tord Kjellstrom<sup>a</sup>, R Sari Kovats<sup>b</sup>, Simon J. Lloyd<sup>b</sup>, Tom Holt<sup>c</sup>,  
Richard S.J. Tol<sup>d</sup>**

*Abstract.* Global climate change will increase outdoor and indoor heat loads, and may impair health and productivity for millions of working people. This study applies physiological evidence about effects of heat, climate guidelines for safe work environments, climate modelling and global distributions of working populations, to estimate the impact of two climate scenarios on future labour productivity. In most regions, climate change will decrease labour productivity, under the simple assumption of no specific adaptation. By the 2080s, the greatest absolute losses of population based labour work ability as compared with a situation of no heat impact (11-27%) are seen under the A2 scenario in South-East Asia, Andean and Central America, and the Caribbean. Climate change will significantly impact on labour productivity unless farmers, self-employed and employers invest in adaptive measures. Workers may need to work longer hours to achieve the same output and there will be economic costs of occupational health interventions against heat exposures.

*Key words:* Climate change, heat, work, labour productivity

*Corresponding Authors:* [Richard.Tol@esri.ie](mailto:Richard.Tol@esri.ie); [sari.kovats@lshtm.ac.uk](mailto:sari.kovats@lshtm.ac.uk)

---

<sup>a</sup>. National Center for Epidemiology and Population Health, Australian National University, Canberra, Australia and

Health and Environment International Trust (HEIT), Mapua, Nelson, 7005 New Zealand

<sup>b</sup>. Public and Environmental Health Research Unit (PEHRU), London School of Hygiene and Tropical Medicine

<sup>b</sup>. Public and Environmental Health Research Unit (PEHRU), London School of Hygiene and Tropical Medicine

<sup>c</sup>. Climatic Research Unit, University of East Anglia, Norwich

<sup>d</sup>. Economic and Social Research Institute, Dublin, Ireland

Institute for Environmental Studies, Vrije Universiteit, Amsterdam, The Netherlands

Department of Spatial Economics, Vrije Universiteit, Amsterdam, The Netherlands

Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA, USA

ESRI working papers represent un-refereed work-in-progress by members who are solely responsible for the content and any views expressed therein. Any comments on these papers will be welcome and should be sent to the author(s) by email. Papers may be downloaded for personal use only.

# The Direct Impact of Climate Change on Regional Labour Productivity

## Introduction

“Too hot” working environments are not just a question of comfort, but a concern for health protection and the ability to perform work tasks. This occupational health problem has been known for considerable time and protective methods have been developed. Still, many workers are exposed to unacceptably high temperatures and humidity in work situations that cannot be modified and heat strain and heat stroke are important issues not only for health but also for labour productivity<sup>1-4</sup>. In outdoor, and many indoor, jobs, particularly in low and middle income countries, air conditioning of the workplace is not, and will possibly never be, an option. Global climate change will increase average temperatures, as well as shift the distribution of daily peak temperature and relative humidity – so that heat episodes will become more frequent and more extreme<sup>5, 6</sup>. In order to cope with heat, an instinctive adaptive action by a worker is to reduce work intensity or increase the frequency of short breaks. One direct effect of a higher number of very hot days is therefore likely to be the “slowing down” of work and other daily activities<sup>7</sup>. Whether it occurs through “self-pacing” (which reduces output) or occupational health management interventions (which increases costs), the end result is lower labour productivity (which is defined as the value of output over labour costs)<sup>3</sup>.

When the body carries out physical work, heat is produced internally, which needs to be transferred to the external environment in order to avoid the body temperature increasing.<sup>8</sup> If body temperature exceeds 39°C heatstroke may develop and a temperature of 40.6°C is life-threatening. Before these serious health effects occur, at lower heat exposures, the effects are diminished “work ability”<sup>8, 9</sup>, diminished mental task ability<sup>2</sup>, and increased accident risk<sup>10</sup>. These effects all contribute to a reduced “work ability” and lower labour productivity.

Reduced work ability is a function of environmental humidity, radiant heat, air movement and ambient temperature<sup>11</sup>. In humid and calm conditions, it can occur above 26°C for heavy physical work<sup>12, 13</sup> but individual variations are large and a complex relationship between climate factors, sweat rate and body temperature has been used to establish a “predicted heat

strain model”<sup>14</sup>. Heat strain can occur in arid climates <sup>15</sup>, indoor office environments<sup>16</sup> and factories<sup>17</sup>. Unusual heat waves create particular problems, as during the 2003 heat wave in France<sup>18</sup>. The economic cost of the existing suboptimal climate in US workplaces has been estimated at many billions of dollars<sup>19</sup>.

Quantitative standards to protect workers from heat injury have been developed by the International Standards Organization<sup>13</sup> and NIOSH<sup>20</sup>. More recent national guidelines also appear to be based on these. Most standards use “wet bulb globe temperature” (WBGT) to quantify different levels of heat stress and define the percentage of a typical working hour that a person can work assuming the remaining time is rest. The NIOSH standard also stipulates a WBGT level above which no worker should be expected to carry out ongoing tasks. The standards are stricter for persons un-acclimatized to heat than for those who are acclimatized. For un-acclimatized persons faced with a very energy demanding work task, the need to reduce heat stress starts at WBGT above 22.5°C; for acclimatized persons, this reduction starts at a WBGT of 26°C<sup>13, 20</sup>.

An assessment of the potential impact of climate change on “work ability” and the associated economic costs has not yet been made. Occupational health risk have been given little to no attention in international or national climate change impact and vulnerability assessments <sup>21, 22</sup>. This paper estimates the extent to which climate change may affect labour productivity due to increased ambient temperatures and/or humidity, under future climate scenarios.

## **Methods**

We used global climate model data for different world regions in combination with the relationships between WBGT and work ability to calculate the relative change in population work ability at different future time periods and for different climate scenarios. The analysis went through five steps:

1. Classify populations by world region and climate type and select representative points.
2. Obtain daily climate model data for each point, representing the sub-regional climate zone in which at least 5% of the regional population live.

3. Calculate current and future distributions of daily daytime WBGT ("work WBGT") for each sub-regional climate zone and then generate a single regional work WBGT series using a population-weighted average.
4. Estimate current and future relative work ability, in order to estimate labour productivity losses due to global climate change for each gross labour sector (agricultural, industrial, service).
5. Combine sector-specific estimates to a single regional estimate using the distribution of working population across sectors.

Note that throughout the paper, we assume that changes in labour productivity (an economic concept) are equal to changes in the work ability (a physiological concept) – that is, we abstract from changes in wages. We also ignore changes in behaviour (e.g., shifts in working hours, air conditioning). We estimated “labour productivity” for 21 world regions, where countries are grouped according to health indicators and geography (Figure 1). In order to take into account the diversity of climates within each region, we selected grid cells (from the climate model grid) representative of the main climate types in which people live within each region, based on the Köppen climate classification<sup>23</sup>. A Geographic Information System (GIS) was used to allocate the proportion of the regional population (year 2000) to each climate zone, using the Gridded Population of the World version 3 (GPW v3)<sup>24</sup>. We then selected the climate zones in which at least 5% of the regional population resided (Table 1). A population-weighted centre point was calculated for each of these climate zones and the climate grid cell in which this was located was then chosen. This gave a total of 93 grid cells (Figure 1).

Daily data (24-hour averages) were extracted for these climate grid cells for the years 1960 to 2100 for two climate scenarios: A2 and B2. These climate scenarios are derived from specified emissions scenarios that project future economic growth and technological development within a consistent storyline<sup>25</sup>. The A2 scenario assumes a high population growth and medium rapid economic development and therefore represents a moderately “high” emissions scenario. The B2 scenario assumes that greenhouse gas emissions are reduced through technological change and that there is more emphasis of governments addressing environmental problems through policy implementation. The increase in global mean temperature by the 2080s from pre-industrial levels is projected to be 3.4 °C (2.4 to 6.4) and 2.4 °C (range 1.4 to 3.8) for A2 and B2, respectively<sup>26</sup>.

WBGT is calculated from measurements of the natural wet bulb temperature (Tnwb), the globe temperature (Tg) and the dry bulb air temperature (Ta). WBGT outdoors is  $0.7 T_{nwb} + 0.2 T_g + 0.1 T_a$ , and WBGT indoors is  $0.7 T_{nwb} + 0.3 T_g$ . Note that Tnwb and Tg outdoors are likely to be much higher than Tnwb and Tg indoors, because of the influence of solar radiation. The specialised measurements for WBGT are not available from routine weather stations, and various formulas have been developed to estimate WBGT from the routinely collected data (Ta, relative humidity, etc.). The Australian Bureau of Meteorology<sup>27, 28</sup> proposes a method for estimating “WBGT” from air temperature (Ta) and relative humidity (RH), assuming moderately high heat radiation level in light wind conditions (approximately outdoor work in hot calm environments with some, but not extreme, sun exposure or indoor work with some local heat source).

This method was adopted from one suggested by the American College of Sports Medicine in 1985<sup>28</sup>, but the exact derivation of the formula was not explained. Other authors have proposed different formulas (e.g. Bernard and Pourmoghani<sup>29</sup>) and one of us (TK) has carried out preliminary field tests of measuring the difference between WBGT outdoors and indoors in the same location. TK also used hourly weather station data to assess the difference between 24-hour averages and mean daytime values for Ta and WBGT (6 am to 6 pm). Using 24-hour average temperature and relative humidity from the HadCM3 global climate model<sup>30</sup>, we calculated WBGT using the Australian Bureau of Meteorology equations:

$$\text{WBGT} = 0.567 \times \text{Ta} + 3.94 + 0.393 \times \text{E}$$

$$\text{E} = \text{RH}/100 \times 6.105 \times \exp(17.27 \times \text{Ta} / (237.7 + \text{Ta}))$$

Where Ta = 24-hour average shaded dry bulb air temperature in °C; E = 24-hour average absolute humidity (water vapour pressure) in hPa, hector Pascal; RH = 24-hour average relative humidity in %. The factor 3.94 represents impact of WBGT from radiated heat, and we found that this formula produces too high WBGT values. In our (TK) analysis of hourly data we noted that the difference between 24-hour averages and daytime means in hot places were generally between 3 and 5°C. As a compromise we assumed that the WBGT values calculated from 24-hour values would represent the daytime mean WBGT outdoors.

Daily work WBGT estimates were made for the current climate (years 1961-1990) and three future 30-year time periods centred on the 2020s (2010-2039), 2050s (2040-2069) and 2080s (2070-2099). In order to take into account indoor heat exposures for industrial and service sector workers, we used the approximation that indoor WBGT = outdoor WBGT – 4, based on a deduction of the radiation exposure factor 3.94 from the formula above.

The distributions of the number of days at different work WBGT values within each future time slice period were calculated. Figure 2 shows the distribution of WBGT under the current climate and three future climates for one location in South-East Asia. To provide a single estimate of the daily WBGT distribution for each world region, we combined the distributions for regional cells using population weighting.

Using the ILO and NIOSH standards for acclimatized persons, Kjellstrom<sup>7</sup> produced a graph of “work ability” as the maximum percentage of an hour that a worker should be engaged working (Figure 3). The four curves represent four different work intensities. We assume that 200 W corresponds to office desk work and service industries; 300 W to average manufacturing industry work and 400 W to construction or agricultural work. 500 W corresponds to very heavy labouring work and is not considered in this analysis. Work ability rapidly diminishes within a 10-20 degree range.

We then classified the working population of each region into three sectors: service, industry and agriculture using World Bank data for 1990-2005<sup>31</sup>. In each region, any country without labour data was assumed to have the same distribution pattern as the country with the nearest GDP for which labour data were available. Country data were combined using population-weighted averages to give estimates of labour distributions for each region.

Assuming the different work intensities for each sector (see above), we estimated regional labour productivity as a weighted average based on the distribution of work activities across the three sectors within each region. We assumed that labour patterns change over time consistent with economic growth projected under the A2 and B2 emission scenarios<sup>25, 32</sup> (Figure 4). North America was kept constant and all other regions converged towards this pattern as per capita income increased. Globally, GDP growth is higher under B2, and therefore more rapid convergence to the high income distribution occurs under this scenario than under A2.

We then calculated the number of days with reduced work ability for each day during each 30 year period using the WBGT work ability relationships in Figure 3. The loss in work ability for each day was added up for each 30 year period. The reductions in work ability are presented for the baseline climate (we assume this to be 1961-1990 as it the standard now used for climate impact studies). For the two climate modelling scenarios and three future time periods, the additional reductions in relation to the reference period (no climate change) were calculated. As sensitivity analyses, we performed the same calculations assuming both constant climate and constant labour patterns over time.

## **Results**

Climate change is associated with a shift in the distribution of daily temperatures to include more hot days, and more days with WBGT exceeding the threshold for heat tolerance in individuals. Assuming trends towards less labour intense work and no adaptation to climate change, our model shows significant reductions in labour productivity due to climate warming in a number of regions, particularly in Africa (Table 2). In terms of absolute change in labour productivity (hence reflecting both current and future climate patterns) by the 2080s, the greatest losses (11.4-26.9%) are seen under A2 in South-East Asia, Andean and Central America, and the Caribbean. Under the A2 scenario, Eastern and Western Europe, and Southern Latin America have the smallest losses (0.1-0.2%), with a gain seen in Tropical Latin America (3.0%). Under B2, the combined effects of less warming and greater wealth (meaning more people work in less labour intense jobs) result in considerably smaller impacts in all regions (the greatest loss being 16% in Central America), and overall productivity gains for many (up to 6%).

The difference between the climate scenarios is only apparent after the 2020s. This is due to the latency in the climate system, and any differences reflect natural climate variability and other uncertainties within the climate model. Ideally, an assessment should use a range of outputs from a range of climate models rather than a single model.

The estimates of labour productivity are sensitive to the assumptions about future workforce. As labour moves away from agriculture and toward industry and services as wealth increases the impact of climate warming is reduced (Table 3). The estimated differences in loss compared to baseline can be as high as 10% by the 2050s.



## Discussion

The climate change “attributable” effect is the difference between labour productivity (in terms of lost labour days) under the baseline climate and under the climate scenarios. The relationship in our model are theoretical and potential and may not reflect actual labour productivity losses as there will most likely be some adaptation measures in place, such as the space cooling of offices and factories. It is not possible to validate the labour productivity loss for the current climate – but our measure of labour productivity is based on validated ergonomical guidelines<sup>13</sup>. However, adaptation measures will vary by country, with high income countries having higher rates of adaptation, using more expensive methods, than low income countries.

Countries and individual businesses will vary in their willingness or capacity to adapt to the projected climate change. There is a strong incentive to adapt though. On average, the elasticity of output to labour is 0.75<sup>33</sup>. This implies that, for every 1% reduction in labour productivity, income falls by 0.75%. Without adaptation, the economic losses of reduced labour productivity relative to baseline (Table 2) are up to 20% of GDP (Central America, A2, 2080).

There are several limitations to this study. We only look at one aspect of effects of climate change on labour productivity. The number of days worked depends on the weather in both cold and hot countries. Working hours and work practices may change, and air conditioning may be put in place. Wages would respond to changes in the ability to work and to the costs to enhance that ability; this would determine whether the employer or the employee bears the brunt of the decrease in work ability and it would shape the wider economic consequences. A more comprehensive analysis could address these outputs but is beyond the scope of this exercise. Second, the climate model grid cell output may not accurately represent the observed temperature and humidity exposures for a given location. We therefore only report the aggregated changes in the labour productivity by region under climate warming.

The global burden of ill health from occupational exposures is large and often underestimated and under reported. The current WHO assessment does not include the effects of heat or cold<sup>34</sup>. The direct effect of climate warming on direct [worker] productivity has not been investigated, as far as we are aware. Although some models have converted health impacts

(mortality) into productivity losses, this is based on the assumption that mortality due to climate-sensitive diseases in adults will affect productivity at the regional level<sup>35</sup>.

Changes in productivity due to reductions on cold stress are not included because a different association applies between productivity and exposure to severe outdoor cold climate at work in polar or temperate regions.. Exposures to indoor cold are better regulated as they generally occur in high income countries. For outdoor workers, the projected increases in temperature in polar regions are likely to have productivity implications too, but the numbers affected (in polar and sub polar regions) are very small, compared to workers in temperate, tropical and subtropical regions. We are not addressing performance based on comfort and other issues in the environment, motivation, etc, which may also be important. Changes in temperature will affect days available for outdoor work (decreasing the number of too cold days) but this outcome is also not addressed. We also do not address days lost due to illness (either heat-related or cold-related or other climate-sensitive illnesses) which are an additional climate-change “cost”.

Assumptions about adaptation are key in all assessments of impacts on human systems due to climate change. As with many outcomes, there is a currently insufficient adaptation to climate factors in areas of limited economic development. There is an identifiable cost of climate change in terms of climate-proofing industrial and commercial buildings<sup>36</sup>. However, this is not always possible or may be prohibitively expensive, and it potentially increases greenhouse gas emissions. Further, there are limited adaptation options for outdoor work other than changes to hours and cooled suits. Nonetheless, future research should study adaptation to climate change in labour practices.

## **Acknowledgements**

Financial support by the EU under the FP6 Integrated Project ENSEMBLES (Contract number 505539) is gratefully acknowledged. We also wish to thank Bruno Lemke for his help with developing the climate indices, and Kate Lachowycz for help with developing the model.

## **Figures and Tables**

Figure 1. Location of population-weighted centroids of climate zones which were matched to climate modelling points within the 21 GBD regions (regional boundaries shown as black borders on map).

Figure 2. Distribution of WBGT for South East Asia under A2

Figure 3. Schematic diagram – productivity and WBGT curves

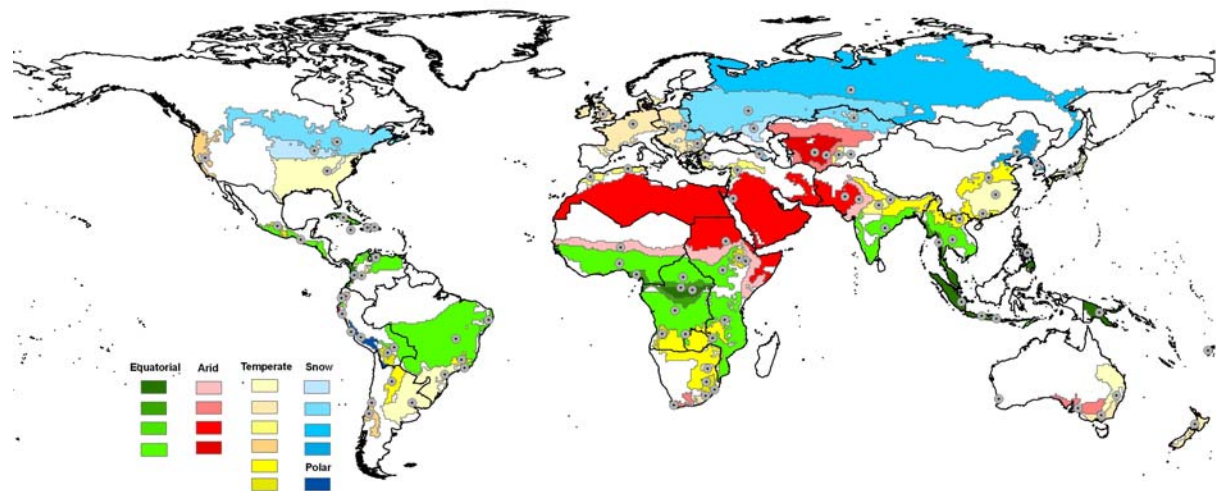
Figure 4. Distribution of gross labour sectors, estimated for baseline and in the 2050s under the A2 and B2 scenarios, for selected regions.

Table 1. Regional characteristics

Table 2. Estimates % labour productivity loss due to climate change by region.

Table 3: Sensitivity of results to assumed labour trends and projected climate change, as change in percent days lost compared to baseline, for A2 in 2050s.

Figure 1. Location of population-weighted centroids of climate zones which were matched to climate modelling points within the 21 GBD regions (regional boundaries shown as black borders on map)



**Figure 2. Frequency distributions of estimated WBGT in South-East Asia in current climate (1961-1990) and three future time periods under A2**

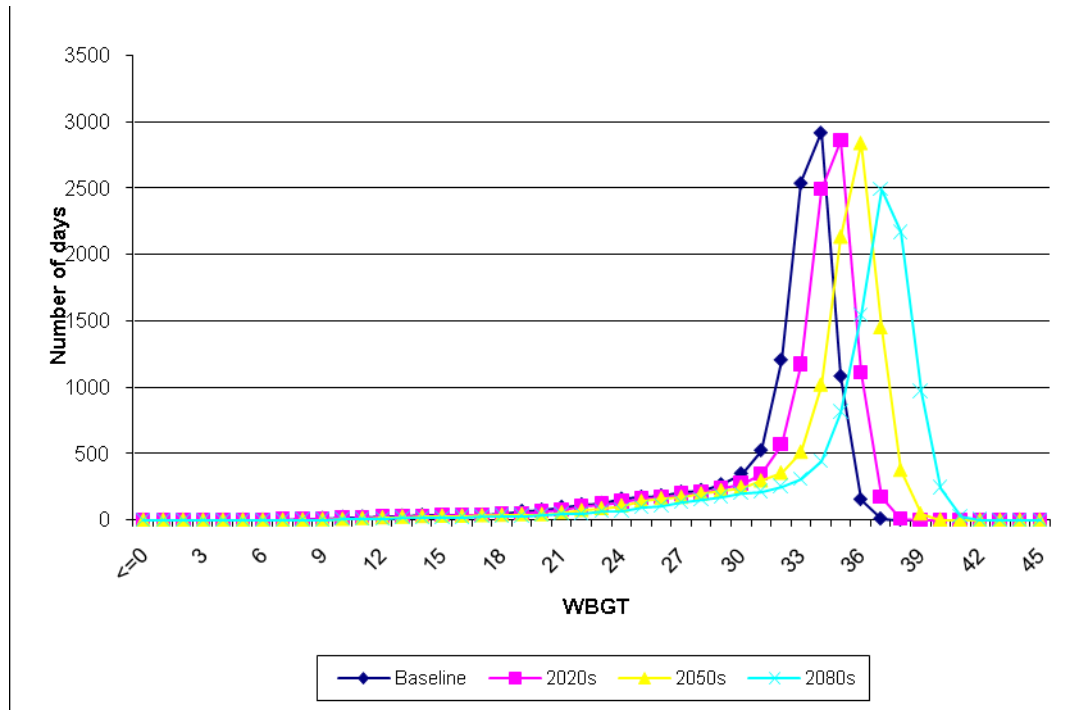
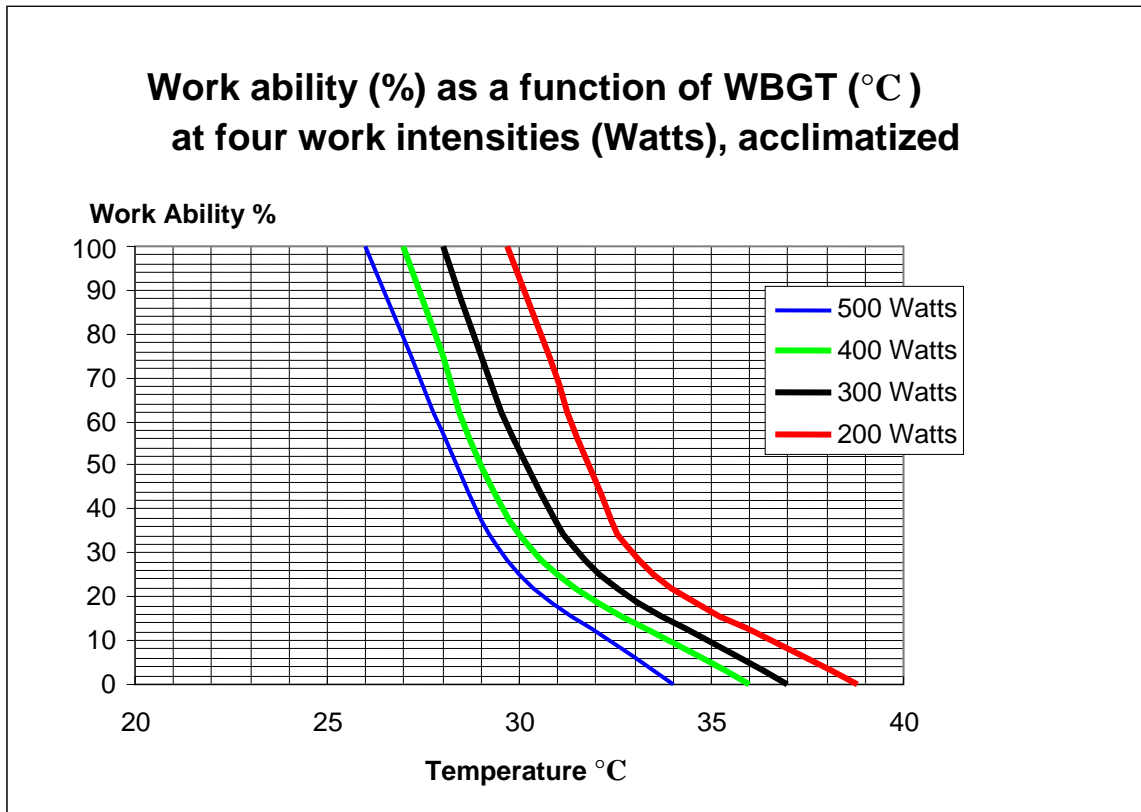
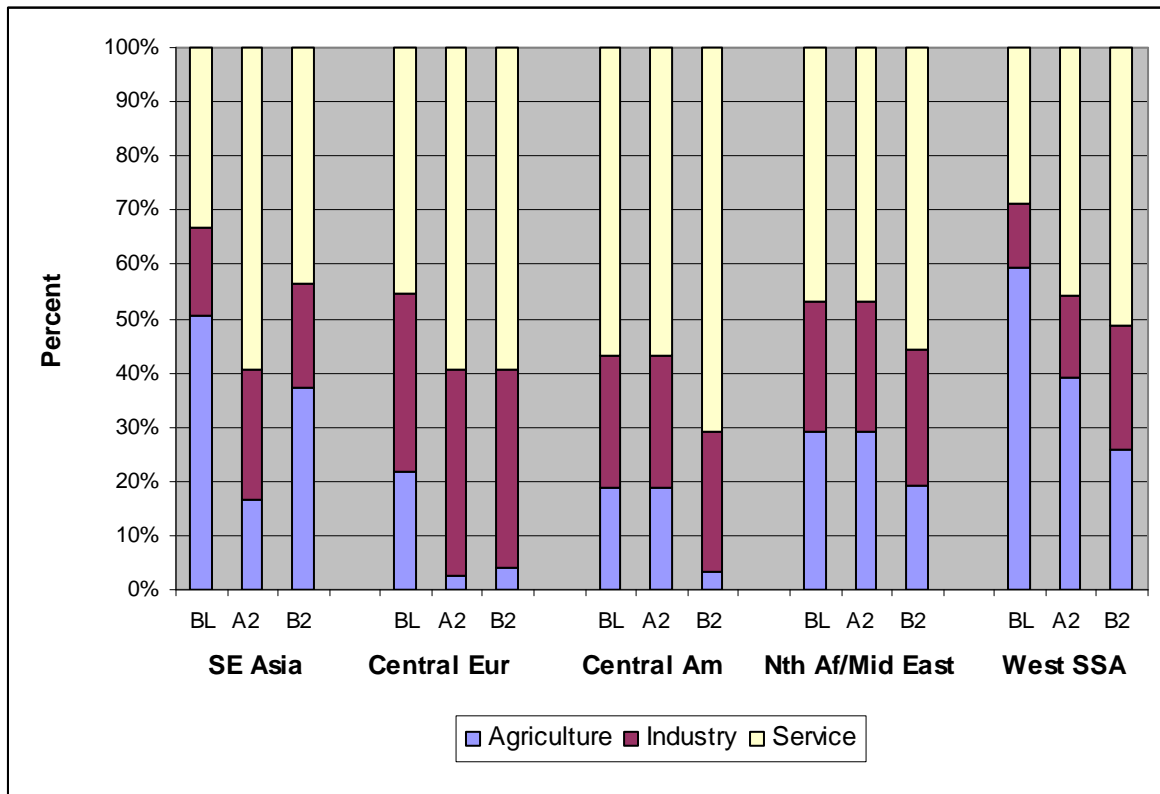


Figure 3. Association between work ability and WBGT for four work intensities. Based on recommendations by NIOSH, 1986 (ref 20)



**Figure 4. Distribution of gross labour sectors, estimated for baseline and in the 2050s under the A2 and B2 scenarios, for selected regions**



\* Regions are: SE Asia – South East Asia; Central Eur – Central Europe; Central Am – Central America; Nth Af/Mid East – North Africa and Middle East; West SSA – Western Sub-Saharan Africa. Bars are: BL – baseline; A2 – A2 in the 2050s; B2 – B2 in the 2050s.

**Table 1. Region characteristics, based on climate zones with at least 5% of regional population.**

World Region	Main climate types* (% population in the region)	Number of climate grid points	% of population represented
Asia Pacific, High Income	warm temperate, fully humid, hot summer (63%) snow, winter dry, hot summer (11%)	2	74%
Asia, Central	warm temperate, summer dry, hot summer (13.2%)	6	52%
Asia, Eastern	warm temperate, fully humid, hot summer (33%) warm temperate, winter dry, hot summer (27%) snow, winter dry, hot summer (11%)	4	79%
Asia, South	equatorial, winter dry (34%) warm temperate, winter dry, hot summer (27%) hot steppe (11%)	5	86%
Asia, South East	equatorial, fully humid (24%) equatorial, winter dry (20%)	7	76%
Australasia	warm temperate, fully humid, hot summer (35%) warm temperate, fully humid, warm summer (26%) warm temperate, fully humid, warm summer (16%)	5	91%
Caribbean	equatorial, winter dry (32%) equatorial, winter dry (28%) equatorial, fully humid (15%)	4	83%
Europe, Central	warm temperate, fully humid, warm summer (63%) snow, fully humid, warm summer (19%)	3	90%
Europe, Eastern	snow, fully humid, warm summer (71%)	3	83%
Europe, Western	warm temperate, fully humid, warm summer (49%) warm temperate, fully humid, warm summer (16%)	2	64%
Latin America, Andean	equatorial, winter dry (14%) warm temperate, fully humid, warm summer (10%)	7	58%
Latin America, Central	warm temperate, winter dry, warm summer (15%) equatorial, winter dry (15%) equatorial, winter dry (14%)	5	55%
Latin America, South	warm temperate, fully humid, hot summer (51%) cold steppe (10%)	4	76%
Latin America, Tropical	warm temperate, fully humid, hot summer (33%) equatorial, winter dry (29%)	5	80%
North America, High Income	warm temperate, fully humid, hot summer (43%) snow, fully humid, warm summer (18%) snow, fully humid, hot summer (10%)	4	80%



North Africa – Middle East	hot desert (37%)	5	63%
Oceania	equatorial, fully humid (62%)	2	71%
Sub-Saharan Africa, Central	equatorial, winter dry (55%) equatorial, winter dry (12%)	6	92%
Sub-Saharan Africa, East	equatorial, winter dry (25%) hot steppe (10%)	6	66%
Sub-Saharan Africa, South	warm temperate, winter dry, hot summer (42%) warm temperate, winter dry, warm summer (19%)	5	87%
Sub-Saharan Africa, West	equatorial, winter dry (61%) hot steppe (22%)	3	91%

\*Only types with  $\geq 10\%$  of regional population are listed; type appears more than once within a region if non-contiguous zones of the same type are present.

**Table 2:** Impact of climate on labour productivity, as percent days lost and incremental loss relative to baseline, by region<sup>1</sup> for A2 and B2 scenarios, assuming changes in labour patterns.

Region	Impact	Baseline		2020s		2050s		2080s	
				A2	B2	A2	B2	A2	B2
AP_HI	%days lost	0.3%	0.2%	0.5%	0.5%	0.9%	2.0%	1.7%	
	Increment		-0.1%	0.2%	0.2%	0.6%	1.7%	1.4%	
As_C	%days lost	0.1%	0.4%	0.3%	0.5%	0.6%	1.1%	0.2%	
	Increment		0.3%	0.1%	0.4%	0.4%	0.9%	0.1%	
As_E	%days lost	10.1%	9.7%	11.3%	10.5%	7.7%	16.4%	10.4%	
	Increment		-0.4%	1.2%	0.4%	-2.4%	6.3%	0.3%	
As_S	%days lost	25.2%	30.1%	22.9%	29.6%	22.8%	32.7%	28.4%	
	Increment		4.9%	-2.3%	4.4%	-2.4%	7.5%	3.2%	
As_SE	%days lost	42.1%	38.2%	42.7%	44.1%	50.3%	59.1%	46.2%	
	Increment		-3.9%	0.6%	2.0%	8.2%	17.0%	4.1%	
Au	%days lost	0.0%	0.1%	0.1%	0.2%	0.2%	0.3%	0.3%	
	Increment		0.0%	0.0%	0.2%	0.1%	0.3%	0.3%	
Ca	%days lost	11.3%	12.3%	13.1%	19.1%	12.6%	25.3%	18.4%	
	Increment		1.0%	1.8%	7.7%	1.2%	14.0%	7.1%	
Eu_C	%days lost	0.1%	0.2%	0.4%	0.1%	0.1%	0.4%	0.3%	
	Increment		0.0%	0.3%	0.0%	0.0%	0.3%	0.1%	
Eu_E	%days lost	0.1%	0.2%	0.2%	0.5%	0.1%	0.2%	0.1%	
	Increment		0.2%	0.2%	0.4%	0.0%	0.1%	0.1%	
Eu_W	%days lost	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	
	Increment		0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	
LA_A	%days lost	1.8%	2.8%	2.7%	5.0%	2.9%	13.2%	6.7%	
	Increment		1.0%	0.9%	3.2%	1.2%	11.4%	5.0%	
LA_C	%days lost	15.5%	23.0%	22.9%	34.1%	19.9%	42.4%	31.5%	
	Increment		7.5%	7.4%	18.6%	4.4%	26.9%	16.0%	
LA_S	%days lost	0.2%	0.2%	0.2%	0.2%	0.3%	0.3%	0.2%	
	Increment		0.1%	0.1%	0.1%	0.0%	0.2%	0.1%	
LA_T	%days lost	11.9%	13.0%	13.3%	5.8%	3.6%	8.9%	6.0%	
	Increment		1.2%	1.5%	-6.0%	-8.3%	-3.0%	-5.9%	
NA_HI	%days lost	0.8%	2.1%	2.0%	4.2%	3.4%	9.0%	5.9%	
	Increment		1.3%	1.2%	3.4%	2.6%	8.2%	5.1%	
NA_ME	%days lost	0.0%	0.2%	0.1%	0.6%	0.3%	0.5%	0.1%	
	Increment		0.2%	0.1%	0.6%	0.3%	0.5%	0.1%	
Oc	%days lost	58.9%	50.8%	58.9%	62.0%	64.8%	61.8%	40.6%	
	Increment		-8.0%	6.0%	3.1%	-18.2%	2.9%	-5.5%	
SSA_C	%days lost	33.6%	41.1%	40.9%	34.5%	22.6%	38.2%	30.3%	
	Increment		7.5%	7.3%	0.8%	-11.0%	4.6%	-3.3%	
SSA_E	%days lost	6.3%	9.3%	10.4%	10.3%	9.8%	16.8%	11.0%	
	Increment		3.0%	3.4%	4.0%	2.8%	10.5%	3.9%	
SSA_S	%days lost	2.2%	3.4%	2.2%	1.8%	3.3%	3.1%	1.2%	
	Increment		1.2%	1.1%	-0.4%	-1.1%	0.9%	-0.3%	

SSA_W	%days lost	40.3%	47.0%	40.3%	43.8%	47.1%	49.6%	32.1%
	Increment		6.7%	6.8%	3.4%	-8.2%	9.3%	1.6%

<sup>1</sup>AP\_HI: Asia Pacific, High Income; As\_C: Central Asia; As\_E: East Asia; As\_S: South Asia; As\_SE: South East Asia; Au: Australasia; Ca: Caribbean; Eu\_C: Central Europe; Eu\_E: Eastern Europe; Eu\_W: Western Europe; LA\_A: Andean Latin American; LA\_C: Central Latin America; LA\_S: Southern Latin America; LA\_T: Tropical Latin America; NA\_HI: North America, High Income; NA\_ME: North Africa/Middle East; Oc: Oceania; SSA\_C: Central Sub-Saharan Africa; SSA\_E: Eastern Sub-Saharan Africa; SSA\_S: Southern Sub-Saharan Africa; SSA\_W: Western Sub-Saharan Africa.

**Table 3:** Sensitivity of results to assumed labour trends and projected climate change, as the incremental percent days lost compared to baseline, for A2 in 2050s.

<b>Change in percent days lost compared to baseline for A2 in 2050s</b>			
<b>Region<sup>1</sup></b>	<b>Constant labour, changing climate</b>	<b>Changing labour, constant climate</b>	<b>Changing labour and climate<sup>2</sup></b>
AP_HI	0.8%	-0.2%	0.2%
As_C	0.7%	-0.1%	0.4%
As_E	7.0%	-5.1%	0.4%
As_S	11.5%	-6.7%	4.4%
As_SE	18.2%	-21.6%	2.0%
Au	0.2%	0.0%	0.2%
Ca	11.7%	-4.0%	7.7%
Eu_C	0.6%	-0.1%	0.0%
Eu_E	0.3%	0.0%	0.4%
Eu_W	0.1%	0.0%	0.0%
LA_A	4.1%	-0.6%	3.2%
LA_C	18.6%	0.0%	18.6%
LA_S	0.3%	-0.1%	0.1%
LA_T	3.6%	-8.3%	-6.0%
NA_HI	3.4%	0.0%	3.4%
NA_ME	0.6%	0.0%	0.6%
Oc	15.2%	-15.1%	3.1%
SSA_C	15.4%	-11.5%	0.8%
SSA_E	8.1%	-2.1%	4.0%
SSA_S	2.8%	-1.6%	-0.4%
SSA_W	15.8%	-13.0%	3.4%

<sup>1</sup>AP\_HI: Asia Pacific, High Income; As\_C: Central Asia; As\_E: East Asia; As\_S: South Asia; As\_SE: South East Asia; Au: Australasia; Ca: Caribbean; Eu\_C: Central Europe; Eu\_E: Eastern Europe; Eu\_W: Western Europe; LA\_A: Andean Latin American; LA\_C: Central Latin America; LA\_S: Southern Latin America; LA\_T: Tropical Latin America; NA\_HI: North America, High Income; NA\_ME: North Africa/Middle East; Oc: Oceania; SSA\_C: Central Sub-Saharan Africa; SSA\_E: Eastern Sub-Saharan Africa; SSA\_S: Southern Sub-Saharan Africa; SSA\_W: Western Sub-Saharan Africa.

<sup>2</sup>This equals the bottom line of the 6<sup>th</sup> column in Table 2.

## Reference List

- (1) Vogt JJ. Heat and Cold. In: Stellman J, editor. *Encyclopaedia of Occupational Health and Safety. Fourth edition. Vol. II.* Geneva: International Labour Office; 1998.
- (2) Ramsey JD. Task performance in heat: a review. *Ergonomics* 1995;38:154-65.
- (3) Mairiaux P, Malchaire J. Workers self-pacing in hot conditions: a case study. *Applied Ergonomics* 1985;16:-85.
- (4) Malchaire J, Kampmann B, Havenith G, Mehnert P, Gebhardt H. Criteria for estimating acceptable exposure times in hot working environments: a review. *Archives of Occupational and Environmental Health* 2000;73(4):215-20.
- (5) Clark RT, Brown SJ, Murphy JM. Modeling Northern Hemisphere summer heat extreme changes and their uncertainties using a physics ensemble of climate sensitivity experiments. *Journal of Climate* 2006;19:4418-35.
- (6) Kjellström E, Barring D, Jacob D, Jones R, Lenderink G, Schar C. Modelling daily temperature extremes: recent climate and future changes over Europe. *Climatic Change* 2007;81(Supplement 1):249-65.
- (7) Kjellstrom T. Climate change, heat exposure and labour productivity. Proc. ISEE 2000, 12<sup>th</sup> conference of the International Society for Environmental Epidemiology, Buffalo, USA, August, 2000. *Epidemiology* 2000.
- (8) Kerslake DM. *The stress of hot environments.* Cambridge: Cambridge University Press; 1972.
- (9) Dawson NJ. Body temperature and exercise performance. In: Hill PM, editor. *Exercise - the Physiological Challenge.* Auckland: Conference Publ Ltd; 1993.
- (10) Ramsey JD. Effects of workplace thermal conditions on safe working behaviour. *Journal of Safety Research* 1983;14:105-14.
- (11) Parsons KC. *Human Thermal Environments.* 2 ed. London: Routledge; 2002.
- (12) McNeill MB, Parsons KC. Appropriateness of international heat stress standards for use in tropical agricultural environments. *Ergonomics* 1999 June;42(6):779-97.
- (13) ISO. *Hot Environments - Estimation of the heat stress on working man, based on the WBGT-index (wet bulb globe temperature).* ISO Standard 7243. Geneva: International Standards Organization; 1989.
- (14) Malchaire J, Kampmann B, Mehnert P et al. Assessment of the risk of heat disorders encountered during work in hot conditions. *Int J Occ Environ Health* 2002;75(3):153-62.
- (15) Mommadov IM, Sultanov GF, Grigoryan AG, Ovezgeldyeva GO, Khemraeva MG. Forecast of the health status, working capacity and professional successes under arid zone conditions. *Human Physiology* 2001;27:76-83.

- (16) Wyon DP. The effects of indoor air quality on performance and productivity. *Indoor Air* 2004;14(suppl 7):92-101.
- (17) Rodahl K. Occupational health conditions in extreme environments. *Annals of Occupational Hygiene* 2003;47:241-52.
- (18) Delache X. Evaluation des coûts de la canicule de l'été 2003 en France: premiers éléments de bilan. *Recherche Environnement* 2003;8:3-4.
- (19) Fisk WJ. Health and productivity gains from better indoor environments and their relationship with building energy efficiency. *Annual Review of Energy and the Environment* 2000;25:537-66.
- (20) NIOSH. *Criteria for a Recommended Standard: Occupational Exposure to Hot Environments (Revised Criteria 1986)*. Washington DC: National Institute for Occupational Safety and Health; 1986.
- (21) IPCC. *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, 2007.
- (22) Tol RS. Why worry about climate change? A research agenda. *Environmental Values* 2008;17(4):437-70.
- (23) Beck C, Grieser J., Kottek M, Rubel F, Rodolf B. Characterising global climate change by means of Koppen climate classification. Offenbach: Deutscher Wetterdienst; 2005.
- (24) Center for International Earth Science Information Network (CIESIN) CU, Centro Internacional de Agricultura Tropical (CIAT). Gridded Population of the World, Version 3 (GPWv3). [3]. 2005. Palisades, NY, Socioeconomic Data and Applications Center (SEDAC), Columbia University.
- (25) IPCC. *Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*. New York: Cambridge University Press; 2000.
- (26) IPCC. *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, 2007.
- (27) ABOM. About the WBGT and Apparent Temperature Indices. *Australian Bureau of Meteorology* 2008; Available at: URL: [http://www.bom.gov.au/info/thermal\\_stress/#approximation](http://www.bom.gov.au/info/thermal_stress/#approximation).
- (28) ACSM. Prevention of thermal injuries during distance running. *American College of Sports Medicine. Med J Aust* 1984;141(12-13):876-9.
- (29) Bernard TE, Pourmoghani M. Prediction of workplace wet bulb globe temperature. *Applied Occupational and Environmental Hygiene* 1999;14:126-34.

- (30) Johns TC, Gregory JM, Ingram WJ et al. Anthropogenic climate change for 1860 to 2100 simulated with the HadCM3 model under updated emissions scenarios. *Climate Dynamics* 2003;20(6):583-612.
- (31) World Bank. World Bank Labor and Employment Statistics. 1-4-2005.
- (32) CIESIN. *Country-level GDP and Downscaled Projections based on the A1, A2, B1, and B2 Marker Scenarios, 1990-2100 [digital version]*. Palisades, NY: CIESIN, Columbia University; 2002.
- (33) Romer D. *Advanced Macroeconomics*. 2nd ed. Columbus: McGraw-Hill; 2005.
- (34) Concha-Barrientos M, Nelson DI, Driscoll T et al. Selected occupational risk factors. In: Ezzati M, Lopez AD, Rodgers A, Murray CJ, editors. *Comparative Quantification of Health Risks: Global and Regional Burden of Disease due to Selected Major Risk Factors. Vol.2*. Geneva: WHO; 2004. p. 1651-801.
- (35) Bosello F, Roson R, Tol RS. Economy-wide estimates of the implications of climate change: human health. *Ecological Economics* 2006;58:579-91.
- (36) Roaf S. *Adapting buildings and cities to climate change*. London: London Architectural Press; 2005.

Year	Number	Title/Author(s) ESRI Authors/Co-authors <i>Italicised</i>
2008		
	259	Damage Costs of Climate Change through Intensification of Tropical Cyclone Activities: An Application of FUND Daiju Narita, <i>Richard S. J. Tol</i> and David Anthoff
	258	Are Over-educated People Insiders or Outsiders? A Case of Job Search Methods and Over-education in UK Aleksander Kucel, <i>Delma Byrne</i>
	257	Metrics for Aggregating the Climate Effect of Different Emissions: A Unifying Framework <i>Richard S.J. Tol</i> , Terje K. Berntsen, Brian C. O'Neill, Jan S. Fuglestedt, Keith P. Shine, Yves Balkanski and Laszlo Makra
	256	Intra-Union Flexibility of Non-ETS Emission Reduction Obligations in the European Union <i>Richard S.J. Tol</i>
	255	The Economic Impact of Climate Change <i>Richard S.J. Tol</i>
	254	Measuring International Inequity Aversion <i>Richard S.J. Tol</i>
	253	Using a Census to Assess the Reliability of a National Household Survey for Migration Research: The Case of Ireland <i>Alan Barrett</i> and <i>Elish Kelly</i>
	252	Risk Aversion, Time Preference, and the Social Cost of Carbon David Anthoff, <i>Richard S.J. Tol</i> and Gary W. Yohe
	251	The Impact of a Carbon Tax on Economic Growth and Carbon Dioxide Emissions in Ireland <i>Thomas Conefrey</i> , <i>John D. Fitz Gerald</i> , <i>Laura Malaguzzi Valeri</i> and <i>Richard S.J. Tol</i>
	250	The Distributional Implications of a Carbon Tax in Ireland <i>Tim Callan</i> , <i>Sean Lyons</i> , <i>Susan Scott</i> , <i>Richard S.J. Tol</i> and <i>Stefano Verde</i>
	249	Measuring Material Deprivation in the Enlarged EU <i>Christopher T. Whelan</i> , <i>Brian Nolan</i> and <i>Bertrand Maitre</i>



- 248 Marginal Abatement Costs on Carbon-Dioxide Emissions: A Meta-Analysis  
Onno Kuik, Luke Brander and *Richard S.J. Tol*
- 247 Incorporating GHG Emission Costs in the Economic Appraisal of Projects Supported by State Development Agencies  
*Richard S.J. Tol* and *Seán Lyons*
- 246 A Carton Tax for Ireland  
*Richard S.J. Tol, Tim Callan, Thomas Conefrey, John D. Fitz Gerald, Seán Lyons, Laura Malaguzzi Valeri and Susan Scott*
- 245 Non-cash Benefits and the Distribution of Economic Welfare  
*Tim Callan and Claire Keane*
- 244 Scenarios of Carbon Dioxide Emissions from Aviation  
*Karen Mayor and Richard S.J. Tol*
- 243 The Effect of the Euro on Export Patterns: Empirical Evidence from Industry Data  
*Gavin Murphy and Julia Siedschlag*
- 242 The Economic Returns to Field of Study and Competencies Among Higher Education Graduates in Ireland  
*Elish Kelly, Philip O'Connell and Emer Smyth*
- 241 European Climate Policy and Aviation Emissions  
*Karen Mayor and Richard S.J. Tol*
- 240 Aviation and the Environment in the Context of the EU-US Open Skies Agreement  
*Karen Mayor and Richard S.J. Tol*
- 239 Yuppie Kvetch? Work-life Conflict and Social Class in Western Europe  
*Frances McGinnity and Emma Calvert*
- 238 Immigrants and Welfare Programmes: Exploring the Interactions between Immigrant Characteristics, Immigrant Welfare Dependence and Welfare Policy  
*Alan Barrett and Yvonne McCarthy*
- 237 How Local is Hospital Treatment? An Exploratory Analysis of Public/Private Variation in Location of Treatment in Irish Acute Public Hospitals

*Jacqueline O'Reilly and Miriam M. Wiley*

- 236 The Immigrant Earnings Disadvantage Across the Earnings and Skills Distributions: The Case of Immigrants from the EU's New Member States in Ireland  
*Alan Barrett, Seamus McGuinness and Martin O'Brien*
- 235 Europeanisation of Inequality and European Reference Groups  
*Christopher T. Whelan and Bertrand Maitre*
- 234 Managing Capital Flows: Experiences from Central and Eastern Europe  
Jürgen von Hagen and *Iulia Siedschlag*
- 233 ICT Diffusion, Innovation Systems, Globalisation and Regional Economic Dynamics: Theory and Empirical Evidence  
Charlie Karlsson, Gunther Maier, Michaela Trippl, *Iulia Siedschlag*, Robert Owen and *Gavin Murphy*
- 232 Welfare and Competition Effects of Electricity Interconnection between Great Britain and Ireland  
*Laura Malaguzzi Valeri*
- 231 Is FDI into China Crowding Out the FDI into the European Union?  
Laura Resmini and *Iulia Siedschlag*
- 230 Estimating the Economic Cost of Disability in Ireland  
John Cullinan, Brenda Gannon and *Seán Lyons*
- 229 Controlling the Cost of Controlling the Climate: The Irish Government's Climate Change Strategy  
Colm McCarthy, *Sue Scott*
- 228 The Impact of Climate Change on the Balanced-Growth-Equivalent: An Application of *FUND*  
David Anthoff, *Richard S.J. Tol*
- 227 Changing Returns to Education During a Boom? The Case of Ireland  
*Seamus McGuinness, Frances McGinnity, Philip O'Connell*
- 226 'New' and 'Old' Social Risks: Life Cycle and Social Class Perspectives on Social Exclusion in Ireland  
*Christopher T. Whelan and Bertrand Maitre*

- 225 The Climate Preferences of Irish Tourists by Purpose of Travel  
*Seán Lyons, Karen Mayor and Richard S.J. Tol*
- 224 A Hirsch Measure for the Quality of Research Supervision, and an Illustration with Trade Economists  
*Frances P. Ruane and Richard S.J. Tol*
- 223 Environmental Accounts for the Republic of Ireland: 1990-2005  
*Seán Lyons, Karen Mayor and Richard S.J. Tol*
- 2007** 222 Assessing Vulnerability of Selected Sectors under Environmental Tax Reform: The issue of pricing power  
*J. Fitz Gerald, M. Keeney and S. Scott*
- 221 Climate Policy Versus Development Aid  
*Richard S.J. Tol*
- 220 Exports and Productivity – Comparable Evidence for 14 Countries  
*The International Study Group on Exports and Productivity*
- 219 Energy-Using Appliances and Energy-Saving Features: Determinants of Ownership in Ireland  
Joe O'Doherty, *Seán Lyons* and *Richard S.J. Tol*
- 218 The Public/Private Mix in Irish Acute Public Hospitals: Trends and Implications  
*Jacqueline O'Reilly and Miriam M. Wiley*
- 217 Regret About the Timing of First Sexual Intercourse: The Role of Age and Context  
*Richard Layte, Hannah McGee*
- 216 Determinants of Water Connection Type and Ownership of Water-Using Appliances in Ireland  
Joe O'Doherty, *Seán Lyons* and *Richard S.J. Tol*
- 215 Unemployment – Stage or Stigma?  
Being Unemployed During an Economic Boom  
*Emer Smyth*
- 214 The Value of Lost Load  
*Richard S.J. Tol*
- 213 Adolescents' Educational Attainment and School Experiences in Contemporary Ireland  
*Merike Darmody, Selina McCoy, Emer Smyth*

- 212 Acting Up or Opting Out? Truancy in Irish Secondary Schools  
*Merike Darmody, Emer Smyth and Selina McCoy*
- 211 Where do MNEs Expand Production: Location Choices of the Pharmaceutical Industry in Europe after 1992  
*Frances P. Ruane, Xiaoheng Zhang*
- 210 Holiday Destinations: Understanding the Travel Choices of Irish Tourists  
*Seán Lyons, Karen Mayor and Richard S.J. Tol*
- 209 The Effectiveness of Competition Policy and the Price-Cost Margin: Evidence from Panel Data  
Patrick McCloughan, *Seán Lyons* and William Batt
- 208 Tax Structure and Female Labour Market Participation: Evidence from Ireland  
*Tim Callan, A. Van Soest, J.R. Walsh*
- 207 Distributional Effects of Public Education Transfers in Seven European Countries  
*Tim Callan, Tim Smeeding and Panos Tsakloglou*