Climate change impacts on global agriculture Alvaro Calzadilla & Katrin Rehdanz & Richard Betts & Pete Falloon & Andy Wiltshire & Richard S. J. Tol

Most economic activities require water as an input of production but in many regions of the world, there are no markets for water. Water is also often underpriced, free or even subsidized. Because there is often no economic transaction, water use is not commonly reported in the national economic accounts, which hampers the analysis of water resources with economic models. We use the new version of the GTAP-W model, which accounts for water use in the agricultural sector, to analyze expected climate change impacts on global agricultural production. The GTAP-W model (Calzadilla et al. 2011) distinguishes between rainfed and irrigated crop production; therefore, is able to assess the role of green (effective rainfall) and blue (irrigation) water resources in agriculture. This distinction is crucial, because rainfed and irrigated agriculture face different climate risk levels. Agriculture is by far the biggest global user of freshwater resources and consequently highly vulnerable to climate change. In most developing countries, the agricultural sector provides the main livelihood and employment for most of the population and contributes considerably to national GDP. Therefore, reductions in agricultural production caused by future climate change could seriously weaken food security and worsen the livelihood conditions for the rural poor (Commission for Africa 2005).

The World Bank (2007) identifies five main factors through which climate change will affect the productivity of agricultural crops: changes in precipitation, temperature, carbon dioxide (CO2) fertilization, climate variability, and surface water runoff. Increased climate variability and droughts will affect livestock production as well. Crop production is directly influenced by precipitation and temperature. Precipitation co-determines the availability of freshwater and the level of soil moisture, which are critical inputs for crop growth. Higher precipitation or irrigation will reduce the yield gap between rain fed and irrigated agriculture, but it may also have a negative impact if extreme precipitation causes flooding. Temperature and soil moisture determine the length of growing season and control the crop's development and water requirements. In general, higher temperatures will shorten the frost period, promoting cultivation in cool-climate marginal croplands. However, in arid and semi arid areas, higher temperatures will shorten the crop cycle and reduce crop yields (IPCC 2007). A higher atmospheric concentration of carbon dioxide enhances plant growth, particularly of C41 plants, and increases water use efficiency (CO2 fertilization) and so affects water availability (e.g. Betts et al. 2007).

Climate variability, especially changes in rainfall patterns, is particularly important for rainfed agriculture. Soil moisture limitations reduce crop productivity and increase the risk of rainfed farming systems. Although the risk of climate variability is reduced by the use of irrigation, irrigated farming systems are dependent on reliable water resources, therefore they may be exposed to changes in the spatial and temporal distribution of river flow (CA 2007). The aim of our paper is to assess how climate change impacts on water availability might influence agricultural production world-wide. As climate variables we use predicted changes in global precipitation, temperature and river flow under the two IPCC SRES A1B and A2 scenarios from Falloon and Betts (2006) and Johns et al. (2006) and include the effect of CO2 fertilization as well. All these variables play an important role in determining agricultural outcomes. Temperature and CO2 fertilization affect both rainfed and irrigated crop production. While precipitation is directly related to runoff and soil moisture and hence to rainfed production; river flow is directly related to irrigation water availability and hence to irrigated production.

The analysis is carried out using the new version of the global computable general equilibrium (CGE) model GTAP-W which includes water resources and allows for a rich set of economic feedbacks and for a complete assessment of the welfare implications of alternative development pathways. Therefore, our methodology allows us to study the impacts of future availability of water resources on agriculture and within the context of international trade taking into account a more complete set of climate change impacts (see Section 2 for more details on the literature). The remainder of the paper is organized as follows: the next section briefly reviews the literature on economic models of water use including studies of climate change impacts. Section 3 describes the revised version of the GTAP-W model. Section 4 describes the data used and lays down the simulation scenarios. Section 5 discusses the principal results and Section 6 concludes.

Economic models of water use

Economic models of water use have generally been applied to look at the direct effects of water policies, such as water pricing or quantity regulations, on the allocation of water resources. Partial and general equilibrium models have been used to do this. While partial equilibrium analysis focus on the sector affected by a policy measure assuming that the rest of the economy is not affected (e.g. Rosegrant et al. 2002), general equilibrium models consider other sectors or regions as well to determine the economy-wide effect. Most of the studies using either of the two approaches analyze pricing of irrigation water only (for an overview of this literature see Johansson et al. 2002). Studies of water use using general equilibrium approaches are generally based on data for a single country or region assuming no effects for the rest of the world of the implemented policy (for an overview of this literature see Dudu and Chumi 2008). All of these CGE studies have a limited geographical scope. Berrittella et al. (2007) and Calzadilla et al. (2011) are an exception. Using a previous version of the GTAP-W model, Berrittella et al. (2007 and 2008) analyze the economic impact of various water resource policies. Unlike the predecessor GTAP-W, the revised GTAP-W model, used here, distinguishes between rainfed and irrigated agriculture. The new production structure of the model introduces water as an explicit factor of production and accounts for substitution possibilities between water and other primary factors. Applications of the model include an analysis of the economy-wide impacts of enhanced irrigation efficiency (Calzadilla et al. 2011) and the investigation of the role of green (rainfall) and blue (irrigation) water resources in agriculture (Calzadilla et al. 2010).

Despite the global scale of climate change and the fact that food products are traded internationally, climate change impacts on agriculture have mostly been studied at the farm (e.g. Abler et al. 1998), the country or the regional level (e.g. Darwin et al. 1995; Verburg et al. 2008). Early studies of climate change impacts on global agriculture analyzed the economic effects of doubling the atmospheric carbon dioxide concentration based on alternative crop response scenarios with and without CO2 effects on plant growth. Results indicate that the inclusion of CO2 fertilization is likely to offset some of the potential welfare losses generated by climate change (e.g. Tsigas et al. 1997; Darwin and Kennedy 2000). Global CGE models have also been used to study the role of adaptation in adjusting to new climate condition. The results suggest that farm-level adaptations might mitigate any negative impacts induced by climate change (e.g. Darwin et al. 1995; Parry et al. 1999; Tubiello and Fischer 2007). However, none of these studies have water as an explicit factor of production. Our GTAPW model is the first global model to do this. Moreover, most of these studies are based on scenarios related to a doubling of CO2 concentration, not taking into account the timing of the expected change in climate. Despite the considerable uncertainty in future climate projections (IPCC 2007), detailed information on the impacts of changes in precipitation, temperature and CO2 fertilization on crop yields is available, as well as the benefits of adaptation strategies. However, there is a lack of information about potential impacts of changes in river flow on irrigated agriculture. Our approach, based on the global CGE model GTAP-W, allows us to distinguish between rainfed and irrigated agriculture as well as to analyze how economic actors in one region/sector might respond to climate-induced economic changes in another region/sector.

The GTAP-W model

In order to assess the systemic general equilibrium effects of climate change impacts on global agriculture, we use a multi-region world CGE model, called GTAP-W. The model is a further refinement of the GTAP model (Hertel 1997), and is based on the version modified by Burniaux and Truong3 (2002) as well as on the previous GTAP-W model introduced by Berrittella et al. (2007). The new GTAP-W model is based on the GTAP version 6 database, which represents the global economy in 2001, and on the IMPACT 2000 baseline data. The IMPACT model is a partial equilibrium agricultural sector model combined with a water simulation model (Rosegrant et al. 2002), it provides detailed information (demand and supply of water, demand and supply of food, rainfed and irrigated production and rainfed and irrigated area) to the GTAP-W model for a robust calibration of the baseline year and future benchmark equilibriums. The GTAP-W model has 16 regions and 22 sectors, 7 of which are agricultural crops.4 The most significant change and principal characteristic of version 2 of the GTAP-W model is the new production structure, in which the original land endowment in the value-added nest has been split into pasture land (grazing land used by livestock) and land for rainfed and for irrigated agriculture. The last two types of land differ as rainfall is free but irrigation development is costly. As a result, land equipped for irrigation is generally more valuable as yields per hectare are higher. To account for this difference, we split irrigated agriculture further into the value for land and the value for irrigation. The value of irrigation includes the equipment but also the water necessary for agricultural production. In the short-run the cost of irrigation equipment is fixed, and yields in irrigated agriculture depend mainly on water availability [see supplemental material, Figure S1, for the tree production structure]. Land as a factor of production in national accounts represents "the ground, including the soil covering and any associated surface waters, over which ownership rights are enforced" (United Nations 1993). To accomplish this, we split for each region and each crop the value of land included in the GTAP social accounting matrix into the value of rainfed land and the value of irrigated land using its proportionate contribution to total production.5 The value of pasture land is derived from the value of land in the livestock breeding sector. In the next step, we split the value of irrigated land into the value of land and the value of irrigation using the ratio of irrigated yield to rainfed yield. These ratios are based on IMPACT data.6 The procedure we described above to introduce the four new endowments (pasture land, rainfed land, irrigated land and irrigation) allows us to avoid problems related to model calibration. In fact, since the original database is only split and not altered, the original regions' social accounting matrices are balanced and can be used by the GTAP-W model to assign values to the share parameters of the mathematical equations. For a detailed description of the adjustment process and economic behavior in GTAP-W see supplemental material. The distinction between rainfed and irrigated agriculture within the production structure of the GTAP-W model allows us to study expected physical constraints on water supply due to, for example, climate change. In fact, changes in rainfall patterns can be exogenously modelled in GTAP-W by changes in the productivity of rainfed and irrigated land. In the same way, water excess or shortages in irrigated agriculture can be modelled by exogenous changes to the initial irrigation water endowment.

Data input and design of simulation scenarios

We analyze climate change impacts on global agriculture based on predicted changes in the magnitude and distribution of global precipitation, temperature and river flow from Falloon and Betts (2006) and Stott et al. (2006). They analyze data from simulations using the Hadley Centre global Environmental Model version 1 (HadGEM1: a version of the Met Office Unified Model, etUM) including a dynamic river routing model (HadGEM1-TRIP) (Johns et al. 2006; Martin et al. 2006) over the next century and under the IPCC SRES A1B and A2 scenarios. Their results are in road agreement with previous studies (e.g. Arnell 2003; Milly et al. 2005). HadGEM1 was the version of the Hadley Centre GCM used in the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report (Solomon et al. 2007) and HadGEM1 is described in detail by Johns et al. (2006) and Martin et al. (2006). HadGEM1 has a horizontal latitude–longitude resolution of 1.25°×1.875° for the atmosphere and 1.0°×1.0° for the ocean. Compared to observations, HadGEM1 has too much annual precipitation over the Southern Ocean and high latitudes of the North Atlantic and North Pacific; over land, HadGEM1 is too wet over India and too dry over Southeast Asia, Indonesia, and the coast of western South America (Johns et al. 2006). Falloon et al. (2011) compare river flows simulated with HadGEM1-TRIP to observed flow gauge data, in general finding reasonable simulation of annual flows but much more variable skill in reproducing monthly flows. Future changes in temperature and precipitation projected by HadGEM1 are generally similar to those projected by the range of models presented in Solomon et al. (2007). For example, HadGEM1 projects increases in precipitation over land for the Northern Hemisphere high latitudes, across southern to eastern Asia and central Africa, while decreases in precipitation are projected across the Mediterranean region, the southern United States and southern Africa (Nohara et al. 2006). Under the IPCC SRES A1B and A2 scenarios (Johns et al., 2006; Stott et al., 2006), the global mean atmospheric surface temperature rises projected by HadGEM1 between 1961–1990 and 2070–2100 were approximately 3.4 K and 3.8 K, respectively, slightly warmer than the IPCC multi-model ensemble mean (Solomon et al. 2007). Globally, future precipitation changes projected by HadGEM1 are similar to, or slightly smaller than the IPCC multi-model ensemble mean. For consistency, we note here that while these HadGEM1 simulations did include the impact of elevated CO2 concentrations on runoff, they did not include explicit representations of crops, irrigation, groundwater or dams. In our analysis we contrast a relatively optimistic scenario (A1B) with a relatively pessimistic scenario (A2), covering in this way part of the uncertainty of future climate change impacts on water availability. As described in the SRES report (IPCC 2000), the A1B group of the A1 storyline and scenario family considers a balance between fossil intensive and non-fossil energy sources. It shows a future world of very rapid economic growth, global population peaks in mid-century and declines thereafter. There is rapid and more efficient technology development. It considers convergence among regions, with a substantial reduction in regional differences in per capita income. The SRES A2 scenario describes a very heterogeneous world. It considers self-reliance and preservation of local identities, and continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines. To estimate the expected impacts of these emission scenarios in global agricultural production, we only incorporate predicted changes in climate-related variables affecting agricultural productivity. That is, precipitation, temperature, river flow and CO2 concentrations. The analysis is carried out at two time periods: the 2020s (medium-term) and 2050s (long-term). Both time periods represent the average for the 30-year period centred on the given year; the 2020s represents the average for the 2006–2035 period and the 2050s represents the average for the 2036–2065 period. Predicted changes in precipitation, temperature and river flow under the two emission scenarios are compared to a historicanthropogenic baseline simulation, which represents the natural variability of these variables. It is the 30-year average for the 1961–1990 period. We use annual regional average precipitation, temperature and river flow data. Therefore, in the current study we do not consider local scale impacts nor changes in seasonality or climatic extremes. The economy-wide climate change impacts are compared to alternative no climate change benchmarks for each period. To obtain a future benchmark equilibrium dataset for the GTAP-W model we impose a forecast closure (see Dixon and Rimmer 2002) exogenizing macroeconomic variables for which forecasts are available. See the supplemental material for a detailed description of the future baseline simulations.

River flow

Compared to the average for the 1961–1990 period (historic-anthropogenic simulation), Falloon and Betts (2006) find large inter-annual and decadal variability of the average global total river flow, with an initial decrease until around 2060. For the 2071–2100 period, the average global total river flow is projected to increase under both SRES scenarios (around 4 % under the A1B scenario and 8 % under the A2 scenario). The A2 scenario produced more severe and widespread changes in river flow than the A1B scenario. Large regional differences are observed [supplemental material, Figure S2]. For both emission scenarios and time periods, the number of countries subject to decreasing river flow is projected to be higher than those with increasing river flow. In general, similar regional patterns of changes in river flow are observed under the two emission scenarios and time periods. Significant decreases in river flow are predicted for northern South America, southern Europe, the Middle East, North Africa and southern Africa. In contrast, substantial increases in river flow are predicted for boreal regions of North America and Eurasia, western Africa and southern Asia. Some exceptions are parts of eastern Africa and the Middle East, where changes in river flow vary depending on the scenario and time period. Additionally under the A1B-2050s scenario, river flow changes are positive for China and negative for Australia and Canada, while opposite trends were observed for other scenarios and time periods. River flow is a useful indicator of freshwater availability for agricultural production. Irrigated agriculture relies on the availability of irrigation water from surface and groundwater sources, which depend on the seasonality and interannual variability of river flow. Therefore, river flow limits a region's water supply and hence constrains its ability to irrigate crops. Table 1 shows for the two time periods and emission scenarios regional changes in river flow and water supply according to the 16 regions defined in Table S1 [see supplemental material]. Regional changes in river flow are related to regional changes in water supply by the runoff elasticities of water supply estimated by Darwin et al. (1995) (Table 1). The runoff elasticity of water supply is defined as the proportional change in a region's water supply divided by the proportional change in a region's runoff. That is, an elasticity of 0.5 indicates that a 2 % change in runoff results in a 1 % change in water supply. Regional differences in elasticities are related to differences in hydropower capacity, because hydropower production depends on dams, which enable a region to store water that could be withdrawn for irrigation or other uses during dry and rainy seasons.

Precipitation and temperature

Falloon and Betts (2006) point out that predicted changes in river flow were largely driven by changes in precipitation, since the pattern of changes in precipitation were very similar to the pattern of changes in river flow, and the changes in evaporation opposed the changes in river flow in some regions [supplemental material, Figure S3]. Decreases in both river flow and precipitation were predicted for northern South America and southern Europe while evaporation was reduced – hence the reduction in river flow was driven mostly by the reduction in rainfall. In high latitude rivers, increases in river flow and rainfall were predicted along with increases in evaporation, so the river flow changes here were mostly driven by changes in rainfall. In tropical Africa, increases in river flow and rainfall were predicted along with decreases in evaporation, so changes in rainfall and evaporation both contributed to the river flow changes. The regional patterns of temperature increases were similar for the two emission scenarios and time periods [supplemental material, Figure S4]. Larger temperature increases are expected at high latitudes and under the SRES A1B scenario.

Crop yield response

The exposure of irrigated agriculture to the risk of changes in climate conditions is more limited compared to rainfed agriculture which depends solely on precipitation. Temperature and soil moisture determine the length of growing season and control the crop's development and water requirements. Regional crop yield responses to changes in precipitation and temperature are based on Rosenzweig and Iglesias (1994) [see supplemental material, Table S6]. They used the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) dynamic crop growth models to estimate climate change impacts on crop yields at 112 sites in 18 countries, representing both major production areas and vulnerable regions at low, mid and high latitudes. The IBSNAT models have been validated over a wide range of environments and are not specific to any particular location or soil type. Rosenzweig and Iglesias (1994) use the IBSNAT crop models CERES (wheat, maize, rice and barley) and SOYGRO (soybeans) to analyze crop yield responses to arbitrary incremental changes in precipitation (+/− 20 %) and temperature (+2 °C and +4 °C). This data set has been widely used to assess potential climate change impacts on world crop production (e.g. Parry et al. 1999, 2004). In 2009, Iglesias and Rosenzweig (2009) updated this dataset by linking biophysical crop model and statistical models. However, they report the individual effect on crop yields only for the CO_2 fertilization effect, which limits its use in our analysis, because we are interested in assessing the individual impacts of changes in precipitation, temperature, river flow, CO_2 fertilization and adaptation on agricultural production. Besides neglecting the combined effect of these climate variables on crop yields, our analysis face an additional uncertainty related to the use of crop yield responses from only one study. New studies based on statistical models of observed yield responses to current climate trends made an important contribution and provided useful insights on crop yield changes induced by climate change (e.g. Lobell and Field 2007; Lobell and Burke 2010). However, statistical models are data intensive which limits its application. For instance, Lobell and Field (2007) analyze the impact of recent warming on crop yields at the global scale; and Lobell and Burke (2010) and Schlenker and Lobell (2010) project crop yield changes only in Sub-Saharan Africa by 2050. Statistical models are also dependent on data quality.

CO_2 fertilization

Our estimates of the CO_2 fertilization effect on crop yields are based on information presented by Tubiello et al. (2007). They report yield response ratios for C3 and C4 crops to elevated CO_2 concentrations in the three major crop models (CERES, EPIC and AEZ). The yield response ratio of a specific crop is the yield of that crop at elevated CO_2 concentration, compared by the yield at a reference scenario. In our analysis, we use the average crop yield response of the three crop models. The CO_2 concentrations levels in 2020 and 2050 are consistent with the IPCC SRES A1B and A2 scenarios. Thus, for 2020 and under the SRES A1B scenario crop yield is expected to increase by 5.5 and 2.4 % at 418 ppm for C3 and C4 crops, respectively. For the same period, crop yield increases under the SRES A2 scenario are expected to be slightly lower, 5.2 and 2.3 % at 414 ppm for C3 and C4 crops, respectively. CO_2 concentration levels in 2050 are expected to be similar for both SRES scenarios (522 ppm), increasing C3 crop yields by 12.6 % and C4 crop yields by 5.2 %.

Simulation scenarios

Based on the regional changes in river flow (water supply), precipitation and temperature presented in Table 1, we evaluate the impact of climate change on global agriculture according to six scenarios. Each scenario is implemented for the two time periods and emission scenarios presented above. Table 2 presents the main characteristics of the six simulation scenarios. The first three scenarios are directly comparable to previous studies. They show the impacts of changes in precipitation, temperature and CO_2 fertilization on crop yields. These scenarios are implemented in such a way that no distinction is made between rain fed and irrigated agriculture, as was common in previous work. The precipitation-only scenario analyzes changes in precipitation, the precipitation-CO_2 scenario analyzes changes in precipitation and CO_2 fertilization, and the precipitation-temperature-CO_2 scenario analyzes changes in precipitation, temperature and CO_2 fertilization. The last three scenarios distinguish between rain fed and irrigated agriculture—the main feature of the new version of the GTAP-W model. Thus, the water-only scenario considers that climate change may bring new problems to irrigated agriculture related to changes in the availability of water for irrigation. Reductions in river flow diminish water supplies for irrigation increasing the climate risk for irrigated agriculture. In addition, climate change is expected to affect rain fed agriculture by changing the level of soil moisture through changes in precipitation. In this scenario, changes in precipitation modify rain fed crop yields, while changes in water supply modify the irrigation water endowment for irrigated crops. Future climate change would modify regional water endowments and soil moisture, and in response the distribution of harvested land would change. Therefore, the water-land scenario explores possible shifts in the geographical distribution of irrigated agriculture. It assumes that irrigated areas could expand in regions with higher water supply, for simplicity we assume that this land has the same productivity as the currently irrigated land. Similarly, irrigated farming can become unsustainable in regions subject to water shortages. In this scenario, in addition to changes in precipitation and water supply, irrigated areas in GTAP-W are adjusted according to the changes in regional water supply presented in Table 1. That is, the relative change in the supply of irrigated land equals the relative change in water supply. The last scenario, called all-factors, shows the impacts of all climate variables affecting agricultural production. Temperature and CO_2 fertilization affect both rain fed and irrigated crop yields, precipitation affects rain fed crop yields and water supply influences both the irrigation water endowment and the distribution of irrigated crop areas.

Results

Climate change is expected to decrease global agricultural production. The decline is quite modest in the medium term, around 0.5 %, but reaches around 2.3 % in the long term (Table 3, all-factors scenario). However, large regional differences are expected [see supplemental material, Table S7]. We did not find marked differences between the two SRES scenarios. The decline in global agricultural production is slightly more pronounced under the SRES A2 scenario. Expected changes in water supply for rainfed and irrigated agriculture lead to shifts in rainfed and irrigated production. In the 2020s, a moderate precipitation increase reduces the yield gap between rainfed and irrigated crops increasing global rainfed production (Table 3, all-factors scenario). However, in the 2050s, rainfed crop production declines due to heat stress in a warmer climate. Global irrigated production declines in both periods. At the regional level (results not shown), irrigated production declines mainly in the United States, the Middle East, North Africa and South Asia. These are regions with high negative yield responses to changes in temperature and where irrigated production contributes substantially to total crop production. Aggregation hides important sectoral differences. Figure 1 shows the percentage changes in sectoral crop production and world market prices for the all-factors scenario compared to the baseline simulations. Sectoral crop production decreases and market prices increase under both emission scenarios and time periods. With the exception of vegetables, fruits and nuts, larger declines in sectoral production and hence higher food prices are expected under the SRES A2 scenario in the 2020s. Changes in sectoral production and food prices are more pronounced in the 2050s and vary according to the crop type and SRES scenario. Higher market prices are expected for cereal grains, sugar cane/beet and wheat, between 39 % and 43 % depending on the SRES scenario. Production for these crops declines between 3 % and 5 %. Changes in agricultural production and prices induce changes in welfare. For the allfactors scenario, global welfare losses in the 2050s (around 283 and 269 billion USD under the SRES A1B and A2 scenario, respectively) are more than 15 times larger than those expected in the 2020s. Global welfare losses are slightly larger under the SRES A2 scenario in the 2020s and under the SRES A1B scenario in the 2050s (Table 3). The largest loss in global GDP due to climate change is estimated under the SRES A1B scenario at 280 billion USD, equivalent to 0.29 % of global GDP (Table 3). Disaggregating welfare losses according to the contribution of the individual climate variables, Fig. 2 shows changes in global welfare by scenario and individual input variable. Comparing the differences between the scenarios water-land and all-factors or alternatively between precipitation-only and precipitation-temperature-CO2, we can see that adding carbon dioxide fertilization and warming to the mix has a clear negative effect on welfare. Analyzing the individual effects of the input variables on welfare, we find that there is a small positive effect of carbon dioxide fertilization and a large negative effect of warming. However, the negative effect of warming is much smaller if we distinguish between rainfed and irrigated agriculture (by considering changes in river flow) and let irrigated areas adjust to the new situation.

For both time periods, changes in precipitation-only slightly increase world food production under the SRES A1B scenario and decrease under the SRES A2 scenario (Table 3). As expected, the addition of CO2 fertilization in the analysis causes an increase in world food production. However, the CO2 fertilization effect is not strong enough to compensate world food losses caused by higher temperatures (compare precipitation-CO2 and precipitation-temperature-CO2 scenarios, Table 3). For the 2050s and under the precipitationtemperature-CO2 scenario, world food production is expected to decrease by around 2.5 % under both emission scenarios. Our results are thus comparable to Parry et al. (1999), probably because we used roughly the same input data. Other studies foresee an increase in the world food production due to climate change. Comparing the scenarios precipitation-only and water-only, we highlight the advantage of the GTAP-W model that differentiates between rainfed and irrigated agriculture. As the risk of climate change is lower for irrigated agriculture, the initial decrease in global irrigated crop production under the precipitation-only scenario turns into an increase under the wateronly scenario (Table 3). That is, changes in precipitation do not have a direct effect on irrigated crop production but changes in river flow do (water-only scenario). Therefore, irrigated crop production is less vulnerable to changes in water resources due to climate change. While global irrigated production decreases and rainfed production increases under the precipitation-only scenario, an opposite trend is observed under the water-only scenario (except for the SRES A2 scenario in the 2020s). However, changes in total world crop production under both scenarios are similar. This implies that whenever irrigation is possible (water-only scenario) food production relies on irrigated crops. As a result, global water use increases or decreases less and global welfare losses are less pronounced or even positive (Table 3). For the 2050s, global welfare losses are about half those under the precipitationonly scenario. Climate change impacts are expected to be unevenly distributed across world regions, because regional production and welfare are not only influenced by regional climate change, but also by climate-induced changes in competitiveness. The decomposition of welfare changes (Fig. 3) shows that changes in agricultural productivity detriment welfare in most regions. However, as regional impacts are mixed, only the most adversely affected regions suffer a deterioration in its terms of trade and a decline in welfare (mainly the former Soviet Union, South Asia and the Middle East).7 Other regions, such as South America, SubSaharan Africa, Australia and New Zealand, which are less affected by climate change, may experience welfare gains, because their relative competitive position improves with respect to other regions. Therefore, climate change is expected to generate new opportunity cost and modify comparative advantages in food production. Figure 4 shows that welfare losses are associated with a negative change in trade balance (X-M) in agricultural products. The former Soviet Union has the largest decrease in welfare and a negative trade balance in all agricultural products. As soon as regions are able to increase food exports (or decrease food imports) of agricultural commodities, regional welfare becomes positive. Regions like South America, Sub-Saharan Africa and China have welfare gains and a positive trade balance in all agricultural products. These regions are able to grow more food and benefit from international trade.

Discussion and conclusions

In this paper, we use a global computable general equilibrium model including water resources (GTAP-W) to assess climate change impacts on global agriculture. The distinction between rainfed and irrigated agriculture within the production structure of the GTAP-W model allows us to model green (rainfall) and blue (irrigation) water use in agricultural production. While previous studies do not differentiate rainfed and irrigated agriculture, this distinction is crucial, because rainfed and irrigated agriculture face different climate risk levels. Thus, in GTAP-W, changes in future water availability have different effects on rainfed and irrigated crops. While changes in precipitation are directly related to runoff and soil moisture and hence to rainfed production, changes in river flow are directly related to irrigation water availability and hence to irrigated production. We use predicted changes in precipitation, temperature and river flow under the IPCC SRES A1B and A2 scenarios to simulate climate change impacts on global agriculture at two time periods: the 2020s and 2050s. We include in the analysis CO2 fertilization as well. Six scenarios are used to assess the combined and individual effects of the main climate variables affecting agricultural productivity. The results show that when only projected changes in water availability are considered (precipitation-only and water-only scenario), total agricultural production in both time periods is expected to slightly increase under the SRES A1B scenario and decrease under the SRES A2 scenario. As expected, the inclusion of CO_2 fertilization in the analysis causes an increase in world food production and generates welfare gains (precipitation-CO_2 scenario). However, it is not strong enough to offset the negative effects of changes in precipitation and temperature (precipitation-temperature-CO_2 scenario). For the 2050s and under the SRES A1B scenario, global agricultural production is expected to decrease by around 2.64 % and welfare losses reach more than 327 billion USD. Results for the SRES A2 scenario are less pronounced. Distinguishing between rainfed and irrigated agriculture (that is, including changes in rainfall and irrigation water in GTAP-W), we find that irrigated production is less vulnerable to changes in water availability due to climate change. When irrigation is possible, food production relies on irrigated crops, thus welfare losses are less pronounced. For the 2050s, lobal welfare losses account for less than half of the initially drop (compare precipitationonly and water-only scenario). A joint analysis of the main climate variables affecting agricultural production (precipitation, temperature, river flow and CO_2 fertilization) shows that global food production declines by around 0.5 % in the 2020s and by around 2.3 in the 2050s. We did not find marked differences between SRES scenarios. Despite the increase in irrigated crop areas promoted by a higher irrigation water supply, global irrigated production declines between 3 % and 6 %, depending on the SRES scenario and time period. Irrigated crop production declines mainly in regions with high negative yield responses to changes in temperature as well as regions where irrigated production contributes substantially to total crop production (the United States, the Middle East, North Africa and South Africa). Declines in food production rise food prices. Higher market prices are expected for all crops, mainly for cereal grains, sugar cane/beet and wheat (between 39 % and 43 % depending on the SRES scenario). Changes in agricultural production and prices induce changes in welfare and GDP. Global welfare losses in the 2050s are expected to account for more than 265 billion USD, around 0.28 % of global GDP (all-factors scenario). Regional production and welfare are not only influenced by regional climate change, but also by climate-induced changes in competitiveness. Only the most adversely affected regions experience a deterioration in their terms of trade and a decline in welfare. Other regions, which are less affected by climate change, may experience welfare gains, because their relative competitive position improves. Regions which are able to grow more food and benefit from international trade face welfare gains. Climate change is expected to generate new opportunity cost and modify comparative advantages in food production. Several limitations apply to the above results. First, in our analysis changes in precipitation, temperature and river flow are based on regional averages. We do not take into account differences between river basins within the same region. These local effects are averaged out. Second, we use annual average precipitation, temperature and river flow data, therefore we do not consider changes in the seasonality nor extreme events. Third, we have made no attempt to address uncertainty in our scenarios, other than by the use of two emission scenarios from only one climate model, which could generate biased estimates. Forth, in our analysis we do not consider any cost or investment associated to the expansion of irrigated areas. Therefore, our results might overestimate the benefits of some scenarios. Fifth, our model uses Armington assumptions to model substitution between domestic and imported inputs; therefore, regional trade flows are conditional to the calibrated shares and elasticities. These issues should be addressed in future research.

PART 2

Australia produces 362,850 t per annum of pig, representing 0.5% of global production.[1] However, Australia has relatively higher costs of production than Canada, USA or Brazil, the major world suppliers of pork.[1] In order to make the pig industry in Australia financially attractive, some value adding is necessary. This study explores the possibilities of value adding through carbon credits in the pig industry. This research is timely, as the Australian government is implementing a domestic emissions trading scheme by 2012.[2] The pig industry plays a vital role in sustaining Australian rural economies and supplying valuable employment; however, piggeries are renowned for generating a host of environmental issues. For instance, pigs return more than half of the feed they consumed as waste: ∼15,000 pigs (800 t) produce 275,000 L of sewage effluent per day, equivalent to the sewage output of a town with a population of 50,000 people.[3] The disposal of effluent from intensive piggeries can generate water pollution (both surface and ground), eutrophication and phosphate leaching.[4] They can also spread putrid odors, fly infestation, and diseases in the adjoining neighborhoods.[5]In addition, current piggery waste treatment methods (anaerobic lagoon and direct land application) in Australia leads to the production of biogas consisting of methane, which has 21 times more global warming potential than carbon dioxide.[6] If this methane could be captured this could be used for electricity generation (replacing other fuels), that would reduce GHG emissions and would help reduce odor, pest, disease and water contamination problems. Furthermore, due to intensive cultivation systems, cropping lands are highly degraded across the world. To help improve the productivity of cropped areas, fertilizers are increasingly used, as they are considered as an integral part of intensive cultivation.[7,8] Compared to the 1950s, the global use of fertilizers in 1999 was about 23 times in the case of nitrogen (N), almost eight times for phosphorus (P) and more than four times for potassium (K).[7] In Australia, between 1987 and 2000, nitrogen fertilizer use increased by 325%.[8] The production, packing, transportation and application of these fertilizers need a huge investment of energy which leads to GHG emissions.[9] If it is possible to collect wastes after biogas production and replace the energy intensive can generate water pollution (both surface and ground), eutrophication and phosphate leaching.[4] They can also spread putrid odors, fly infestation, and diseases in the adjoining neighborhoods.[5]In addition, current piggery waste treatment methods (anaerobic lagoon and direct land application) in Australia leads to the production of biogas consisting of methane, which has 21 times more global warming potential than carbon dioxide.[6] If this methane could be captured this could be used for electricity generation (replacing other fuels), that would reduce GHG emissions and would help reduce odor, pest, disease and water contamination problems. 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Capturing methane and producing electricity from methane is highly desirable with regard to three GHG reduction public policies: (i) the Australian Government's Mandatory Renewable Energy Target Scheme requires electricity retailers and other large electricity buyers to source an additional 9.5 TWh of their electricity per year from renewable or specified waste-product energy resources by 2010; (ii) the New South Wales Greenhouse Gas Abatement Scheme needs electricity retailers and large users to meet their mandatory targets of emissions reduction; and (iii) the Queensland Government's new 13% Gas Scheme requires electricity retailers and other liable parties to source at least 13% of their electricity from gas-fired generation.[10,11] Therefore, the aims of this study are to estimate: (i) methane emissions from currently used barn flushing wastewater treatment systems; (ii) GHG emissions by generating electricity from biogas (replacement of other fuel sources); and (iii) GHG emissions by replacing inorganic fertilizers with biogas sludge and mineralized water.

Methodology

There are currently piggery projects in Thailand and India that capture methane from animal wastes and used for electricity generation.[12] However, in Australia only one such initiative, the Barrybank Piggery Farm (in Victoria), has been reported.[3,10,13,14] Therefore, in this study data from Barrybank Farm were used to estimate GHG benefits. Berrybank Farm has 15,000 pigs (approximately 53.33kg /pig), which produce 275,000 litres of sewage effluent on average per day. Given the size of the waste stream, Berrybank Farm developed a sophisticated waste management system in November 1989 involving a two-stage anaerobic digestion system. In this system, the pig effluent is transformed into odorless fertilizer and methane gas, which is captured and used for electricity generation. Each day the farm recovers: (i) approximately seven tons of waste solids, used as fertilizer; (ii) 100,000 litres of recyclable water; (iii) 100,000 litres of mineralized water, used as fertilizer; and (iv) 180 KWh of electricity for 16 hours per day. The capital cost of the Berrybank Farm project was approximately $2 million with an estimated payback period of six years. The annual estimated saving for Berrybank Farm is $425,000 which includes $125,000 in electricity, $50,000 in water saving and $250,000 in fertilizer sale.[3,10,13,14] However, the Berrybank Farm has not considered the greenhouse benefits of the project. Barrrybank Farm is estimated to have GHGs benefits at three levels: (1) capturing and avoiding of methane emissions; (2) reducing of GHG emissions by generating electricity from captured methane (replacement of other fuel sources); and (3) reduction of GHG emissions by replacing inorganic fertilizer with biogas sludge and mineralized water.

Results

Avoidance of methane emissions

In Australia, there are two dominant piggery waste treatment methods: anaerobic lagoon system and direct land application method. In the anaerobic lagoon system, wastewater is released into settling ponds which allows water to be separated from the entrained solids. Solids are then collected and used as fertilizers, however there is little demand for undigested solid pig waste. The direct land application method involves wastewater being directly released onto paddocks.[6] The anaerobic lagoon system releases 6.074 $kgCO_2e$ yr^{-1} of methane per kg of meat while the direct land application method releases 7.304 $kgCO_2e$ yr^{-1}. [6] Regardless of the approach used at Berrybank, we considered both waste treatment methods to help develop a range of scenarios to guide future piggery project developers. For the size and number of pigs at Berrybank, calculations revealed that, about 4,859 tCO_2e $yr^{-1}$of methane could be avoided as emissions, if the biogas plant replaces the anaerobic lagoon system, and about 5,840 tCO_2e yr^{-1} for direct land application. Thus, by capturing and using the resultant methane for electricity production, a biogas plant would avoid about 4,859 to 5,840 tCO_2e yr^{-1} methane from being emitted into the atmosphere. Considering the average weight of pigs, climatic condition and waste treatment system, there figures are comparable with Ratchaburi Farms Biogas Project in Thailand.[12]

Estimation of carbon dioxide equivalent (CO_2e) emissions reduction through biogas-powered electricity generation

In Australia, a range of fuels are used for electricity generation each with differing carbon emissions factors (CEF). For example, hydropower and renewable energy do not generate GHG: therefore, their CEF is zero whereas coal's CEF is 0.895 tCO_2/MWh (Table 1). Since we assume that the biogas-powered electricity will be sold to the Australian government, and connected in some form of national grid system, we need average weighted CEF for all fuels. The share of electricity generation in Australia (in 2003) from various sources (fuels mix) was taken from International Energy Agency and their respective CEF were taken from the intergovermental panel on climate change IPCC.[15,16] The average weighted CEF for the Australian electricity sector was found to be 0.761 tCO_2 per megawatt hour (MWh) of energy. To estimate CO_2e emissions reduction from biogas powered electricity generation (tCO_2e yr^{-1}). The Berrybank Farm has been generating 180 KWh electricity for 16 hours a day,[3,13] with the total amount of electricity generated per day of 2.88 MWh ($MWE_{generated}$ = 2.88 MWh). Thus CO_2 avoidance through biogas-powered electricity generation (tCO_2e yr^{-1}) at Berrybank Farm is 800 tCO_2e yr^{-1}.

Reduction of GHG emissions by replacing inorganic fertilizer by biogas solid sludge and mineralized water

Kim and Dale[17] estimated a global warming impact (GWI) value for most fertilizers (Table 2). The GWI value included all three greenhouse gases (CO_2, CH_4 and N_2O) and their impact on emissions to their production, packing, transportation and application. In this study, we used these values to estimate GHG emissions by fertilizers. In the case of mixed fertilizer such as N and P, an average value was used. However, we considered the replacement of chemical fertilizers by biogas wastes, and the transportation and application of biogas wastes which also consume energy.∗ Therefore, the GWI value which also considers energy used for transportation and application of fertilizers needs to be adjusted. The transportation and application of N, P and K fertilizers require 10%, 40% and 40% of the total energy, respectively, with the reminder used in production and packaging.[18] In light of these additional considerations, the GWI value was recalculated for production and packing of fertilizers alone (Table 2). Calculations revealed that the production and packing of one kg of N, P, K and mixed (N & P) fertilizers emit 2943, 804, 385 and 1729 gmCO_2e of GHGs, respectively. Nitrogen fertilizer is usually produced from ammonia. The production of ammonia through Haber process, the most renowned method, requires significant amounts of energy.[18] Therefore, compared to other fertilizers, N fertilizer has higher GWI value. In order to determine the amount of GHG benefits by replacing chemical fertilizers with biogas wastes (solid sludge and mineralized water), it is crucial to know two things: (i) what are the commonly used fertilizers in Australia; and (ii) the percentage of different nutrients in chemical fertilizers and biogas wastes. In Australia, urea, di-ammonium phosphate (DAP) and muriate of potash (MOP, potassium hloride) are commonly used fertilizers for nitrogen, phosphorus and potassium.[19] Among them, urea contains 46% nitrogen, MOP contains 49.5% K, and the DAP contains 18% N and 20% P (Table 3). At Berrybank Farm, on average, the solid sludge contains 3.1% N, 3.5% P and 1% K (Table 4).[4] Likewise, the mineralized water contains 0.24%, 0.12% and 0.12% of N, P and K.[4] We assumed that the biogas sludge replaced DAP and MOP, as the sludge contains both N and P in approximately the same proportion, and the DAP also contains both N & P in similar proportion (18% N and 20% P). But in the case of mineralized water, the N percent is much higher than that of P. Therefore, we analyzed both scenarios: replacement of urea and MOP; and DAP and MOP. From the percentages of N, P, and K in the sludge, we found that 7 t of sludge can produce 217 kg of N, 245 kg of P and 70 kg of K (Table 4). Therefore, 7 t of sludge can work as 1206 kg of DAP for N and 1225 kg of DAP for P. However, we erred on the side at conservative estimates, so the lowest value was considered. This means we assumed that the solid sludge replaces 1206 kg of DAP for N. Similarly, from the percentages of N, P, and K in mineralized water, it is found that the 100,000 L∗ of mineralized water can give 240 kg of N, 120 kg of P and 120 kg of K. Hence, 100,000 L of mineralised water can work as a 1333 kg of DAP for N and 600 kg of DAP for P, but as before, lower conservatives were considered. Thus, mineralized water replaces 600 kg of DAP for P. This is more realistic if the sludge and mineralized water need to be transported long distances, as more energy is consumed and thus more GHG emissions will be released. It is estimated that the replacement of 1206 kg of DAP for nitrogen fertilizer with biogas sludge can save 2084 kgCO2e of GHG emissions per day, whilst the added replacement of 141 kg of MOP can save another 54 kgCO2of GHGs per day (Table 4). Therefore, replacement of DAP and MOP with biogas sludge can reduce 780 tCO2e yr−1of GHG emissions. Likewise, if we replace inorganic fertilizers by mineralized water, ∼413 tCO2e yr−1 (if we replace DAP and MOP) to 595 tCO2e yr−1 (if we replace urea and MOP) of GHG emissions can be reduced (Table 4). Therefore, 1193 t to 1375 tCO2e of GHGs can be reduced annually by using sludge and mineralized water during biogas generation.

Estimation of total greenhouse gas benefit

By capturing methane piggery effluent, utilizing that methane for replacing conventional fuels used in electricity generation, and using wastes for replacing inorganic fertilizers could have significant GHG benefits (Table 5). Capturing and combusting methane could save 4859 tCO2e yr−1 (by replacing the anaerobic lagoon system) to 5840 tCO2e yr−1 (by replacing the direct application system) in GHG emissions. Similarly, using the methane for replacing fuels for electricity generation could save another 800 tCO2e yr−1. Likewise, using the biogas wastes to replace inorganic fertilizers could save 1193 tCO2e yr−1 (if it replaces DAP and MOP) to 1375 tCO2e yr−1 (if it replaces urea and MOP).

In total, a well-managed piggery farm with 15,000 pigs could save 6,852 to 8,015 tCO2e yr−1 (Table 5). This is equivalent to the carbon sequestered from 6,800 to 8,000 spotted gum trees (of 35 years age) in their above-ground and belowground biomass.[20] If the size of the pig farm operation is larger (>15,000 pigs), the GHG benefit could be higher due to enhanced economies of scale of production. The biogas waste not only adds N, P and K but also adds zinc, sulphur, and organic matter which are very important for better soil structure and cation exchange capacity.[21] Similarly, the biogas waste also helps to increase soil pH thereby reducing the use of lime and GHG emissions associated with production, packing, transportation and application of lime. Likewise, bio-fertilizers produce growth-promoting substances such as hormones, vitamins, amino-acids and anti-fungal chemicals, thereby accelerating the plants' establishment. In addition, this project helps to: (i) reduce the odor and fly nuisance problem; (ii) eliminate some pests, and reduce mosquitos breeding areas and thereby improve working and living conditions; (iii) encourage farmers and other potential project developers to value add; (iv) reduce potential surface and ground water pollution problems; (v) recycle water and thereby reduce water usage; (vi) promote technological excellence and innovation in the country; and (vii) encourage integrated farming system (grains for pigs, electricity to make warm pigs and wastes for increased grain production.[3,10,12] Apart from the GHG saving, the added benefits listed above provide considerable support for similar initiatives elsewhere.

Conclusion

The analysis undertaken in this study suggests that capturing methane from piggery effluent, using the methane for replacing fuels for electricity generation, and using wastes for replacing inorganic fertilizers could have significant GHG plus economic benefits. Implementation of similar projects in suitable areas in Australia could have both environmental and financial benefits.

PART 3

How Climate Change Might Save the World

We are faced with questions too big to fail and too big to answer. Most discussions on climate change are blocked; they are caught by catastrophism circulating in the horizon of the problem: what is climate change bad for? From a sociological point of view, because climate change is a threat to humanity, we can and should turn the question upside down and ask: what is climate change good for? The amazing thing is that if you firmly believe climate change is a fundamental threat to all of humanity, then that belief might bring a transformative, cosmopolitan turn in our contemporary life and the world might be changed for the better. This is what I call 'emancipatory catastrophism'. The question then is: how might climate change save the world?

First thesis: Climate change is the embodiment of the mistakes of a whole epoch of industrial capitalism, and climate risks pursue their acknowledgement and correction with all the violence of the possibility of annihilation. Global risks are a kind of collective return of the repressed, wherein the self-assurance of the industrial capitalism, organized in form of nation-state politics, is confronted with the source of its own errors as an objectified threat to its own existence. Thus the global risk of climate change is a kind of compulsive, collective memory of the fact that past decisions and mistakes are contained in what we find ourselves exposed to; and that even the highest degree of institutional reification is nothing but a reification that can be revoked – a borrowed mode of action which can, and must, be changed if it leads to self-jeopardization. Put differently, the sociological significance of climate change lies in the momentum it generates in the re-emergence of the historicity of society and politics on a global scale, thereby allowing us to imagine new beginnings. Therefore, climate change risk can, as we shall see, be made into cosmopolitan communities of shared risks or even into an antidote to war; it induces the necessity to overcome neo-liberalism and to perceive and to practice new forms of transnational responsibility. It empowers the poor countries of the world and gives them a public voice; it puts the problem of cosmopolitan justice on the agenda of international politics; it creates informal and formal cooperation patterns between countries and governments who otherwise ignore each other or even see themselves as enemies. It makes economic and public actors accountable and makes responsible those who do not want to be accountable and responsible, and this happens even when they have the law on their side. It opens up new world markets, new innovation patterns; it changes lifestyles and consumption patterns. Last but not least, it induces new understandings of and caring for nature. All of this happens under the surface of the mantra of disappointments and disillusionments at the Wanderzirkus (traveling circus) of one climate conference after the other. From this perspective, climate change means first of all the end of the end of politics with highly ambivalent implications: global risk imposes a historical necessity for a cosmopolitan turn in politics but at the same time – and exactly because of this – it empowers anti-cosmopolitan movements. In the present moment, however, this re-emergence of politics remains clouded by the dominance of apocalyptic imaginaries in public discourse. It is limited by the inability of sociological thinking to analyse the transformation of the political and imagine new openings. To combat the sources of climate pessimism, we need a new cosmopolitan outlook, in research and politics, capable of grasping the epochal transformations of economy, culture, society and politics set in motion by the global risk of climate change.

Second thesis: Sociologically and politically, the key is to distinguish risk from catastrophe. Risk is not catastrophe, but rather, the anticipation of future catastrophe in the present, as a horizon of the present future. The obsession with risk is to avoid catastrophe; the logic of global risk is one of self-destroying prophesies.

As previous arguments have stated (Beck et al. 2013: 6), global risks are highly ambivalent, since the threat of ending also creates opportunities of new beginnings. Risk arrives as a threat, but it brings hope. Political action and community building in the age of cosmopolitization is made possible by the perceived globality of climatic threats, which melts the cast-iron system of national and international politics and makes it open to change. Global risks create transnational public concerns, public awareness, and situations that demand immediate public action – in other words, a geopolitics of global publics (Volkmer 2012). The question we have to pose for the social sciences is the following: what happens if we put the transformative power of climate change into the focus of theory and research?

Third thesis: The second modernity of world risk society breaks with the models of the reproduction of social and political order, setting in motion a whole range of new cosmopolitan dynamics, trajectories and regimes of transformation. What progressive intellectuals could not foresee is that the revolution they were looking for has already happened, albeit not in the transformation of the means of production, but rather in the movements of the carbon circle. In a time when people on both the left and the right lament the lack of revolutionary spirit, it is left to the history of nature's cunningness to make clear that the revolution is occurring. This is an unseen and unwanted revolution – a global revolution of the side-effects of side-effects. Talk of the 'anthropocene' signals that geologists have now caught up with the reality of world risk society (Beck 2009; Latour 2013). The reinvention of politics and the return of 'societal history' (Gesellschaftsgechichte) is not happening intentionally. It is not driven by utopias, or even by political struggles. Instead, it emerges from the laboratories of future-making in economy, science, technology and law, as a modality of not-knowing and not-identifying the causes and consequences. As shown so clearly in the case of the anthropogenic release of carbon, the reflexivity of second modernity arises from the fact that society now finds itself confronted with the unwanted and unintended side-effects of its own modernizing urge. To paraphrase John Dewey from The Public and Its Problems (1954), a world risk society is one in which the unintended and accumulated consequences of myriad habitual actions have rendered existing social and political institutional frameworks obsolete, producing a heightened awareness that narratives of mastery and control are impossible fictions. The geological faults laid bare by the global risks in world politics have served to frustrate routine expectations and to doom the trusted instruments of theory and politics to failure. This applies not least to sociologists, whose theories and empirical studies tend to inquire into the reproduction of the social and political order instead of its transformation. The relevant authors go on to inquire with reference to the present and the future about how society continues to reproduce itself, whether in the class system (Pierre Bourdieu), the system of power (Michel Foucault), the bureaucracy (Max

Weber) or the autopoietic system (Niklas Luhmann). However, if we look at the decisive events and trends of recent decades – I have in mind the Chernobyl disaster, the collapse of the Soviet Union, the terrorist attacks of 9/11 on the World Trade Center, climate change, the credit crunch, and the crisis of the euro – we find they have two features in common. First, before they actually happened they were inconceivable; and, second, they are global both in themselves and in their consequences. They are literally world events and they enable us to perceive the increasingly dense network of interconnections between people's lives and actions and to realize that these interconnections can no longer be comprehended with the tools and categories appropriate to the nation-state. These events were not just inconceivable in practical terms within the paradigm of the nation-state and its reproduction; they fall completely outside the national framework and thus render it open to question. At the dawn of first modernity, the classics of sociology developed a style of analysis which was simultaneously diagnosing 'social transformation' – based on the arch-distinction between tradition and modernity – and, paradoxically, forgetting the historicity of modernity itself. History was caged into the framework of national history and the unforeseeability of the future was tamed via narratives of rationalization and progress. The presentism of classical sociology led to the creation of a temporally 'blind' concept of modernization, in which history is always fundamentally the same. Underneath the diagnostics of innovation and social change, the secular religion of the nation dominates and constraints all social and political thinking. This is the in-built contradiction of classical sociology, from Hobbes and onwards: even as history implies an expectation of the unexpected and of the eruption of the 'very other', this kind of expectation is domesticated into the reproduction of the past – or else grasped as a threat of chaos and disorder (cf. Beck and Levy 2013). Grasping these transformations, however, requires a fundamental break with the dominant metaphysics of social reproduction, which always shows the circular re-emergence of the same basic patterns and dualisms of modernity. Such a break, however, which acknowledges the re-emergence of historicity, represents an epistemological and political threat in that it challenges the established scientific disciplines and their various monopolies on expert authority. This is visible, for instance, in the way presumptions of the reproduction of socio-political order is built into dominant constructions of globality, including in macroeconomic forecasts and techno-scientific constructions of the global climate (cf. Guyer 2007; Szerszynski 2010). Framed by the metaphysics of reproduction, such globalities may be learned, exported, and used as a common model for integrating and domesticating politics. Since the future is conceptualized as part of the experience of the past, there is no basic disconnect but rather only a matter of linear extensions. It is a model close to timeless eternity: present society dominates and colonizes the future, thus rendering it controllable. To sociology, breaking with the reproduction of social order and working towards a social theory of cosmopolitan transformation implies its own set of epistemological and methodological difficulties. In first modernity, there exists an elective affinity between orthodox appeals to the reproduction of social structures and the practice and authority of empirical sociology: the metaphysics of reproduction allows for the establishment of social laws and regularities, enabling sociologists to make prognoses, do comparative studies, and so on. In second modernity, the situation of sociologists is akin to what Tocqueville said of the 'human spirit': if modernity breaks with continuity, since the past stops to throw its light on the future, the human spirit (i.e., the sociologist) is lost in darkness! When taking historicity seriously, then, sociologists find themselves in a difficult situation, since they can no longer use the past or the present to talk about the future; from now on, they have to concentrate on the future itself, without the security belt of the past. Cosmopolitan sociology, in short, must reorient itself towards an unknown and unknowable future, made present in the temporal horizons of global risk. With global risks, old monopolies on reality definitions are being dissolved, and expert definitions of reality relying on the metaphysics of reproduction become irrational. The apocalyptic climate change is, maybe, the best documented fact we ever had. We never knew more about the present global warming, but knowing seems not to stimulate action but rather the opposite: to deny the facts.

Fourth thesis: The main source of climate pessimism, which underlies the present dominance of apocalyptic imaginaries, lies in a generalized incapacity to rethink fundamental questions of social and political order – specifically, the understanding of 'the political' including the dualism between national and international politics. The secondary side-effect of climate change has transformed the logic of 'either-or' (national politics) into a 'both-and' of 'global domestic politics' (Beck 2012). In this sense, there is a certain affinity between the theory of risk society and Ernst Bloch's principal of hope – because global risk implies the message that it is high time for us to act! That is the paradox of encouragement we derive from global risks.

Many environmentalists and climate scientists believe that because of the looming catastrophe, science has to dominate politics; some even argue (behind closed doors) that in order to save the world, politics needs a technocratic turn against democracy. But there is also an important ignorance concerning environmental issues which is shared not intentionally but unintentionally just by referring to the concept of 'environmentalism'. Speaking of 'the environment' implies separating the world of politics from the world of nature and its destruction. If 'the environment' only includes everything which is not human and not social – that is, only 'nature' – then the concept is sociologically and politically empty. If the category of 'the environment' includes human action and society, then it is scientifically mistaken and politically suicidal. The concept of 'catastrophic environmentalism' is emptying ecology of its politics, as Bruno Latour has shown in Politics of Nature (2004). If climate scientists and ecologists ever had the clout necessary to meet the threats they were so good at revealing, it is because they hoped to bypass politics for good. John Urry criticizes excess capitalism. Here again we have the same deadlock: capitalism is seen as a major force of the reproduction of order. It is conceptualized as 'excessive' in a (somehow) linear way, but the question of 'transformation of capitalism by the production of excessive global risks' is not being asked with the same intellectual energy and imagination. Anthony Giddens rethinks the politics of climate change implicitly affirming and reproducing of the international relations. In principle, climate change can be related to this image of national and international politics in two ways: firstly, politics of climate change can be seen and analyzed as subordinate to the reproduction of the Westphalian order; secondly, climate change can be seen as a major force transforming it – redefining, remaking – state and interstate politics. If a theorist chooses the first framing of the problematic, like Anthony Giddens does, then his diagnosis is locked in the system of national and international politics. He doesn't take into consideration the increasing dysfunctionality of nation-state politics in itself and of all kinds of organizations and institutions on the international and the national level which are facing the existential risks. Under the stress of time he raises the question of what state politics can do for climate politics. He analytically excludes the global observation that there is an emancipation against state politics on its way which might continue until the 'political' itself has been reshaped. In his book The Nomos of the Earth, first published in 1950 and written in Berlin during the Second World War, Carl Schmitt seems to have touched early on the nerve in the relationship between geopolitics and climate change and the transformation of the world order. The concept of Nomos by Schmitt means the concrete spatial order of a community. It is a 'law of nature' which exists prior to any particular positive laws. 'Der Nomos der Erde' is thus roughly equivalent to 'world order' or 'the Law of the Earth' and thus defines a problem space in which notions of world order, climate change, and international politics intersect. Schmitt is above all a territorial thinker. But he is more than that; he is a thinker believing in the anthropological necessity of an earthbound character of humanity. Nomos, as he puts it, is a 'fence word' (Schmitt 2003: 75): it creates territory, defines locality, marks places, separates backyards, and defines households. Nomos therefore is the counter concept of ‘globalization’ and ‘cosmopolitization’, forces which strip human kind of its ties to the earth and orientation on it. Schmitt’s Nomos reminds us that we find ourselves totally unprepared to deal with the material conditions of our atmospheric existence. He looks at the transformation of Nomos, but at the same time makes it very clear: there is no transformation of politics. “A world in which the possibility of war is utterly limited, a completely pacified globe, would be a world without the distinction of a friend and enemy and hands a world without politics.” (Latour 2013: 35) One of the main objections which come to mind is that Schmitt liked what he saw. He raised the friend-foe-dualism; he distilled from the perverse, war-driven politics of 20th century Europe to the rank of eternal law of all and any politics. In and for this world of uncertainties Schmitt has the vision and mission of a transcendental truth: the unconditional, unchanging, irreversible concept of ‘the political’ – the inner-connection between war and politics. As Bruno Latour (2013) puts it: “Schmitt’s choice is terribly clear: either you agree to tell foes from friends, and then you engage in politics, sharply defining the borderlines of real enough wars – ‘wars about what the world is made of’ –; or you shy away from waging wars and having enemies, but then you do away with politics, which means that you are giving yourself over to the protection of an all-encompassing State of Nature.” Surprisingly, Latour agrees. “It will be Germany May 1945: unconditional surrender. It’s a stark choice, I agree: either nature extinguishes politics, or politics resuscitates nature – that is, finally agrees to face Gaia… How I wish I could entertain you with smoothing words about the splendor of natural parks, the beauty of God’s Creation or the stunning new discoveries of the earth system sciences! But the dark job of politics has to be done first. For this we have to define (a): What is the threat, (b) who are the enemies and (c) which sort of geo-politics we will end up with?” (Latour 2013: 106)

Fifth thesis: Realistically, it might be impossible to achieve a positive consensus in world risk society, but it is most likely to achieve a negative consensus on what, under all conditions, has to be avoided: the global catastrophe. From this arrives the cosmopolitan imperative: cooperate and share or do not cooperate and die. Here we have reached a radical and surprising outlook: that creating cosmopolitan communities of shared risk does not depend first of all on existing structures or (national or international) institutions, or even on democracy. Rather it depends on what has been neglected in the debates on climate change and what sociologists ‘once upon a time’ named ‘society’; or to say it in other words: a new social basis or contract for an agreement and simultaneous action across borders against a backdrop of anticipated catastrophes. In this context, the common interest to cooperate starts to become part of each competitor’s national self-interest. The new cosmopolitan politics of climate change is about bridging the friend-foes split of national politics. A common interest in survival beyond borders can be constructed. Therefore in world risk society, paradoxically, cooperation between foes is not about self-sacrifice, but rather, about self-interest. To put it another way, we could say that the more intense, visible, and threatening the anticipation of the emerging catastrophe to humanity becomes at one level, the greater the drive towards bridging differences and creating cosmopolitan risk communities (between world cities) – facing all kinds of resistances, frictions, contradictions and dilemmas. Having seen that creating trans-border risk communities fundamentally depends neither on democracy nor on existing institutional structures but actually on a new kind of cosmopolitan common sense – enabling an agreement to act simultaneously – we arrive at yet another surprising conclusion: that the issue of whether each nation’s (or city’s) decision to cooperate in such an agreement is made democratically or in some other way is entirely secondary. The primary issue is simply the fact that all nations (or cities) have agreed to cooperate – the fact they see cooperation as in their self-interest. Only then are cosmopolitan risk communities between democratic and non-democratic nations/cities possible.

From this we could imagine that while democratic nations may decide to participate in binding transnational and trans-local law (Blank 2006) or cosmopolitan regimes as a result of their authoritarian internal democratic processes, non-democratic nations may do so by the simple decision of their own government. So far, we have asked what the basic conditions for the rise of cosmopolitan politics are. However, we have to ask the opposite question as well. What are the basic obstacles for a cosmopolitan turn in politics?

Sixth thesis: The reproduction of the national order depends simply on this principle – elections are organized nationally; democratic legitimated politics is, so far, monopolized by the nation-state. We have to distinguish clearly between legitimation and the (in) effectiveness of politics. Because the monopoly of legitimation by the nationstate still exists and is being reproduced, even nation-centric politics becomes dysfunctional. There is no answer to global problems, but there is no voting for cosmopolitan politics so far. In the European crises it can be observed that taking the next step to a cosmopolitan Europe might bring about accusations of breaking the constitutional law. Thus, it is the national law system as well reproducing the national order of politics. However, it is not only national law and national politics but international competition as well that obscure the cosmopolitan turn in politics. In other words, it is not that politicians don't understand the urgency to revive politics transnationally. It is perhaps not a question of better knowledge or of 'cosmopolitan enlightenment', but rather, it is that they fear that the turn to cosmopolitan politics will harm the economic competitiveness of their national industries in the global market. The problem, then, lies not so much with the individual politicians or government, but with the competitive relationship between nation-states. It lies with the fact that no government can rely on all other governments to implement the same regulations. Indeed, each can fairly confidently rely on others not doing so because all of them seem to have no choice but to keep their economies internationally competitive. The reproduction of the national order of politics and society does rest on this fear all nations have of losing out. Therefore, there is a hidden coalition between neo-liberalism and nationalism – against the cosmopolitan turn. The international competition between nation-states empowers mobile capital. The more individual states are replaceable and interchangeable with one another, the more the power of capital grows. Also, we should not underestimate that cosmopolitization is seen as an aggression which threatens the national order in the eyes of nationalists. Many people experience cosmopolitization through global risks as an outside attack to national sovereignty and identity. Because cosmopolitization overrules even 'anthropological certainties', the reaffirmation of those certainties becomes the main resource for anti-cosmopolitan movements both inside and outside of the party systems. For example, in Europe, there has been a revolutionary movement, but this movement is not in favor of (more) Europe but rather of less Europe, and it is anti-European in its motives and mission. Last but not least, cosmopolitization can lead to two opposite forms of cooperation and integration: either participation in terms of equality (reciprocity) or hierarchical dependence: hegemony. As Europeans, South Americans, etc. have experienced in the NSA scandal, on one hand, the superpower USA defines its national security interests globally, ignoring the security interests of their partners and friends, while on the other, asking them for help and cooperation to do so. Between more or less powerful nations there is a great temptation to exploit the need to cooperate with other nations for hegemonic purposes.

Seventh thesis: Cosmopolitization is irreversible and normative while political cosmopolitanism is not. Cosmopolitization, i.e. the fact that in a world of global risk and existential interconnectedness 'the other' cannot be excluded any longer, does provoke contradictory reactions: anti-cosmopolitan mentality, identities, movements, and cosmopolitan consciousness and necessities for cosmopolitan visions and agendas at the same time.

There is a false separation between cosmopolitan politics and the politics of conflict (Martell 2009). I argue that we are at a moment where nations have a choice between:

(a) a cosmopolitan regime which adapts to another cosmopolitanmodernity so that new threats can be countered

(b) a return to Hobbesian war of all against all in which military might replace global law. (Beck 2006: 125)

Those alternatives – that is the point! – do not exclude each other. In fact, in order to solve global problems in a cosmopolitan way, (a) is a necessary condition, but also recognition that this will be structured by (b) and conflict between groups such as states over the solution, in which actors would be best off assessing were to take sides in the conflict rather than hoping for consensus. The first (a) needs to be pursued, but within a context that understands that it will be a matter of conflict and struggle between competing interests rather than one of 'cosmopolitan consensus'. We have to look at the conflictual basis that makes cosmopolitan politics problematic. The goodness of the good is not enough to make the case for cosmopolitanism. It must also be realistic, and an optimist of the cosmopolitan outlook can also be a pessimist of the cosmopolitan mission. Analyzing the problems of real cosmopolitanism involves looking at its ambivalents, ambiguities and ideological misuses. We have to raise the issue of how normative visions in the past have been linked to 'imperialism, colonialism, two World Wars, the Holocaust, the Stalinist Gulag'. My hope is that the normative cosmopolitan vision will not be 'torn apart' by its own 'contradictions and adversaries'. Thus 'for social science and politics, hope is too little' (Beck 2000: 95). There is a pragmatic approach to cosmopolitan politics (Martell 2009), an understanding of the conflicts involved over, say, environmental issues; judgments on what sides certain economic interests, political objectives and outcomes lie; calculations about possibilities for alliances or multilateral (rather than global) agreements along such lines; and politics around such a view of conflict and alliances. This is an international politics – a means in pursuit of cosmopolitan and humanitarian objectives. But it is based on conflict and alliances where they can be sought out and built, rather than on a hope for global common consciousness in a world divided by divergent economic interests and ideologies. The main misunderstanding arises from my statement: The cosmopolitan condition is irreversible: 'the falling of leaves in autumn can't be prevented by looking the other way, and certainly not by insisting that you hate winter… Even the most radical anti-cosmopolitanism can re-erect the old boundaries only in theory, not in reality.' (Beck 2006: 117) This is what Luke Martell and others (Yishai Blank, etc.) find most controversial. At the same time, of course, you can watch the cosmopolitan momentum of climate change in the dynamics of national-international politics, but obviously there is a national backtack. In the face of the most perilous challenges of our time the nations of the world are paralyzed. Are the problems too big, too interdependent, too diverse for the nation-state? Or is it the national orthodoxy which renders the cosmopolitan turn in the case of climate politics ineffective? Are there any other potent actors to be considered as pioneers of cosmopolitan politics? Yes, and these are: global cities.

Eighth thesis: We have to distinguish between nations and (world) cities in the age of cosmopolitization. Nations dominantly re-nationalize and cities dominantly become cosmopolitan actors in structures and identities. If this can be proven to be the case, then the emancipatory potential of climate change is present and observable in different (world) cities differently; but it is less present and observable in different nation-states differently. This, indeed, could be one of the, or the indeed the most important, major clue of our research project and findings – and of methodological cosmopolitanism: making visible world cities as cosmopolitan actors and architects imagining new openings in and for a world at risk. The cosmopolitan vision has its location in the city. Stadtluft macht frei ('urban air makes you free'). The air of the city is the air of freedom, but the air of the city can make one sick as well. In global cities the visibility of climate catastrophe collides and explodes with the longing for democratic participation and political freedom. Large cosmopolitanized cities share far more with other cities across the world in terms of challenges and the resources they need than with the rest of the area within their national states. Also, cities share a specific position in the global governance system. There is a 'cosmopolitan affinity' among cities when it comes to global problems and needed resources. Making the city a pioneer for cosmopolitan politics might be one of the most effective ways of 'achieving protection without national protectionism' (Sassen 2013: 170). If we open up macro level regimes to this sub-national scale, it becomes critical to recognize the specificity and the specialized differences of the local level. Three features stand out in this regard. 'The city level makes possible the implementation and application of forms of scientific knowledge and technological capacities that are not practical at a national level. The cities' multiple ecologies enable the mixing of diverse forms of knowledge and diverse technologies in ways that the more abstract 'national space' does not. This difference also means that the city introduces a type of environmental governance option that takes a radically different approach from the common and preferred choice of an international carbon-trade regime. Their aim becomes addressing the carbon and the nitrogen cycles in situ by implementing measures that reduce damage in a radical way'. Also, the city level substitutes the traditional vertical forms of governance by forms of horizontal governance, as can be seen in diverse urban initiatives to solve climate change problems. Climate change politics has a major obstacle: the invisibility of manmade climate change. But this invisibility on the abstract level of global and national modeling is being overturned because climate change becomes visible by suffering. This everyday visibility by suffering can indeed turned into a mover of cosmopolitan politics. City politicians and leaders have had to confront these direct impacts of global conflict and environmental crisis on the movement of people. And, last but not least, in the urban space you find economically and politically successful transnationally-connected middle class professionals (living here and there simultaneously, working here and there simultaneously), who are sensitive to transnational problems and do have a powerful status in city elections, as observed lately in New York City, but also in Zurich, Munich, Seoul, San Francisco etc. "At the same time local governments are increasingly becoming major actors in the emerging global legal order. They are obtaining international duties, powers, and rights; enforcing international standards; forming global networks involved in the creation of international standards; and becoming objects of international regulation. It has indeed become impossible to understand globalization and its legal ordering without considering the role of localities: They have become prime vehicles for the dissemination of global capital, goods, work force, and images. The evolving global status of local governments manifests itself in international legal documents and institutions, transnational arrangements, and legal regimes within many countries. To date, however, there has been almost no academic account of this significant legal transformation. International legal theory has remained captive to methodological nationalism, according to which they are mere subdivisions of states and thus undeserving of any theoretical analysis." (Blank 2013) Given the nation-states' resistance to cross-border collaboration and cosmopolitan politics, the 'turn to the city', epistemologically and politically, is important to, in order to discover or establish alternative institutions for cosmopolitan communities of shared risk, address the multiplying problems of a cosmopolitanized modernity without surrendering the democracy that nation-states traditionally have secured. ‘In order to save ourselves from both anarchistic forms of globalization, such as war and terrorism, and monopolistic forms, such as multi-national co-operations, we need global democratic bodies that work, bodies capable of addressing the global challenges we confront in an ever more interdependent world.’ (Barbar 2013: 4) Nations, inclined by their nature to rivalry and mutual exclusion, seem to be part of the problem and not of the solution in the world risk society of the 21st century. In a post-national world global cities might re-conquer a central position similar to that which they inhabited long ago in the pre-national world. Humankind began its adventure to politics in the ‘polis’ – the city. The city was democracy’s pioneer. But for millennia, cities relied on monarchy and empire and then on newly invented nation-states to produce und reproduce social and political order. Today the nation-state is failing on global risks. The cities, which in history were the social ground for civic movements to freedom, might in today’s cosmopolitanized world of global threats once again become democracy’s best hope.