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KONINKLIJKE ACADEMIE
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ACADEMIE ROYALE
DES SCIENCES D'OUTRE-MER

DEVELOPING COUNTRIES FACING GLOBAL WARMING: A POST-KYOTO ASSESSMENT

Guest Editors: M. DE DAPPER, D. SWINNE & P. OZER

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FWO VLAANDEREN
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International Symposium

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Foreword

On 29 November 1999, the "Global Warming" Working Group of the Royal Academy for Overseas Sciences organized an International Colloquium on *Developing Countries facing Global Warming: Kyoto 1997 and Beyond*, focusing on the uncertainties of the causes — anthropogenic and/or natural — of Global Warming. It was prompted by the decisions taken at the United Nations Conference of Parties on "Global Climate Change", held in Kyoto in December 1997, which had generated a complex and difficult situation for developing countries. The purpose of the Colloquium was to bring in a one-day session a state of the art of as many aspects — scientific, political, economic, ethical — of the debate as possible and this for a large audience. Therefore, twelve experts were invited to communicate their, often confronting, viewpoints. Time did not allow for discussion on the day of the Colloquium itself. The conference was attended by Ambassadors and their representatives, officers of the European Commission, scientists, students, decision-makers from the public and private sector, officials of Non-Governmental Organizations and various other interested people, 265 participants in total*.

The success of this scientific gathering proved again that the questions and the debate on environmental issues such as "Global Warming", and more particularly the position of developing countries facing this threat, were more relevant than ever and that the Royal Academy for Overseas Sciences, fully in line with their mission statement, had the possibility and the duty to play a prominent role in this regard. In order to fulfil that role, the "Environment and Development" Commission was set up.

On 12 and 13 June, 2009, ten years later, on the occasion of UNEP's Environment Day and in anticipation of the UN Climate Conference to be held in Copenhagen in December 2009 — where a new climate deal was to be forged —, the Royal Academy for Overseas Sciences, through their "Environment and Development" Commission, organized a follow-up International Symposium *Developing Countries facing Global Warming: a Post-Kyoto Assessment.*

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* Proceedings published in 2000: 199 pp., 25 figs.

Although there is still reason for debate on its causes, Global Warming is unequivocal, and the inhabitants of planet Earth, especially the large majority living in developing countries, will have to face the consequences: whatever mitigation, adaptation will be the strategy for a decent existence. This time the conference focused on the consequences of Global Warming and the Kyoto Protocol for developing countries.

In order to reach an updated state of the art on a wide scope of topics and to give a forum to as many scientists as possible — experienced and young ones —, a call for oral and poster communications was put out.

Themes on the consequences of Global Warming included:

— Political consequences: climate refugees, conflicts, megacities, world security, ...
— Economic consequences: new markets, livelihood, ...
— Food security;
— Vector-borne diseases for Man: dengue, malaria, ...
— Vector-borne diseases for livestock: tsetse, ...
— Natural hazards: changing monsoon regime, droughts and floods, hurricanes, landslides, ...
— Water issues: surface and groundwater, large rivers, ...
— Sea-level rise consequences: deltas, coastal zones, harbours, ...
— Ecological consequences: wetlands, tropical forests, coral reefs, ...
— Consequences for soil and land use;
— Landscape impacts: soil erosion, desertification, glacial landscapes, ...

Among the consequences of the present Kyoto Protocol, themes included:

— Mitigation and adaptation;
— Biofuels;
— CO_2 reduction and emerging economies: India, China, consequences for the North, ...
— Carbon storage by reforestation;
— Clean Development Mechanisms;
— Emission trading;
— Technology transfer: Genetically Manipulated trees and crops, GM controversy, novel potential antimalarial drugs, new irrigation techniques, ...

Eventually sixteen oral communications and thirty-six poster presentations were selected by the scientific committee. In order to allow for discussion the conference, attended by some two hundred participants, lasted two days and ended with a round-table debate *Towards a New Protocol* fuelled by a panel of eleven experts representing developing countries, IPCC, government agencies, scientific institutions and independent consultants.

The “Environment and Development” Commission is confident that the present volume of proceedings — full papers as well as abstracts — will stimulate further discussion and relevant research. However, this is only a small step forward: so much has still to be done to get to a fair world wherein everybody can live a decent life!

Morgan De Dapper
President of the
“Environment and Development”
Commission

Communications
Developing Countries facing Global Warming: a Post-Kyoto Assessment

International Symposium
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pp. 13-14.

Environmental Performance of Tropical Bio-diesel Trees [1]

by

Wouter ACHTEN*, Raf AERTS*, Wouter MAES*, Erik MATHIJS**, Bert REUBENS*, Antonio TRABUCCO*, Bart MUYS*, Virenora Pal SINGH***, Pieter VANDENBEMPT* & Louis VERSCHOT****

KEYWORDS. — Life Cycle Assessment; *Jatropha curcas*; Oil Palm; Land-Use Impact; Water Use.

SUMMARY. — Biofuels are globally under considerable pressure, caused by sky-high expectations and serious concerns on environmental and social impacts. Concerning sustainability, biofuels essentially need to meet two minimum requirements: (i) be produced from renewable feedstock and (ii) have an impact which is less negative than their fossil substitute.

To evaluate biofuels against these two requirements, in-depth analyses are necessary. Our research group (FORECOMAN) combined its expertise in restoration ecology, sustainability evaluation, energy, water and carbon balances and erosion control to evaluate the environmental performance of tropical bio-diesel trees in collaboration with partners. For the overall environmental performance evaluation the Life Cycle Assessment (LCA) tool is used.

In this poster we present previous and recent preliminary LCA results of bio-diesel production from both oil palm and *Jatropha curcas* (energy balance, global warming potential, eutrophication potential, acidification potential and land-use impact on ecosystem quality). Since *J. curcas* is an under-researched crop which gains acreage in the South hand-over-hand, we also present specific results on water use, allometry, drought strategy, soil erosion control potential and the global land suitability of *J. curcas*.

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NOTE

[1] This research is funded by the Flemish Interuniversity Council — University Development Co-operations (VLIR-UDC) and is a collaboration between K. U. Leuven and the World Agroforestry Centre (ICRAF).

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pp. 15-26.

CO_2 Emission Reduction and the Emerging Socio-Economic Development in Developing Countries: a Case Study of India

by

Rais AKHTAR*

KEYWORDS. — Greenhouse Gas (GHG) Emission; Distributional Responsibility; Colonial Exploitation; Inequalities.

SUMMARY. — There is a growing pressure from developed countries on the developing world to reduce greenhouse gas (GHG) emission, since the rising of greenhouse gas emission in developing countries, according to them, poses threat to the developed nations.

Developing countries in general and India in particular are facing a great challenge to accelerate the pace of socio-economic development and minimizing inequalities, created mainly during the colonial period of exploitation. We are in dire need of energy (per capita electricity consumption in India is 618 KW and in the USA 14,240) for the process of infrastructure development. It is evident that most developing countries, including India, have the lowest per capita CO_2 emission (1.2 t per capita as compared to 20.6 t in the USA), as well as the lowest Gross Domestic Product (GDP) per capita; still the major developed nations ask developing nations to reduce greenhouse gas emission, fundamental to their socio-economic development.

Thus, under the Kyoto framework, the principle of "common but differentiated responsibility" must be the foundation of future emission negotiations. This will help attain the objectives of equity and human development through expanding access to energy demand of developing countries. We must bear in mind that both developed and developing countries are suffering from climate change. The Katrina disaster in 2005 in the USA and the European heat wave of 2003 have shown the world that the developed world is equally vulnerable.

The paper deals with the energy scenario in India with focus on energy consumption and pinpoints various measures taken by the Indian government to reduce environmental deterioration through minimizing the level of greenhouse gas emission, and strengthening the socio-economic development in order to attain the objectives under the Millennium Development Goals (MDGs).

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Introduction

India is a large developing country with diverse climatic zones inhabited by about 700 million rural population directly dependent on climatic sensitive sectors: agriculture, forests and fisheries.

The adverse impact of climate change in the form of declining rainfall and rising temperatures and thus the increased severity of drought and flooding would threaten food security and livelihood.

Developmental Scenario

Despite scientific and technological progress in India since independence in 1947, development strategies have not percolated to grass root level. Besides there are wide inequalities at inter and intrastate levels. These inequalities are widening over time and space. Few of them may be mentioned: 1) poor infrastructure facilities; 2) weak institutional mechanisms; 3) lack of financial resources and vast sectoral and regional variability adversely affect the adaptive capacity of the country to climate change; 4) regional inequalities.

Climate change would represent additional stress on the ecological and socio-economic systems that are already facing tremendous pressure due to rapid industrialization, urbanization and economic development. In view of this it has rightly been stated in India's Eleventh Five-Year Plan document in response to climate change: "The most important adaptation measure is development itself. Achieving rapid growth as targeted in the Eleventh Plan is therefore a key element in adaptation" (GOI 2007).

Climate Change Scenario

The latest high-resolution climate change scenarios and projections for India, based on Regional Climate Modelling (RCM) system, known as PRECIS, developed by Hadley Center and applied for India using IPCC scenarios A2 and B212, show the following (IPCC 2007):

- An annual mean surface temperature rise by the end of the century, ranging from 3 to 5 °C under A2 scenario and from 2.5 to 4 °C under B2 scenario, with warming more pronounced in the northern parts of India;
- A 20 % rise in all India summer monsoon rainfall and further rise in rainfall is projected over all states except Punjab, Rajasthan and Tamil Nadu, which show a slight decrease;

— Extremes in maximum and minimum temperatures are also expected to increase and similarly extreme precipitation also shows substantial increases, particularly over the west coast and west-central India.

Indian Scenario

(based on the United Nations Framework Convention on Climate Change (UNFCC) Summit at Poznan, Poland)

In 1998 and 2003 (tab. 1), India lost more people due to extreme weather events caused by climate change than any other country, with an average of 4,532 people killed every year (German watch). An example of mortality due to extreme event of heat wave in India would be appropriate.

El Niño 1998 severely affected the climate scenario in India with extreme events: heat waves claimed the highest mortality (figs. 1, 2) (KUMAR 1998).

In 1998, major parts of the country extending from north India, parts of north-east India, and the northern parts of peninsular India experienced a severe heat wave during the second half of May 1998. The heat wave, which

Table 1
Heat waves in India

Year	No. of deaths	Year	No. of deaths
1979	361	1994	434
1980	156	1995	412
1981	72	1996	20
1982	16	1997	20
1983	185	**1998**	**1,662**
1984	58	1999	126
1985	142	2000	57
1986	156	2001	70
1987	91	2002	806
1988	637	**2003**	**1,539**
1989	44	2004	117
1990	2	2005	587
1991	252	2006	135
1992	114	2007	476
1993	42	2008	294

Source: IMD Reports on Disastrous Events, Pune.

was one of the most severe heat waves for fifty years, resulted in the death of more than 2,600 people. In Orissa, one of the poorest states, the temperature rose to a scorching 49.5 °C and killed nearly 1,300 people. Bihar, West Bengal, Andhra Pradesh, Uttar Pradesh, Maharashtra and Punjab states also suffered with temperature soaring to 45-49 °C (AKHTAR 2007). Even south interior Karnataka and parts of Tamil Nadu were under the grip of severe heat wave conditions during this period. Chennai recorded the second highest maximum temperature: 44 °C of the present century on May 24, which was 8 °C above normal. The highest ever recorded maximum temperature, 45 °C, had occurred in Chennai on May 21, 1910.

It is a fact that the people residing at a place for a sufficiently long time get more or less acclimatized to the normal weather conditions of that place. Thus, though the maximum temperature of north-west India, especially Rajasthan, was nearing 50 °C, the death toll in Rajasthan and the north-west part of the country was less, compared to that of Orissa. The large number of deaths in Orissa was perhaps due to lack of adaptability to such extreme conditions. A comparative scenario of heat wave mortality between European and Indian heat waves in 2003 shows that heat wave mortality was the second highest in India. This shows that the 2003 heat wave was not confined to Europe but was a global phenomenon.

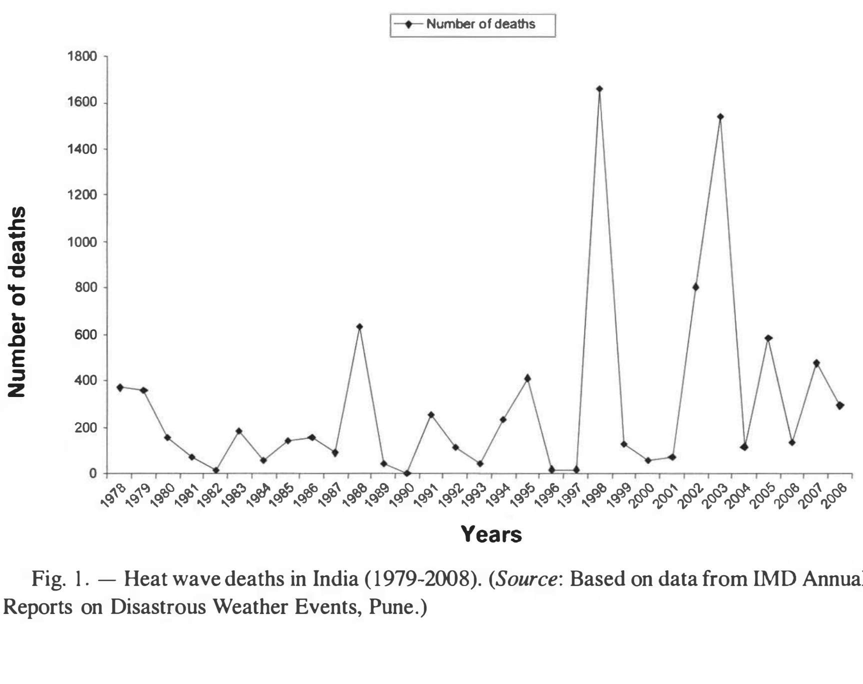

Fig. 1. — Heat wave deaths in India (1979-2008). (*Source*: Based on data from IMD Annual Reports on Disastrous Weather Events, Pune.)

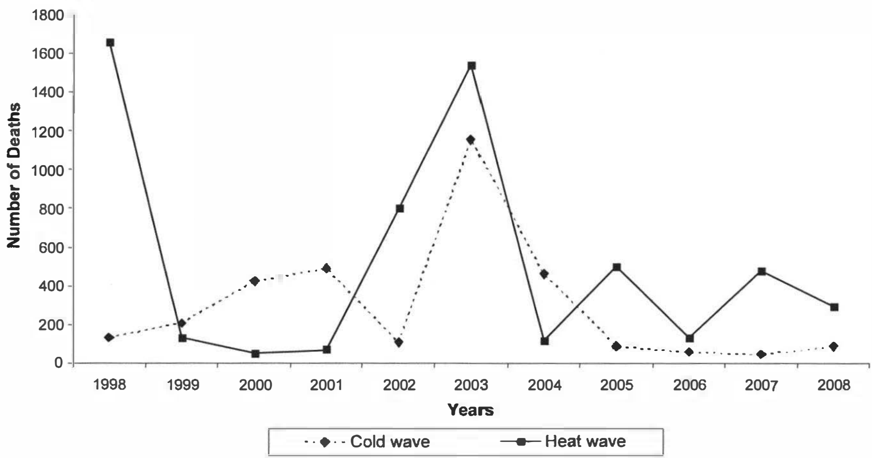

Fig. 2. — Heat wave and cold wave mortality in India: comparative pattern (1998-2008). (*Source*: Based on data from India Meteorological Department, Pune.)

It is said that on an average total losses and average losses as percentage of GDP, India would rank seventh among the countries most affected by extreme weather events in the last decade. The Indian subcontinent is at the risk of emerging as a 'hotspot' of new infections evolving from wild animals, in areas where human populations are growing and coming in conflict with animals. Shrinking biodiversity is also a cause for this alarming trend (KINVER 2008).

Kyoto Framework

The essence of the discussion related to the Kyoto Protocol pertains to:

— Public debate, in which nations increasingly highlight the threat posed by rising greenhouse gas emission in developing countries.
— The principle of "common but differentiated responsibility": one of the foundations of the Kyoto framework does not mean that developing countries should do nothing. The credibility of any multilateral agreement will hinge on the participation of major emitters in the developing world.
— The basic principles of equity and the human development imperative of expanding excess to every demand that developing countries have the flexibility to make the transition to a low-carbon growth path at a rate consistent with their capabilities.

— Colonial rule in countries of Asia, Africa and other regions, which is responsible for exploiting the resources for their own benefits without any development actions in the colonies. This has created disparities and lack of access to facilities and energy. *These aspects cannot be ignored.*

However, we can change the composition of production in the economy in favour of less CO_2 intensive activities. This can be done either by changing the structure of trade so that more CO_2 intensive products are imported or the structure of consumption and other final demands may be changed by reducing the budget share of CO_2 intensive goods in total final demand.

Development Dynamics: Energy Consumption

It is a sad reflection of the development dynamics of the world economy that in 2001, there were ninety countries with 4,860 million, or 80 %, of the world population that were yet to reach per capita electricity consumption of 4,500 kwh, sixty countries with population of 4,166 million claiming 70 % of the world population do not use even 1,750 kwh per capita and have a Human Development Index (HDI) ranging from 0.32 to 0.80. Even there is no comparison between the poor in America and the rich in developing countries in terms of energy consumption. A report suggests that the poor American lives in a larger house or apartment than the average West European does. Poor Americans eat far more meat, are more likely to own cars and dishwashers and are likely to have more basic modern amenities, such as indoor toilets, than the West European population (Rector 1990). Obviously, while comparing with India, poor Americans consume more energy than the rich population in India.

Such wide disparity would seriously question any *global policy of energy use on socio-economic development at different levels of energy consumption*, hence the idea of "differentiated responsibility".

India's Response

With a share of just 4 % of global emissions, any amount of mitigation by India will not affect climate change. A substantial commitment to reduce emissions by the major industrialized countries will be required.

Nevertheless as contribution to the global emission reduction efforts the eleventh plan (2007-12) focuses on ensuring that the emission intensity of India's GHG continues to decline.

The correct approach in mitigation is to define the obligations of different parties on the basis of common but differentiated responsibility and differences in respective capabilities. India's view on burden sharing is based on this approach. India's National Environmental Policy of 2006 requires 'equal per capita entitlements of global environmental resources to all countries'.

At the meeting of the G8+5 in Heiligendamm in July 2007, the Indian prime minister indicated that we are determined to see that *India's per capita emissions never exceed the per capita emissions of the industrialized countries.*

This formulation focuses on per capita emissions rather than total emission as the relevant variables and also provides industrialized countries with incentive to reduce their level of emission as quickly as possible.

Focus on adaptation: the most important adaptation measure is development itself. A stronger economy is more able to adapt both in terms of cost of adaptation and technological capability:

- Action in the area of agricultural research to evolve varieties that can cope with likely climate change;
- Action to cope with likely increases in water stress;
- Action to be able to cope with a greater frequency in natural disaster;
- India will also initiate action to increase our access to cleaner and renewable energy by fully exploiting existing resources (*e.g.* hydropower and wind power developing nuclear power, and also supporting research in newer areas such as biofuels from agro-waste, solar energy, etc.);
- India's Clean Development Mechanism (CDM) potential is a significant component of the global CDM market. Till 14 February 2008, out of a total of 871 projects being accorded host country approval, 314 projects in India have been registered by the CDM Executive Board, so far the highest in any country.

Although India does not have GHG reduction targets, the country has undertaken reforms that have spurred economic growth and broken the barriers to efficiency: pollution control, energy conservation, energy efficiency.

The improvements in petrol and diesel quality have facilitated the adoption of India 2000 (Euro-I equivalent) emission norms in the entire country and Bharat stage II (Euro-II equivalent) emission norms in the four metros. Euro-III equivalent norms have been adopted in seven mega cities since 2005 to further reduce sulphur content (GUPTA 2005). The best known of these measures is the court-mandated conversion of not only DTC (Delhi Transport Corporation) buses in Delhi but all commercial passenger vehicles — buses, three-wheelers and taxis to Compressed Natural Gas (CNG). This has resulted in the improvement of Delhi's air quality, which was once categorized as the "fourth most polluted city" in the world. Some of the major Supreme Court rulings on vehicular pollution during 1990-2002 are as follows (GUPTA 2005):

Case of Ruling	Year	Court Ruling	Status	Instrument Type
Vehicles: a serious population issue	1990	Registration of defective vehicles suspended effective from 1991, financial incentives for new CNG vehicles.	Done	CAC, MBI
Lead phase-out of all vehicles	1994	Lead-free petrol to be sold in metros and low lead petrol in entire country, catalytic converters for petrol-driven cars made available by April 1995.	Done	CAC
Government vehicles	1996	All official government cars to be fitted with catalytic converters or a CNG kit by August 1996.	Done	CAC
Ban on old commercial/ transport vehicles	1998	All commercial and transport vehicles more than 15 years old not permitted to ply in Delhi and other metros. Commercial vehicles in Delhi should convert to CNG, effective from April 2001.	Delayed/done in Delhi	CAC
Buses to use natural gas	2001	Delhi should convert to CNG, effective from April 2001.	Delayed	CAC

Environmental Legislations in India

1. The Water (Prevention and Control of Pollution) Cess Act, 1977.
2. The Air (Prevention and Control of Pollution) Act, 1981.
3. The Environment (Protection) Act, 1986.
4. The Indian Forest Act, 1927.
5. The Public Liability Insurance Act, 1991.
6. The National Environment Tribunal Act, 1995.
7. Energy Conservation Act, 2001.
8. Electricity Act, 2003.
9. The Biological Diversity Act, 2002.
10. The Prevention of Cruelty to Animals Act, 1960.
11. The Indian Wildlife (Protection) Act, 1972.

12. The Batteries (Management and Handling) Rules, 2001.
13. The Municipal Solid Wastes (Management and Handling) Rules, 2000.
14. Noise Pollution (Regulation and Control) Rules, 2000.
15. The Ozone Depleting Substances (Regulation and Control) Rules, 2000.
16. The 2-T Oil (Regulation of Supply and Distribution) Order, 1998.
17. Coastal Regulation Zone.
18. The Scheme on Labelling of Environment-friendly Products (ECOMARK).
19. Eco-sensitive Zone.
20. Environmental Clearance-General.
21. Reorganization of Environmental Laboratories and Analysts.

Only recently the government has announced tough environmental measures towards issuing environmental clearance for any industrial/development project proposal. Thus, India is doing a lot toward improving environment in both rural and urban areas.

CO_2 Emission Reduction and India

A comparative study of per capita CO_2 emission based on data from World Development Indicators shows that carbon emitted in India is as low as 1.2 metric tonnes per person as compared to the world average of 4.5 tonnes, 20.6 for the USA and 4.6 for China.

In the case of share in global CO_2 emission (in %), USA stood first with 23.06 %, followed by China with 14.07 %, while India is at fifth place with 4.07 %.

The focus on India's concern should be on more fundamental issues such as alleviation of poverty and creating basic conditions for human development. Take for example the access to electricity: in India only 56 % of the population have access to electricity, in contrast to 100 % in the USA, 99 % in China, and 97 % in Brazil and in Mexico. Per capita energy use in India is 512.4 *[kgoe/a] compared with figures* 7,794.8 and 1,138.3 for the USA and China respectively.

CO_2 Emission and Per Capita GDP

There is a positive relationship between GDP per capita and CO_2 emission. The following figures based on data from World Development Indicators reveal that there is a positive relationship between GDP per capita (Purchasing

Power Parity (PPP) US$) and CO_2 emission per capita in developing countries. Unless this positive relation is broken without affecting per capita income, India must not agree to any binding emission cuts (fig. 3).

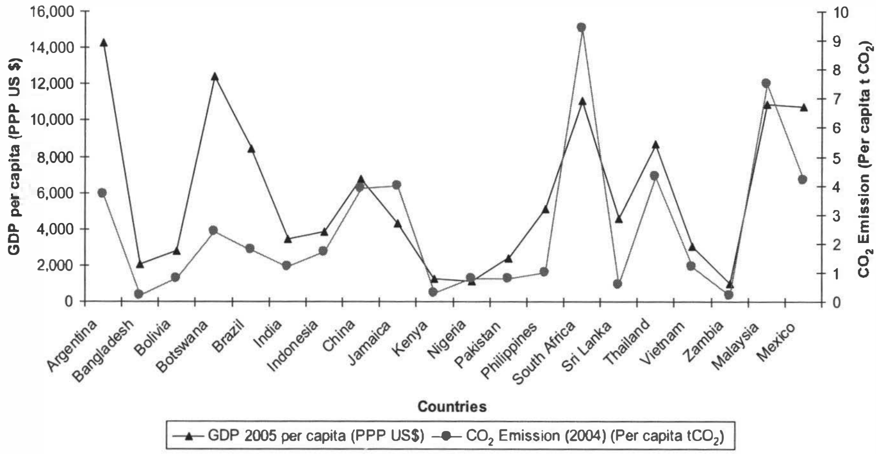

Fig. 3. — GDP per capita (PPP US $ 2005) and CO_2 emission per capita (t CO_2 2004) of selected developing countries. (*Source*: Based on World Development Indicators, World Bank, Washington DC 2008.)

It has been recognized that CO_2 emission reduction imposes costs in terms of lower GDP and higher poverty (fig. 4).

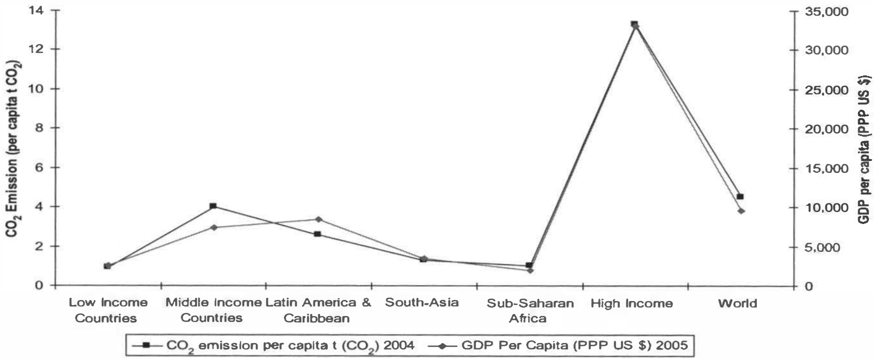

Fig. 4. — GDP per capita (PPP US $ 2005) and CO_2 emission per capita (t CO_2 2004). (*Source*: Based on World Development Indicators, World Bank, Washington DC 2008.)

Conclusion

The challenge lies in determining a basis for collective action which is fair, provides equitable entitlement to the global environmental space with burden sharing in a way which recognizes the very different levels of development and also the very different degrees of historical responsibility for causing the problem in the first place. Such differentiation among world countries has been accepted by the UNFCC and the Kyoto Protocol. Besides, the colonial powers who exploited the resources and suppressed the development in their respective colonies must come forward to provide clean and green technologies and help in the process of regional development. This must be effectively operationalized to create an environment of trust and cooperation. Unfortunately, both the Copenhagen and Cancun Climate Change Conferences have failed to agree to a negotiated treaty to help financially and technologically all developing countries without hurting the process of developmental activities which are vital in promoting and enhancing welfare measures for the people.

It is relevant to quote the famous statement of Mahatma Gandhi who was asked if he would like to have the same standard of living for India's teeming millions as in Britain. He quipped, "It took Britain half the resources of the planet to achieve this prosperity. How many planets will a country like India require!" Gandhi believed that "the Earth provides enough for Everyman's needs but not for Everyman's greed".

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I admire the help of my daughter Shirin Rais in the preparation of figures 3 and 4 of this paper.

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Extreme Rainfall and Temperatures in the Region of Mainé-Soroa (South-East Niger) in the Context of Global Warming

by

Karimou AMBOUTA*

SUMMARY. — The climate of the Department of Mainé Soroa (South-East Niger) is of saharo-sahelian type characterized by a three-month rainy season from mid-June to mid-September followed by a nine-month dry season. In this context, climatic change may increase vulnerability of this fragile arid environment by increasing extreme climate events such as the frequency and the intensity of heavy rainfall and heat waves. Those may damage agriculture, livestock, natural resources and threat societal survival in this poor region of the world fully depending on the state of the environment.

In order to analyse significant variations in rainfall and maximum temperature patterns, the Pettitt test was applied to annual means of both parameters. On the other hand, the extreme values distribution of Gumbel was used to qualify and quantify climatic extremes. Results suggest that extremes in maximum temperatures increased in a statistically significant way. However, the frequency of extreme rainfall events did not present any significant trend.

This study should be extended to the entire meteorological network of Niger and of the Sahel in order to confirm those trends on a regional scale.

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The Nile Delta: Scenarios for the Sea-level Rise Impacts

by

Shady ATTIA*

KEYWORDS. — Nile Delta; Sea-level Rise; Impacts; Scenarios; Defence Strategy.

SUMMARY. — The Nile Delta in Egypt is particularly vulnerable to the effects of global warming. A relative rise in sea level of 1 m would submerge much of the delta region within 30 km of the coast during the next 100 years. Rising sea levels would have significant long-term impacts on physical, biological and socio-economic conditions of the Nile Delta affecting at least six million people. These include the damage and destruction of communities, erosion of beaches, salt water intrusion and flooding of more than 1,200 km^2 of Egypt's Delta Coastline. Unfortunately, no national mitigation and adaptation strategy for sea-level rises has been outlined in Egypt. Even existing defence strategies are limited to civil engineering. Given the damage potential this study investigated and developed two scenarios for prospective impact of sea-level rise. In the first part of the study, two scenarios were modelled with the help of GIS maps: for a 0.50 m and a 1.00 m global sea-level rise. The results identify and map the most vulnerable areas to sea-level rise and the expected implications. The second part of the study suggests the initiation of a vision for a national development plan that is based on a long-term coastal defence strategy. This vision focuses on general solutions and opportunities to solve the sea-level problem. This not only includes giving priority to landscape, geomorphology and water, but also suggests a serious water management strategy that allows reliable food production and developing a safe new urban front. Finally, the poster presents and illustrates the more interesting results of long-term impacts on the Nile Delta and suggests starting planning for coastal adaptation of the Nile Delta.

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Integrating Adaptation to Climate Change into Development Aid Policies: Case of the EU

by

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KEYWORDS. — Climate Change Adaptation; Development Aid; Mainstreaming.

SUMMARY. — Climate change and its impacts on human societies exacerbate some development issues. This problematic recently became a fundamental issue for development aid policy makers. Growing environmental deterioration will be a strong challenge to short-term gains of poverty reduction. On the contrary, investing in environmental sustainability could be a way to achieve higher economic and social returns. How can development aid support this path is the question we propose to explore in this paper.

The vulnerability and the lack of capacity of developing countries regarding climate change have been underlined many times. Therefore, the "mainstreaming" of adaptation as a transversal development issue has become a priority in the international policy texts these last years. However, there is a gap between the discourse and the practice of development aid. Action bringing short-term gains is favoured by development institution. Climate change is a problematic issue, because it implies taking action based on climate scenarios. These are not exempt from large uncertainties. However, tackling this issue will be necessary. It will in return bring gain in terms of sustainable development, since "traditional" development issues, as poverty alleviation and other Millennium Development Goals (MDG), are challenged by climate change impacts.

Being involved in a research on adaptation to climate change in western Africa, we have performed in-the-field observations of adaptation strategies. Moreover, we have carefully analysed the policy papers and practices of EU aid policy and its relations to adaptation to climate change. In this paper we propose to highlight the relevance of integrating adaptation to future climate change impacts as an asset to reach traditional goals of development and as a mean to avoid future economic, social and human losses.

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Geographical Distribution of Clean Development Mechanism (CDM) Projects: Barriers Analysis and Actions to undertake for the African Continent

by

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KEYWORDS. — Clean Development Mechanism (CDM); CDM Geographical Distribution; Africa; Barriers; Strategic Actions.
SUMMARY. — The Clean Development Mechanism (CDM), which was supposed to be an opportunity for developing countries to achieve sustainable development, highlights many disparities in the geographical distribution of its project activities. Particularly in the case of Africa's Least Developed Countries (LDCs), whose participation in the carbon market still remains very weak. Investment from developed countries is also limited. The barriers to development and implementation of CDM project activities in this area are linked on the one hand to the general organization of projects by African countries, and on the other hand to the organization of the clean development mechanism itself. The necessary actions to promote African CDM projects could be undertaken both at national and international levels.

1. Introduction

The CDM is a tool under the Kyoto protocol allowing industrialized countries with a commitment to reduce greenhouse gases (GHGs) to invest in projects that reduce emissions in developing countries at a much lower overall cost, as an alternative to more expensive emission reductions in their own countries.

The basic principle of the CDM is simple: developed countries can invest in low cost abatement opportunities in developing countries and receive credit

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for the resulting emission reductions, thereby reducing the cutbacks needed within their borders. Thus an investor implements a project which reduces emissions in a host country and receives emission credits — the so-called Certified Emission Reductions (CERs) — in return. The host country benefits from project activities resulting in CERs, and the investor uses them for compliance requirements or for financial gain in the context of International Emission Trading (IET) (UNFCCC 2002) or the European Union Emissions Trading Scheme (EU ETS) (European Commission 2004).

According to Article 12 of the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) (1998), the CDM pursues objectives which can be seen from the three following angles: to assist non Annex I Parties in achieving sustainable development — the objective of sustainable development; to assist Annex I Parties in achieving their quantified emission limitation and reduction commitments at low cost — the compliance objective; and to contribute to emission reductions in global GHGs in order to stabilise their concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system — the ultimate objective of the Climate Convention.

2. Main CDM Implementation Regulations

2.1. CDM Overview

CDM administration: the CDM is supervised by the Executive Board, which itself operates under the authority of the Parties (UNFCCC 1998). The Executive Board is composed of ten members, including one representative from each of the five official United Nations regions (Africa, Asia, Latin America and the Caribbean, Central Eastern Europe and the OECD), one from the Small Island Developing States (SIDS), and two each from Annex I and non-Annex I Parties (UNFCCC 2002).

Participation requirements: in order to participate in the CDM, all Kyoto Protocol Parties must meet three basic requirements (UNFCCC 2002). Those requirements state that participation is voluntary; that participant parties shall designate a national authority for the CDM, responsible for approving and evaluating CDM projects and defining the host country's sustainable development criteria (Michaelowa 2006), and that participant parties must have ratified the Kyoto Protocol. Moreover Annex I Parties must meet additional requirements (UNFCCC 2002).

Project eligibility criteria: the Kyoto Protocol stipulates several criteria that CDM projects must satisfy, but there are two critical criteria which could be broadly classified as additionality and sustainable development. From additionality, Article 12 of the Kyoto Protocol states that projects must result in reductions in emissions that are additional to any that would occur in the absence of the project activity (UNFCCC 1998). From a sustainable development point of view, the Kyoto Protocol specifies that the purpose of the CDM is to assist non-Annex I Parties in achieving sustainable development. There is no common guideline for the sustainable development criterion and it is up to the developing host countries to determine their own criteria and assessment process (FENHANN *et al.* 2004). Many countries have already defined criteria in the context of the Commission on Sustainable Development (CSD), Agenda 21, and can use them (MICHAELOWA 2003), and the criteria for sustainable development may be broadly categorised in three different categories: social, economic and environment criteria (FENHANN *et al.* 2004).

CDM project cycle: the CDM principles and their supervision by the institutions have given rise to a sequence of procedures that every CDM project activity has to complete before it gets CERs (MICHAELOWA *et al.* 2007). This sequence of steps is commonly known as the CDM project cycle (fig. 1) and has two main phases: the design phase (including the following steps: methodology development, project design documents development, approval, validation and registration of project), and the implementation phase (including monitoring, verification, certification and CERs issuance steps).

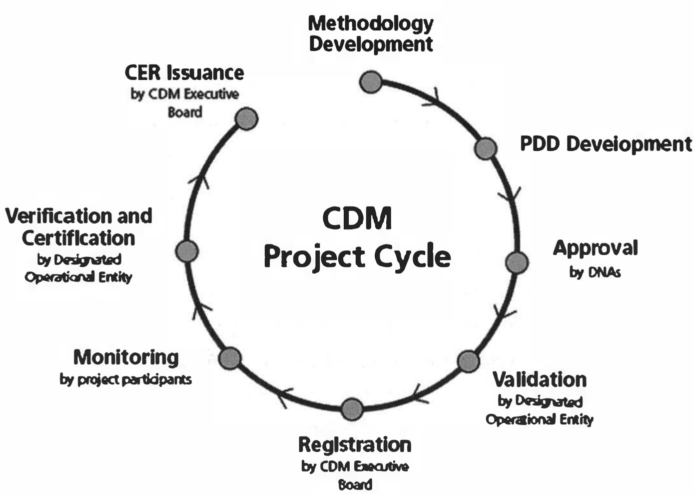

Fig. 1. — The CDM project cycle (*source*: MICHAELOWA *et al.* 2007).

Baseline and additionality: in order to measure the improvements generated by a project activity, *i.e.* the additional GHG emission reductions and the contribution to sustainable development, the setting of a baseline scenario is necessary (MULLER PELZER 2008). According to Article 12 of the Kyoto Protocol (1998), CDM projects should result in measurable reductions in GHG. In this way, the concept of measurable reduction is based on a comparison with some defined level of GHG emissions. This comparative level, against which the reductions of GHG emissions due to a CDM project are measured, is called a baseline, which the Marrakech Accord defines as "the scenario that reasonably represents the anthropogenic emissions by sources of greenhouse gases that would occur in the absence of the proposed project activity" (UNFCCC 2002).

Parties involved in the CDM process: several Parties are involved in the CDM projects process. According to the United Nations Environment Programme (UNEP) project CD4CDM (2007), the main actors include the project host for providing the land, facilities or resources that are required to undertake the CDM project in the developing country location of the project; the CDM project developer responsible for driving the project through the CDM project cycle; the CDM project participant (Party to the Kyoto Protocol, *i.e.* a government, involved in the project, or a private entity authorised by a Party involved to participate in the project); the Focal Point for a CDM project, *i.e.* the project participant or participants named in the Modalities of Communication; the CERs buyer, *i.e.* theoretically any entity (an Annex I Party or authorised by an Annex I country) which purchases CERs from a project; the designated operational entity (DOE) which is required to validate the project prior to registration as a CDM project activity, and to verify the emission reductions of a project prior to issuance of CERs; the designated national authority (DNA): the DNA of the developing country in which the project is located is required to authorise the project (by issuing a letter of approval) prior to validation and the DNA of Annex I countries is required to approve any Annex I project participants; the CDM-Executive Board responsible for administering the procedures relating to the registration of projects and issuance of CERs.

2.2. CDM Projects Supply and Demand

CDM projects demand: since the beginning of the CDM projects market, European buyers dominated the CDM market. Indeed, they represent the bulk of the purchases of emission reductions with a combined 41 % of total volume purchased in 2004 (LECOCQ & CAPOOR 2005); about 56 % in 2005 (CAPOOR

& Ambrosi 2006); this rate reached 86 % in 2006 (Capoor & Ambrosi 2007); and their market share reached almost 90 % in 2007 (Capoor & Ambrosi 2008). The United Kingdom still remains the world leader in CDM demand which had 54 % in 2006 and 59 % in 2007 of all total volume purchased; and two-thirds of the volume purchased from Europe was purchased by private firms, against one-third by governments (Capoor & Ambrosi 2008).

CDM projects supply: on the other hand, since the beginning of the CDM projects market, the supply CDM market has been dominated by the Asian and Latin American countries especially China, India, Brazil and Mexico. Indeed, from January 2004 to April 2005, Asia represents 45 % and Latin America 35 % of the volume supplied (Lecocq & Capoor 2005); between January 2005 and April 2006, the share of Asia reached 73 % (Capoor & Ambrosi 2006). From 2006 China has dominated the CDM market on the supply side with a 61 % market share of volumes transacted (Capoor & Ambrosi 2007), and it still was the world leader in CDM supply with a 73 % market share in terms of 2007 transacted volume (Capoor & Ambrosi 2008).

2.3. CDM Projects Transaction Costs

Transaction costs are those costs that arise from initiating and completing transactions to secure CERs; these consist of pre-operational costs, implementation costs, and trading costs (Fenhann *et al.* 2004). In the CDM context, transaction costs are costs involved in all stages of the project from the planning project idea to the CERs issuance. According to the UNEP project CD4CDM (2007), transaction costs associated with the CDM may include, as for conventional projects, planning phase, construction phase and operation phase costs. Those transaction costs vary widely between projects and depend also on other various factors such as timing (linked to the project life time), size (large scale versus small scale), type (renewable versus HFCs, PFCs & N_2O reduction) and location (area with high or low risk) of projects.

2.4. Financing of CDM Projects

As in the case of transaction costs, financing CDM projects concerns all stages of the project, essentially the planning and construction phases; the operating phase provides revenue and need not be funded. "It has been observed that the majority of the CDM-specific project costs occur during the planning phase and they must therefore be regarded as high risk, since they will not be recovered if the project fails to be implemented" (UNEP & Ecosecurities 2007). Thus those costs must be covered by risk capital (equity or grants, because they will not be repaid if the project is not realised). According to the UNEP & Ecosecurities (2007), the main sources of finance for these CDM-specific project costs during the planning phase are: government tenders and carbon funds; private sector CDM project developers; and project hosts. On the other hand, the potential sources of finance for the construction phase include lenders; private sector CDM project developers; project hosts; equipment suppliers; and CER buyers (UNEP & Ecosecurities 2007).

3. Worldwide CDM Distribution Overview

The geographical distribution of the CDM is uneven, both in terms of project numbers and the volume of credits expected to be generated. Indeed, the great majority of CDM projects seem to target countries with strong economies in transition, such as China, India, Brazil and Mexico in particular (UNFCCC database), these countries being the ones where a large amount of the foreign direct investment already flows to (ELLIS *et al.* 2004). There is little doubt that foreign investments are likely to be profitable in those countries. From a development policy point of view, it is obvious that the countries most in need are located in the Sub-Saharan and Southern Asian regions (NUSSBAUMER 2006).

3.1. Worldwide Status of CDM Projects

According to the UNEP-Risoe Centre CDM pipeline analysis and database update on August 2009, in total 4,588 CDM projects were included in the pipeline, not counting the 596 projects rejected and the 31 ones withdrawn. 1,750 of all the projects are registered and a further 205 were in the registration process, while 2,633 projects were at the validation stage. 535 CDM projects have already been issued with CERs, as shown in table 1.

3.2. CDM Project Distribution by Category

The UNFCCC classifies CDM project activities by fifteen scopes (UNFCCC database) divided into eight categories (UNEP-Risoe Centre database) including Renewables, HFCs, PFCs & N_2O reduction, CH_4 reduction & Cement & Coal mine/bed, Supply-side Energy Efficiency, Fuel switch, Demand-side Energy Efficiency, Afforestation & Reforestation, and Transport as shown in table 2. Note that the distribution of CDM project activities in those categories and the volume of CERs from them still remains uneven.

Table 1
Status of CDM projects in August 2009

Status of CDM projects	Number
At validation	**2, 633**
Request for registration	81
Request for review	20
Correction requested	69
Under review	35
Total in the process of registration	**205**
Withdrawn	31
Rejected by DOEs	480
Rejected by EB	116
Registered, no issuance of CERs	1, 215
Registered, CERs issued	535
Total registered	**1, 750**
Total number of projects (including rejected and withdrawn)	**5, 215**

Source: UNEP-Risoe Centre CDM pipeline analysis and database, August 2009.

Table 2
Number of CDM projects and volume of CERs by category

Category	No. of projects		2012 kCERs	
HFCs, PFCs & N_2O reduction	103	2.2 %	741,468	28.3 %
Renewables	2,690	58.6 %	966,559	36.9 %
CH_4 reduction & Cement & Coal mine/bed	923	20.1 %	547,483	20.9 %
Supply-side EE	501	10.9 %	301,741	11.5 %
Fuel switch	121	2.6 %	17,808	0.7 %
Demand-side EE	189	4.1 %	28,720	1.0 %
Afforestation & Reforestation	49	1.1 %	12,362	0.4 %
Transport	12	0.3 %	4,994	0.2 %
Total	**4,588**	**100 %**	**2,621,135**	**100 %**

Source: UNEP-Risoe Centre CDM pipeline analysis and database, August 2009.

This justifies the fact that all sectors involved in the CDM project activities have different attractiveness in carbon investment.

3.3. Geographical Distribution of CDM Projects

At the regional level, the distribution of CDM projects also shows disparities between countries or regions. This is illustrated in table 3, which shows the dominance of China and to a lesser extent India. Together, these two countries account for more than 70 % of expected credits from proposed CDM project activities to 2012, and nearly 65 % of proposed CDM projects. An unequal distribution observed is not surprising, given that countries vary widely in terms of their size, GHG emissions, GHG-reduction potentials and cost of GHG reductions, investment climate, risk and policy towards the CDM. Nevertheless, the current geographical distribution of proposed CDM projects is striking.

Tables 2 and 3 show respectively the great disparities between categories of projects and host countries, in terms of the number of proposed CDM project activities and the volume of CERs from them, with the marginal position occupied by the African continent. Indeed, the shares taken by China and India make those countries the most attractive to foreign investors, which explains their good investment climate. Indeed, according to the International Energy Agency (2007), China and India are the emerging giants of the world economy and international energy markets.

Table 3

Geographical distribution of proposed CDM projects

Country	Total CDM projects		2012 kCERs	
China	1,804	39.3 %	1,541,284	55.4 %
India	1,168	25.5 %	427,393	15.4 %
Brazil	347	7.6 %	174,332	6.3 %
Mexico	156	3.4 %	65,723	2.4 %
Africa (all countries)	105	2.3 %	80,569	2.9 %
Republic of Korea	67	1.5 %	105,052	3.8 %
Others	941	20.4 %	386,982	13.8 %
Total	**4,588**	**100 %**	**2,781,335**	**100 %**

Source: UNEP-Risoe Centre CDM pipeline Analysis and database, August 2009.

4. The Specific Case of African CDM Project Activities

4.1. Status of CDM Project Activities in Africa

In spite of the African marginalisation in CDM project activities, some results are registered in this area. In fact, we have seen that, until August 2009, there were 105 projects in the African CDM pipeline (2.3 % all of worldwide CDM projects) which will provide 80,569 kCERs in 2012 (2.9 % all of expected credits from proposed CDM project activities to 2012), but all those projects still remain insufficient for the continent. The disparities revealed in CDM project activities throughout the developing world are also observed in the African area: projects located in South Africa, Egypt and in the Maghreb (Morocco, Algeria and Tunisia) take in alone more than 50 % of all CDM projects on the continent. The share of sub-Saharan Africa (excluding South Africa) also still remains very weak, as shown in table 4.

4.2. Initiatives undertaken to promote CDM Projects in Africa

Since the CDM began to present differences in the distribution of project activities throughout the developing world, particularly in the African region, the international community has become aware that some measures and policies are necessary at all levels in order to reduce these disparities and allow these developing countries to promote their sustainable development. Among those measures and policies we can list:

- Definition of small-scale clean development mechanism project activities as mentioned in the decision 7/CP7 of the Marrakech Accords (UNFCCC 2002, decision 7/CP7);
- Adoption of simplified modalities and procedures for small-scale clan development mechanism project activities such as contained in the annex to decision 17/CP7 of Marrakech Accords (UNFCCC 2003, decision 21/CP8);
- Removal of the registration fee for projects involving emission reductions of below 15,000 tons per year; and a lower share of proceeds for the first 15,000 CERs issued per year (UNFCCC 2006, 27th report of Executive Board);
- Abolition of the payment both of the registration fee and of the share of proceeds at issuance for CDM project activities originating in the least developed countries and in sub-Saharan countries (UNFCCC 2007, 35th report of Executive Board & UNFCCC 2008);

Table 4
Status and geographical distribution of CDM projects in Africa

Host country	At validation		In registration		Registered		Total	
	Projects	2012 kCERs	Projects	2012 kCERs	Projects	2012 kCERs	Projects	2012 kCER
Cameroon	1	460	0	0	0	0	1	460
Cape Verde	1	340	0	0	0	0	1	340
Congo DR	3	551	0	0	0	0	3	551
Egypt	7	3,462	1	2,061	4	10,749	12	16,272
Ethiopia	1	181	0	0	0	0	1	181
Ivory Coast	0	0	0	0	1	253	1	253
Kenya	13	2,364	0	0	1	551	14	2,914
Liberia	1	215	0	0	0	0	1	215
Madagascar	1	210	0	0	0	0	1	210
Mali	2	281	0	0	0	0	2	281
Morocco	5	908	0	0	5	1,692	10	2,599
Mozambique	1	228	0	0	0	0	1	228
Nigeria	5	9,268	0	0	2	18,401	7	27,669
Rwanda	1	74	0	0	0	0	1	74
Senegal	1	319	0	0	0	0	1	319
South Africa	13	4,097	1	92	15	15,556	29	19,745
Swaziland	1	252	0	0	0	0	1	252
Tanzania	4	949	0	0	1	1,112	5	2,062
Tunisia	0	0	0	0	2	4,125	2	4,125
Uganda	8	911	1	30	1	290	10	1,230
Zambia	1	588	0	0	0	0	1	588
Africa	**70**	**25,658**	**3**	**2,182**	**32**	**52,729**	**105**	**80,569**

Source: UNEP-Risoe Centre CDM pipeline analysis and database, July 2009.

— The Nairobi Framework initiative with the specific target of improving Sub-Saharan Africa's level for participation in the CDM;
— The UNFCCC CDM Bazaar launched and managed by the Secretariat of the UNFCCC and the UNEP Risoe Centre, which serves as a platform for exchange of information on clean development mechanism project opportunities;
— The Guidance on the registration of project activities under a programme of activities as a single CDM project activity (UNFCCC 2007, 32nd report of Executive Board), etc.

Nevertheless, those measures and policies, which have been taken in order to increase the share of participation of African countries in the carbon market, remain inefficient, because their share is currently almost insignificant. This situation raises some barriers related to attracting interested investors into developing and achieving CDM project activities which are developed along the following lines.

5. Some Identified Barriers to African CDM Project Activities

An analysis of African CDM projects' state of the art reveals the existence of barriers to development and achievement of CDM project activities in this area. Those barriers can be inherent on the one hand in the general organization of African countries, and on the other hand in the CDM organization itself. Among them we can mention:

— Valuation issues for greenhouse gas reduction options: the difficulties in calculating real greenhouse gas emissions reduction potential in different sectors are mentioned in the 27th CDM Executive Board report in 2006. There is still a great lack of expertise to assess greenhouse gas potential reduction in some sectors possibly eligible to CDM project activities, due to the urgent need of staff qualified in this technical area.

— Financial issues: in Africa, many countries suffer from insufficient access to funds for technical assistance and capacity building and insufficient access to project financing and risk management tools. CDM projects can have widely varying capital cost requirements, depending both on the project type, and whether or not the CDM costs encompass the entire project, or just a CDM "add-on" (ELLIS & KAMEL 2007). African countries' financial capacity limits refer to their growth level, Human Development Index (DHI) and Gross Domestic Product (GDP), which still remain below the average for the rest of the developing world (UNDP 2007); a negative trade balance and a high level of debt (FMI 2008, CHEVALIER-DELANOUE & ROSSIGNOL-WINNER 2008).

— Structural and institutional issues: weak institutional and administrative capacities; fragmentary strategies and policies relevant to and supportive of CDM requirements; poor, unavailable or unreliable public information; lack of a stable legal and financial framework for foreign investment; absence of financing possibilities (UNFCCC 2006, 26th report of Executive Board). Among other things, there is therefore a real need for staff qualified in the technical and management domains required to set up projects satisfactory to CDM standards, both at African and international levels. Otherwise, some of the poorest countries lack the institutional capacity required in order to become potential host-countries (KIM 2003).

— CDM specific capacity issues: among other issues, there is a definite lack of CDM-related awareness and experience in relevant sectors, investment conditions and managing small scale projects. These failures seem related to a number of basic principles needed which are not fulfilled, such as activities related to poor information and weak capacity building, both of which are not well-developed.
— CDM process issues: these include facilities and procedures not being in place; complexity of processes and methodologies; high transaction costs; and lack of clarity with regard to the relationship of official development assistance involvement in the project cycle (UNFCCC 2007, 35th report of Executive Board). In particular, the process of assembling CDM projects is complex in the first place because of the long period required to accomplish it (UNFCCC 2002).
— African governance system issues: many African countries are characterized by political instability which causes several structural and organisational issues and compromises the governance system in those countries. Therefore much remains to be about governance in all African countries regarding economic stability, in order to reduce the high level of corruption and provide a politically stable climate. In fact, according to NOURY & SEKKT (2004), the risk of political conflicts discourages economic agents from investing.
— Uncertainty regarding the CDM process: there are currently several doubts about the CDM future after 2012, and also the uncertainty about the modalities of the continuation of this mechanism after the Kyoto Protocol deadline.
— Reticence of foreign investors: in this carbon market, investors fear the risk of investing in an uncertain climate in host countries. Otherwise, by reason of the law of supply and demand on the one hand, investors will give priority to large scale projects which maximize economies of scale and minimize transaction costs (MICHAELOWA & JOTZO 2005), and on the other hand, the easily replicable projects.

Those barriers have interrelations between them which can be taken as another significant barrier in this case. In fact, removal of one barrier may not be sufficient to encourage and/or increase investment in CDM project activities if other, more significant, barriers remain. For barriers mentioned above, those interrelations can be presented as shown in figure 2.

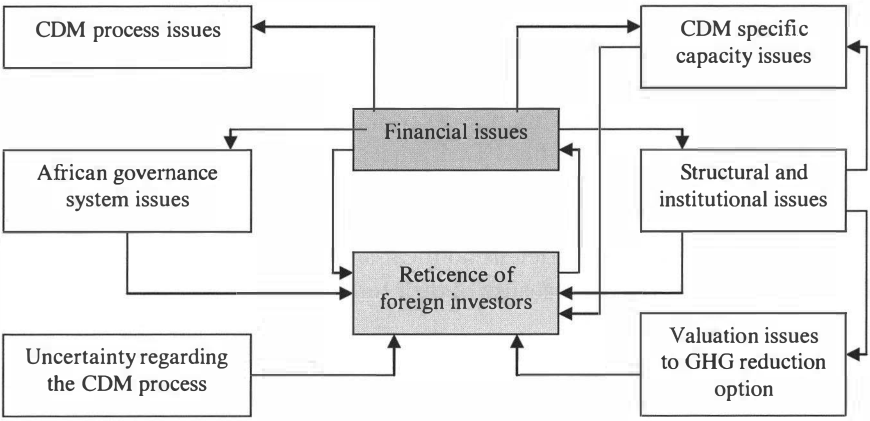

Fig. 2. — Interconnections between barriers (*source*: author).

6. Some Strategic Actions to Undertake

Some of these barriers can be removed or reduced by national governments, *e.g.* by changing domestic investment legislation or approval processes. Nevertheless, other barriers are more difficult to overcome, such as political and economic stability. Overcoming barriers to CDM projects in Africa, as well as in each other least developed country, can be undertaken at both levels: nationally and internationally.

National actions: at a national level, there is a wide range of actions that African governments could undertake locally to help raise interest in CDM project development. These encompass actions which facilitate investment in general, as well as improving the CDM specific framework and institutions, and could include among others:

- Encouraging and developing an enabling environment and framework for clean investment with stable fiscal and regulatory regimes and reforms in eligible sectors;
- Establishing and enhancing national designated authorities and building up their capacities in order to enable them to wield really their authority;
- Building up the capacities of local public and private economic actors, and developing capacities for local institutional actors;
- Establishing a national CDM committee in each country and developing a national CDM strategy locally, as tools which could help governments to develop the institutional framework related to CDM project activities;

— Establishing a group of national experts who should evaluate CDM projects potential in different sectors and their potential reduction in greenhouse gases;
— Providing an appropriate framework attractive to investment by establishing new laws related to the CDM process, *i.e.* one which is simple and transparent, in order to attract more foreign investors;
— Developing and maintaining an efficient institutional framework and trying to establish an efficient political and economic stability at a local level as far as possible, because of their influence on investment, especially foreign investment;
— Developing and launching an information and awareness programme for institutional and economic actors in all socio-economic sectors of countries on the opportunities for development and implementation of CDM project activities.

International actions: measures and policies undertaken or agreed by the international community can also influence the expansion and geographical spread of the CDM project activities. The following actions could be recommended:

— Modifying buyer/investor criteria on project location, type or size: the importance of centralised purchase of CERs increases the influence of a fund's criteria in shaping the geographical distribution of the CDM market as a whole. In fact, large buyers with development agendas have the ability to absorb risk and should increase their CDM activity in sectors where projects are highly replicable (Ellis & Kamel 2007).
— Clarifying the post-2012 climate regime: the post-2012 climate regime must be clarified in order to know if the CDM process could continue in one form or another after 2012. This allows the demand for CDM projects to be established as well as influencing the potential supply and value of associated credits. Otherwise, an unknown post-2012 regime will skew CDM activity towards low lead-time/large volume projects, which are sometimes concentrated in certain sectors and countries (Ellis & Kamel 2007).
— Information sharing and regional co-operation on CDM system: among the measures and policies that can help to promote CDM in Africa are the information sharing and regional co-operation. The international community should strive to promote such actions in all these countries where the CDM has not yet been developed.
— Supporting the developing countries: the international community should encourage all Kyoto Parties to cooperate bilaterally in order to develop and implement CDM project activities and in particular to facilitate a

South-South type of cooperation. It will be also desirable to encourage those Parties to try to stimulate investments in CDM projects in the context of their broader development and finance policies.

— Involving the private sector: the private sector has an important role to play in the CDM project activities process, so it is really essential to encourage financial institutions, in particular regional development banks, to provide seed funding to develop CDM project activities and to be actively involved in developing and promoting them, especially in Africa.
— Making incentive measures and policies: incentive measures must also be adopted to promote the CDM in Africa. Thus, given the current state of development and implementation of CDM projects activities in Africa, the Executive Board could establish a quota or bonus system on African certified emission reductions which could be one of the solutions to raising the rate of CDM projects in Africa.

7. Conclusion

The clean development mechanism created a new carbon market which could help developing countries to finance their economies. Nevertheless, its evolution has not produced the expected solutions, especially in the least developed countries in Africa.

Despite a rapid growth in worldwide transactions in carbon financing, an open challenge of the CDM remains its geographical distribution. The CDM projects located in Africa, especially in the sub-Saharan continent, are still neglected by commercial investors because of many barriers hindering the increased distribution of CDM projects in African countries as well as in other least developed countries.

Some additional measures and policies have been suggested which could be undertaken both at national and at international levels. Some of those changes in policy frameworks and enabling conditions could have a relatively rapid impact on CDM potentials and interest in different countries. But other potential actions highlighted above could have a longer-term effect on CDM potential and activity in particular countries or sectors.

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The Impacts of Climate Change in the Humid Tropics: Selected Hydrological Issues linked with Forest-Land Management

by

Mike BONELL*

KEYWORDS. — Climate Change; Land Cover Change; Precipitation; Runoff; Humid Tropics; Tropical Forest and Land Management; North-East Queensland.

SUMMARY. — Throughout the Fourth Assessment Report (FAR) of the IPCC (2007), a critical message is that global temperature increases will increase tropospheric water vapour and thus accelerate the hydrological cycle. Higher precipitation (both in amount and intensity) is expected in the tropics most notably in the South-East Asian monsoon region, the tropical Pacific Ocean and East Africa. Thus flood magnitude and frequency is also expected to increase which will enhance land degradation, and thus food and environmental security. On the other hand, most tropical regions have undergone dramatic land cover changes (LCCs) since the middle of the 20th century as a result of a complex array of non-climatic drivers (*e.g.* rapid demographic expansion, demands for agricultural land, socio-economic development). Such drivers have led to a progressive depletion of natural tropical forests. The FAR-IPCC acknowledged there was a greater uncertainty in the projected change in precipitation due to potential vegetation-climate feedbacks in the Amazon basin region (and the African Sahel outside of the humid tropics) where LCC is continuing.

Initially an overview of selected issues will be provided that challenge the hydrological community within the context of projected changes in precipitation and runoff in the humid tropics, as outlined in the FAR-IPCC. Brief attention will also be given to scale issues linked with the possible impacts of existing LCC on precipitation and runoff. The keynote will then focus on high rainfall intensity events, runoff and the consequences for forest-land management in the humid tropics. A fundamental message is that there is already scientific knowledge, and associated 'adapted' forest-land management practices (that have been adjusted in line with new scientific information), within tropical cyclone-prone regions of high rainfall intensity such as parts of the 'maritime continent' of the Western Pacific. Despite the current uncertainties in the

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GCM precipitation projections, there is scope for the transposition and adaptation of such knowledge from these very active meteorological areas to other parts of the tropics in preparation for an acceleration of the hydrological cycle. Use will be made of the example of Hurricane Mitch in Central America (October 1998) to highlight this point linked with work in the Wet Tropics Area of North-East Queensland, Australia.

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Malaria: Is Global Warming a Real Threat?

by

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KEYWORDS. — Malaria; Global Warming.

SUMMARY. — Malaria transmission is temperature dependent. Below the temperature of 18 °C, the development of malaria parasites in a vector mosquito is completely blocked, and between 20 and 30 °C transmission may increase considerably. Moreover, the survival and reproduction of the mosquito vector are enhanced when temperature and humidity increase. It is then not surprising that simplistic models announce a reintroduction of malaria as a consequence of global warming in temperate areas and an increase in other regions of the world, such as the highlands in Africa. This intuitive approach pleases the media and feeds some categories of "activists". However, the true mechanisms of malaria transmission can only be assessed by considering a multitude of variables, and temperature is only one of them. Principal determinants for malaria epidemics are ecological and societal changes. To evaluate the risk, soil occupation, housing conditions and human behaviour should be linked to the ecology and behaviour of the local vector. The relative importance of temperature is well illustrated in Europe, where micro-environments, such as overcrowded poor housing habitats, are in favour of the parasite development in the vector and this even during the winter months. In temperate Europe, malaria reached its peak period during the Little Ice Age (16th to 18th centuries). A brief recrudescence of malaria was even observed in Finland in 1941 among soldiers, and transmission occurred indoors during the winter period. Environmental changes (*i.e.* drainage, new agronomic practices), improved housing conditions, separate cattle sheds, urbanization and improved medical care eliminated malaria in Europe in the late 1950s. Nowadays, malaria vectors are still present and autochthonous malaria transmission cannot be excluded. However, under current economic circumstances it is unlikely that endemic malaria will be reintroduced in Europe. The driving force for increased malaria in the African highland can be attributed to the destruction of papyrus swamps replaced by irrigated fields required to face the explosive population growth. Absence of immunity, poor housing conditions, drug resistance and deficient health systems explain further the upsurge of malaria in the highlands. Vector control and case management are effective measures to disrupt the cycle of diseases-poverty, while simplistic predictions based only on temperature lead to resignation.

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Household Accessibility to Services and Resources in a Philippine Upland Community during the 2005 La Niña Season: relating Climate Change Impacts to Livelihoods

by

Marc Elgin DELGADO* & Frank CANTERS*

KEYWORDS. — Accessibility; Spatial Analysis; La Niña.

SUMMARY. — Global warming has increased the intensity and frequency of El Niño and La Niña events in recent decades due to warmer ocean temperatures. During La Niña conditions, major parts of the Philippines experience above normal rainfall conditions, including the increase number of tropical cyclone events that lead to flooding in coastal areas and landslides in the uplands. Communities living in the uplands are vulnerable to La Niña because heavy rainfall limits the accessibility of households to resources that are required to maintain sustainable livelihoods. In this study, a combined Participatory-Geographic Information System (P-GIS) and Sustainable Livelihoods (SL) approach was used to analyse the spatial accessibility of households to existing services/resources during the La Niña season of 2005 in Claveria, an upland community in the Philippines. The GIS-freeware programme Flowmap (ver 7.0) was used to measure accessibility. We focused the accessibility analysis on the important SL capitals that the community itself identified. Results showed that local people perceive accessibility in terms of monetary costs and not in distance units, thus we used this indigenous spatial representation in our outputs to increase their applicability among the stakeholders. Accessibility analysis revealed that people spend 50 to 60 % more than their daily per capita poverty threshold to be able to reach essential livelihood destinations, including services and infrastructures that will sustain their agricultural activities, provide educational and health support, and obtain basic social benefits. Various scenarios were investigated to improve accessibility in the face of climate change to highlight the practicality of our approach in policy-making and service planning for rural development.

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The GM Controversy is blocking the Development and Implementation of Novel, Environmentally-favourable Agricultural Innovations / Products

by

Dulce DE OLIVEIRA* & Marc VAN MONTAGU**

SUMMARY. — The Earth is warming up and, regardless of whether this is part of a natural cyclical trend or due to anthropogenic factors, this climate change will have a profound impact on environment and on mankind. The key question is: what as a community can we do to mitigate and adapt? We should consider climate change as an unprecedented opportunity to redesign our society and the way in which we interact with the environment.

Classical petroleum-based production of energy and chemicals will have to be replaced by biomass as raw material. There is no alternative. Genetically Manipulated (GM) crops will play an important and unavoidable role.

It is therefore urgent that scientists tackle the disinformation spread by the antiscience movements and explain to society and decision-makers that our economy and environment need GM crops.

Environment and Development

Environmental experts have produced robust scientific data indicating that the average global temperatures have steadily increased throughout the mid-20th century (IPCC 2007). There are of course disagreements as to whether this temperature rise is unprecedented or within normal climatic variations, and as to the extent to which human activities have contributed significantly to this temperature rise. While this may be an exciting debate in itself however,

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it fails to address the underlying issues. Simply put, the Earth is warming up, and regardless of whether this is part of a cyclical trend, or due to anthropogenic factors, these changes are likely to have a profound impact on the environment and on mankind. The key question therefore is: what as a community can we do to mitigate and adapt to the problems associated with climate change? Indeed, we should consider the phenomenon of climate change as an unprecedented opportunity to redesign our society and the way in which we interact with the environment.

The main problems associated with climate change are: how can we ensure food security for the ever-growing human population and how can we improve the quality of life of the four billion people who currently live on less than 3 € a day while at the same time preserving natural resources and biodiversity? Finally, on a global level, biodiversity continues to decline dramatically as natural ecosystems are being turned over to fields for the production of not only food and feed, but also bulk commodity products and biofuels [1]*.

There is little doubt that economic development as has been practised to date is damaging the natural environment. Despite this, our quality of life is critically dependent on the presence of a healthy ecosystem. For example, both food production and economic development require abundant sources of clean water and air, as well as fertile soils and an abundance of natural diversity. The rich plant biodiversity not only provides us with food fibre and energy, but is also a source of many life-saving drugs, helps to protect us from floods and soil erosion, functions as a sink for our wastes, and is able to buffer climate change through carbon capture and sequestration. The continuous degradation of our natural capital is thus jeopardizing mankind's prospects for global sustainable development.

These problems are however highly complex, and the solutions will require a fundamental shift in the way we perceive the world and our place in it. A situation whereby unrestrained economic growth occurs at the expense of the environment, at the same time that around one billion people are subsisting under conditions more fitting to the 14th century, is simply no longer acceptable. It is clear that the whole of humanity should be able to share equally in the economic, social and cultural benefits of our natural diversity. So, while preservation of our biodiversity is a priority, this is easier said than done and once again, the solutions will require concerted actions of different segments of society as well as the political will and commitment of all nations.

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* Numbers in brackets [ ] refer to the notes, p. 64.

The Costs of Agriculture

Agriculture is a major cause of environmental degradation. Practices such as deforestation and land clearing, cattle feedlots and the intensive use of fertilizers are estimated to contribute around one third to total human greenhouse gas emissions (GHS). At the same time, the agricultural sector remains most sensitive to climate change effects and will also be impacted first. Consequently, rural households will need to adapt to an increased frequency of extreme meteorological events, or in the longer term, even to completely new climatic conditions. It is expected that the tropics in particular will be affected by these changes and that this has the potential to wreak havoc in tropical production systems, with profound knock-on impacts on the livelihood of local impoverished populations.

Climate experts predict that the increase in global temperatures will also reduce the amount of land available for agriculture, as the rise in sea levels will submerge low-lying cropland and increase the risk of flooding (IPCC 2007). Climate change is also likely to reduce crop yields of much of the land currently under cultivation, creating a risk that food production will decrease just as demands are increasing. This is because the productivity of most major staple crops decreases sharply at temperatures much above 30 °C. For example, for each 1 °C increase in temperatures between 30 °C and 40 °C during flowering, there is a ~10 % loss in yield for maize, sorghum, wheat or rice. In addition, plants will develop faster at higher temperatures and do not have enough time to accumulate sufficient photosynthate in grains and fruits (FEDEROFF *et al.* 2010).

Our changing planet requires the widespread adoption of more efficient and sustainable agricultural practices to reduce the negative effects of intensive agriculture on the global environment, and at the same time to improve food security. The ability of agriculture to adapt and to withstand climate change is thus a pressing issue and success will depend on major investments across the entire rural value chain. In the case of low-input agricultural systems, constraints to crop growth and yield are so overriding that the impact of increasing temperatures is likely to be less significant and the application of existing agronomic practices such as improved crop, soil and water management practices will, even at higher temperatures, result in substantially higher yields. In any agricultural system though, closing the 'yield gap' [2] will require new innovations, be it in providing information and infrastructure or in generating new varieties that are better adapted to specific, local environments. In this context science and technology can make a substantial impact and it is essential to continue and strengthen the training of scientists in all these areas.

Environmentally-favourable GM Innovations

Agronomic strategies to alleviate the impact of climate change on agricultural production include: (i) a reduction of GHS; (ii) the generation of crops adapted to suboptimal or harsh environmental conditions; (iii) improved strategies for crop pest and diseases protection; and (iv) increased yields, especially under suboptimal growth conditions. Innovations in plant biotechnology are already making substantial contributions to all these fields and have the potential to do much more in the near future.

GHG Mitigation and Good Agricultural Practices

Agriculture currently accounts for around 14 % of GHG emissions, without taking into account land-use changes such as deforestation which contribute an additional 17 % (IPCC 2007). Sustainable land management practices can however help to minimize these GHG emissions while plant biotechnology can contribute the new varieties that will enable farmers to adopt more sustainable farming systems without loss of yields. Indeed there are GM plants already on the market that help to reduce agricultural CO_2 emissions. For example, GM insect-resistant crops (*Bt* crops) require fewer insecticide treatments, which means that less fuel is required for crop spraying, that CO_2 emissions are lower and there is a smaller ecological footprint. Similarly, herbicide-tolerant (HT) GM crops reduce fossil fuels as tractor usage for tillage is reduced.

Agriculture GHG emissions can be also reduced by 'trapping' CO_2 in the soil and soil carbon sequestration is now considered to be an important strategy to help combat increased atmospheric CO_2 levels. Agricultural soils, once depleted of the majority of their carbon stocks, have a significant CO_2-sink capacity and can thus help to reduce the return of CO_2 to the atmosphere. One recommended practice here is to reduce conventional tillage as non-till farming reduces the loss of CO_2 because the crop residues remain on the soil surface. This also enhances soil stability making it less vulnerable to erosion, which in turn also improves carbon sequestration by preserving its 'sink' capacity. The residues left on the soil surface by non-till practices also create a cooler and wetter soil microclimate which can be highly beneficial in warmer and drier climates. Here again, transgenic HT crops can be important contributors as they allow the farmer to adopt non-till farming.

Another important GHG is nitrous oxide (N_2O), which represents ~1/3rd of agricultural GHGs but which has a global warming potential around three hundred times higher than CO_2 (Stern review 2006). The interaction of common soil bacteria with nitrogen fertilizer results in the formation and release of N_2O and this production is more pronounced under wet conditions and when the availability of nitrogen exceeds plant requirements. Therefore, a decreased use of nitrogen fertilizer not only reduces ground and soil water pollution, but also reduces the formation of N_2O.

GM crops that are able to utilize soil nitrogen more efficiently have the potential to lower agriculture's environmental impact. Recently, the company Arcadia Biosciences [3] has developed a Nitrogen Use Efficiency (NUE) technology that enables GM plants to do just this. Field trials have demonstrated that NUE plants consistently achieve higher yields than conventional varieties with applications of up to 50 % less nitrogen fertilizer. This technology is currently being optimized for major staples such as canola, rice, wheat, corn, cotton, sugar beet and sugarcane. Since nitrogen fertilizers are a significant proportion of the farmer's costs, there are major incentives for growers to embrace this new technology. The benefits include reduced costs, enhanced yields and, at the same time, reduced GHG emissions and water pollution.

Crop Environmental Adaptations

Crop adaptation to altered climate conditions is probably more important than prevention, particularly as the significance of man-made contributions to changing weather patterns is still unclear. Regardless of the cause however, we need to address the problems of maintaining production under conditions of *e.g.* water limitation, drought and salinity. As it is, agriculture is already responsible for the consumption of ~70 % of the entire human freshwater consumption and this value is set to increase as global temperatures rise (DESA, CSD, *Agenda 21*). Associated with this, unsustainable irrigation practices also lead to the loss of farmland due to salinization.

Research on developing drought-tolerant crops is one of the most highly active fields in plant biotechnology. Both public research institutes and private companies are investing heavily in stress-tolerance programmes, and GM lines of maize, cotton, canola and soybean are already in field trials. It is expected that drought-tolerant maize varieties will be commercialized as early as 2011 (Reuters 2008). In addition, existing HT GM crops already present on the market reduce soil water losses since they require less ploughing before planting. Many similar products are likely to be released soon.

These include Canola plants engineered to contain reduced levels of the key stress-related protein PARP (poly(ADP-ribose) polymerase). In field trials, these plants showed yield increases of up to 44 % compared to wild-type varieties (DE BLOCK *et al.* 2005). Another promising approach is the use of transcription factors with pleiotropic effects across several stress-response pathways of the plant. These key regulatory genes have been shown to increase productivity by up to 30 % under water-deficit stress (CENTURY *et al.* 2008).

Agricultural systems will also have to adapt to the diminishing land surface areas. As temperatures rise, the area of land available for cultivation diminishes. On the one hand this is due to an increase in desertification and on the other, rising sea levels will submerge low-lying croplands. In addition, population growth and industrialization removes land from farms. All of these factors emphasize the importance of maintaining or increasing yields to cope with population growth under conditions of diminishing resources. Transgenic plants with improved biotic and abiotic stress resistance can make a significant contribution here by allowing crop production on land areas that are otherwise unusable, *e.g.* due either to disease pressures, pollution or soil degradation, or due to cultivation outside of the normal habitat of the crop species.

The Negative Impact of the GM Controversy

International organizations acknowledge that a second agricultural revolution is required to address the growing threats to global food security in the coming decades. This means that science and technology will have to introduce and implement innovations at a faster rate than as occurred during the Green Revolution of the 20th century [4]. Biotechnology, and advances in plant-breeding technologies are already making a huge contribution here, but it is important to highlight that the GM crops currently on the market have been developed by wealthy countries to address the needs of their own farmers, and that any potential benefits to poor, subsistence-level farmers are simply a spillover effect. Much more could and should have been done, especially as plant biotechnological research, funded primarily by public research institutions, has produced numerous breakthroughs that can help to alleviate many of the entrenched problems of impoverished nations, including hunger, malnutrition, diseases and environmental degradation (FARRE *et al.* 2009).

GM Regulation

However, the next step, the development of new products from the results of this research, is beyond the scope of public research institutions. Historically, it has been the private sector that has been responsible for the application of knowledge advances, and herein lies the shortcoming. Notwithstanding the large number of scientific breakthroughs, the rate of development of new biotech crops to tackle the problems of subsistence farmers is frustratingly slow, despite the fact that it has been repeatedly stated that there is a common *moral imperative* to ensure that pro-poor, pro-environment and pro-economy technologies find their way to those who need them the most. It is therefore absolutely essential that measures are immediately taken to achieve this fundamental humanitarian task. Specifically, we urgently need to: (i) increase funding for public sector programmes that aim to address the major constraints of poor farmers trying to provide a sustainable, sufficient and safe supply of foods. As outlined above, these include higher productivity, enhanced nutrition, improved disease and insect resistance, drought tolerance, increased fertilizer use efficiency, etc.; (ii) establish, promote and fund international cooperation networks to allow an efficient knowledge transfer to scientists of developing countries for the establishment of relevant crop improvement programmes; (iii) support existing breeding programmes and quality seed production systems, particularly in those developing countries where a strong seed industry is non-existent; (iv) develop the mechanisms to empower scientists of developing countries to allow them to participate in — and contribute to — the emerging global knowledge-based bio-economy; and last but not least (v) promote efficient, science-based regulatory frameworks for GM crop introduction, to avoid the costly overregulation that is currently limiting the introduction of pro-poor GM crops.

The cumbersome and costly regulatory infrastructure in particular is the major obstacle to the development and widespread adoption of new biotech crops. All our progress will be worthless if society is unwilling or unable to embrace the benefits of agricultural biotechnology. Unfortunately, critics of plant biotechnology have mounted an active campaign of misinformation and obfuscation around GM crops, claiming that their introduction will lead to a loss of biodiversity and that they have not been sufficiently tested. In fact, this is not the case. Despite intensive testing, absolutely no adverse effects of GM crops on consumer health or the environment have been substantiated; on the contrary, a number of potentially beneficial health and environmental effects have been noted. While the detractors continue to claim that GM crops are the monopoly of the multinationals and will only serve to enslave the Third World, the truth is that it is the developing countries that stand to gain most from this technology, particularly in times of a shifting climate. The adoption of GM crops will help these lands to stabilize agriculture production and to provide food and economic security to their populations.

The result of the present "anti-GM" environment is that GM crops are one of the most overregulated technology sectors in existence. It is therefore of critical importance to move beyond the populist, ill-informed biases against agricultural biotechnology and, instead, to develop transparent regulatory frameworks based on robust scientific evidence. This will help to lower the financial barriers of regulatory filings that are restricting the introduction of new biotech products to the market. These are currently so astronomical that only multinational firms are able to afford them. There is no SME or developing country that is able to develop and market a plant biotech product. For as long as decision-making bodies continue to ignore the science behind the rationale, threats to food security and health problems will remain in these regions.

However, it is also the responsibility of scientists to create the necessary channels to share facts and information with all the different stakeholders, and to provide a platform to openly discuss the concerns, benefits and opportunities associated with this new technology. Above all, we need to impress upon society at large that current agricultural techniques, be they classical or organic, are non-sustainable and highly detrimental to both the environment and biodiversity. GM crop-based agriculture remains our greatest opportunity for the development of a modern, environmentally friendly agriculture that is still able to meet the food needs of our ever-growing population [5]. However, only through cooperation and mutual understanding will it be possible to capture and develop the true potential of this exciting technology and to create a more liveable and environmentally stable society.

NOTES

[1] One dramatic example is the decline of forests in Malaysia, which is accelerating faster than in any other tropical country. The main cause is its conversion into rubber tree and oil-palm plantations.

[2] Yield Gap is the difference between realized productivity and the best that can be achieved using current management and genetic material (Godfray *et al.* 2010).

[3] http://www.arcadiabio.com/

[4] http://www.fao.org/newsroom/en/news/2007/1000646/index.html

[5] Actually biotechnology brings us as close as possible to the ideal agriculture system: a high-yielding organic agriculture.

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Combating Global Warming by planting Trees? Some Case Studies from Tropical Africa

by

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Keywords. — Plantation; Carbon Storage; Africa; Biomass; Forestation.
Summary. — Tropical forests contain half of the world's terrestrial biomass. Consequently, about 25 % of the terrestrial carbon is stored in tropical forests. Nowadays, as a part of the Clean Development Mechanisms of the Kyoto Protocol, carbon storage in plantations or natural forests can be used to receive carbon credits. Unfortunately, large inventories and long-term research are rare in tropical regions, especially in the natural forests of tropical Africa.

On the other hand, the use of plantations with known planting densities facilitates the estimates of volume and biomass. This study focuses on African plantations and presents the results of several planted forests in Ivory Coast and the Democratic Republic of Congo. Indigenous as well as exotic species with different planting schemes were analysed. Knowing the age of installation of the plantations, estimates of the annual biomass growth can be generated. The studied species are limba (*Terminalia superba* Engl. & Diels), afrormosia (*Pericopsis elata* (Harms) Meeuwen), teak (*Tectona grandis* L.), sipo (*Entandrophragma utile* (Dawe and Sprague) Sprague), tiama (*Entandrophragma angolense* (Welw. ex C. DC.) C. DC.), okoumé (*Aucoumea klaineana* Pierre), dibétou (*Lovoa trichilioides* Harms), bilinga (*Nauclea diderrichii* (De Wild.) Merr.), *Acacia mangium* Willd., *Acacia auriculiformis* A. Cunn. ex Benth. and the clone of the two *Acacia* species.

For most of the species, inventory data on diameter and height were available. Direct measurements of biomass are time-consuming and expensive. Therefore,

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the use of general models is accepted. The model of CHAVE *et al.* (2005) produces reliable biomass estimates, tested and validated for a large diameter range and based on diameter measurements and specific gravity. Measurements of specific gravity were made on xylarium specimens of the Royal Museum for Central Africa and compared with literature data before inserting them in the biomass model. The presented overview of carbon storage capacity of several plantation systems and possible species can provide a tool for decision-making in planning the establishment or transformation of plantations.

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Impact of Climate Change on the Ecological Functioning of Lake Tanganyika

by

Jean-Pierre DESCY*, S. STENUITE, S. PIRLOT, M.-A. HARDY, B. LEPORCQ, A.-L. TARBE, N. BERGAMINO, S. HORION, Y. CORNET, S. LOISELLE, L. ANDRE & P.-D. PLISNIER

KEYWORDS. — Climate; Large Tropical Lake; Productivity.

SUMMARY. — Studies published some years ago, based on comparisons of data 1975 and 2002, have shown a significant impact of climate change on the plankton and primary productivity of Lake Tanganyika. The authors of these studies believe that this reduction of primary production is related to water column stability, and that it may influence consumer production and fishery yield. This opinion has been challenged by other scientists, who reported estimates of plankton and fish production higher than those from earlier studies. Research conducted by Belgian laboratories, in the framework of studies supported by Belspo and FNRS, have allowed to bring new elements to this debate. The conclusions of these studies, based on in situ observations and on interpretation of satellite images, do confirm a decrease of primary production during the past decades, as well as a relationship between climatic variables and fishery yield. Furthermore, the present food web structure of the lake pelagic zone favours microorganisms of the microbial food web, and may result in a low trophic transfer efficiency and in a further decrease of consumer production.

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Wealth Increases for Burkinabe Households despite Climate Variability

by

Sarah D'HAEN* & Eric LAMBIN

KEYWORDS. — Society-Environment-Climate Interactions; Income Diversification; Rainfall Variability; Livelihood Strategies; Sub-Saharan Africa.

SUMMARY. — We suspect that the beneficial influence of current macro-economic and social trends tends to be underestimated in agricultural and rural models of household vulnerability to climatic variability in the Sahel. We claim that these trends provide Sahelian households with a range of opportunities to diversify their income generating activities. This income diversification allows them to decrease their economic vulnerability to potential adverse effects of climate variability. We consider that, even though household income might be affected by climate variations, overall household wealth does not suffer significantly from climate variability effects.

We analysed wealth and income generating strategies for agricultural and non-agricultural households for both rural and urban environments in Burkina Faso, using data from multiple national surveys between 1998 and 2005 (+/– 24,000 observations). Our results show that the majority of Burkinabe households increased their wealth between 1998 and 2005. We observed clear differences in wealth between urban and rural areas, between farmers and non-farmers, and between different regions in the country. We observed higher wealth for households who diversify more. We focussed on the differences in wealth between households with climate dependent diversification strategies and households with non-climate dependent strategies. We found that, even for farmers with no cattle and who cultivate only cereals, wealth improved significantly between 1998 and 2005. Our data suggests that diversification in most households is not associated with climate variability but rather with local and regional social and economical trends.

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Multilevel Framework to tackle Food Security Problems aggravated by Climate Change

by

Luc D'HAESE*, Valerie VANDERMEULEN**, Stijn SPEELMAN**, Pascal-Firmin NDMINIRA***, Marijke D'HAESE**, Annemarie DE WINTER**** & Jacinta LEMBA**

KEYWORDS. — Sub-Saharan Africa; Food Security; Climate Change (CC); Analysing Framework.

SUMMARY. — This article aims at providing a multilevel framework for analysing and tackling the effects of climate change on food security. Because adaptation to climate change is a complex issue, it needs to be looked at on various geographical levels (from the continental scale to the local scale) and on various levels of governance (subregional institutions, governments, local government, and households) (NIANG 2007). This study therefore analyses the different dimensions of food security (food availability, access, utilization and system stability) and their link with climate change at household, community and regional level. Given the vulnerability of the continent the focus will be on sub-Saharan Africa.

Introduction

The food price crisis of 2008 has fueled the debate on global food security and has questioned the feasibility of the Millennium Development Goals as set by the United Nations: reducing poverty and tackling malnutrition (LUDI

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2008). The first Millennium Development Goal combines halving the proportion of people suffering from poverty (< 1 $/day) and halving the proportion suffering from malnutrition between 1990 and 2015. The subtarget for the reduction in hunger and malnutrition is to reduce by half the prevalence of underweight children under five years of age, and to halve the proportion of the population that cannot secure a minimum level of dietary energy intake. It is estimated that currently one fourth of all children in developing countries are underweight, and therefore at risk of having future health problems (MDG monitor 2009). Malnutrition is closely related to food security and hunger and can be defined as "the situation when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO 2008). It contains four parts, namely food availability, food system stability, food utilization [1]* and food access. Although progress has been made in some parts of the world in recent years, overall the problem of food security and malnutrition is worsening (MDG monitor 2009).

It is furthermore troubling that even positive trends in food security achievements were reversed over the last few years due to increasing food prices (WIGGINS & LEVY 2008). Although different reasons for this are cited (rising demand for food worldwide, economic growth, urbanization, use of food crops for biofuel and inappropriate agricultural policy), supply disruptions are one of the main causes (United Nations 2008). Supply of food crops on the world market is increasingly limited due to crop failures caused by extreme weather conditions. This increased occurrence of abnormal weather conditions such as storms, persistent droughts and flooding, has been attributed to climate change caused by human activity. Climate change is also accounted responsible for global warming, increasing sea levels and changing seasonal patterns. Apart from affecting food availability, climate change impacts on the other three dimensions of food security, namely food accessibility, food utilization and food system sustainability (FAO 2008). By its negative effects on food security climate change endangers rural and urban livelihood, leading to disrupted supply chains, asset losses, falling purchasing power, health problems and the above-mentioned increasing food prices (FAO 2008).

This article aims at providing a multilevel framework for analysing and tackling the effects of climate change on food security. The different dimensions of food security (food availability, access, utilization and system stability) are

* The number in brackets [ ] refers to the note, p. 86.

analysed at three levels, namely, the household, community and regional level. Furthermore, adaptation to climate change is a complex issue that needs to be looked at from the standpoint of various geographical levels (from the continental scale to the local scale) and of various levels of governance (subregional institutions, governments, local government, and the people) (NIANG 2007). Because of the vulnerability of the continent the focus will be on sub-Saharan Africa.

At household level, the question can be asked which aspects of food security are particularly sensitive to climate change. Evidence is presented from recent household surveys in the north of Burundi. The determinants of the household's food insecurity are then linked to the impact of climate change. At community level, the research question focuses on how the outcomes of food security projects are affected by climate change. A survey carried out last year in Kenya enables us to compare the different approaches taken by five projects that attempt to improve food availability and access of households that are confronted with persistent droughts, a pertinent problem within the climate change context. At regional level, we question the relationship between food security, development policies and climate change.

The paper starts with a short elaboration on the link between food security and climate change. The next sections focus on the household, community and regional level, respectively. The paper ends with a discussion and conclusion on the issue of food security problems aggravated by climate change.

Climate Change and Food Security

Although the causes and impacts of climate change (CC) are much debated, there is no consensus on the exact definition of the term (LEMBA 2009). Within this paper we define climate change as long-term changes in average weather conditions, unrelated to what caused these changes. In this perspective, climate change is characterized by (FAO 2008):

— An increase in the global mean temperatures (such as an increase in maximum temperatures on hot days, increase in minimum temperatures on cold days or/and increase in annual occurrence of hot days);
— Gradual changes in precipitation (increase in frequency, duration and intensity of dry spells and droughts);
— An increase in frequency and intensity of extreme weather events (such as high winds, heavy rains, storms or floods);
— Greater weather variability (more pronounced seasonal weather patterns).

According to COHEN *et al.* (2008), particularly in the tropics and subtropics climate change will lead to more intense and longer droughts than have been observed over wider areas since the 1970s. In addition, the frequency of heavy precipitation events is expected to increase over most land areas and it is very likely that heat waves and heavy precipitation events will continue to become more frequent and that future tropical cyclones will become more intense (COHEN *et al.* 2008).

Looking at the definitions and interpretations, it is clear that climate change might affect each of the four parts of food security (SCHMIDHUBER & TUBIELLO 2007) (see also fig. 1).

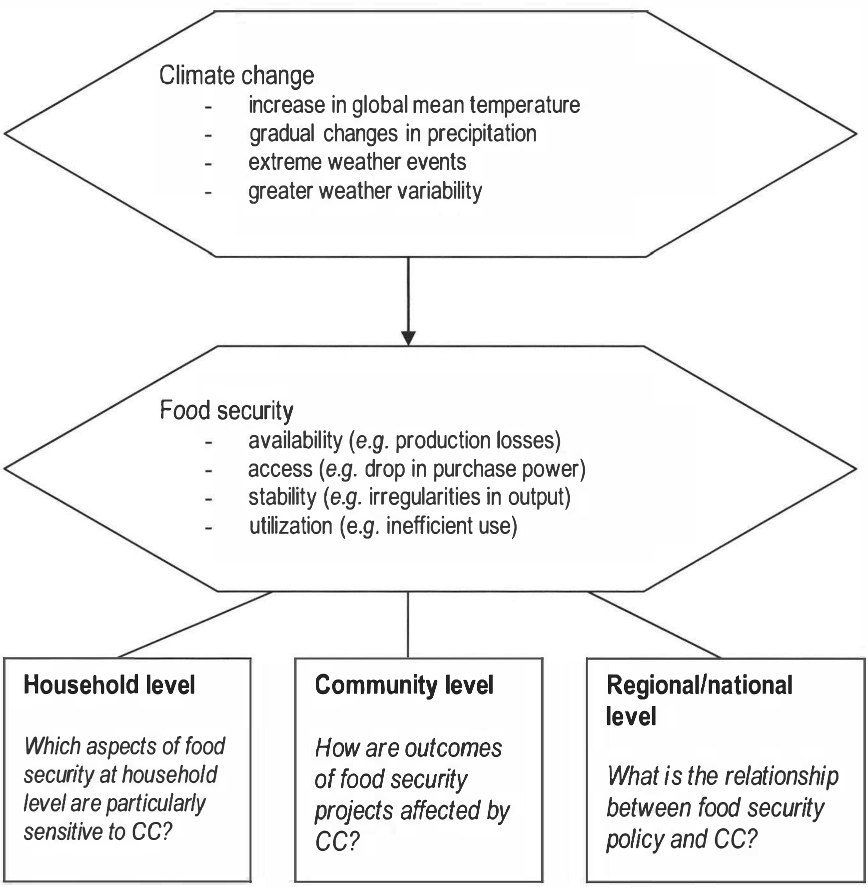

Fig. 1. — The relation between climate change and food security based on FAO (2008).

The impact of climate change on food production and **availability** can be directly caused by the changes in agro-ecological conditions (such as temperature and precipitation) or indirectly by affecting growth and the distribution of incomes which will lead to changes in the demand for food. Furthermore, climate-related animal and plant pests and diseases and alien invasive aquatic species will adversely affect the production of food. The actual impact of climate change and variability on food production (food availability) will be mixed and vary regionally (FAO 2008). According to LOBELL *et al.* (2008), Southern Africa and South Asia will suffer the most negative impacts on several crops that are important to large food-insecure populations. This is due to the fact that in seasonally dry and tropical regions, even small local temperature increases (1-2 °C) will lead to a substantial decrease in crop productivity which will reduce food availability (EASTERLING *et al.* 2007). Recurrent severe droughts in several countries in Africa over the past three decades illustrate the potentially large effects of climate variability on crops and livestock. It is projected that by 2020, between 75 million and 250 million people in Africa will be exposed to increased water stress due to climate change (COHEN *et al.* 2008).

Changes in the patterns of extreme weather events will not only affect the availability of food, but will also affect the **stability** of food supplies (COHEN *et al.* 2008). A reduction in the production potential of tropical developing countries, many of which have poor land and water resources and are already faced with serious food insecurity, may add to the burden of these countries (HITZ & SMITH 2004, FISCHER *et al.* 2005, PARRY *et al.* 2005).

Furthermore, climate change can affect the ability of individuals to **use food effectively**, by altering the conditions for food safety and changing the disease pressure from vector, water and food-borne diseases. The risk of flooding of human settlements may increase, from both sea-level rise and increased heavy precipitation in coastal areas. This is likely to result in an increase in the number of people exposed to diarrhoeal and other infectious diseases, thus lowering their capacity to utilize food effectively (COHEN *et al.* 2008). In this way a vicious circle of infectious diseases and compound hunger can be created.

Lastly, **access** to food will be limited by climate change because farmers earn less income out of agriculture and can therefore not buy all the food they need. In addition, climate variability and change will likely contribute substantially to rising food prices (CLINE 2007, LUDI 2008) although food prices are also heavily affected by macro-economic shifts. Through rising food prices climate change can limit the acquisition of appropriate foods for a nutritious diet and decrease the purchasing power of food aid programmes, in this way adversely affecting food access of households.

It is important to highlight various and heavy indirect effects from climate change. First of all, climate change might have an adverse effect on infrastructure. Due to an increase of difficulties in road and water transport modalities, operational costs for road transportation or shipping agriculture inputs and agriculture products will increase. Damages from climate change on energy infrastructure and on agro-industry infrastructure and equipment will have a significant negative impact on energy supply for agro-processing. This might lead to a negative impact on food production and supply, an increase in input prices at producer level as well as an increase in food prices at consumer level. Secondly, climate change may result in disturbances of the financing systems, most importantly of the rural- or microfinance systems. Disruptions in (agricultural) production may cause defaults of reimbursements from microfinance institutions' borrowers, bringing those institutions to high risk of falling in financial crisis or "bankruptcy" situation. The loss of these smaller financial institutions might jeopardize seriously the access of farmers as well as other households to the needed financing.

It is clear that food security based on agriculture is under significant threat from climate change (CGIAR Challenge Programme 2008). Mainly groups whose adaptive capacity is constrained, including smallholder and subsistence farmers, pastoralists, traditional societies, indigenous people, coastal populations and artisanal fisher folk, will suffer complex, localized impacts of climate change because they are highly vulnerable to extreme events (COHEN *et al.* 2008).

Household Level: Which Aspects of Food Security at Household Level are Particularly Sensitive to the Impact of CC and how do Farmers adapt?

The vulnerability of households to climate change is primarily determined by their dependence on agriculture. Environmental variations cause production and yield uncertainty, rendering farmers uncertain about the outcome of their productive activities (UPTON 1996). In many African countries the importance of agricultural activities, combined with the farming sector's reliance on the quality of rains during the rainy season, make the region vulnerable to food insecurity related to climate change (SHEWMAKE 2008). According to ADEJUWON (2006), the food security of these farm households is affected by the existent poverty, child dependence burden, health status and educational attainment.

It is very important to look at the current situation of farm households when wanting to discuss the impact of climate change. This has been put forward by, amongst others, SHEWMAKE (2008) who states that since climate change in the future is very uncertain and various scenarios are possible, more attention should be given to adaptation of households to the current climate. Although farm households seem to be aware of climate variability (BRYAN *et al.* 2009), they do not mention climate change as the main factor that drives them to adapt their strategy (MERTZ *et al.* 2009). A full understanding of the current vulnerability and how the complex structures evolve over the coming decades, is therefore necessary for developing strategies to cope with future climate change (BOHLE *et al.* 1994).

Up to now, farmers in Africa have always been faced with climatic variability and have developed adaptation strategies including crop diversification, mobility, livelihood diversification or migration. When confronted with a changing environment first minor adjustments such as diet changes or increased reliance on off-farm income sources are expected to take place, followed by the disposal of assets, notably poultry and goats and major shifts in practice such as outmigration (MOMBESHORA *et al.* 1995). Understanding this pattern is vital if external support is to complement local coping strategies. Non-farm income generating activities are critical to people's survival, both during drought and non-drought periods. Evidence from Zimbabwe (MOMBESHORA *et al.* 1995) shows that droughts prompted an expansion in trading activities and a widespread diversification of nonfarm livelihood activities, among men and women, as well as a shift in investment in agriculture. Other effects reported are scarcity of draught power following the death of many cattle and the inability of people to afford new animals. The negative effect of climate change on farm income also lowers investments in inorganic fertilizers and often leads to more intensive investments in home field plots using limited draught power and organic materials for soil fertility (MOMBESHORA *et al.* 1995). Understanding these patterns is vital if external support is to complement local coping strategies.

Within a study by VAN DE VELDE (2007-2008) on Burundi, it was found that food security (measured through the Household Food Insecurity Access Scale (HFIAS) developed by USAID (COATES *et al.* 2007)) and household's vulnerability are mainly determined by the household structure, the farm size, the production of food crops, the farming strategy, other income activities and investment costs (tab. 1).

Although VAN DE VELDE (2007-2008) mentions that the situation in Burundi has been particularly bad because of plant diseases, droughts and hail storms (which might be related to climate change), he did not immediately introduce climate change factors in his research. However, based on the definition of climate change and the relationship with food security as

Table 1

Food security, household factors and climate change (based on VAN DE VELDE 2007-2008)

Factor	Impact on food security	Possible relation to CC
Household size	More household members result in better food security status	None
Farm size (surface per household member)	The larger the surface, the better food security status	Decrease in land fertility
Crop diversification	More crop diversification leads to more food security	Change in crops, changed productivity
Farming strategy	Households with more diversified farming strategies have better food security status	Changed importance and productivity of certain farming activities (fores-try,...)
Off-farm income	Off-farm sector participation increases food expenditure but does not influence food security levels	Increased importance of off-farm sector, institutional development of viable rural non-farm economy
Investment costs	Households having access to drained or irrigated fields have better food security status. No clear link between inputs/ha and food security status	Need for more irrigation installations. Need for different more efficient inputs (seeds, pesticides)

described earlier, we can assume that climate change will enhance some of the difficulties that farm households are dealing with today and will even increase uncertainty. Changes in rainfall will call for different production systems of food crops, which have been shown to influence household food security. The unpredictability of certain weather changes might lead to the loss of some food crops. Changes in the general production environment will call for more and different investments, such as irrigation installations.

Community Level: How are Outcomes of Food Security Projects affected by CC?

Because of the high level of food insecurity in African countries, many food security projects have been developed in the past as well as today. The rationale for food security intervention is to enhance the outcome of food security by reducing exposure to shocks or risks or increasing the ability of households to manage shocks (LEMBA 2009). One of the occurring external risks or shocks, alongside the physical, political and social environment, is climate change.

Food security projects are mainly based on diagnosing community problems, consulting with development practitioners and forging linkages with research, extension, market (inputs, credit and output) and other organizations (public, health, water, social services). The idea is to facilitate the community to gain adequate access to livelihood resources (LEMBA 2009). In this way households can either improve food production or access to food can be ameliorated.

In order to estimate how such food security interventions are affected by climate change and how they can deal with it in a useful and effective way, we discuss a study executed by LEMBA (2009) in Kenya. The main objective of the study was to provide an intervention model for sustainable food security in Kenya's dry lands. Therefore, a research was set up in twenty-two Kenyan dry land districts. Quantitative and qualitative, primary and secondary data were collected amongst project managers and beneficiaries. Five different interventions on household food security have been selected and researched. Table 2 gives an overview of the five studied projects.

Table 2
Projects and activities (based on LEMBA 2009)

Project name	Activities
Makueni Agricultural Project (MAP)	Training of groups and individuals: water access, crop production, livestock production
ICRISAT project (ICRISAT)	Dry land crop technology
Community-based Nutrition Intervention Project (CBNIP)	Training of extension agents/training of community/transfer of technology
Kenya Rural Enterprise Programme (KREP)	Credits and savings
Kibwezi Irrigation Project (KIP)	Transfer of irrigation technology

To understand why certain interventions were ineffective in enhancing access to specific resources, respondents were asked to state the problems encountered during participation. It can be seen (fig. 2) that for the projects that aimed at increasing food security by improving agricultural production without focusing on water access (ICRISAT and CBNIP) insufficient rainfall is an important limiting factor. In this way, climate change, which is expected to increase the frequency of droughts, can have a highly negative effect on interventions, which theoretically are supposed to improve the food security status of participants. This result suggests that interventions aiming at increasing productivity should be designed with minimal expectation of rainfall or should include the improvement of the access to water as one of the project objectives. Another possibility is to focus on improved income level and stability (such as the KREP project) and thereby increase the access to food instead of focusing on food production. The analysis by LEMBA (2009) showed that this is an effective strategy for regions where irrigation is not an option.

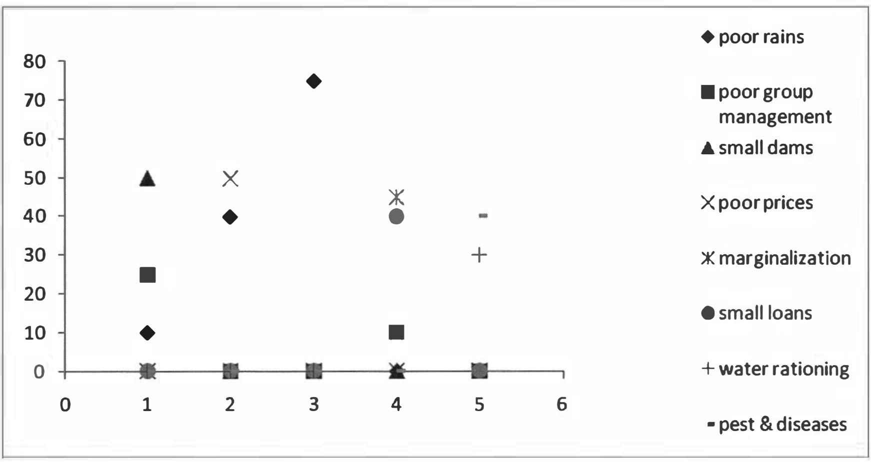

Fig. 2. — Problems reportedly encountered (percent) during participation in the interventions. Numbers 1-5 denote MAP, ICRISAT, CBNP, KREP and KIP interventions respectively.

National and Regional Level: What is the Relationship between Food Security Policy and Climate Change?

A traditional view on food security policy (or development policy in general) in the face of climate change is that climate change is a barrier to development while at the same time development is a threat to climatic conditions. Nowadays, policy and science accept that there is a more mutually dependent relationship between climate change and development policies (GARG *et al.* 2009). In many cases climate change policies can go hand in hand with other development activities because they jointly support the same goals (HALSNAES & TRAERUP 2009).

On the one hand (relation 1 in fig. 3), climate change affects development policies (HALSNAES & TRAERUP 2009). GARG *et al.* (2009) mention how the achievement of vital national development goals are often adversely affected by climate change. Halsnaes and Traerup state that "key goals related to poverty reduction, water, food energy, education and health are critically influenced by climate change", and that "adaptation measures therefore should be tackled in the context of development policies" (HALSNAES & TRAERUP 2009). Policies on food security should include climate change, *e.g.* by encouraging agronomic research, providing irrigation or increasing its efficiency, maintaining or improving flood control and facilitating human migration (DARWIN 2001). At state level, this kind of support implies the creation of an enabling environment of development and maintenance of key social infrastructures: roads, health and education as well as budgetary allocations to development activities at community and institutional level. In sum, improved systems of food production, distribution and access may all contribute to systems adapted to cope with climate change (GREGORY *et al.* 2005). The policies at national and regional level will serve to support and regulate interventions upon which local development objectives can be built. These local objectives are not uniform due to the multiple factors affecting food security (ERIKSEN & LIND 2009).

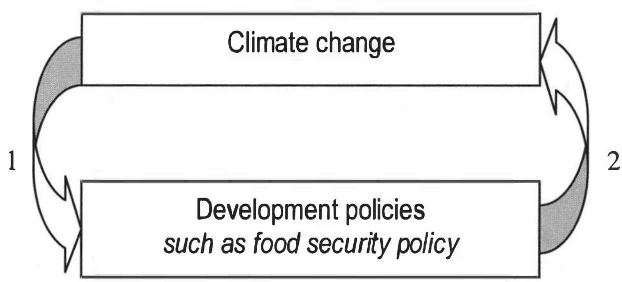

Fig. 3. — The mutual dependent relationship of climate change and development policies.

On the other hand (relation 2 in fig. 3), existing and realized development policies might have an impact on many aspects of climate change. These impacts can be positive or negative. GARG *et al.* (2009) have found, based on an Indian case study, that improving some development variables can reduce the adverse impacts on the system due to climate change. For example, by increasing and stabilizing food production within a region air pollution caused by transportation of food from elsewhere might be reduced. However, other development or food security variables may exacerbate the impacts of climate change on society if the variables themselves produce a negative impact on the system. For example, by supporting the exploitation of industrial food processing without taking into consideration the environmental impact of this industry. According to HALSNAES & TRAERUP (2009), development policies should be implemented in such a way that they at least do not increase the problems around climate change. Within the development and climate paradigm this relationship is taken to a next level stating that development is the driving force, the key element for combating and dealing with climate change (GARG *et al.* 2009).

This means that African as well as other developing countries' governments need to integrate their response to climate change fully into economic planning and management. Because of its local nature, adaptation to climate change requires approaches centred on local communities and national plans of action. But given the scale of the problem, local and national approaches alone are inadequate. It is crucial that regional solutions be found for regional issues, particularly in confronting transboundary challenges that individual states cannot face alone (IDRC 2007). Many African countries have shared environmental concerns, and in some cases, share natural resources and membership in the same regional and subregional organizations (IDRC 2007). Therefore dealing with climate change will also demand regional coordination.

African countries have to deal with many difficulties in integrating adaptation concerns into national or regional policy. The staff capacity for planning, monitoring and evaluation is low; data on adaptation options is limited and mechanisms for information sharing and management across sectors is lacking; and the awareness of adaptation to climate change among stakeholders and the population is limited. Other factors that exacerbate the overall level of vulnerability in sub-Saharan Africa include the political instability, widespread illiteracy and poverty of the rural population (UNFCCC 2007).

A way to improve the capacity of **national** governments to develop climate change adaptation policies is by initiatives such as National Adaptation Programmes of Action (NAPAs) from the United Nations Framework Convention on Climate Change. The NAPAs should be seen as an essential step in the development of adaptation capacity of developing countries. They provide the means and tools essential for the developing countries to present and negotiate a country-driven action programme. In many countries the NAPAs have been effective to raise awareness at least among national stakeholders, and to put climate change adaptation on the development agenda (OSMAN-ELASHA & DOWNING 2007).

At the **regional** level the African Union and its regional economic communities such as COMESA can play an important role as continental building blocks, elaborating a common vision and a shared conviction on a path of sustainable growth and development. They can act as instruments to ensure full integration of climate adaptation and mitigation measures in the region's development agenda (NIANG 2007).

One such regional African initiative is the "Combating Climate Change in Africa" programme within the plan of action of NEPAD (New Partnership for Africa's Development). This programme revolves around three priorities:

— Ecosystems, regions and people most vulnerable to climate change need to be identified;
— Adaptation strategies need to be developed for the identified regions and sector;
— Demonstration and pilot projects need to be implemented to show the way forward.

Simultaneously, capacity-building support will have to be provided to enable important institutions to function effectively (NEPAD 2003).

Although it is too soon to evaluate the real impact of such initiatives, they look quite promising for helping Africa to reduce the impact of climate change by creating a regionally integrated action approach.

Discussion and Conclusion

Writing about food security policy in relation to climate change is not an easy task. Both concepts cannot easily be defined and both are characterized by having multiple sub-layers. More importantly, it is clear that they are interconnected. The article has tried to give a short overview of three levels in which the confrontation between climate change and food security is remarkable.

At household level, we have found that although climate change has been acknowledged by many households in developing countries (BRYAN *et al.* 2009), they are more concerned about the current climate impact on food security than the expected future evolutions (SHEWMAKE 2008, MERTZ *et al.* 2009). Households in Zimbabwe (MOMBESHORA *et al.* 1995), for example, have changed and diversified their activities because of droughts in the region. Furthermore, environmental and climatic characteristics within a region are not the only important aspects that affect the food insecurity of a household. Food security is, based on a case study in Burundi, influenced by the household structure, income activities, farm size, farm strategy, production of crops and investment costs. Most of these characteristics are extremely vulnerable to climate change.

At community level, we have found that climate change should be included in food security projects as an important external risk or shock, alongside the physical, political and social environment. This importance has been demonstrated with a case study in Kenya, which has shown that the success of a project is very vulnerable to the direct impact of climate change on production and food access.

At regional level, we have described the interrelation of different policy actions. We have concluded that there needs to be a policy developed that takes into account climate change as well as development and food security issues; and this at different policy levels. Thereby a positive vicious circle can be created of improving food security and dealing with climate issues.

At all levels it is clear that an integrated approach is necessary in tackling food security problems aggravated by climate change. A multilevel framework should be built that encompasses various geographical levels (from the continental scale to the local scale) as well as various levels of governance (subregional institutions, governments, local government, and the people). Although climate change is often assumed to have negative effects on food security by endangering rural and urban livelihood, leading to disrupted supply chains, asset losses, falling purchasing power, health problems and the above-mentioned increasing food prices (FAO 2008), the short overview given in this article tells us that there might also be a positive relationship between climate change and food security. In fact, an improvement in food security might lead to a drop in climate problems and this drop might in turn lead to fewer problems with food security.

NOTE

[1] When the aspect of utilization is considered, some authors (for example BENSON 2004) use the terms nutrition security instead of food security.

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An Agent-based Model to understand Climate Change Impacts on Livestock in Southern Africa

by

Elise DION* & Eric LAMBIN

KEYWORDS. — Agent-based Modelling; Epidemiology; Landscape; Foot-and-Mouth Disease; Climate Change Scenarios.

SUMMARY. — We have developed an agent-based model (ABM), EPI-FMD, to better understand the spatial and temporal dynamics of pathogens between human/livestock/wildlife interfaces. The study area is situated at the fringe of a large wildlife conservation area.

An ABM is a simulation tool representing interactions between multiple agents on a spatially-explicit environment (FERBER 1999). The spatial and temporal distribution of these agents and their interactions is taken into account through a set of independent rules, which define their behaviour and their interactions with other agents. The model integrates environmental factors like land cover, topography, distance to rivers, vegetation. Disease transmission emerges from multiple local-scale interactions between individuals and their environment (AUCHINCLOSS & DIEZ ROUX 2008).

This model, derived from empirical data, is focused on the transmission of foot-and-mouth disease at the interface bordering the Kruger National Park (KNP) in South Africa, where African buffaloes (*Syncerus caffer*) spread the disease and are responsible of outbreaks in cattle herds. Wildlife and cattle are separated by a fence but it is permeable given that it is regularly damaged by various physical, socio-economic or climatic factors.

This analysis will allow exploring the dispersal of the foot-and-mouth virus through space and time to elaborate risk maps. Various scenarios are tested by simulation. The consequences of climatic changes on disease transmission in the study area are explored. For example, climatic factors significantly affect contact rates of animals through increase density and species range of population around water holes during droughts and by controlling fluctuations in population size and density (REDFERN *et al.* 2005). The scenarios estimate the sensitivity of FMD transmission to various factors and landscape changes on transmission risk. One clear advantage of ABM is to explore a wide range of assumptions. This model will be easily adapted to a larger transmission context of contagious non-vector borne disease.

This project is part of the broader EPISTIS project, funded by the Science Policy, and conducted with several partners in Belgium and South Africa.

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Greening Chemical Protocols for the Preparation of Novel Potential Antimalarial Candidates

by

Delphine FORGE*, Annie MAYENCE*, Périne NORMAND*, Florent PERON*, Aurélie PIETKA*, Marie SCRÈVE*, Dimitri STANICKI* & Jean Jacques VANDEN EYNDE*

KEYWORDS. — Drugs; Environment; Green Chemistry; Malaria; Pollution.

SUMMARY. — Decreasing waste production and preventing environmental pollution at all levels of the life cycle of a (chemical) product, from its conception to its destruction, represent real contributions to the fight against global warming and motivate scientists who are engaged in the development of a (more) sustainable chemistry. That leads us to design innovative experimental procedures affording drugs and drug candidates for the treatment of malaria, and other (tropical) diseases, under environmentally friendly conditions.

1. Introduction

For several years our department has focused a large part of its activities on the exploitation of the principles of green and sustainable chemistry to access drugs and drug candidates (VANDEN EYNDE & MAYENCE 2000). Among those drugs, mention should be made of pentamidine (fig. 1), which is clinically used to cure *Pneumocystis carinii* pneumonia, leishmania, and human African trypanosomiasis (sleeping sickness). It is also a drug candidate of interest to fight malaria. However, the substance is plagued with severe drawbacks including poor bioavailability and toxic side effects. In our efforts to identify novel more potent and safer analogs, we have recently demonstrated that other bisbenzamidines (fig. 1) and some bisbenzimidazoles (fig. 1) can act as highly promising antiplasmodial agents efficient against both chloroquine-susceptible

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and chloroquine-resistant strains of the parasite responsible for malaria (MAYENCE *et al.* 2004, 2008). In order to further develop some leads, it is important to conceive experiments enabling to prepare the expected derivatives in high yields, at low cost, and under benign conditions.

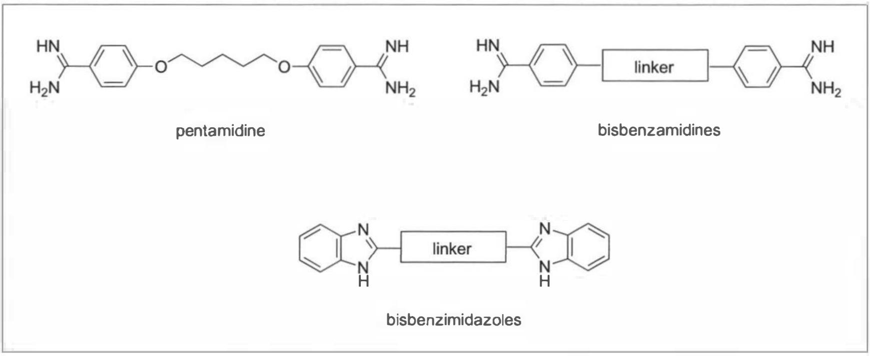

Fig. 1. — Chemical structures of pentamidine and some promising leads to treat tropical diseases.

2. Green and Sustainable Chemistry

In response to the poorly fair image of chemistry among the public, there is a huge current of ideas aiming at demonstrating that health protection and well-being on our planet are certainly not in conflict with the capacity of the chemists to create or transform molecules. That movement is now recognized under the names of green chemistry, sustainable chemistry, chemistry for the environment, environmentally friendly chemistry, environmentally benign chemistry, and other similar denominations. That novel branch of chemistry has nothing to do with ecology or chemistry of the environment. It is primarily exploited to design procedures preventing pollution and limiting waste. It requires boldness, innovation, and creativity because most of the established protocols and manufacture processes have to be reconsidered in order to become green. For the "Organization for Economic Cooperation and Development" (OECD), sustainable chemistry is "the design, manufacture, and use of environmentally benign chemical products and processes to prevent pollution, produce less hazardous waste, and reduce environmental and human health risks" (OECD web site).

It is quite difficult to define the birth date of green chemistry. Somehow, green chemistry can be considered as the achievement of a long process that probably started at the end of the 1960s when the pollution level of the Cuyahoga river (Ohio, USA) was so high that the river caught fire. The chemical disasters of Seveso (Italy) in 1976, Bhopal (India) in 1984, and Toulouse (France) in 2001 are also important milestones that led to environmental policies including the Clean Air Act, the Pollution Prevention Act, The Seveso directives, and, more recently, the REACH regulation. Mobilization of governments must also be underlined since they initiated *e.g.* the conferences of Rio in 1992, Kyoto in 1997, Bali in 2007, and Copenhagen in December 2009. But, beside these political responses, chemists also declared their will for a better control of chemical substances and their use. The first conference on green chemistry on the European continent was held in Venice (Italy) in 1997. In 1998, Paul Anastas, from the US environmental protection agency, and John C. Warner, from the university of Massachusetts at Boston (USA), published the twelve principles of green chemistry that are reproduced hereafter (ANASTAS & WARNER 1998):

- Prevention: it is better to prevent waste than to treat or clean up waste after it has been created.
- Atom economy: synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final products.
- Less hazardous chemical syntheses: wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
- Designing safer chemicals: chemical products should be designed to preserve efficacy of function while reducing toxicity.
- Safer solvents and auxiliaries: the use of auxiliary substances (*e.g.* solvents, separation agents, *etc.*) should be made unnecessary wherever possible and innocuous when used.
- Design for energy efficiency: energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.
- Use of renewable feedstocks: a raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.
- Reduce derivatives: unnecessary derivatization (use of blocking groups, protection/deprotection, temporary modification of physical/chemical processes) should be avoided whenever possible.
- Catalysis: catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
- Design for degradation: chemical products should be designed so that at the end of their function they do not persist in the environment and break down into innocuous degradation products.

— Real-time analysis for pollution prevention: analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.
— Accident prevention: substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

These principles of green chemistry were followed by the twelve principles of green engineering (ANASTAS & ZIMMERMAN 2003), which enable to enlarge the concept from laboratory scale to manufacture plants. Therefore, we can now hope and expect a thorough modification of the judgement of scientists and decision-makers to encourage and support the spread of a new age of chemistry.

More information on sustainable chemistry can be found on the web sites of the organization for economic cooperation and development, the Japan chemical innovation institute, the US environmental protection agency, the American chemical society, the interuniversity consortium of chemistry for the environment (Italy), and the royal society of chemistry (UK).

3. Global Warming, Tropical Diseases and Green Chemistry

As a consequence of global warming and the intensification of exchanges around the world, it is now widely admitted that tropical diseases are slowly invading regions of the planet that were not affected a few years or decades ago. Developing countries as well as industrial countries located outside the tropics are not exceptions anymore and their populations are actually facing new threats of epidemics. Malaria is among those temperature-dependent sicknesses, that have been illustrated during this symposium by Marc Coosemans, one of the invited speakers.

A problem in the treatment of malaria is that *Plasmodium falciparum*, the deadliest parasite responsible for the disease, has been able to adapt itself to chloroquine and some other drugs used in prophylactic and curative medications. Therefore there is still a need for novel substances allowing to fight both the resistant and susceptible strains of the parasite.

Pentamidine (fig. 1) is an old drug tested by Lourie in Sierra Leone at the end of the 1930s for the treatment of sleeping sickness (LOURIE 1942). It is still in clinical use to cure that disease and it is also prescribed in the cases of leishmania and *Pneumocystis carinii* pneumonia. In addition the compound also emerged as a drug candidate exhibiting activity against several strains of *P. falciparum* but it is plagued by a poor bioavailability (BELL *et al.* 1990). That means that it cannot be administered in the form of pills but rather by injections. Such a situation prohibits its use as an antimalarial.

Consequently, some research groups, including our laboratory, have demonstrated that several substances that are structurally related to pentamidine also constitute promising potential antimalarials. A first series of congeners includes numerous bisbenzamidines in which the aromatic moieties are linked by flexible or rigid spacers. Whichever the spacer is, one of the key steps in the preparation of those derivatives is the transformation of a nitrile function into the amidine group. Classically that transformation is effected by the so-called Pinner reaction (fig. 2) that involves the conversion of the nitrile into an imidate, by the action of an alcohol and gaseous hydrochloric acid, followed by a reaction with ammonia or an amine (PINNER & KLEIN 1877). Use of gaseous hydrochloric acid is obviously not a green operation. That prompted us to study a thio-Pinner reaction based on the work of LANGE *et al.* (1999). In that thio-Pinner approach, the acid and the alcohol are replaced by a thiol, namely N-acetyl cysteine. This is an odourless experiment that can be performed under neutral conditions. A source of ammonia, in the form of an ammonium salt, is directly introduced in the reaction medium, thus reducing the sequence to one step only. Hydrochloric acid is no more required, reaction times are reduced, energy is saved, and the N-acetyl cysteine could be recycled. The scope of the thio-Pinner approach is under study in our laboratory.

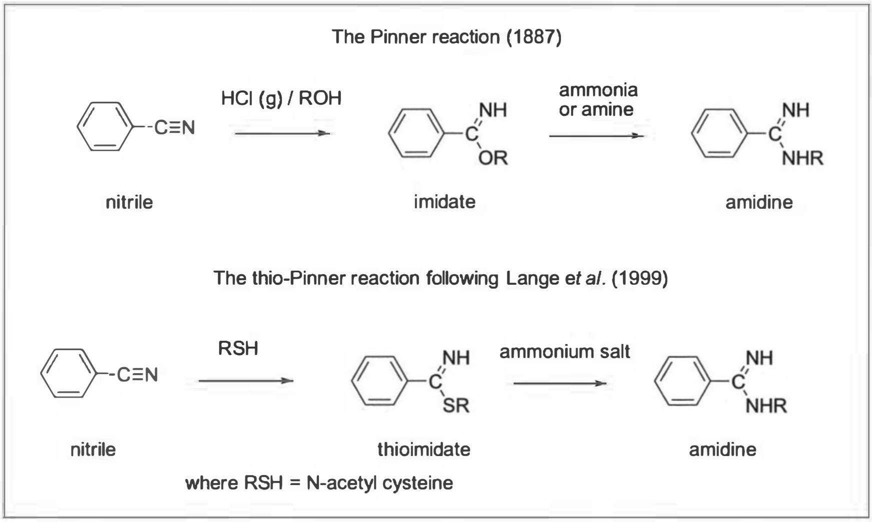

Fig. 2. — Greening preparation of amidines derivatives.

More recently, we claimed in a patent application that the bisbenzimidazoles skeleton depicted in figure 1 emerged as an interesting hit deserving further development (MAYENCE *et al.* 2008). Among the challenges to be accepted it is necessary that the procedures affording those drug candidates are characterized by high yields and low cost. This is because it is generally considered that the price for a treatment of malaria in developing countries cannot exceed 1 US $. Our current work demonstrates that experiments exploiting the principles of green chemistry enable to fulfil those requirements. Indeed we are considering the possibility of limiting the amounts of organic solvents used in the preparations. That obviously reduces the cost of the process, slows down the depletion of fossil resources because most organic solvents are derived from the petrochemical industry, and decreases pollution risks because less substances are displaced, stocked, or manipulated. It should be mentioned that solvents are often used in quantities exceeding 100 fold those of the reacting species. In another process we are studying, we are favouring the use of readily recyclable materials (catalysts and auxiliaries) to prevent accumulation of waste. Finally, we are frequently considering the possibility of performing the experiments by shifting from conventional heating to microwave-assisted heating. There are several advantages in the use of devices allowing to rise up the temperature of a reaction medium through microwave irradiation. Indeed the ramp leading to the expected final temperature is often limited to a very short period, by far shorter than that associated with a conventional heating. Moreover, microwave-induced heating requires less power so that globally it is an energy-saving procedure. It has also been proved that chemical transformations performed in a microwave oven or a similar device (it can be a flow system) frequently afford the expected compounds in higher yields than when performed under conventional conditions. In addition, fewer side-reactions occur so that a higher purity of the final derivatives is also often observed, thus reducing or even eliminating the number of operations and the amounts of solvents required to purify the targeted substances.

4. Conclusion

Although contributions of the chemical industry to global warming cannot be denied, scientists now have tools in hands allowing to transform molecules under environmentally friendly conditions. Those tools belong to a movement called green and sustainable chemistry and aiming at prevention of pollution and waste accumulation. In our laboratory we exploit them to design and prepare drugs and new drug candidates for the treatment of malaria and other diseases mostly affecting populations of developing countries.

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http://www.oecd/org/documentprint/0,3455,en_2649_34375_1909638_1_1_1_1,00html

The Japan chemical innovation institute
http://www.gscn.net

The US environmental protection agency
http://www.epa.gov/greenchemistry

The American chemical society
http://www.acs.org

The inter-university consortium of chemistry for the environment (Italy)
http://www.incaweb.org

The royal society of chemistry (UK)
http://www.rsc.org/Membership/Networking/GCN/index.asp

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Impacts of Climate Change on Tropical and Subtropical Ecosystems

by

Louis FRANÇOIS*, E. FAVRE*, A. HENROT*, M. DURY*, P. WARNANT*, M. OUBERDOUS* & G. MUNHOVEN*

KEYWORDS. — Vegetation; Tropical; Subtropical; Climate Change; Modelling.
SUMMARY. — Climate change projected for the 21st century will have significant impacts on tropical and subtropical ecosystems. The temperature rise will be lower in these regions than in higher latitudes. Precipitation and soil moisture variations, both in average and extreme values, will thus probably be the most important factor of change in these ecosystems. Some areas will undergo reduced precipitation with more severe and/or more frequent droughts, while precipitation will increase in other regions. Regions with more severe droughts will also be affected by an increase of wildfire frequency which may have large impacts on vegetation density and distribution. Other changes will also arise from the sea-level rise, especially in the mangrove ecosystems. These various changes will lead to a redistribution of the major tropical and subtropical biomes and, if their amplitude is too large, they may cause species extinction, inducing severe loss of biodiversity. The CARAIB dynamic vegetation model forced with 21st century climate scenarios of the IPCC will be used to illustrate and analyse these potential impacts of climate change on vegetation distribution and species habitat shifts in tropical regions. The plant classification of this model has recently been improved to better describe tropical and subtropical plant vegetation types.

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Deficit Irrigation Guidelines by using Crop Water Productivity Modelling as Decision Support

by

Sam GEERTS*, Magali GARCIA** & Dirk RAES*

KEYWORDS. — Deficit Irrigation; Crop Water Productivity Modelling; AquaCrop; Drought Stress.

SUMMARY. — One of the effects of global warming is the increase of climate extremes in various parts of the world. In many of those locations, droughts are increasingly occurring with negative consequences on food security. To tackle the problem of increased drought in agriculture, guidelines for sustainable alternatives should be prepared. Knowing that developing countries are most vulnerable to external shocks, these countries should be targeted when investigating possible solutions.

As an example, this study presents the case of quinoa (*Chenopodium quinoa* Willd.) in the Bolivian Altiplano. This is a high altitude region with very harsh cropping conditions. Frequent droughts cause yield gaps in rain-fed quinoa cultivation, and therefore pose a direct thread on livelihood security. A possibility to stabilize yields is applying deficit irrigation (DI). Field experiments carried out at various locations in the region (2004-2007) demonstrated that deficit irrigation can result in reliable quinoa yields and a high crop water productivity (WP). By limiting water applications to drought-sensitive growth stages, DI aims at maximizing water productivity and at stabilizing — rather than maximizing — yields.

In these fleld experiments with different drought levels and irrigation strategies, the technique of DI was optimized for quinoa in the regions. With the same data, a crop water productivity model could be calibrated and validated, namely AquaCrop, the new crop model from FAO. With crop models, one is able to assess the conjunctive effect of the different environmental factors on crop yield.

In the present study the validated AquaCrop model is used to simulate yields of quinoa for long series of historical climate data (> 30 years) for representative locations throughout the Bolivian Altiplano. Biomass levels at the start of the critical growth stage (flowering and early grain filling) were derived and subjected to frequency analysis to derive expected biomass levels after dry, normal and wet conditions during

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the vegetative stages. From the start of the critical growth stage onwards (flowering and early gram filling), three weather conditions (dry, normal and wet) were simulated, starting from the previously derived partial biomass levels in the vegetative stage. For the three weather conditions, optimal quantities of deficit irrigation could be derived to avoid water stress during the sensitive growth stages. By summarizing these results in easy readable charts, they become useful at policy, extension and farmer level. If extrapolated to other crops and regions, the presented methodology can be a simple and illustrative decision support tool for sustainable agriculture based on DI in countries with limited water resources, facing increased drought risk due to global warming.

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Prediction of N_2O Emission from Tropical Forest: a Modular Biosphere Simulation Environment (MobiLE) Approach

by

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KEYWORDS. — Biogeochemical Model; N_2O Emission; ForestDNDC-tropica; Tropical Forest.

SUMMARY. — With regard to global climate change, soils are of significant importance as sources for atmospheric trace gases such as nitrous oxide (N_2O). Tropical forest soils account for 18 % of the global N_2O emission. Furthermore, various studies have shown that the magnitude of N_2O emissions from tropical forest soil is highly variable on spatial and temporal scales. To contribute towards more reliable estimates of the N_2O emissions from tropical forest ecosystems, detailed biogeochemical model, ForestDNDC-tropica, has been modified and parameterized to simulate C and N turnover and associated N_2O emission from tropical forest ecosystems. The biogeochemical model consists of submodels for the simulation of soil climate, decomposition, plant growth and N-trace gas production, consumption and emission. This simulation is done by considering soil properties (texture, soil organic carbon, mineral soil pH and bulk density), vegetation parameters (above-ground biomass, wood mass, leaf mass and floor mass) and climate data (daily precipitation, minimum and maximum temperature). Recently, global N_2O emissions have been simulated for tropical forest soils (0.9-2.4 Tg N yr-1) (WERNER *et al.* 2007) using this biogeochemical model. However, for tropical ecosystems measured trace gas fluxes (for model validation) are extremely scarce. Moreover, also model driving variables are only available on a large spatial resolution.

The overarching goal of this project is to assess the effect of spatial resolution of the model driving variables (soil, vegetation and climate data) on the quantity and quality of N_2O simulations. Our study site is located in the Nyungwe forest, a national park situated in the southwest of Rwanda between latitudes 2°17' and 2°49'

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south and between longitudes 29°03' and 29°29' west. This forest occupies an area of about 100,000 ha in a mountainous landscape with steep slopes, separating the Nile and the Congo catchment. The vegetation between 1,900 and 2,250 m altitude is characterized by *Entandrophragma excelsum, Parinari excelsa, Prunus africana* and *Octotea usambarensis*. The soil and climate data of Nyungwe forest is to our knowledge the most detailed for tropical regions. The soil data (147 soil profiles) were extracted from the national soil map (scale 1:50,000) and associated soil profile database (VERDOODT & VAN RANST 2006a, b). Information on spatial distribution of the vegetation parameters will be extracted from the Lund-Potsam-Jena Dynamic Global Vegetation Model. Soil, climate and vegetation data will be integrated into a raster GIS database covering Nyungwe forest and will be stored in a plain geographic projection. Rendering all this information in the ForestDNDC-tropica model will result in an estimate of N_2O emissions from the Nyungwe forest soil. Therefore, it is assumed that model outcome using these high-resolution datasets gives least uncertainty. By decreasing the resolution of the driving parameters we will evaluate how this effects model output. Extensive validation and sensitivity studies will be performed against actual N_2O emission, measured during laboratory incubation experiments. Therefore we will use soil of 31 of 147 soil profiles.

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Global Warming Effects on Weather Conditions in the Bolivian Amazon: a Post-Kyoto Assessment

by

Alvaro GONZALEZ SANCHEZ*

KEYWORDS. — Weather Parameters; Bolivian Amazon; Global Warming; Developing Countries; Kyoto Protocol.

SUMMARY. — In 1997, the Kyoto Protocol was established with the aim to reduce greenhouse gas emissions in order to deal with global warming. Eleven years later, an evaluation on two climatic parameters, precipitation and temperature, was performed in the Bolivian Amazon (South America) around Santa Cruz city, the second largest city of Bolivia, based on the data obtained from de official authority. The available data consist of two data sets with daily records, one since 1944 and the other since 1986, both until March 2009, in two weather stations nearby Santa Cruz.

The data have been preprocessed in order to check their quality and, in the case of precipitation, a filling of gaps using the double mass analysis has been executed. The analysis has been performed on monthly and yearly basis. In precipitation, by checking maximum events and the total amount of rainfall in the established periods and in terms of temperature, maximum and minimum daily have been evaluated.

It has been observed that the total annual depth of rainfall does not vary with respect to the historical data; nevertheless, some trends can be observed at monthly scale. In April 2008 a depth of 175 mm was observed; this value is the maximum of the whole historical series under normal conditions. It also shows that the amount of rainfall in December 2008 (28 mm) was the lowest in many years.

In the case of maximum temperature in 2008, it reached a value that can only be compared with others like 2007 and 2004 (years that where influenced by

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the ENSO, El Niño phenomena). The minimum temperature had also increased in 2008 to 7.8 °C, where the lowest historical measured temperature was not higher than 7 °C under normal conditions.

Concluding, the major effects in precipitation and temperature are situated in 2007 and 2008; since no ENSO has been reported in this period, these changes may be due to global warming. The total amount of rainfall remains the same, but with a clear shift in time, and with an increase of its intensity, which results in other problems, such as flooding, the latter also resulting in other problems, *e.g.* diseases. In 2008, the Bolivian Amazon reported flooding events and also Dengue fever, the largest epidemic in the last few years. Temperature has also increased its maximum and minimum values and these changes can only be compared with those years influenced by strong ENSO phenomena.

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Landscape Impacts of Climate Change in Developing Countries

by

Andrew GOUDIE*

KEYWORDS. — Global Change; Coasts; Deserts; Rivers; Erosion.

SUMMARY. — Changes in climate will have an impact on various landscapes in developing countries in coming decades, and the degree of impact will vary according to factors such as threshold reliance, compound effects, the degree of climate change in particular zones, and the sensitivity of landforms themselves. The paper explores the role of climate change and other anthropogenic changes on coastal landscapes, river systems and cold environments, and drylands, concentrating on those locations that will be 'hot spots'.

Introduction

Global climates will probably change substantially (IPCC 2007) during this century and will affect the operation of geomorphological hazards and the nature of landscapes in developing countries as a result of changes in temperatures, precipitation amounts, rainfall intensities, and soil moisture conditions. It should be remembered that climate change will work in tandem with various anthropogenic activities including changes in land cover and land use (SLAYMAKER *et al.* 2009) which could be of equal or greater importance (tab. 1). Some environments will change more than others — 'geomorphological hot-spots' — (GOUDIE 2006a), especially when crucial thresholds are crossed. There are four types of reasons why some geomorphological processes, hazards and landform assemblages will show particularly substantial modification as climate changes.

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Table 1
Climate change and other human pressures on selected environments from developing countries

Environment	Climate change pressures	Other pressures
Mangrove swamp	Sea-level rise and spread of salinity up estuaries	Deforestation, pollution, fish farming, infilling
Coral reef	Sea-level rise, excess temperatures leading to bleaching, greater hurricane attack	Pollution (including siltation), trawling, dynamiting, introduction of invasive predators, mining, dredging, etc.
Rainforest	Rainfall change leading to drought, change in albedo, more fire, etc.	Deforestation, burning
Deltas	Sea-level rise, landward spread of salinity, increased erosion, hurricane attack	Sediment starvation and less freshwater flow (because of dams), subsidence caused by over-pumping of water, hydrocarbons, etc.
Desert margin	Reduced soil moisture, dune reactivation, reduction in river flow, contraction of drainage net	Land disturbance, over-cultivation, deforestation, inter-basin water transfers
Sandy beaches	Sea-level rise leading to increased erosion, more storm surges	Sediment starvation, vegetation removal, updrift engineering structures, mining

The first of these is threshold reliance. Some landforms and land-forming processes change across crucial climatic thresholds. For example, aeolian activity in drylands is dependent on wind energy, sand supply and the nature and extent of vegetation cover. If the last falls below a certain level due to a reduction in moisture availability, wind action is sharply intensified. Another example of threshold dependence is the coral reef. These features of tropical coastlines are highly sensitive to any changes in cyclone activity but also to coral bleaching caused by elevated sea-surface temperatures (as has happened during recent El Niño years in the Caribbean and elsewhere) and to sea-level rise itself. Terminal lake basins, such as those of the African Rift valleys or Lake Chad, are other landforms that have shown very rapid and substantial variations in response to Holocene and twentieth century changes in temperature, precipitation and evapotranspiration.

Secondly, there are many examples of landform change being promoted by a combination of climate changes and other human pressures — the compound effect. Indeed, desertification is often most intense when climatic (drought) and human pressures (*e.g.* over-grazing, deforestation, or over-cultivation) coincide. In coastal regions, the effects of rising sea levels are compounded by local subsidence caused by fluid (water, hydrocarbons) abstraction while beaches, marshes and deltas starved of sediment by the damming of rivers and the construction of coastal defences will be especially prone to erosion and inundation as sea levels rise (Blum & Roberts 2009).

Thirdly, some landforms are robust, while others are less so. For example, *dongas* (erosional scars) in colluvial aprons in southern Africa are gully systems that have a history of cut and fill in response to climate and land cover changes. This is because they are developed in materials that have high exchangeable sodium percentages and thus are prone to severe erosion if the vegetation cover is changed. Likewise, once their protective vegetation cover is removed, sand dunes in semi-arid areas are easily reactivated. Similarly, muddy and sandy coastlines will plainly be more prone to erosion than hard-rock coastlines, and heavily lithified reefs will be more resistant than less lithified ones (Woodroffe 2008).

Fourthly, the severity of climate change, and thus its likely impact, will vary spatially. Reductions in soil moisture and stream flows may be especially great in some areas that are currently relatively dry, so that stream networks will shrink (Goudie 2006b, De Wit & Stanciewicz 2006). Features such as the dambos of central Africa are among those fluvial systems that may be considerably altered. Warming will have an especially strong impact on river behaviour in areas where winter precipitation currently falls as snow, such as the mountains of South Asia or the Andes. Giorgi (2006) developed a Regional Climate Change Index (RCCI) based on four variables: changes in mean regional precipitation and inter-annual precipitation variability, and changes in regional surface air temperatures and their inter-annual variability. On this basis certain climate change hot-spots were identified, including the Mediterranean and North eastern European regions, Central America, Southern Equatorial Africa and the Sahara, and Eastern North America. Similarly, Sheffield & Wood (2008) recognised some potential future long-term drought hot spots, including the Mediterranean, West Africa, Central Asia and Central America.

Coastal Landscapes

If temperatures climb then so will sea levels. This is partly because of the steric (temperature) effect which modifies the volume of water in the oceans, but also because of melting of the cryosphere (ice). Rising sea levels will impact on a large proportion of the Earth's human population (FitzGerald *et al.* 2008).

Thirteen of the world's twenty largest cities are located on coasts. Areas at less than 10 m in altitude (the so-called Low Elevation Coastal Zone – the LECZ) account for ca 2 % of the world's land area but contain 10 % of the population. While only 13 % of urban settlements with populations of less than 100,000 occur in the LECZ, the figure rises to over 65 % among cities of 5 million or more. Many of the most severely impacted countries with respect to the effects of sea-level rise are in developing countries (DASGUPTA *et al.* 2009), including Vietnam, Guyana, Suriname, Belize, Benin, Egypt, Jamaica and Tunisia.

Sea-level rise of around 50 cm is likely to occur by 2100 (MILLER & DOUGLAS 2004). However, should Greenland melt at a faster rate than is currently predicted, the amount of rise will be greater, plausibly leading to 0.8 m of sea-level rise by 2100 (PFEFFER *et al.* 2008). The effects of global sea-level rise will be compounded in areas that undergo subsidence resulting from either tectonic movements, or isostatic adjustments or extraction of solids and liquids (MILLIMAN & HAQ 1996). Many deltas are zones of subsidence because of the isostatic effects of the sedimentation that caused them to form and because of the progressive compaction of the sediments of which they are composed. Sectors of the world's coastline that are subsiding include the deltas of the Indus, Ganga, Nile, Mekong, Tigris-Euphrates and Zambezi, where so many people in the developing world live. Fifty-one of the world's deltas have a combined population of over 325 million, and the Nile delta alone has a population of around 50 million (SYVITSKI 2008). The Niger Delta has high rates of subsidence because of oil and gas abstraction. Deltaic coasts are likely to be threatened by submergence as sea levels rise, especially where prospects of compensating sediment accretion are not evident, or where sediment is now trapped upstream by dams and in irrigation channels (STANLEY 1996, ERICSON *et al.* 2006). Deltas could also be affected by changing tropical cyclone activity, which might cause storm surge effects to be magnified (KARIM & MIMURA 2008).

BROADUS *et al.* (1986) calculated that were sea level to rise by just 1 metre in 100 years, 12-15 % of Egypt's arable land would be lost and 16 % of the population would have to be relocated. Alexandria, Rosetta and Port Said are at particular risk and even a sea-level rise of 50 centimetres could mean that 2 million people would have to abandon their homes (EL-RAEY 1997). In Bangladesh, a 1 metre rise would inundate 11.5 % of the total land area and affect 9 % of the population directly.

Many of the world's major urban centres might be flooded in whole or in part, sewers and drains rendered inoperative (KUO 1986), and peri-urban agricultural productivity reduced by saltwater incursion (CHEN & ZONG 1999).

Bangkok is an example of a city that is threatened by a combination of accelerated subsidence and accelerated sea-level rise (NUTALAYA *et al.* 1996). Between 1960 and 1988, 20 to 160 centimetres of depression of the land surface occurred. Given that Bangkok is situated on a very flat, low-lying area, where ground-level elevations range from only 0 to 1.5 metres above mean sea level, this is serious. SALES (2009) discusses the various threats posed to another Asian urban area, Cavite City in the Philippines.

Coral reefs, because of their low lying nature, may also be subject to over-washing, inundation and salt water incursion as sea level rises (WOODROFFE 2008), particularly if, because of pollution or siltation, they are unable to grow upwards at an adequate rate to keep up with sea-level rise. They may also suffer from increasing ocean acidification. Some of the extra carbon dioxide being released into the atmosphere by the burning of fossil fuels and biomass is absorbed by sea water. This produces carbonic acid which will cause the oceans to become more acidic (*i.e.* to have a lower pH than now). Several centuries from now, if we continue to add carbon dioxide to the atmosphere, ocean pH will be lower than at any time in the past 300 million years (DONEY 2006). This will harm those organisms like corals that depend on the presence of carbonate ions to build their hard parts (ORR *et al.* 2005). Another threat to coral reefs is coral bleaching caused by excessive sea-water temperatures (BAKER *et al.* 2008). The frequency of thermal stress events is likely to increase, leading to declines in coral cover, shifts in the composition of corals and other reef-dwelling organisms, and stress on the human populations who rely upon these ecosystems for food, income and shoreline protection (DONNER 2009).

Reefs play an important role in coastal protection against storms so that "we can anticipate that decreasing rates of reef accretion, increasing rates of bioerosion, rising sea levels, and intensifying storms may combine to jeopardize a wide range of coastal barriers" (HOEGH-GULDBERG *et al.* 2007, p. 1742).

Mangrove swamps are widespread in the developing countries of the tropics. They are ecologically important and also offer some protection against coastal erosion. Many mangroves communities will be affected by sea-level rise. Species zonation may change, with trees to seaward being inhibited by extended submergence times, while those on the landward margins might be able to extend, provided that suitable habitat was available and assuming that their migration was not impeded by sea walls and other anthropogenic structures. A key issue is the extent to which the rate of sediment deposition in the swamps can keep pace with the rate at which sea level is rising. In the great river deltas, on high oceanic islands with considerable runoff from rainfall or in those situations where large quantities of marine sediments can be trapped, mangroves may be able to grow up at a rate greater than that of sea-level rise. However, some mangroves are relatively slow growing and this may make them susceptible to fast rates of sea-level changes. On the other hand there may be some expansion in the range of mangroves as sea surface temperatures rise (HOGARTH 1999).

More generally, sea level rise may cause an acceleration in the rate of erosion of soft coastlines. Many of the world's coastlines are already suffering from erosion because of such factors as sediment starvation caused by a reduction in the amounts of material being delivered to beaches by rivers that have been dammed. However, following the Bruun Rule, and bearing in mind that storms and surges may become more intense, it is likely that this ongoing erosional tendency will be increased (CAI *et al.* 2009). Barrier islands, which, for example, occur widely around the Indian coastline, are dynamic and often densely settled landforms that will tend, as sea level rises, to be exposed to higher storm surges and greater flooding.

Finally it is worth reiterating that global sea-level change will not be the only factor that creates future hazardous conditions and change on coastlines. Humanly induced subsidence, sediment retention behind dams, unwise engineering schemes, mining of beach sediment, and removal of protective coastline vegetation, may be at least as important. Indeed, such actions have already been implicated in the changes that have taken place in the morphology of the Nile Delta and its lagoons over the last half century (EL BANNA & FRIHY 2009). Moreover it is not just sea-level rise that will be caused by global warming. There will also be changes in storm characteristics, wave climate, river inputs of water and sediment, and the like (DAY *et al.* 2008).

Fluvial Landscapes, Erosion and Mass Movements

Rainfall intensity is a major factor in controlling such phenomena as flooding, soil erosion, and mass movements (SIDLE & DHAKAL 2002). Under increased greenhouse gas concentrations some GCMs exhibit enhanced global precipitation intensity and shortened return periods of extreme events (NEW *et al.* 2001). Increased rainfall events in various countries over recent warming decades lend support to this notion. In their analysis of flood records for twenty-nine river basins from high and low latitudes with areas greater than 200,000 square kilometres, MILLY *et al.* (2002) found that the frequency of great floods had increased substantially during the twentieth century, particularly during its warmer later decades.

A big issue of particular concern with regard to precipitation trends relates to the El Niño — Southern Oscillation (ENSO), which is important with respect, *inter alia*, to the occurrence of floods and debris flows in the South American deserts (HOUSTON 2006). The situation here is far from clear, for as AN *et al.* (2008, p. 3) have put it "dynamical understanding of ENSO responses to global warming is still in a toddling stage!" Some models suggest a weakening of ENSO activity under a global warming scenario, while others do not.

It is possible, though by no means certain, that as the oceans warm up, so the geographical spread, intensity and frequency of hurricanes will increase (EMANUEL 1987, KNUTSON & TULEYA 1999). These are a major hazard for human communities and also have a whole series of hazardous consequences, including accentuated river flooding, greater wave heights (KOMAR & ALLEN 2008), coastal surges, the triggering of landslides and accelerated land erosion and lagoonal siltation. The relationship between sea surface temperature increase and increasing global hurricane activity has been confirmed by HOYOS *et al.* (2006) and SAUNDERS & LEA (2008). SANTER *et al.* (2006) have demonstrated that human factors have caused the increase in sea surface temperatures and cyclone development in both the Atlantic and Pacific regions, while ELSNER *et al.* (2008) have shown that the strongest tropical cyclones have become more intense in recent decades. There is also the possibility that tropical cyclones, at present relatively unimportant in South America could become more significant, as presaged by Hurricane Catarina, which hit southern Brazil in March, 2004 (PEZZA & SIMMONDS 2005).

In Amazonia, global climate changes may cause droughts to intensify, but could occur concurrently with regional climate changes caused by land-use change (*e.g.* albedo modification, alteration of surface roughness, and reduction in transpiration of moisture). The area could become subject to substantial regional drought and to forest dieback. Were this to happen, the regime of the Amazon, the nature of its channels, and its sediment budgets could be transformed. This is still a matter of considerable debate, but there are those who argue that global climate change, combined with regional climate change promoted by deforestation, could produce substantial drying especially in the east and south east of Amazonia, but only to a lesser extent in northwestern Amazonia (MALHI *et al.* 2008, BETTS *et al.* 2008).

Lakes will respond to the temperature and precipitation changes that may result from global warming. Major falls of up to 9 m by the end of the present century have been predicted for the Caspian (ELGUINDI & GIORGI 2006).

Mass movements will be impacted upon by changes in hydrological conditions. In particular, slope stability and landslide activity are greatly influenced by groundwater levels and pore-water pressure fluctuations. Geomorphologists have modelled changes in soil erosion that may occur as a consequence of rainfall changes (FAVIS-MORTLOCK & GUERRA 1999, YANG *et al.* 2003) though it is difficult to determine the likely effects of climate change compared to future land management practices (WILBY *et al.* 1997).

Glacial Landscapes

Changes in the cryosphere have taken place in recent decades, and may intensify in the future (LI *et al.* 2008). In many parts of the world glaciers are retreating and this is likely to be a trend that accelerates with global warming.

For instance, most South American glaciers have been suffering from intensified retreat (see, for example, THOMPSON 2000, KASER & OSMASTON 2002) and many may disappear in the next two decades (RAMIREZ *et al.* 2001, MAGRIN *et al.* 2007). Although an increase in glacier melting initially increases runoff, the eventual disappearance of glaciers will cause abrupt changes in stream-flow because of the lack of a glacial buffer or reservoir during the dry season (BRADLEY *et al.* 2006, VUILLE *et al.* 2008). The disappearance of glaciers can cause slope instability (VILÍMEK *et al.* 2005) by reducing their buttressing effect and by exposing rock slopes to severe weathering (FISCHER *et al.* 2006) that produces rock falls. Such slopes (HOLM *et al.* 2003) can become unstable, generating a risk of increased landsliding and debris avalanches (KIRKBRIDE & WARREN 1999, HAEBERLI & BURN 2002). It is also possible that melting glaciers will produce large proglacial lakes which may subsequently fail, so producing down valley floods (HARRISON *et al.* 2006, VILÍMEK *et al.* 2005). Glacial lakes in areas such as the Himalayas of Nepal and Bhutan are rapidly expanding as they are fed by increasing amounts of meltwater. Outburst floods from such lakes are extremely hazardous. Increased rates of glacier melting may indeed for a period of years cause an increased incidence of summer meltwater floods (see, for example, the study by LIU *et al.* (2009) on the Yangtze), but when the glaciers have disappeared, river flow volumes may be drastically reduced (BRAUN *et al.* 2000), leading to severe water shortages.

Aeolian Landscapes

Changes in climate could affect wind erosion either through their impact on erosivity or through their effect on erodibility. The former is controlled by a range of wind variables including velocity, frequency, duration, magnitude, shear and turbulence. Unfortunately, General Circulation Models (GCMs) as yet give little indication of how these characteristics might be modified in a warmer world, so that prediction of future changes in wind erosivity is problematic. Erodibility is largely controlled by vegetation cover and surface type, both of which can be influenced markedly by climate. In general, vegetation cover, which protects the ground surface and modifies the wind regime, decreases as conditions become more arid. Likewise climate affects surface materials and their erodibility by controlling their moisture content, the nature and amount of clay mineral content (cohesiveness) and organic levels. However, modelling the response of wind erosion to climatic variables on farm land is vastly complex, not least because of the variability of soil characteristics, topographic variations, the state of plant growth and residue decomposition, and the existence of windbreaks. To this needs to be added the temporal variability of aeolian processes and moisture conditions and the effects of different land management practices (LEYS 1999), which may themselves change with climate change.

Wind erosion leads to dust storms. The nature of future dust activity will depend on three main factors: anthropogenic modification of desert surfaces (MAHOWALD *et al.* 2006); natural climatic variability (*e.g.* in the El Niño Southern Oscillation or the North Atlantic Oscillation); and changes in climate brought about by global warming. `If soil moisture declines as a result of changes in precipitation and/or temperature, there is the possibility that dust storm activity could increase in a warmer world (WHEATON 1990). A comparison between the USA Dust Bowl years of the 1930s and model predictions of precipitation and temperature for the Great Plains of Kansas and Nebraska indicates that mean conditions could be similar to or worse than those of the 1930s under enhanced greenhouse conditions (ROSENZWEIG & HILLEL 1993). In contrast, however, in northern China, there is some evidence that dust storm activity has decreased in recent warming decades, partially in response to changes in the atmospheric circulation and associated wind conditions (JIANG *et al.* 2009) and might decrease therefore still further in a warming world (ZHU *et al.* 2008). If dust storm activity were to increase as a response to global warming it is possible that this could have a feedback effect on precipitation that would lead to further decreases in soil moisture (MILLER & TEGEN 1998).

The impact and occurrence of dust storms will depend a great deal on land management practices, and recent decreases in dust storm activity in North Dakota and the High Plains have resulted from conservation measures (TODHUNTER & CIHACEK 1999).

Sand dunes, because of the crucial relationships between vegetation cover and sand movement, are highly susceptible to changes of climate. Some areas, such as the South West Kalahari (STOKES *et al.* 1997) or portions of the High Plains of the United States (GAYLORD 1990) may have been especially prone to changes in precipitation and/or wind velocity because of their location in climatic zones that are close to a climatic threshold between dune stability and activity. Development in the use of luminescence dating of sand grains and studies of explorers' accounts (MUHS & HOLLIDAY 1996), has led to the realisation that such marginal dune fields have undergone repeated phases of change at decadal and century timescales in response to extended drought events during the Holocene (FORMAN *et al.* 2008).

Perhaps the most detailed scenarios for dune remobilization by global warming have been developed for the mega-Kalahari in southern Africa (THOMAS *et al.* 2005). Much of this vast region is currently vegetated and stable, but GCMs suggest that by 2099 all dune fields, from South Africa and Botswana in the south to Zambia and Angola in the north will be reactivated. This could disrupt pastoral and agricultural systems. and might lead to loss of agricultural land, the overwhelming of buildings, roads, canals, runways and the like, abrasion of structures and equipment, damage to crops, and the impoverishment of soil structure. However, the methods used to estimate future dune field mobility are still problematic and much more research is needed before we can have confidence in them (KNIGHT *et al.* 2004).

Once again, however, it is important to stress that the activity of sand dunes and of dust storms may be dependent on drought interludes, but that the effects of such interludes, both in the past (see, for example, COOK *et al.* 2009, SEIFAN 2009) and in the future may be greatly affected by miscellaneous anthropogenic activities.

Conclusions

It is evident that future climate change will have an impact on the frequency, distribution and intensity of a wide range of geomorphological landscapes. As human population levels rise and cities become ever larger, any increase in geomorphological hazard severity would have a growing impact. Some hazards will undoubtedly become more serious and others less so, but a great deal depends on the exact nature of the geomorphological environment in which human populations dwell. However, climate change is not the only cause of future geomorphological change. Indeed, it may not even necessarily be the most important. It could, for example, be argued that land cover removal will have a greater impact on soil erosion and on stream water quantity and quality than changes in climate. However, if future climatic change works in the same direction as other anthropogenic pressures, then the consequences may be especially powerful.

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Tracking Mesoscale Convective Systems in the Sahel and assessing their Sensitivity to Vegetation Changes

by

Clémence GOYENS*, D. LAUWAET & N. VAN LIPZIG

KEYWORDS. — Mesoscale Convective Systems; Precipitation; Tracking; Sahel.

SUMMARY. — Mesoscale Convective Systems (MCS) can be broadly defined as an ensemble of strong convective cells which evolve into a single mesoscale cloud. MCS can reach a spatial dimension of 125,000 km^2 and a live duration of several days while producing heavy precipitation. In the semi-arid African Sahel region, MCS represent an important source of rainfall (70-90 % of the total annual rainfall). Understanding the behaviour of these systems is thus very important in this vulnerable region. Globally, MCS regulate the transport of energy, heat, moisture and momentum in the atmosphere and therefore influence the input of energy in the climate system through the radiative effect of the high-level clouds and moisture content. Since MCS play a significant role in the Earth's climate system, features governing those systems may be considered as drivers of climate change.

The main objective of the present study is to improve our understanding of the relationship between covective initiation, structure of the cloud ensemble, the development into a MCS and their efficiency as a precipitation source. This will help to forecast the rainfall intensity of a MCS. The study area is centered over the Lake Chad region extending from 0 to 30° E and 5 to 20° N. Infrared (10.8 μm) images from the geostationary satellite Meteosat-8 are used to track the systems occurring in the rainy season of 2006 from June 1st till September 22nd. The radiance of the cloud tops in the infrared channel are converted into brightness temperatures such that convective clouds, which are characterized with very cold cloud tops, can be identified and delineated. For each cloud several properties such as cloud area, cloud top temperature, life duration, mean propagation speed and coordinates of the cloud centre, are calculated and related to the cloud's precipitation efficiency. The latter was estimated using images of NASA's Tropical Rainfall Measuring Mission (TRMM) covering the same area and time period. In this way, a classification system of the MCS can be developed and their behaviour can be better understood.

A second objective of this study is to investigate the effect of vegetation changes on MCS. The vegetation in the Sahel is strongly linked to the build-up of Convective

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Available Potential Energy (CAPE), which in turn influences the location and intensity of MCS. The effect of both an increase and a decrease in vegetation cover is investigated using a regional atmospheric model with a high horizontal resolution. The model simulations span a period of forty-two days in the rainy season and correctly reproduce rainfall amounts and atmospheric profiles. Total precipitation is found to be insensitive to the applied vegetations changes, but the latter do have an impact on the rainfall patterns and the location of the mesoscale convective systems. The main axis of rainfall shifts to the south when the vegetation is decreased, leading to even drier conditions in the Sahel.

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The Effect of Global Warming on Large Rivers and Deltas

by

Avijit GUPTA*

KEYWORDS. — Large Rivers; Deltas; Enhanced Seasonality and Floods; Channel Metamorphism; Source-to-sink Variations.

SUMMARY. — The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) lists certain consequences of climate change that should impact large rivers. These include retreat of mountain glaciers, early melting of snow and ice, changes in annual rainfall, enhanced seasonality, an increase in strength of large storms, higher rainfall from extreme events, and a rising sea level. The effects of such changes on rivers have not been worked out. Anthropogenic changes to the channels and drainage basins complicate the picture, as they tend to override the signals of climate change. It is, however, possible to evaluate the probable robust changes on large rivers using (1) principles of fluvial geomorphology and (2) past analogues. It is likely that rivers would be metamorphosed by climate change — becoming wider, shallower, floodprone, and with a high rate of sedimentation and avulsion in deltas. The changes in the appearance and behaviour of major rivers may also reflect their source-to-sink variations. We may need a new set of rules for understanding, utilising, and managing rivers.

Introduction

Normally, rivers are adjusted to their drainage basins. The physiography of the basins and the nature and volume of water and sediment in the channels determine riverine forms and functions. However, these factors change over time. Rivers went through repeated changes in phase with the Quaternary Marine Isotope Stages. In the early Holocene, a number of rivers carried higher discharges and bigger sediment loads, with associated adjustment of

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their forms and functions. Subsequently, these rivers changed to their present appearance and behaviour (Blum 2007, Goodbred & Kuehl 2000, Goodbred 2003, Knox 2007). The on-going climate change is expected to alter various aspects of the global environment, such as the melting of glaciers, precipitation characteristics, and sea level. These are already happening and rivers should be expected to adjust their appearance and behaviour with the changes.

The impact of climate change on large rivers can be determined by (1) observations, (2) modelling and (3) examining analogues from the past. Observations of ongoing changes are the best but we do not really have them yet. The existing models are not in agreement (Blum 2007) or of required resolution. Even if we improve in this area, modelling is a generalisation and specific instances may deviate considerably from the expected trend. We can also use environmental analogues from the past, especially late Pleistocene. The technique of looking back to the past in order to look forward to the future has been reviewed by Blum & Tornqvist (2000) and Blum (2007). Both models and past analogues provide a generalised forecast, which may have to be modified before its application to a specific river in order to predict its future form and function at the level required for channel and floodplain management. We need to anticipate trends such as increase and decrease of clastic load, instability in channel pattern, and increased propensity for overbank flooding or avulsion. A lack of direct observations in this area forces us to find such answers from the basic premises of hydrology and geomorphology.

Climate Change and Rivers

The latest review by the Intergovernmental Panel on Climate Change (IPCC) provides an opportunity to list the robust factors expected to modify the appearance and behaviour of rivers (IPCC 2007). As IPCC reports are based on scientific consensus, it is not unreasonable to accept the findings as basic premises and build on them. The principal factors that arise from climate change and are likely to affect river systems are

— Retreat of mountain glaciers;
— Melting of snow and ice earlier in the year;
— Changes in annual rainfall with regional variations;
— Enhanced seasonality;
— Regional increase in droughts;
— Increase in the strength of large storms (we may define these as tropical cyclones of category 4 and 5);

— Increased rainfall from extreme events;
— Sea-level rise (various estimates exist, regional differences may happen).

The possible effects of these on river systems have yet to be explored in detail, but it is obvious that the effect of climate change on rivers will vary and a single generalised prediction is not very useful. Rivers have to be evaluated individually. Not all the factors listed above will affect all rivers, and if we trace a major river from source-to-sink, the type and intensity of the listed factors would vary along channel. Such variations will depend primarily on (1) the probability of a particular kind of change at a specific location on the river and (2) the changing channel physiography along a large river. Anticipating the nature and behaviour of a particular river a hundred years from now is very difficult but needs to be carried out.

Form and Function of Rivers

We start with three basic premises:

1. Ideally, rivers are in dynamic equilibrium.
2. A large river is a source-to-sink system that transfers water and sediment along its channel.
3. We can use analogues from the geological past, especially from the Quaternary, to determine the adjustment of a river to climate and sea-level changes.

Rivers are conduits for transferring water and sediment from the land to the ocean. The dimensions, appearance and behaviour of river channels depend on a multitude of variables. Of these four are of prime importance: water, sediment, sediment texture (grain size) and channel slope. The form and function of a river depend simultaneously on these four variables, and a change in any or more of them would cause the river to seek a new equilibrium by modifying its appearance and behaviour. Figure 1, which shows this relationship, is a simplified diagram from an unpublished drawing by W. Borlaug based on an equation derived by E. W. Lane (1955), as mentioned in Blum (2007). One or all of these four variables may be altered by climate change causing rivers to adjust to new conditions. The degree of change, however, would vary among rivers, making generalisation difficult.

Blum (2007) has reviewed the nature of adjustment in large rivers due to past climatic changes. The nature of change is difficult to predict as the linkages between the forcing mechanism of climate change and the river's

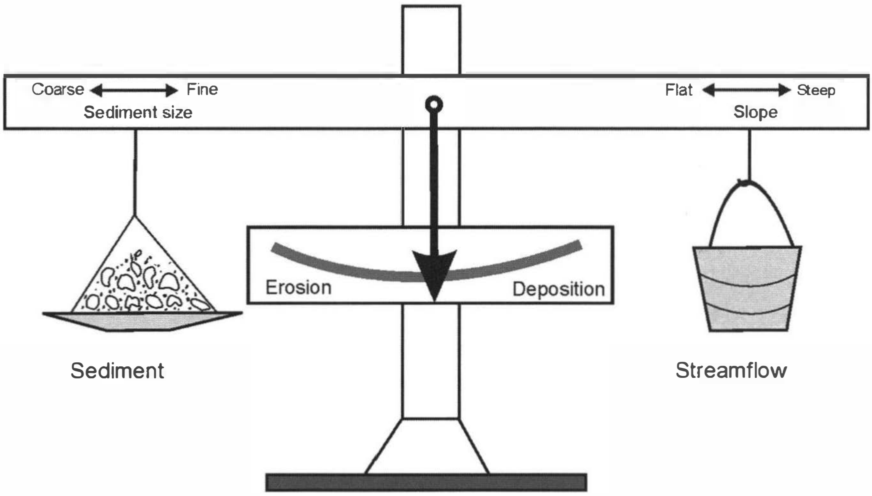

Fig. 1. — Schematic diagram of a river in dynamic equilibrium adjusted to four key variables: streamflow, sediment volume, sediment grain size and slope. Generalised from various diagrams based on LANE 1955.

response to it are nonlinear and probabilistic. The scale of large river systems adds further complexity to the relationship. Large rivers are polyzonal and the lowest part of the basin may need to integrate different signals from different parts of the basin. The adjustment may continue over a long period of time, the upper and lower parts of the river may not be in phase, and climate-driven changes in discharge and sediment may operate on the channel at different time-scales. We can, however, determine the direction of change, using simple relationships as in figure 1.

Effect of Climate Change on Major Rivers

UPPER AND MIDDLE COURSES

Given the factors listed earlier that are derived from climate change, rivers of the future should have an annual pattern of water and sediment discharge that would be different, at least in degree, from the present one. The pattern, however, will vary among different parts of the world as demonstrated directly by the runoff map produced in MILLY *et al.* (2008) and indirectly by the rainfall maps in IPCC (2007).

Figure 2 conceptualises a large river system with its source in the high mountains and the sea as its sink. It has been generalised from CASTELLFORT & VAN DEN DRIESSCHE (2003) and BLUM (2007). Such a river system has three parts: headwaters in the mountains, the long channel with its valley changing from bedrock in the mountains to mixed bedrock-alluvial or all alluvial in the plains, and the delta in alluvium. With climate change, glaciers would retreat in the mountains and ice and snow melt early in spring. Normally, about 80-90 % of the sediment of a major river is derived from the mountains. This sediment would travel down the river earlier and its peak may or may not coincide with that of river water. The supply of the sediment would be even more enhanced by increased slope failures in the upper valleys due to the melting and removal of glaciers. Higher episodic rainfall would occur if the mountains are located across the common tracks of major storms. Thus the early part of climate change may produce huge volumes of sediment, which may be stored temporarily in the bedrock valleys or as alluvial fans at highland-lowland contacts. Over time such sediment would be gradually transferred and stored along the mixed bedrock-alluvial and alluvial valleys and, as the valleys widen downstream, in alluvial floodplains. A sequence of climate and sea-level changes and river adjustments has been described by GOODBRED (2003) for the basin of the Ganga for roughly the last 50 ka. During MIS 3 (58-24 ka), the regional climate was cool and moderately wet. The river carried a moderate discharge and moderate to high sediment load. Glaciers advanced in the Himalaya Mountains with aggradation in the mountain valleys. The arrival of the sediment caused aggradation in the mountain-front megafans, and the alluvial valleys beyond. Incision and aggradation happened in the delta, shelf and deep-sea Bengal fan. During MIS 2 (24-18 ka), the climate was cold and dry, leading to low flow and sediment load in the river. There was limited glacier advance and very little activity in the entire basin. In contrast, climate during late MIS 2 and early Holocene (18-7 ka) was warmer and very wet. Both river discharge and sediment load was very high. There was a brief period of glacier advance and widespread incision occurred in the megafans and alluvial valleys. Rapid aggradation occurred further down the basin, in the delta, shelf and Bengal fan. Since the mid Holocene the climate has been warm and wet with high discharge and sediment load. The Himalayan glaciers retreated and valley aggradation and incision both happened in the upper valleys. Slow aggradation was the norm in the lower alluvial plain and delta, and on the shelf and the fan. The aggradation was relatively higher in the delta. Climate change with melting glaciers, altered annual rainfall, and enhanced large storms appears to be another step in this sequence of events, a step we need to foresee because of the high population in the river valleys and deltas.

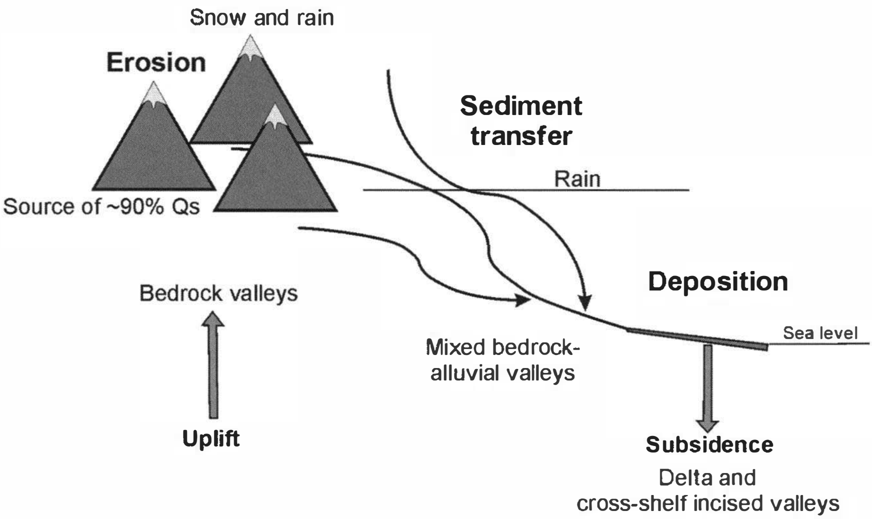

Fig. 2. — Schematic diagram of a large river system. Generalised from CASTELLTORT & VAN DEN DRIESSCHE 2003 and BLUM 2007.

The transfer of sediment downvalley is likely to be episodic due to the enhanced seasonality in discharge and high rainfall from an increased number of large storms. We may expect overbank flooding, and transfer and storage of sediment in both downstream and cross-valley directions as currently happens for a number of major rivers. The Amazon (DUNNE *et al.* 1998, MEADE 2007) and the Ganga (SINGH 2007) are good examples. This pattern of sedimentation, however, may be complicated by regional constrictions and widening of river valleys (DUNNE *et al.* 1998, GUPTA & LIEW 2007) and the polyzonal nature of major river basins. Zones of enhanced floodplain deposition and efficient downstream transfer of sediment load may alternate along the major river valleys. In sum, following GOODBRED (2003), we may visualise enhanced sediment production and valley aggradation in the early stages of climate change followed by a stage of transfer and storage of such sediment.

The possible outcomes of the impact of climate change along the upper and middle courses of large rivers in the near-future can be listed.

— More dependency of large rivers on rainfall and less on snowmelt.
— Lengthening of the duration of low flow. Our understanding of groundwater discharge (baseflow) fluxes from climate change, however, is still unclear.

— Changing of the mean discharge; the direction of change depending on the nature and intensity of climate change in the region concerned.
— Varying types and intensities of change in tributaries, as large basins are polyzonal.
— Likely increase in size of large floods. Small changes in mean rainfall may increase the size of large floods (KNOX 1993).
— Deviations from the general pattern during El Niño Southern Oscillation years.
— Changing of the present pattern of transfer and storage of sediment (fig. 3), including the pattern of coupling (fig. 4) between (a) valley slopes and streams and (b) tributaries and the main river (HARVEY 2002).

It is therefore likely that at least some of the rivers would display a stronger seasonal component in their flow, with episodic large floods imprinted on the annual distribution. This may lead to metamorphism of such rivers. They would become wider, shallower and floodprone. The rivers would record a high rate of episodic sediment transfer and long-term storage of sediment, if accommodation space is available in the valleys.

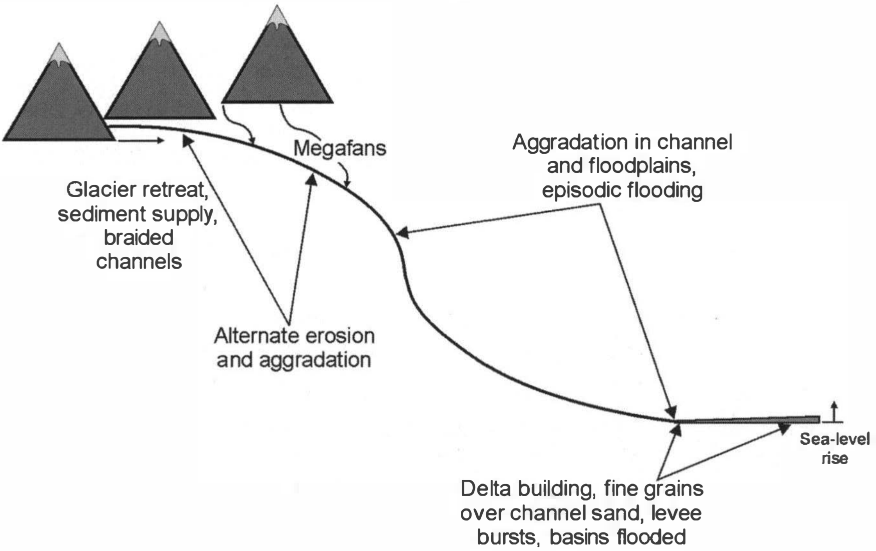

Fig. 3. — Schematic diagram of expected changes in a large river system. Based on discussion in GOODBRED 2003. Note difference with figure 2 and the temporary storage and transfer of sediment.

Fig. 4. — Coarse sediment supplied to the Jinsha Jiang (upper course of the Yangtze), Tiger Leaping Gorge. Note coupling of sediment between the hillside and the Jinsha and between the steep tributary and the Jinsha. The sediment will be moved in the next high flow.

Lower Courses and Deltas

The lower courses of major rivers and their deltas may need to adjust not only to different patterns of water and sediment arriving from polyzonal sub-basins upstream, but also to the specific variables of climate change. These include a rising sea level resulting in more accommodation space for sediment, increased coastal erosion and saline intrusion, and effective inland penetration by enhanced tropical cyclones. These changes will bring in levee breaks and crevasse splays, sedimentation in flood basins and filling of wetlands, and avulsions and abandonment of distributary channels in low flat deltas. Such changes have been projected on a map of the Ganga-Brahmaputra delta (fig. 5). Blum & Aslan (2006) modelled the changing style of avulsion in deltas over time, based on past sedimentary records from the passive Texas Gulf Coast. According to their model, the early stages of deltaic modification with a rising sea level involve valley filling, channel occupation, and low aggradation. This is followed in time by high aggradation in channels, frequent crevassing, and filling of the flood basins by avulsion. In the final stage, the old channels are reoccupied and aggradation is low in the nearly-filled valley. Given a rising sea level, effective inland penetration by tropical cyclones, and arrival of increased amount of sediment from upstream, we may expect avulsions in channels and

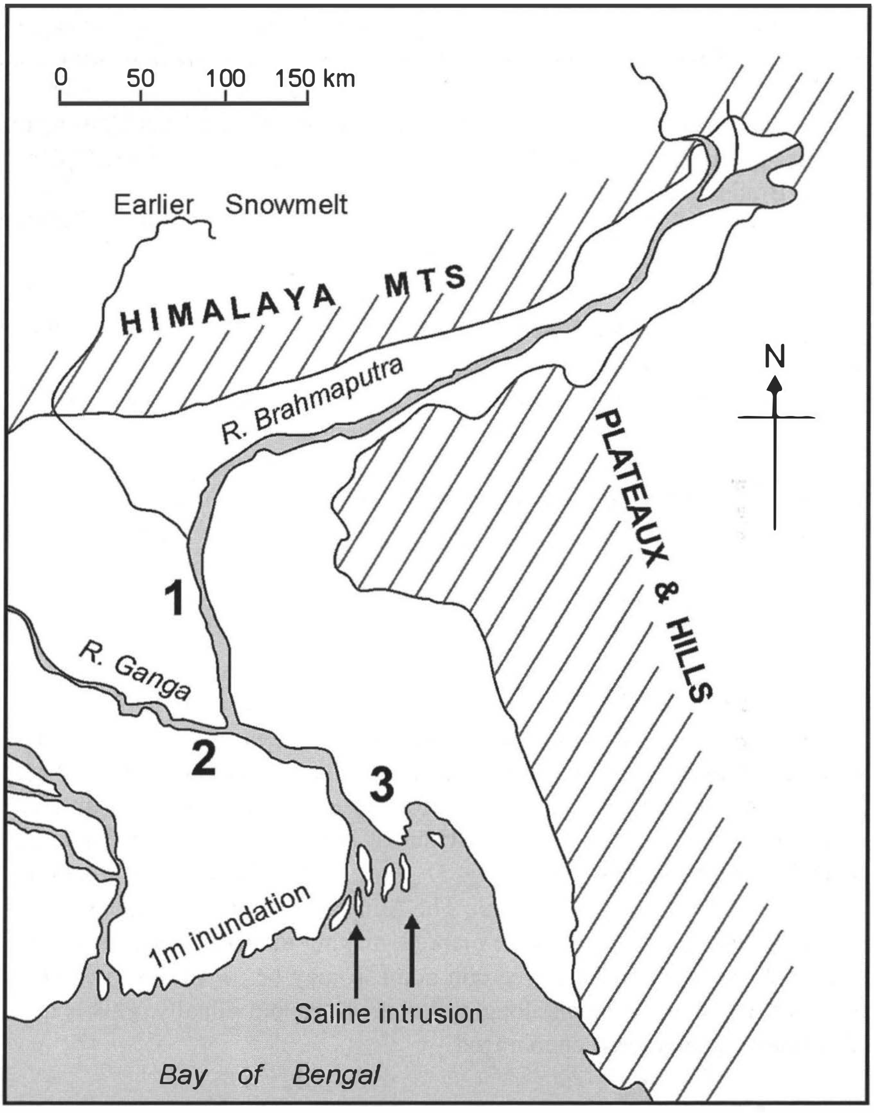

Fig. 5. — Possible effects of climate change projected to Ganga-Brahmaputra Delta with approximate inundation of land by 1 m rise of sea level. 1. Upper delta changes: crevasse splays, avulsions and flood basin filling; 2. Lower delta changes: fines deposited over channel sand; 3. Increased hazard of tropical cyclones, coastal erosion and saline intrusion.

filling of flood basin in deltas. This will certainly have tremendous repercussion on the life of the people in the deltas affecting (a) villages on levees, (b) established transport systems along river networks, and (c) farming in flood basins. Channel abandonment, avulsion, passage of most of the upstream discharge to a small distributary thereby enlarging it and abandoning the former major deltaic distributary in a moribund condition, are not uncommon in deltas and have been reported at least for the deltas of the Mississippi and Ganga-Brahmaputra.

A Source-to-sink Review

We have reviewed separately the possible effect of climate change on the upper and lower parts of a large river. A river, however, is a source-to-sink system and such effects should be seen in integration. Large rivers of the future may have to cope with retreat of glaciers, increased sediment supply, and enhanced seasonality in discharge in their headwaters. This is likely to lead to slope failures and braided channels in the mountains and building of large fans at the highland-lowland contact zone (Goodbred 2003). Emerging from the mountains, the upper part of the river valley would experience alternate periods of erosion and deposition. Aggradation in the channel and floodplain and episodic flooding could be common characteristics. The lower course of the river may display enhanced delta-building, deposition of fine grains over channel sand, bursting of levees, and flooding of low areas (fig. 5).

This is a much simplified account but which provides an integrated picture. Large river basins, however, are usually polyzonal in nature and the form and function of rivers themselves change from reach to reach (fig. 6). Morphological pattern of channels and behaviour of rivers vary along their courses, often driven by geological conditions. Dunne *et al.* (1998) have described such a situation for the lowland Amazon. The Amazon is the biggest, and changes in other rivers may be even more marked, making modelling and generalisations unsatisfactory beyond a certain point. It may be necessary to examine the effect of climate change along each large river individually. This is not a bad thing and should be encouraged.

Complications

It is difficult to generalise a source-to-sink climate change scenario for large rivers because a number of factors complicate the overall pattern. River basins are polyzonal and a given type of climate change may impact various parts of the channel and drainage basin differently. Noises from anthropogenic changes may override signals from climate change (Blum 2007). For example, a huge

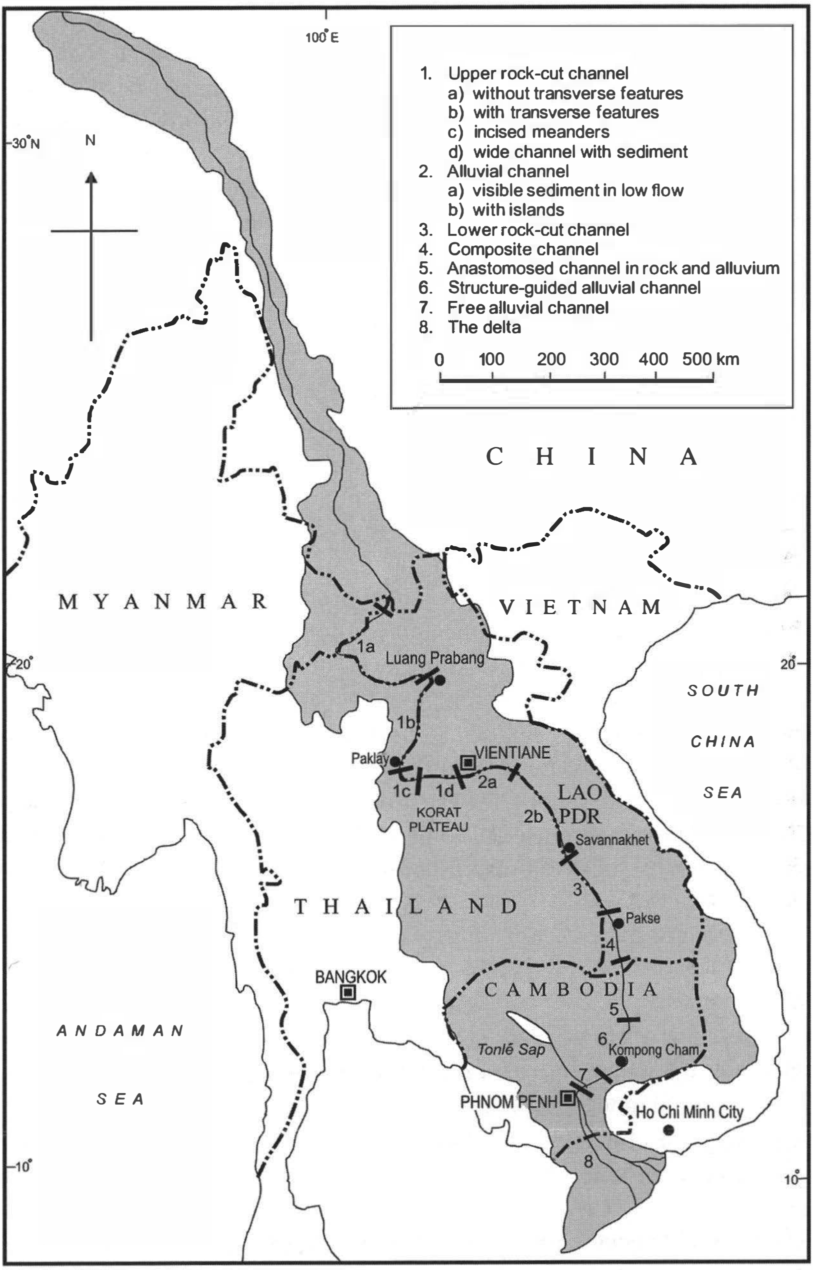

Fig. 6. — The lower 2,500 km on the Mekong, divided into 8 river units. The effect of climate change is expected to vary among these units. Examples like this suggest that the effect of climate change need to be studied for individual rivers. (Reprinted from GUPTA & LIEW 2007, copyright 2007, with permission from Elsevier.)

number of impoundments across river channels store water and block the downstream passage of sediment (MAHMOOD 1987, VOROSMARTY *et al.* 2003). Different styles of anthropogenic alteration of the drainage basins make it difficult to construct a general scenario for all rivers. The effect of the climate change is neither the same nor uniform across the world (MILLY *et al.* 2005, 2008), and we need to study rivers as individual cases. Perturbations to the normal climate such as ENSO may create higher floods in rivers (AALTO *et al.* 2003), and we need to determine whether the impact of climate change would differ during such years. Finally, we do not know the length of time that would elapse before the effect of climate change would show up significantly in large rivers.

Given such variations in rivers, drainage basins, and environmental impacts, it seems rational to accept that climate change may impact different rivers differently. A general model could be useful for indicating trends but not for quantitatively predicting changes for utilising or managing rivers. As neither the effect of climate change nor the state of rivers is uniform, we need to study rivers as individual cases. Furthermore, a loss of stationarity (MILLY *et al.* 2008) in river data due to climate change and anthropogenic modifications of their channels and basins would complicate hydrological computations such as the magnitude of 50-year floods. Continuity of observation therefore is crucial and so is the need for field research. Some generalisations are possible but we need to study large rivers and deltas individually to reliably estimate hydrological data, channel behaviour and the potential for water utilisation. River valleys and deltas are among the most densely populated parts of the world and such endeavours are needed to determine basic regional and local scale consequences for ecosystems, inhabitants and economies arising from metamorphosed rivers.

Conclusion

Although the general aspects of climate change are known and accepted, we have no real knowledge about its impact on large rivers. We can determine major effects of climate change on rivers from the basic tenets of geomorphology and hydrology. As the impacts vary regionally and as impacts are also expected to vary over different reaches of a river, it is more reliable and efficient to study rivers individually. The widespread anthropogenic changes over channels and drainage basins, however, may mask the signals of climate change, at least partially. It is obvious that changes in the form and function of large rivers involve the livelihood, even existence, of a very large number of people. Ideally we should go beyond the usual percentage-based estimates of hydrological and morphological changes and be able to predict channel behaviour such as bank erosion, channel shift or erosion of the delta-face in specific locations. Such information would be extremely useful but remains impossible to gather at the current state of our knowledge. We need to study the major rivers individually in order to construct a new set of rules for understanding, utilising and managing large rivers.

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Climate Change and Conflict in Sub-Saharan Africa: the Mother of all Problems?

by

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KEYWORDS. — Africa; Conflict; Climate Change; Coping Capacities.

SUMMARY. — The impact of climate change is increasingly explained as one of the most serious security threats of the future and a far greater threat to the world's stability than international terrorism. For some, current conflicts as the one in Darfur (described by Ban ki Moon as a 'climate culprit') are (partly) driven by climate change and environmental degradation. It is argued that climate change includes the risk of reshaping the productive landscape, of exacerbating food, water and energy scarcities and of contributing to destabilisation, unregulated population movements and tension. Even if environmental changes induce increased competition between users of scarce goods, the authors want to challenge the common assumption that climate change is a driver of conflict. Drawing on recent examples of conflicts between pastoralist communities in eastern Africa, it will be argued that there is no clear empirical evidence of direct links between environmental stress and conflict and that existing models are largely inspired by neo-Malthusian models of human-resource relations. For the authors, however, the shift from increased competition over resources to open conflict depends on existing coping capacities of societies and the policies, institutions and processes that define access to resources.

From Climate Variability to Climate Change

"Because this global challenge [climate change] can only be met by a global response, we reiterate our willingness to share with all countries the goal of achieving at least a 50 % reduction of global emissions by 2050, recognizing

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that this implies that global emissions need to peak as soon as possible and decline thereafter. As part of this, we also support a goal of developed countries reducing emissions of greenhouse gases in aggregate by 80 % or more by 2050 compared to 1990 *or more recent years.*"

This is paragraph 65 of the G8 declaration "Responsible leadership for a sustainable future" released 9 July 2009 at l'Aquila, Italy. It illustrates on the one hand that the political discussions on climate change have shifted from the acceptance of the principle of climate change, to finding a new year of reference for analysis and policy. The year of reference now is 1990, which is particularly problematic for countries like the US and Canada, whose respective emissions have increased by 18 % and 26 %. On the other hand, a major part of the discussions on climate change are about the reduction of greenhouse gas (GHG) emissions as the COP15 negotiations at Copenhagen have illustrated [1]*. Although very important, this is not the biggest concern for the African continent. Africa will have to deal with the effects of climate change despite the fact that their own contribution to GHG emissions is minimal. Over the last decade, the Intergovernmental Panel on Climate Change (IPCC) has provided extensive scientific proof that there is almost certainly a substantial human contribution to the development and the evolution of climate change. But even if warming occurs worldwide, what makes the African continent different compared to other regions in the world, is the accumulation of different climate change effects.

First, scientific data suggest that Africa is warming up faster than the global average [2], as figure 1 illustrates.

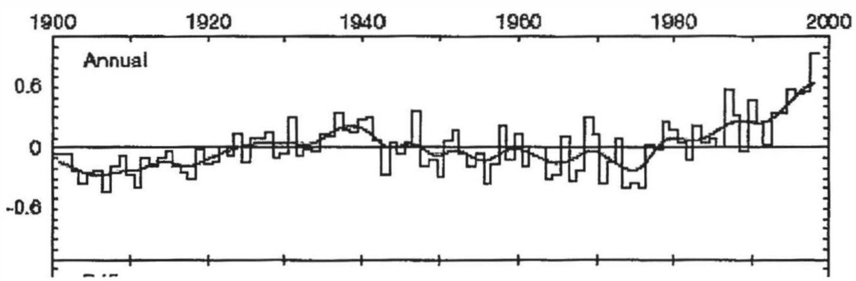

Fig. 1 . — African annual mean temperature anomalies from 1900 to 2000.

* The numbers in brackets [ ] refer to the notes and references, pp. 148-149.

Secondly, there is not one continent wide "African Climate Change Effect". Africa is as diverse as it is big. Some areas of Africa will become drier, other areas wetter. For some it might mean prosperity due to an increase of rain and vegetation. For most other areas, however, it will mean dire adversity. Since the climate variations do not take into account the formal frontiers of countries, this might also be a future cause for concern even it remains to be seen how this concern will materialize.

According to the German Advisory Council on Global Change (WBGU) [3], current climate models do not allow us to make a reliable forecast about the average precipitation in the Sahel zone. The Sahel zone is a semi-arid strip of land that passes through Senegal, Mauritania, Mali, Burkina Faso, Niger, Nigeria, Chad and Sudan. For the Western Sahara in particular the current models even produce contradictory results, as some say that there will be more rain, while others predict desertification. There is consensus, however, about the high vulnerability of the Sahel region and the fact that climate change effects could be amplified by the fragile character of states in the region, by the susceptibility to socio-economic crises as well as by violent conflicts within these countries.

The third matter to take into account is the agricultural sector, on which climate change has a very direct impact. The IPCC report published in 2007 highlighted that Africa is the most vulnerable continent to climate change because of weak capacities to adapt. In rural environments, adaptation strategies have been put in place to deal with what already exists in terms of climatic variations. These may not be able to allow communities to cope with future climate change that may increase the frequencies or amplitudes of floods or droughts and the temperature. Agricultural productivity is likely to decline with repercussion on food security. For Southern Africa in particular, it is likely that the simultaneous occurrence of desertification, salinization and regional water scarcity will cause declining grain harvests and thus have a direct effect on food security.

For the Sahel and Southern Africa, overgrazing, deforestation and non-sustainable agriculture are vital issues to tackle because these are human induced climate vulnerabilities. These matters will only get worse if weak economic and political structures cannot address widespread poverty and social inequality, because tackling these fundamental problems will provide the building stones for a sustainable recovery. CHEVALIER (2008-9) concludes that: "climate variability therefore threatens to destroy the foundations of African economies and the livelihoods of millions of people. For this reason it is necessary...to consider climate change in the context of socio-economic development, and ...to point out the interconnectedness between climate change and development in sub-Sahara Africa." [4]

Climate Wars?

"Darfur in a convenient military and political shorthand — an ethnic conflict pitting Arab militias against black rebels and farmers. Look to its roots, though, and you discover a more complex dynamic. Amid the diverse social and political causes, the Darfur conflict began as an ecological crisis, arising at least in part from climate change." In some literature, Ban Ki Moon's Op-Ed in *The Washington Post* "A Climate Culprit In Darfur" dated 16 June 2007 is quoted as a recognition of the fact that the conflict in Darfur is the first climate change conflict; some even called it the first climate war. This is not what this quote and the entire comment in question actually says: it articulates the existence of a complex dynamic of social, political and economic causes to which climate change can be added, that lay at the basis of the conflict in Darfur.

It can be agreed though that climate change is a threat to the African continent and that it will have a major impact on life through a series of possibly cascading events: desertification could trigger a vicious circle of degradation, migration and conflicts over territory. Migration in turn may increase conflicts in transit and destination areas. This in turn may significantly increase instability in weak or failing states by overstretching the already limited capacity of governments to respond effectively to the challenges they face. [5] The EU military operation EUFOR Chad is a good example of the cascading effect that climate change could have. The mission was confronted with what was called "unintended feedbacks". One of these unintended feedbacks from the conflict on the environment in Chad and Sudan was the change in the set-up of the population. There was an increase in urbanization in Darfur and Eastern Chad due to the improved security. The increase in urbanization attracted Internally Displaced Persons (IDP) and (climate) refugees next to urban centres, which was problematic because it took away the best cultivable lands. In turn, this put food security under pressure due to a lack of arable land and water. [6] This example reinforces the idea of the cascading effect that multilayered conflicts can have. It also illustrates the paramount importance of in-depth knowledge of the local and regional socio-economic and political context. Climate change can only aggravate these circumstances if this state of affairs remains unaddressed and if coping mechanisms fail to be implemented.

Climate Change as a Threat Exacerbator

"Climate change is best viewed as a threat multiplier which exacerbates existing trends, tensions and instability. The core challenge is that climate change threatens to overburden states and regions which are already fragile and conflict prone. It is important to recognize that the risks are not just of humanitarian nature; they also include political and security risks that directly affect European interests." [7] This quote from HR/SG Javier Solana exemplifies that climate change can be seen as a "threat exacerbator" augmenting existing pressures and creating "threats" for international and human security. In his paper, Solana identifies six "threats": conflict over resources, loss of territory and border disputes, environmentally-induced migration, situations of fragility and radicalization, tension over energy supply and pressure on international governance.

Even if growing political awareness of the issue of climate change vis-à-vis violent conflict is proof of a recognition of the complexity of the matter, this awareness includes the risk of political (ab)use of climate change as a threat. The UN Secretary General Ban Ki Moon created a diplomatic window of opportunity for the Sudanese President Al-Bashir by writing "A Climate Culprit In Darfur" to revive the dialogue with the Sudanese government and the international community. Drawing attention to the issue of climate change would have allowed the President of Sudan to save face and accept an internationally brokered compromise. Instead President Al-Bashir later abused that same opportunity given to him to rid himself of all blame for the current conflict in West Sudan and its history all-together.

Climate Change as Driver of Conflict?

Climate change is seen as a new paradigm. The question we need to ask, however, is if climate change could be considered as an actual driver of conflict. Is there an actual relation between climate change and security and, if so, in what way should it be interpreted? Dabelko (2009) draws our attention to four lessons when addressing the climate security link. First, the relation between climate change and violent conflict should not be oversold. Climate change is expected to exacerbate conditions that can contribute to conflict, but characterizing climate change as producing a new kind of conflict is both wrong and counterproductive. To illustrate this pitfall, Dabelko brings forward the political and economic motivations for fighting in Darfur, stressing the fact that climate change and limited natural resources should not draw away attention from the political relationships, power struggles and ethnic grievances contributing to conflict. On the contrary, the interplay between environmental issues, political relationships, ethnic and other grievances should be integrated into the wider analysis. Secondly, ongoing natural resource and conflict issues should not be neglected. There is already a considerable body of research on natural resources and conflict that has very little to do with climate change.

Issues like lack of access to resources, pressure by patronage systems and abuse of people at the bottom of the chain of command are only a few of the quandaries that this research addresses. Climate change could potentially pose a considerable additional threat but even with a stable climate, the existing problems this research brings to the fore are difficult to tackle: abuse of power, lack of governance, poverty aggravated by a lack of food, clean water and infectious diseases threaten lives daily and can hardly be neglected. Thirdly, it should not be simply assumed that climate change will produce massive migration. Climate change will most probably push people to move as we will illustrate in the example of Ilemi Triangle, but the notion of 'climate migration' is increasingly framed as a given without being problematized. Fourthly, it should not be forgotten that climate mitigation efforts can introduce social conflict. Since confronting climate change can have unanticipated consequences, mitigation efforts must be conflict-proof to avoid creating new inequities and instigating new conflict. [8]

Competing Frameworks of Analysis

Only anecdotal research is available on the influence of climate change in conflict areas. Neo-Malthusian models of human-resource relations heavily influence most of that research but there are competing perspectives of analyses. The first perspective is that of Thomas Malthus (1798) who wrote "An Essay on the Principle of Population" [9] in which he challenged the unrestrained optimism about human progress inspired by Enlightenment philosophers. Over the course of two centuries, his bleak vision of human history and the future of humankind has had a considerable impact. Malthus put forward to "fixed laws of nature": the first was "food is necessary to the existence of man"; the second was "the passion between the sexes is necessary for the existence of mankind". Malthus concluded from his assumptions that the power of population was indefinitely greater than the power of the earth to produce food and the outcome was inevitable: too many people for too little food resulting in violent conflict. Translated in modern terms, the neo-Malthusian baseline says that high rates of demographic growth lead to collapse of resources and that collapse in turn results in instability. One example is the argument put forward by Thomas Homer-Dixon, who starts from neo-Malthusian assumptions to state that there is a link between population growth, environmental scarcity and violent conflict. [10]

The second perspective is that of a research tradition of technological optimists referred to as cornucopians. They postulate that scarcity exists by definition when a resource is not in infinite and unconditional supply. They give primacy to the human ability to overcome scarcity through technology and the application of knowledge. GLEDITSCH & URDALL (2002) illustrate the implications of this research tradition with the example of fresh water and use Homer-Dixon's metaphor of the pie as the symbol for the fixed amount of resources that are available according to the neo-Malthusian tradition. "The level of technology influences the size of the pie; in the case of fresh water, technology both determines the quantity that can be extracted from the ground and the capacity to purify polluted water." [11] Another assumption the cornucopians put forward is elasticity without any absolute limitations for the supply of many natural resources. If we apply this to the example of water again it implies that technology determines the amount of water each individual needs through water saving techniques. That in turn means that a larger population can be served with the same amount or even with less water.

According to the cornucopians, most scarcities are local rather than universal, which means resources that are available in abundance in one place can be traded against another that is scarce there and vice versa, thereby benefiting from comparative advantages.

The third analytical perspective places violent conflict in the context of the political history and structural forms of violence in which things like population growth and environmental scarcity occur. As MATTHEW (2002) stated in "Environment, Population and Conflict": "the scarcity-conflict image is somewhat misleading insofar as it fails to situate conflict in a broader context of the robust capacity to adapt to environmental and other stresses that is manifest in most societies. This capacity can take decades to be activated or become successful, something that short-term political analysis may fail to pick up." [12] The combined influence of population growth, availability of resourses and climate change needs to be thoroughly examined further, in case-specific historical and political contexts. However, it is quintessential to take into account the importance of adaptation and coping strategies, that are paramount in overcoming the tangible effects of climate change.

From Threat Exacerbators to Threat Minimisers

Overall, there are problems of water scarcity, desertification and soil salinization, but poverty, demographic pressure, increasing urbanization and economies that are highly dependent on agriculture are root causes of a large number of violent conflicts in sub-Saharan Africa that stay unaddressed.

These longstanding issues, combined with widespread governance insufficiencies, illustrate the need for adequate adaptation strategies that have thus far been lacking. The real catch for African countries is that those who will be hit hardest by the impact of climate change lack the capacity to deal with its consequences. This lack of capacity has nothing to do with climate change but bring us back to development basics like poverty eradication, governance, conflict management, and local and regional cooperation.

CHEVALIER (2008-9) puts forward that: "it is thus imperative that efforts to mitigate and adapt to climate change should be presented as complementary to the broader economic agendas of African countries, and that they should not be seen as impeding wider development objectives." [13] The Institute for Development Studies states that if climate change adaptation and mitigation policies are to be successful they need political support from African leaders and they need to be development led. [14] In September 2009 Ban Ki Moon, the Secretary-General of the United Nations, published a report entitled " Climate change and its possible security implications". In this report, he acknowledges the existence of climate change as a threat exacerbator and identifies what he calls threat minimizers. These threat minimizers are: adaptation, economic development, governance, capacity building, mitigation and conflict prevention embedded in sustainable development.

Two examples illustrate that the complexity of situations on the ground where climate change can play a role as threat exacerbator is only one factor in an intricate play of social, economic and political elements and conflict mitigation strategies.

The Karamoja is a region in the northeast of Uganda bordering with Kenya to the west and South Soudan in the north. This region is prone to food shortages due to unpredictable weather patterns but also illustrates how the difficulties with food production and management can cascade into other coping mechanisms like cattle raiding and the proliferation of guns. In the Karamoja region rainfall is unpredictable and there has been a drastic reduction of the vegetation cover of between 4 and 8 % during the last ten years. Throughout the century, it has changed from savannah grassland over steppe to thickets and shrubs today

The World Food Programme (WFP) has a permanent base in Karamoja and has been distributing food there since 1963. It was one of the first operations that WFP did in Africa. The droughts have reoccurred almost permanently since 1982. Prolonged drought periods like this have destabilizing effects on a society. People flee from the region if they can, but the most tangible effects are for the pastoralists who have to roam the land in search of suitable pasture for their cattle. The reduction of pastures reduces the number of cattle and intensifies cattle raiding. In the past, raiding was mainly a survival response, taking place when disease and famine struck a community. To restock depleted livestock, they went and raided others. Now people do raids to get income, it is done at any time and perpetrated for commercial gain. Raiding used to be controlled by the Council of Elders who allowed the use of small weapons like spears, bows and arrows, but currently armed youth gangs use machine guns to control crowds to take their cattle.

In the Ilemi Triangle, a disputed territory that seats where the border of southeastern Sudan joins with northwestern Kenya and southwestern Ethiopia the problems are very similar. Due to climate change the pastoralists had to cross over into each other's grazing grounds thereby disrupting the traditional co-existence in this transborder region and resorting to armed conflicts.

Inadequate coping strategies also have their bearings on the cultural traditions of pastoralist communities in the Horn of Africa, more specifically on the initiation of young warriors. After initiation, the warrior is allowed to marry by paying an appropriate bride price, which ranges from 50 to 100 cattle or a few Kalashnikovs… The dowry places enormous pressure on young men, whose choice is between accumulating livestock through traditional animal husbandry, which could take many years, or resorting to a quick fix, and that is raiding. The reinforcement of the culture of arm bearing is the synthesis of various factors. First the insecure social relationships, where the traditional instruments of intercommunity conflict management are weak, and pristine tradition is an enormous burden for the young male right of passage. Rustling for livestock and using guns are means to actualize the right of passage into manhood. Secondly, there is a symbiotic relationship between security and economic development, in the sense that as climate change degrades the productivity of land, raiding becomes a coping mechanism. Finally, the proliferation of guns in the periphery of the State is the outcome of international vectors, particularly civil conflicts, which have emanated from State collapse and a product of domestic manipulation by irresponsible leaders.

Conclusion:
Climate Change and Conflict in Sub-Saharan Africa:
the Mother of all Problems?

Multiple factors have an impact on the possibility of armed conflict: poverty, scarcity and access to natural resources, population characteristics, ethnic and religious fractionalization, education levels, geography and previous conflict. [15] Climate change is only one of the many security, environmental, and developmental challenges facing Africa. Climate change is in effect, a "threat exacerbator" that makes existing concerns, such as water scarcity and food insecurity, more complex and intractable. However, it is non-climate factors — poverty, governance, conflict management, international and regional diplomacy — that will largely determine whether and how climate change moves from being a development challenge to presenting a security threat. The preconditions for conflict create pressure on the social architecture of societies but it is the ability to adapt and the capability of subsequently developing coping strategies that determine whether a potential conflict will erupt or not.

A balanced policy on climate change should thus take into account the fact that climate change is a cross cutting issue. This brings the need for coordination between different responsibilities to the fore: there is a need for long-term capacity building and cooperation on development basics but we also need to monitor the security evolution on the ground closely. It is not because there is no conflict directly related to climate change so far that there are no indirect influences that may have a major impact on the safety of African society. The most successful policy on climate change for the African continent would be one that integrates development and international security concerns.

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Sustainability Indicators for Clean Development Mechanism (CDM) Projects in Vietnam

by

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KEYWORDS. — Clean Development Mechanism (CDM); Sustainability; Indicators; Delphi; Vietnam.

SUMMARY. — CDM is one of the flexible instruments of the Kyoto Protocol designed to combat climate change. It aims at reducing the costs of meeting emission targets by allowing for geographical and temporal flexibility.

Projects that are carried out under the CDM have a twofold objective: to offset greenhouse gas emissions and to contribute to sustainable development in the host country. However, the latter objective is marginalized in the vast majority of CDM projects. As a booming developing country, Vietnam will most probably become an increasingly attractive host country for CDM and other post-2012 projects. In order to guarantee that these projects generate substantive sustainability advantages to the host country, indicators have been developed through a participative exercise.

In order to develop a customized framework of indicators to assess the sustainability of CDM projects in Vietnam, a two-round Delphi exercise was set up. A range of indicators was compiled, based on the scientific literature and on sustainability indicators developed for the Vietnamese Quang Tri Province. This list was subsequently presented to a group of Vietnamese experts, who selected the most relevant indicators in a two-round process.

The iterative approach embodied by the Delphi method allowed to select the most relevant indicators in a Vietnamese context. The results, which have been analysed by the authors, show a strong focus on economic efficiency, health aspects and pollution.

In a next project phase a case study on a wind power project will allow us to refine and adjust the indicator set to real-life situations.

Applying a locally developed set of sustainability indicators to existing and future CDM projects will ultimately result in sustainable and climate-friendly development projects.

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The Moroccan Coast facing the Effects of Global Change

by

Abdellah LAOUINA*

KEYWORDS. — Morocco; Sea-level Rise; Coastal Dynamics.
SUMMARY. — This paper has for objectives: 1. to describe and quantify the effect of global change in terms of sea-level rise and change of the coastal dynamics; 2. to analyse the state of vulnerability of the Moroccan coast towards these changes and their effects on the littoral fringe, in biophysical and socio-economic terms; 3. to present, as conclusion, some means to mitigate these effects and the forms of possible adaptation to reduce the potential impacts.

1. Introduction

The coast can be defined as a space where a strong interaction earth/sea occurs in terms of physical, economic and social dynamics. It is a reduced space with social, cultural and landscape value, constituted by original, precious, productive and fragile ecosystems, and desired by multiple actors (BERRIANE & LAOUINA 1993). It is the privileged place for starting up economic activities, and a highly strategic space, where many dynamics converge, but with powerful effect of degradation:

— Pollution of continental and maritime origin;
— Pressure on the space, as the population continues to grow, in relation to the strong attractiveness to the rural population and the tourists, in particular in rush time;
— Natural dynamics of erosion/sedimentation on the coast;
— Current dynamics of sea-level rise, of anthropological origin.

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In Morocco, two essential values are threatened by global change and its effects: 1. the physical and biological natural resources, some of which are irreplaceable, rare species, for example; or the cost of protection or management which, in a purpose of sustainability, is very high (*e.g.*, sand beaches); 2. the sectors of human and economic activities, which look for the littoral location as preferential or necessary site: seaports, oil and chemistry industry, modern thermal power stations, maritime fishing, fish farming, seaside tourism and marinas,...

According to the IPCC scenarios, the Moroccan coast will be strongly impacted by climate change and its indirect effects; it will thus be confronted with major socio-economic and environmental difficulties if adaptation measures are not taken.

Spaces at risk from being directly affected by sea-level rise are restricted enough in Morocco, because the low banks are finally of a rather low shelf space, compared with the rocky and high banks. The Moroccan coast (fig. 1) is indeed relatively rectilinear, except for some widely opened bays (Al Hoceima, Tangier, Azemmour, Essaouira, Agadir, Dakhla) and some prominent capes in the Mediterranean Sea. But these lowlands are really precious in terms of economical value, due to the concentration of activities in their territory. Moreover, the total length of the coast is only 3,500 km, about equivalent to the linear extension of the shoreline, because of the weakness of the indentations, the low depth of the gulfs and the rarity of the pre-littoral islands. On the other hand, the other aspects of climate change, the effects on biodiversity in particular, can have a generalized and fairly important impact.

However, it is very difficult to estimate the potential change in coastal zone and the vulnerability of the coast to sea-level rise, because of the interaction of multiple factors at the interface earth-sea-atmosphere. Crucial data for this evaluation are still not available:

— Detailed topography of the coast and the submarine natural platform;
— Distribution of the precious ecological, landscape and patrimonial values;
— Recent maps of human occupation and analysis of human activities;
— Enough long-term data on the extreme meteorological and marine events.

The potential effects of global change on the coast are multiple:

— Extension of flooding and submersion, in particular on beaches, wetlands and lowlands, of the coastal plains.
— Erosion of the shoreline, in particular sand beaches and cliffs in soft rocks.

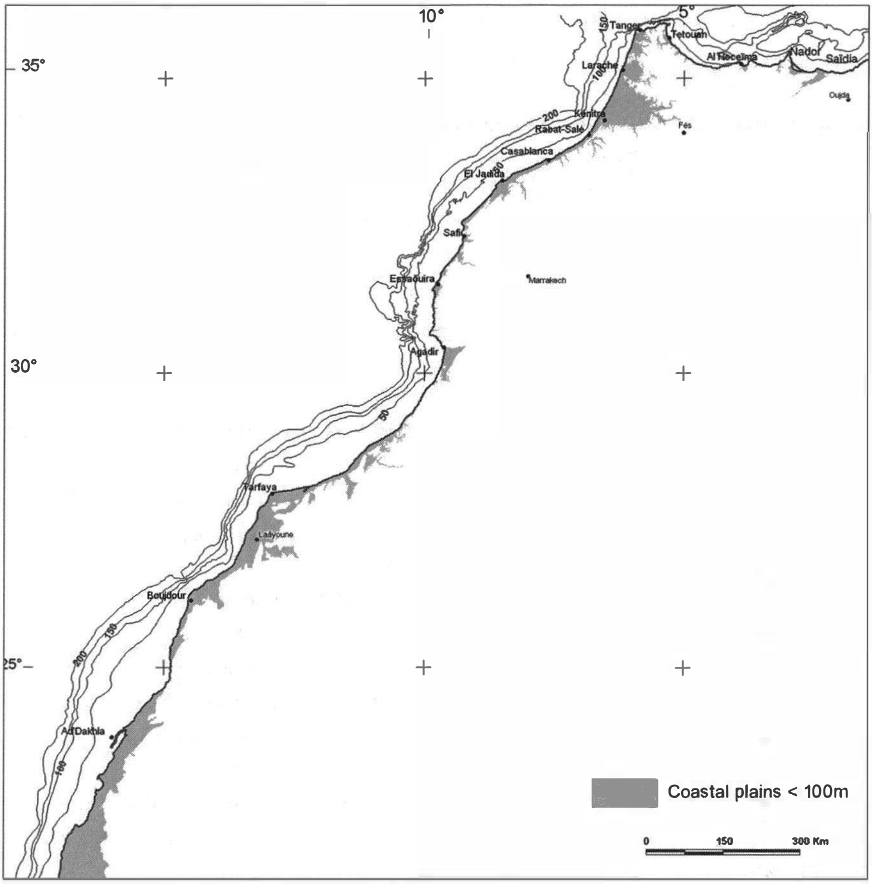

Fig. 1. — The Moroccan coastal zone and marine platform.

— Intensification of the flood impacts on the coast in periods of storms.
— Salinity increase at the level of estuaries and modification of the amplitudes of tide in rivers and bays; intrusion of salt water in aquifers and rise of the water table in the lowlands.
— Modification of the modes of accumulation of sediments.
— Biological effects on ecosystems and coastal marine biodiversity.

The impact of global change and sea-level rise concerns all aspects connected to the quality and availability of water resources, beach erosion and loss or degradation of coastal infrastructures. The potential socio-economic impact is not less important:

— Direct loss of the economic, ecological and cultural values, because of the loss of the submerged areas, the infrastructures and the coastal habitat environments.
— Indirect impacts connected to hydraulic, chemical (salinity) and biological changes, among which the vulnerability of the fishing sector. The vulnerability of sea fishing depends on the exposure of this sector to the risks resulting from climate change and local environmental and socio-economic conditions; indeed, degradation of the environment increases this vulnerability; socio-economic conditions (price, effort of fishing, organization of the profession) also intervene in the same direction. We record impacts on the structure, distribution and production of the fish stocks. Finally, the greater frequency of extreme meteorological events, such as storms, affects the security and efficiency of the fishing activity. This is why it is difficult to estimate what is related to climate change and what can be explained by other factors.

The examination of such a problem is based on the following questions:

— What are the diverse scenarios of change as regards sea level and littoral dynamics?
— What are the potential impacts (biogeophysics and socio-economic) of these various scenarios on the Moroccan coasts and their adaptation capacity?
— What are the impacts of climate change, other than flooding and erosion (salt intervention, impacts on biodiversity, fishing, tourism)?
— What are the effects of the 'artificialization' of the coast on the increase of its vulnerability and thus on unexpected impacts of global change on the weak coastal environment?
— What are the effects of certain equipments built upstream on the shoreline, as water and sediment storage in dams, which have an impact on the coast, because of the trapping of alluviums and thus the modification of the sedimentary budget and then changes in the shore topography and dynamics?

The methodology recommended by the Intergovernmental Panel on Climate Change (IPCC) for such a study is:

— Determination of the geographical area and description of the natural and socio-economic context;
— Analysis of the IPCC scenarios and the choice of the scenarios to be used (climatic, sea-level rise and marine dynamics);
— Determination of the topographic rise of coasts studied from the elaboration of Digital Elevation Models of zones with low topography and thus potentially affected coasts;

— Evaluation of the impact of biogeophysics (on regional maps) and determination of zones at risk from flood and zones at risk from coastal erosion;
— Evaluation of the socio-economic impacts;
— Identification of actions for the establishment of long-term development plans of the coastal zone and formulation of strategies of answer and evaluation of their cost and effects, with options of technical, institutional and legislative order;
— More precise estimation of the cost of the proposed options of response, to incite the decision makers to take into account global change in future projects of development and management of the coast.

However, given the deficit in data in several domains, the analysis will remain limited to some of the aforesaid questionings.

2. Scenarios of Carbon Emission and their Possible Effects

The socio-economic scenarios, differentiated in terms of greenhouse gas emissions, give ranges of warming up from 1,1 to 6,4 °C before the year 2100, and thus ranges varied in terms of impact on the coast, through the warming up of the sea water, the changes of its chemistry and its dynamics and the sea-level rise, more or less accelerated. For Morocco, both scenarios, A1B and B2 (tab. 1, 2) give the following projections in terms of temperature rise in four large 'quarters' of the country as defined by the second national communication to the UNCCC.

Table 1
Estimation of temperature increase at various dates according to two scenarios

	Mean annual temp. (°C)	**2015**		**2045**		**2075**	
		A1B	**B2**	**A1B**	**B2**	**A1B**	**B2**
Eastern Morocco	17.1	17.9	18.0	19.2	19.2	21.0	20.4
North	19.3	19.9	20.0	21.0	21.0	22.4	21.9
Centre	17.6	18.2	18.1	19.4	19.4	22.0	20.4
South	20.1	20.5	20.7	21.7	21.7	23.0	22.5

Source: *Secrétariat d'Etat à l'Environnement*, 2009, second national communication.

But, for the sea-level rise, these values of thermal increase on a regional scale do not count. What account it is the global heating of the earth and the marine waters and its effect on the melting of snow and polar ice.

Table 2

Mean data as expected for the end of the 21st century (IOC 2008)

	A1B*	B2**
pH (in 2000: 8,1)	7.9	7.9
T° increase of the sea surface (compared to 1980-99) (°C)	2.2	–
Sea-level rise, compared to the 1980-99 level (m)	0.35	0.32

* A1B: scenario of rapid development with equilibrium between the use of fuel energies and alternative ones.

** B2: scenario with research of local solutions for sustainable development.

The difference between both scenarios, in terms of quantification, seems small. But the difference will be essentially at the level of the proactive response of the countries that build on scenario B2, while the answer within the framework of scenario A1B will be reactive and thus rather late. The voluntarist side, which plans the scenarios of type B, leaves the possibility of leading a policy of positive and early adaptation, anticipating the effects of climate change.

3. Modification of the Ocean Temperatures

The oceanic ecosystem that develops along the Moroccan coast is called an upwelling ecosystem (Orbi 1998, Hilmi *et al.* 1999, Zizah *et al.* 1999). The upwelling results from transport of surface water towards the wide sea, inferred by winds that blow parallel to the coast, under the regime of trade winds. It is thus a kind of compensation of this surface transport, which is insured by the rise of deep water. With this movement are associated important concentrations in nutrient salts, which support a strong primary production. It is this specificity that is on the base of a food chain, which distinguishes an upwelling ecosystem from the other oceanic ecosystems.

The system of the Canary Islands is one of the four main world upwelling ecosystems, with that of Benguela, Humboldt and California. These eco-systems supply more than 40 % of the captures of the world fisheries, while they represent less than 3 % of the ocean surface. They are characterized by a great variability, connected with the variability of the climate and with their structural instability.

At present, the upwelling still bears the effects of climate change. The major risk is a reduction of this system, which would end in the warming up of surface waters, because of the slightest movement of waters under the influence of the trade wind. We would thus have fewer rises of deep waters and thus less concentration in mineral salts and nutriments. The biological wealth of waters would be sharply decreased.

At the same time, warmer waters along the Moroccan coast would be responsible for more air turbulence and thus for convective movements, which would give more chance to the cyclone genesis, responsible for catastrophic local disturbances.

The rise of the sea-water temperature, by effect of climate change, risks modifying the biological structure by the invasion of species adapted to the new conditions (among which harmful seaweeds such as *Caulerpa taxifolia*). This invasive species are already present on the southern coast of Spain and in Algeria. It risks developing on the Mediterranean coast of Morocco (Tahiri *et al.* 1994).

The 'coloured waters' phenomenon, already noticed and caused by the regular appearance of planktonic seaweeds in massive and unexpected blooms, risks developing more, due to pollution and warming up. These blooms produce harmful toxin for the fish (massive mortalities) and the human health, in case of consumption of bodies having accumulated this toxin.

We can thus retain two major risks, the effects of which can appear in fast term, maybe even unpredictably:

— The loss in biological wealth, and thus fish production, of the Atlantic coast because of the reduction of the upwelling;
— The development of harmful species, with effect of contamination of other organisms, with economic value and grave sanitary accidents.

4. Sea-level Rise

4.1. Monitoring the Sea Level

Morocco recently developed a network of monitoring the tide and sea-level with radar Probe/microwaves and data-logger. The measures have a step of time of ten minutes. Today, the Direction of Harbours and Public Marine Domain has nine of these new radars in Dakhla, Laayoune, Tantan, Agadir, Kénitra, Mohammedia, Jorf Lasfar, Tangier and Nador. Besides, the Topographic

National Agency manages two tide gauges in Casablanca and Al Hoceima. All the data are collected and analysed in Rabat. On the other hand, the old tide gauge of Casablanca became a not operational tool.

These parameters are useful in domains as varied as:

- Harbour hydrography: real-time observation of the heights of water for the safety of the navigation in the entrance of channels and ports, prediction of the tide, etc.;
- Modelling: definition of the constraints of hydrodynamics in the oceanographic modelling and of coastal hydrodynamics;
- Risk prevention: statistical study of high levels, etc.;
- Geodesy: unification of the networks of levelling.

Besides the monitoring of the sea level, the measure of the state of the sea is important for determining the risks of flood. But the measures of swells along the Moroccan coast are little developed; in certain ports they are even determined by simple visual observations. On the whole Moroccan coast, only the port of Mohammedia ensures measures on the long term and surveillance of the state of the sea.

The strongest frequency of extreme sea levels on the coast, connected with marine meteorological events of stronger intensity, explains the long-lasting transformation of the morphology of coasts.

4.2. Impacts of Sea-level Rise

The first threat lies in the permanent flooding of marine waters on the lowest coasts, such as banks of deltaic plains, maritime swamps and beaches.

These environments are vulnerable, in particular there where human occupation weakened the capacity to compensate for the sea-level rise with the supply of sediments accumulated in the back coast (dune of the high beach) and where man reshaped or fixed the dune.

The rhythm of sea-level rise can seem very low and thus insensible; it is nevertheless for cumulative effect; it is especially exaggerated when it comes along with seasonal levels and with tide raised; the damages caused by floods and destructions can then be catastrophic. According to the studies, there was an increase of intensity, height and frequency of waves during the last three decades.

Littoral plains and wet zones (Merja Zerga, Sidi Moussa, Oualidia, Khnifiss, Sebkha Bou Areg, Smir), estuaries of exoreic oueds, more or less closed bays (Dakhla, Tangier, Al Hoceima), beaches and coastal islands (Essaouira, Jaffarines, Cala Iris, Skhirat) are the environments that are most vulnerable to the flood by marine waters (Stour *et al.* 2002).

The flood of the wet zones could compromise their ecological, social and economic value and would oblige the populations that depend on these values to change their activities. The sea-level rise can also have for consequence an extension and a deepening of lagoons. Channels in the lagoon of Moulay Bousselham already show this phenomenon.

The coastal ridges could also be cut up easily, letting penetrate a bigger volume of marine waters, which could be harmful for the halophilic vegetation of the shores — which would be subjected to a longer duration of flood and a higher salinity —, for all the species sensitive to salinity, as well as for the equipments of protection (dikes, piers, ears, etc.). The case of the lagoon of Nador (fig. 2) is edifying. The area includes, besides the surrounding hills, inclined plans overhanging the lagoon and used for irrigated rich agriculture. In the recent Quaternary and in the Holocene, the littoral drift of NW had built an offshore bar of pebbles and sands covered by dunes of 8 to 10 m, thus isolating a space of more than 100 sq. km of lagoon surface. The pass often changed location and was permanently maintained open by dredging; recently, a new pass was dug because of the challenge it represents for aquaculture in the lagoon.

The Nador area recorded a radical transformation of the environment, with a decrease of the economic importance of the lagoon, because of the competition between intensively irrigated farming, the use of fertilizers and pesticides, urbanization (strong pollution of the discharges, in spite of the treatment process) and fish farming (Hilmi 2005). Besides, the sedimentary contributions fill the less deep zones and bring about the mudding of the lagoon. The increase of the marine level could compensate in principle for this sedimentation and offer new conditions of oxygenation of the lagoon, because of the stronger hydro dynamism. But we cannot predict how the pass lagoon/sea will react and what the new conditions of salinity and biological productivity will be like.

The comparison of a DEM (Digital Elevation Model) of the lagoon and its edges, with demarcation of level 1 m, a map of land use and a map of the water table, clearly indicate the incurred threats. The easily flooded zone will be about 7 sq. km, with, in particular, swamps, ponds of lagunage, dikes of ports, some built-up areas and approximately 40 % of the sandy beaches of the ridge of the lagoon. In this ridge, breaches are going to open during storms. Twenty-two per-cent of the total coast length will record a very high vulnerability and 42 % a high risk. The vulnerability to the salt intrusion will concern approximately 21 sq. km (Niazi *et al.*, unpublished poster).

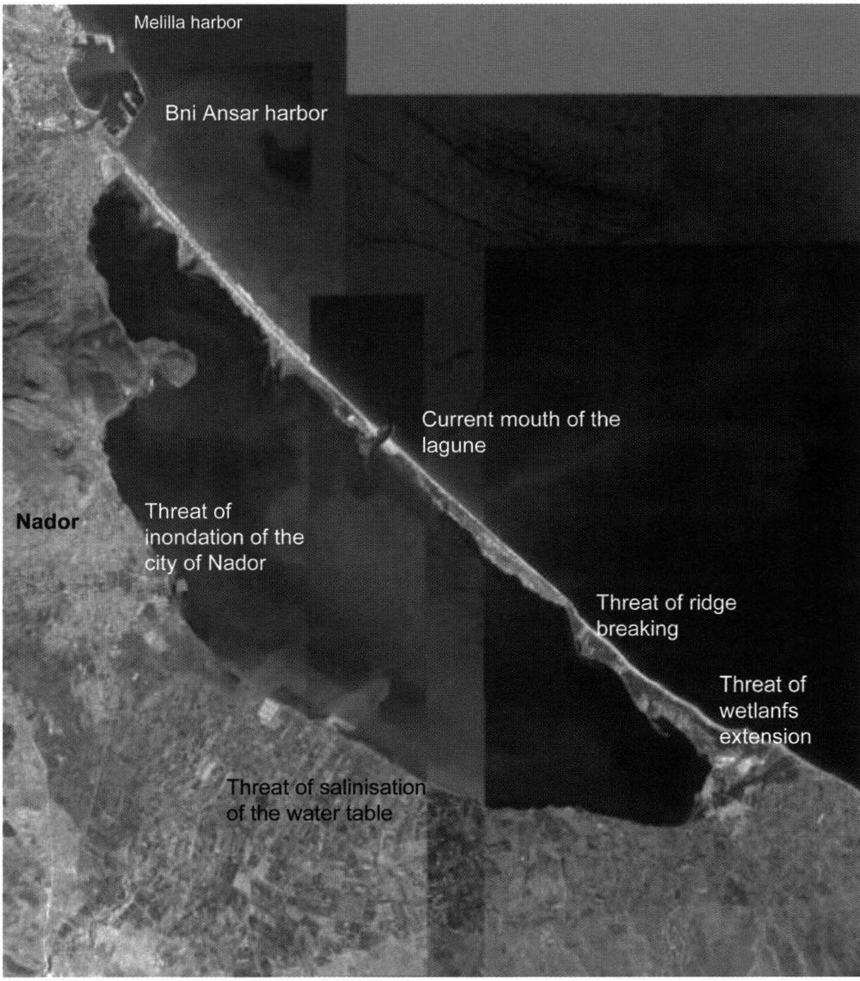

Fig. 2. — The Nador lagoon and the location of risks related to climate change (*source*: Google Earth).

On the chemical plan, the risk of desalination by excessive contribution of freshwater can have a destructive effect on the fauna. Drought and seal-level rise could increase the salinity. Preservation of the balance is thus fundamental. Pollution represents an even greater risk for the lagoon. Blocking the pass with sand can entail a phenomenon of eutrophication. Moreover, biological enrichment is stressed by urban discharges, although partially purified.

On the Atlantic coast, lagoons and the coastal wetlands of Mharhar, Sidi Moussa-Oualidia and of Khnifis incur the same risks. In the cases of Nador and Oualidia the risk is double because, besides the physical and biochemical degradation, the aqua-cultural activity is threatened. In other cases, the ecological risk is fundamental, in consideration of the precious values of these environments, which are visited by migratory birds and therefore constitute an eco-touristic potential.

The lagoon of Khnifis (El Agbani *et al.* 1988, Idrissi *et al.* 2004), in the south of Morocco, is a biological reserve of world interest for the avifauna. It shows an alternating and bidirectional current, in which the currents of ebb tide are more important than those of stream, which explains the wealth in nitrogenous and phosphatic elements, especially in periods of deep water. Besides, intervenes the nourishing wealth in elements due to the effect of offshore upwelling. The environment is thus convenient for shellfish farming (Idrissi *et al.* 2004). Sea-level rise will have as main consequence a bigger penetration of marine waters, but the sedimentation will not necessarily increase, condition to expect a balance.

In the very low plains, the flood related to the sea-level rise will have very important effects. This was shown for the plain of Saïdia, where a high rate of beach erosion occurs.

5. Coastal Erosion

In Morocco, two thirds of the beaches are under erosion; cliffs too move back, in particular between Jorf Lasfar and Oualidia. On the contrary, multiple port facilities continuously have to undergo dredging operations. Sea-level rise can only worsen these trends. Great parts of the beaches give evidence of rapidly expanding seaside tourism foundations. Erosion is a major, already current risk there. This erosion is due to a deficit in sediments, aggravated by human influence, because of the construction of dams, the extraction of sands on the coast and errors committed in the arrangement of coasts.

With the increase of the sea level, we shall record a greater distribution of the swell towards the shoreline; the released energy is necessarily bigger, because of the reduction of the braking operated usually on the bottom of the beach. Cliffs move back under the flood of waves during stormy weather; sea-level rise will accelerate this recession.

Saïdia - Ras el Ma is a perfect example of this problem. Besides, it is the zone that has been studied in depth by multiple researchers (Snoussi 2008). It represents the most important beaches of north-oriental Morocco because it covers a shelf space of more than 20 km, showing a fast economic and urban development. The modes of arrangement contain risks of degradation (destruction of the vegetation cover, construction of rows of villas directly on the dune, setting-up of equipments for sales promotion directly on the beach, difficulties of purification); these threats can increase in the future under the influence of an exaggeration of the regressive trends because of climate change.

For the last century, the area of Saïdia (fig. 3) has been directed to the satisfaction of the regional and national request. Moreover, the rhythm of touristic attendance was bound to Moroccans living in Europe, for their holidays. Recently, the perspective of international tourism and the powerful investments that were realized completely changed the data. The coastal resources of the region became much more precious in consideration of the granted investments. The risk of degradation connected to global change thus becomes more pronounced.

From the Algerian border to Ras el Ma, there are wide continuous sandy beaches on both banks of the Moulouya delta (LAOUINA 1987a, b); the coast is particularly rectilinear, lined inward by important dune accumulations, fixed by a planted forest of great fragility, because of the weakness of the soil and the strong pressure. Climate change is expected to increase the already engaged dynamics. Various sandy accumulations of dunes constitute an unstable sandy stock, subject to wind deflation and marine erosion and to

Fig. 3. — The coastal strip of the Saïdia - Moulouya plain (*source*: Google Earth modified).

what any careless exploitation would allow to destabilize. Dunes had been planted with eucalyptus and juniperus in the 1940s. Besides, since the implementation of the project to protect the ecological site of Moulouya, important efforts of fixation of dunes were undertaken. But this zone is at present subjected to a strong pressure for the development of seaside tourism and urbanization; the preservation of dense and wide enough vegetable strips between the occupied grounds had to represent a condition of fundamental stability, which regrettably was not respected.

All the studies recommended to forbid the exploitation of sand because it would accelerate the already perceptible marine erosion. The cape of Ras el Ma, in the western extremity, which protects the beach of Saïdia from the swells of NW, did not protect the coast against the present trend of sand erosion. The studies, however, recommended to forbid the occupation of the marine public domain and to put up the tourist installations far behind, to allow the continuation of the sedimentary exchange continent/sea and to prevent the loss of sand on the beach. Natural windows were preserved and the zone of the Moulouya delta constituted the most favourable environment because the most spectacular and the most varied.

The delta is in permanent evolution (ZOURARAH 1994) because of the transformations the course of the oued and its flow have undergone. It recently recorded an important movement of its location which can have an impact on the balance of the beaches in the region and on the functioning of the fishing port close to Ras el Ma. This harbour records now a blocking of its entry because of the transit of sands with the drift.

Signs of deficit of the sandy stock on the coast, such as the presence of micro-cliffs on the shoreline because of the construction of dams on Moulouya, begin to be visible on dunes and beaches (MOULIS 2004). In addition, several aeolian breaches in the sandy ridge could be directly bound to the over-occupation by the tourists who cross dunes on foot but also with motorized machines.

Today, the important tourist and urban development will durably modify this coastal region, both in socio-economic and environmental terms. The construction of the port of Saïdia, increased the deficit in sediments due to the interruption of the littoral drift towards the western part of the coastal plain, evidence of which is given by the accumulations of sand on the harbour dikes and the early blocking with sand of the port.

The implemented tourist project, near the ecological site of the Moulouya delta, risks increasing even more the vulnerability of the littoral plain by concentrating the flows of attendance (SNOUSSI 2008). According to a projection made by this author, on horizons 2050 and 2100, with maximal flood levels, during extreme storms, of 2 and 8 m respectively, wide spaces of the plain of Saïdia can be flooded. According to this study, beaches will in any case be subjected to more erosion than at present, in particular those of the western sector between Ras El Ma and the mouth of Moulouya, and that of the sea resort of Mediterranean Saïdia. The study even estimated the economic value of assets susceptible to be lost, which would be 1,19 billions DH with the level of extreme flood of 2 m. Tourist developments will be touched first.

A diachronic analysis was made by Snoussi (2008); it is based on the comparison of four air photographs spread out from 1958 to 2004, on the scale of 1/20,000. The coast of the left bank of Moulouya showed a 2,09 m progradation per year, in connection with the destruction of the delta and the redistribution of its materials by the east resulting littoral drift. The right bank of Moulouya recorded a fast retreat which reached an average of 11,89 m per year, mainly connected to the installation of dams. In the future, with the use of sandy dunes for constructions, and with the implementation of the new touristic harbour, the trends will be exaggerated.

The cliff sectors show lower erosion phenomena, but which can be locally spectacular. It is the case in the Massif of Bokkoya, a calcareous mountain situated in the coastal central part of the Rif chain, in Al Hoceima's province. The maritime edges are characterized by steep cliffs overtaking by places of 300 m high. They are often instable and show slidings and fast collapses for the totality of the landscape. These phenomena are very difficult to fight against and are expected to increase with the sea-level rise.

6. Salinization Phenomena

The phenomenon of salinization by intrusion of marine waters is expected to be a major impact of global change on coastal areas. Its study is nevertheless difficult, because it is necessary to determine what the effect of water-table overexploitation by pumping and of marine intervention because of sea-level rise is like. The effects are the following:

- The separation between continental freshwater and marine salty waters moves laterally towards the continent and the piezometric water-table level risks being heightened;
- The intrusion of salt water in groundwater and the floods will raise a greater problem of preservation of the agricultural speculations in littoral environment;
- There will be important impacts on the drinking-water supply.

The phenomenon of salinization by intrusion of marine waters may affect estuaries and coastal aquifers. Sea-level rise is going to cause penetration towards the upstream of salt water, through the groundwater of the coastal plains. The increase in salinity of surface water will doubtlessly have repercussions on fauna and flora and on the possibilities of using waters for human activities. Hence, there will be reduction of the volume of useful subterranean freshwater. This intervention is going to stress the already perceptible effect of the overexploitation by pumping.

The penetration of the salt tide more upstream is already felt in several estuaries, but we need temporal series of data to confirm it. But other anthropological factors, such as the excess of freshwater pumping, interfere with this dynamics.

The section of Saïdia - Ras el Ma shows the salinization of the delta wetlands and their vegetation degradation because of water pumping upstream (DAKKI 2003). In addition, urbanization, pollution by pesticides and fertilizers, and seasonal tourist attendance threaten the quality of these wet zones. Sea-level rise risks reconstituting the wet zones, but with a new configuration, more salty, and thus with a new biological context. Besides, reduction of the freshwater contributions and construction of dams on the Moulouya river strengthened the penetration more upstream of marine waters. To it are added the returns of water from drainage of the irrigated perimeters, which are characterized by some salinity. Subterranean waters of the coastal plain thus become very salty. In spite of drainage works to fight against this salinization, the cultivated grounds are more and more abandoned or have to change cultivations.

The marine intrusion is thus verified (MENIOUI 2008). This phenomenon is more marked in the western part of the plain, where it reaches the hyperhalin stage. The evaluation of the environmental state of the wet zones of Moulouya, which was realized within the framework of the project MedWet-Coast-Morocco (DAKKI 2003), revealed a certain number of dysfunctions and threats weighing on the site. If the losses in habitat environments are still relatively low, the site underwent big modifications at the level of nature and relative extent of these habitats, because of the profound morphological modification due to the reduction of the sedimentary contributions and the decrease in freshwater contributions towards the water table. The main threats concern decrease in hydrological function, losses in biodiversity and decline of the economic values of the wet zone.

7. Fishing and Fish Farming

Sea-level rise could affect littoral activities (coastal small-scale fishing, shells and seaweed harvests). Besides, aquaculture activities, which are bound to physicochemical conditions (salinity, temperature, oxygenation, etc.), should adapt to the changes in sea level and to the increase in temperature and salinity (FAO 2006, ORBI & BERRAHO 1999, SAKROUHI 1990, Secrétariat d'Etat à l'environnement 2009).

One of the potential impacts of global change lies in the movement of multiple species, outside their domain of origin, in search of the conditions adapted to their requirements. The variations of salinity, inside a space close to the coast (swamps, lagoons, estuaries), with hypo-salt zones and hyper-salt zones, explain the very big variety of habitat environments within the same zone. Any sea-level rise is going to interfere with this spatial distribution. As a rule — in principle —, it pulls a marinization, which is an increase of depth and salinity, and a certain homogenization, which represents a reduction in terms of biodiversity and a loss in biological potential, but the appearance of a new classification according to the new zone of humectation.

The Alboran sea is a good example: it is characterized in its western part by stability of the seawater, and thus by biological poverty, while towards the east, in a zone of diffluence, towards N and S, waters are colder and more nourishing. The big zooplanktonic wealth is explained by the low importance of the continental shelf. The zone of main wealth is situated east of Al Hoceïma, with concentration around the Cape of the three Forks. But several species and habitat environments are threatened by urban pollution (hot spots of Tangier, Tétouan, Al Hoceïma, Nador and Saïdia) and overexploitation.

Temperature variations in mineral salts, nutriments and organic matter in suspension, representing a source of food for the marine and lagoon animal life, constitute the main factors of the current biological changes.

In the lagoon of Nador, herbariums of zoosteres, and muds with shells are environments which, the first ones, risk to be affected by climate change. Indeed, marinization risks reducing strip cycles of dumping — emersion favourable to the development of herbariums.

In the Cape of the three Forks — zone of strong productivity, because of the presence of habitat environments with phanerogams and fish farming, which benefits marine mammals —, caves which accommodate seal monks risk being submerged, what would mean the definitive exodus of this species. We have already recorded a considerable biological impoverishment there, because of tourism and disturbances, in particular by visitors of Melilla.

In all these sections, several habitat environments are threatened: beaches, dune ridges, with on top a juniperus cover and wet zones. The majority of the species are very sensitive and badly bear the change of characteristics of their environment. An increase in water temperature from 1 to 2° would have a major effect on the growth rate, the sensibility in diseases and thus on the abundance of these species. Naturally, some species will take advantage of it, either because the new conditions are more convenient for them, or because they will less undergo the competition of the others, which will have migrated. But all the balance can be affected by the disappearance of one of the links of the food chain.

The red coral and the molluscs will be very affected in case of confirmation of the acidification, because of the effect on their calcitic bodies. All the ecosystems needing light and requiring an alternation of dumping — emersion will find difficulties being reconstituted on an upper floor with regard to their current coastal extension.

This environment degradation will have effects on fishing and picking. Overfishing, excessive picking and harpoon fishing worsened the stocks of several species. Human activities on the oriental Mediterranean coast recorded a very strong development in the past, in particular the extension of fish farming in Nador and on the estuary of Moulouya. Both fish farming companies, MAROST and SAM, failed for bankruptcy, further to the reduction of their activity. Better protection against pollution and follow-up of the impacts of marine rise could allow the restart of these activities, which have a high potential.

8. Conclusion: Response to Climate Change and its Effects in the Littoral Domain

To face global change and its impacts on coastal zones, it is necessary to adopt measures of adaptation for the long term. Some of these measures represent structural reforms, such as the application of the principles of integrated management of coastal zones (SNOUSSI 1998), the creation of an institution responsible for the management and development of coastal zones, in an integrated and forward-looking vision, the legal reform relative to the maritime public domain. Protective measures for the short and middle term will nevertheless be necessary to counter the immediate effects.

As a response to sea-level rise, we can adopt two attitudes: an attitude of resistance to the current dynamics, or an attitude of abandonment of certain lands already submerged by the sea or in process.

The resistance is justified there where the economic stakes are fundamental, as, for example, to protect an existing town, by setting up heavy equipments of defence. The financial cost can be very high; moreover, the operation will also bring about a considerable environmental cost, because the coast risks to be distorted. The operation can finally create dynamic disturbances susceptible to pull imbalance. The least bad way is to feed the shoreline with sand, and thus to compensate for the rise of the sea level. It is the example from the Netherlands, where, continuously, several millions of cubic metres of sand are put down on the bank. The cost for the preservation of 1 km of beach by recharging in sand is as high as that for the maintenance of 1 km of highway.

The choice of recession consists in the abandonment of positions previously occupied, but in process of degradation. This happens in the USA, where damaged dikes are not reconstructed. It is better to adopt a policy of compensation for equipments and abandoned establishments; it supposes the revision of the zoning maps of lands and new realignments of the arrangements. There where the shoreline is not occupied, it is better to let the sea move and operate a simple translation with compensation of the owners of grounds, because the defence is unjustified.

The new arrangements, in project, naturally are to be conceived far from the shoreline, by bounding a not building strip of 100 m, from the higher limit of the maritime public domain. Sometimes, if the recession is fast, by application of the principle of precaution, it is better to leave 500 m.

The strategy has to be based on:

— A selective protection of the various coastal zones according to their more or less big vulnerability to climate change.
— The choice to ally the continuation of the traditional activities and the launch of innovative ones, allowing to develop the economic and social value of the coastal zones.
— The consideration of the sustainable development in the social, economic, environmental standing.
— The necessity of having scientific validated data (climatic, biological, chemical, physical, etc.), allowing to reach a sustainable integrated management for the coastal zones and the sea. The sustainable development of the coastal zones in terms of conservation of the landscapes, resources, biodiversity and halieutic stocks passes by an ecosystemic approach and a scientific support. It is thus necessary to develop transnational programmes to exchange the knowledge, facilitate the technology transfer and learn from scientific research.

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Clean Biomass Gasification and Energy Generation by Fuel Gas Catalytic Filtration

by

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KEYWORDS. — Biomass Gasification; Tar; Catalytic Filtration.

SUMMARY. — It is well known that biomass is one of the important primary and renewable energy sources. The use of biomass through thermo-chemical process (*e.g.* gasification) offers the potential to reduce the global CO_2 emission because biomass is neutral in carbon dioxide circulation. Moreover, using biomass can reduce the high dependence on traditional non-renewable energy sources such as fossil fuels.

When biomass is gasified at high temperature, it generates a fuel gas that can be used to generate heat, electric power or as a raw material for the synthesis of chemicals, liquid fuels, or other gaseous fuels such as hydrogen for transportation. Typically, the fuel gas contains not only CO, H_2, CO_2, CH_4, H_2O and other hydrocarbons, but undesirable contaminants (*e.g.* tar, particles, nitrogen compounds). Hence, widespread use requires simplified as well as high efficiency gas cleaning processes to remove the contaminants. This study focuses on the further improvement of a one-step cleaning unit using a high temperature catalytic candle filter by investigating the effect of catalyst compositions (active component, promoter and secondary support) in order to improve the activity of catalyst at lower temperatures, more compatible with the operation temperature of small air blown gasifiers.

According to extensive experimental results (material characterization and screening tests), the best catalyst was obtained by depositing an alumina-zirconia mixture to increase the internal surface of the porous filter matrix, followed by Ni-MgO (promoter), resulting in a composition of 1.73 wt% ZrO_2 + 1.43 wt% Al_2O_3 +1.03 wt% Ni and 0.47 wt% MgO. We recently discovered that addition of a small amount of O_2 (1-3 vol%) to the fuel gas in typical conditions (100 ppm H_2S, 2.5 cm / s face velocity, 1 g / Nm^3 naphthalene as tar model compound), dramatically increased the conversion of naphthalene. For example, at 800 °C, the naphthalene conversions were 98.2 % with 1 % O_2 versus 79.5 % without O_2 in the feed.

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Long-term experiments were performed using a catalytic filter disc at 800 °C (a typical gasifier outlet temperature) during 250 hours with 1 g / Nm^3 naphthalene and 1 % O_2. The conversion of naphthalene is ranging from 98.2 to 99.4 %, while no coke formation was detected over 250 h. Adding a small amount of oxygen to the fuel gas allows almost complete removal of tars at low temperature without significantly modifying the gas composition and resulting in significantly simpler and less expensive equipment, as no reheating of the producer gas coming from the gasifier is needed.

With this catalytic cleaning unit, the biomass gasification derived fuel gas is clean enough to be directly used in a gas engine or turbine or be further treated for other applications.

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Assessing Carbon Stocks and Greenhouse Gas Fluxes in Tropical Forests. Links with Climate Change International Negotiations

by

Jean-Paul MALINGREAU*, F. ACHARD** & P. DEFOURNY***

KEYWORDS. — Carbon in Forest; Deforestation; REDD; Monitoring.

SUMMARY. — Tropical deforestation may contribute up to 20 % of the world's anthropogenic greenhouse gas emissions, mainly through CO_2 emissions (burning and decay). The global net carbon flux resulting from land-use changes during the 1990s, predominantly deforestation in the tropics, has been estimated by IPCC at 1.6 $GtCyr^{-1}$. However, uncertainties in this land-use change flux of the global carbon budget are high (with a range from 0.5 to 2.7 GtC yr^{-1}). Furthermore, the fraction of CO_2 anthropogenic emissions that is absorbed by the world vegetation can significantly vary in time and thereby influence the net total.

Several components must be examined to improve estimates of emissions from forest conversion in the tropics. They relate to i) the initial carbon stocks in the forested ecosystem (tC/ha), ii) area (ha) affected by the various types of deforestation processes, and iii) evolution of carbon stocks and fluxes caused by those changes (tC/ha/year). Forest conversion can take many forms in space and in time and a range of alternative land uses can follow deforestation.

Estimating deforestation would be a major challenge without the use of satellite imagery, in particular over remote regions. Technical capabilities have advanced since the 1990s and operational forest monitoring is now feasible for most developing countries in the tropics. In this paper we address the issue of estimating deforestation from a pan-tropical perspective. We present a method based on a global sampling scheme of satellite images which is intended to provide precise forest change estimates at continental levels.

The present method could be used, with some adjustments, by developing countries in the perspective of setting up a formal mechanism for addressing "reducing emissions from deforestation and degradation" (REDD) in the context of the United Nations Framework Convention on Climate Change (UNFCCC). A monitoring activity serving

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such objective requires a capacity to estimate changes throughout all forests within a country's boundaries. Forest monitoring programmes in tropical countries can benefit from pan-tropical and regional observations to ensure consistency between different national monitoring systems; the proposed systematic sampling scheme can be used as the base for more intensive schemes at national level.

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Development of a Protocol for Micropropagation *Jatropha curcas* L.

by

Samson MEDZA MVE*, André TOUSSAINT*,
Jean-Pierre BAUDOIN* & Guy MERGEAI*

KEYWORDS. — *Jatropha curcas* L.; Regeneration Protocol; Proliferation; Biofuel.

SUMMARY. — *Jatropha curcas* L. is considered as one of the most interesting potential sources of non-edible biofuel. Its propagation by seed has the disadvantage to give rise to heterogeneous plant populations with highly variable morphological and phenological traits because of the outcrossing mating system. In natural conditions the oil seed content can vary between 4 and 40 % due to segregation. This study focuses on the development of a regeneration protocol from nodal explants that could be of great help in the multiplication and the release of elite clones of *J. curcas*. It compares the growth and development of two genotypes from Senegal and Madagascar. The explants are taken from two months old mother plants, grown in a growth chamber under the following environmental conditions: 12 h light per day, ± 28 °C and 60 % relative humidity. The sterilization method consisted in washing the nodes with a 5 % Dettol water solution, immersing them in 70 % alcohol water solution for 30 s, plunging them in a 10 % calcium hypochlorite water solution and rinsing three times in sterile distilled water. Sterilized explants are cultured *in vitro* on the Murashige and Skoog medium (1962) containing 8.87 µM of BAP and 4.93µM of IBA (MC1). The development of apical and axillary buds produced young stems after three weeks. These stems are isolated from the explants and subcultured. Two proliferation media (MP) were evaluated: MS (1962) [MP1] and a medium containing Quoirin and Lepoivre's micro-elements, macro-elements and vitamins of MS [MP2] to which were added 13.31 µM BAP, 9.85µM IBA, 50 mg/L L-glutamine, 25 mg/L citric acid and 25 mg/L adenine sulfate. All experiments were carried out in wecks containing ± 100 ml of culture medium. The pH of all media was adjusted to 5.7 ± 0.1 prior to autoclaving at 118 °C at 1.1 kg sq. cm for 15 min. Cultures were incubated under 12 h/light/dark cycles (artificial light, 80 µmol per sq. m per s) at 27 ± 2 °C.

After one week of culture, the MCl environment allowed 100 % budbreak of axillary and apical buds. They became shoots after three weeks without difference

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between the two genotypes tested (Madagascar and Senegal). The vitro-plants presented a multiplication rate (number of nodes / stem) significantly different according to the proliferation media on which they were transferred (3.1 ± 3 for MP1, 2.5 ± 2.1 for MP2, $p = 0.018$), and according to the genotype (1.1 ± 2.1 for Senegal accession, 2 ± 1.2 for Madagascar accession, $p = 0.014$). Difference in growth expressed by the length of stems was also highly significant between the two proliferation media (7.5 ± 3.8 in MP1, 3.1 ± 3.9 in MP2, $p = 0.001$).

These preliminary results will help to improve the proliferation rate and allow us to start the investigations regarding the rooting stage and the monitoring of the compliance of the produced vitro plants after the phase of acclimatization.

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The Reforestation of Vietnam in the Light of Kyoto

by

Patrick MEYFROIDT* & Eric LAMBIN

KEYWORDS. — Deforestation; Reforestation; Land-Use Policy; Biomass Carbon Stock; Leakage.

SUMMARY. — For developing countries, land-use and forestry activities offer a cost-efficient way to mitigate global warming. This study assessed forest cover change in Vietnam during the last two decades, its causes and effects for issues relevant for carbon emissions mitigation policies.

First, using Fuzzy Kappa and other indicators, we compared forest cover estimates and spatial patterns from global and national land cover maps from the early and late 1990s, and compiled other available statistics for years before and after that period. This showed that a forest transition — *i.e.* a national scale shift from net deforestation to net reforestation — occurred in Vietnam: the forest cover dropped to 25-31 % of the country area in 1991-93, and then increased to 32-37 % in 1999-2001 and 34-42 % in 2005. The reforestation occurred at a higher rate than deforestation in the previous decades, and was due, in similar proportions, to natural forest regeneration and to planted forests.

Secondly, we analysed the causes of these forest changes using local case studies, multiple regressions and material flows analysis in the forestry sector. Several internal political, socio-economic and land-use processes contributed to this reforestation. The policy and forest changes had large impacts on people's livelihoods. The reforestation in Vietnam is also associated with a displacement of deforestation to other countries representing 39 % of the regrowth of Vietnam's forests from 1987 to 2006. About half of the wood imports during this period were illegal. Sixty percent of this displacement corresponds to the leakage generated by policies restricting the exploitation of natural forests.

Thirdly, we described the key environmental attributes of this transition. Carbon stocks in forests followed a similar transition, decreasing to 903 (770-1307) TgC in 1991-93, and then increasing to 1374 (1058-1744) TgC in 2005. In Vietnam, the forest carbon sink during the 1990s was larger than the carbon emissions from fossil fuels. However, forest density declined during the same period, with an increasing

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proportion of young and degraded forests. The effects on habitats measured with landscape pattern indices were contrasted: in several regions, the reforestation decreased forest fragmentation, while in others clearing of old-growth forests continued and/or forest fragmentation increased. This shows that recovery of area and carbon stocks can be accompanied by a degradation of other ecosystem functions and services of forests.

Other forest transitions exist in Tropical Asia and in Latin America. Knowledge about the causes, pattern and environmental impacts of the forest transition in Vietnam is therefore relevant to understand possible emerging regional trends that would have implications for global environmental change. The case of Vietnam shows that reforestation and avoided deforestation can contribute efficiently to mitigate carbon emissions. But forests are not only a carbon sink, they also provide many other ecosystem functions and services and are crucial for the livelihoods of local inhabitants. Policies allocating credits to countries for reforestation and avoided deforestation should pay attention to other ecological and social functions of forest, and should monitor illegal timber trade and discount the displacement of wood extraction to other countries.

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Global Warming Effect on Developing Countries: Case of Tanzania

by

John MGANGA*

KEYWORDS. — Effects of Greenhouse Gases (GHG); Awareness Creation; Poverty; Policy Makers.

SUMMARY. — In developing countries lifestyle and production methods are characterized by natural processes. Dynamics of climatic conditions aggravated by increased greenhouse gases (GHG) emissions. Besides global warming issues, local drivers, such as poverty, reliance on rainfall for agriculture — which is the main economic source for the majority —, low technology to produce goods and delivering services, extensive use of solid fuel, high population growth and high urbanization compared to service capacity, contribute to the challenges. The lack of service capacity includes lack of coordination in issues related to needs, challenges and solutions are major factors that aggravate decline of economy, social welfare and environment in developing countries.

In Tanzania global warming impacts affect almost every aspect of life. Increase in temperature results in unpredictable rainfall. This results in reduced water level in dams by 6.2 m and meaning increasing water supply problems and a reduction in hydroelectricity production in 2003 to 2006. Other consequences are a decrease of the ice cap volume on Mount Kilimanjaro by 50-80 % and long dry seasons in the last two decades, causing droughts that affected agricultural activities and food shortages. On the other hand, high precipitation levels have caused floods and destruction of infrastructure in 2006. Health issues, such as desease outbreak, and malaria cases, have increased to levels never experienced before, especially in highland areas such as Arusha, Kilimanjaro and Lushoto.

These problems can be solved when the community is involved and educated to increase awareness. The use of affordable technology, locally available materials and resources, reduction of imported advanced technology and products, the use of renewable sources of energy when appropriate and available may encounter the challenges. Policy makers need to accept experts and / or technical advice. Further, the global community needs to join efforts to tackle global warming effects. The effects could be more severe than current models and predictions state, certainly if no actions are taken to alleviate the situation.

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From 'Climate Refugees' to 'Survival Migrants': the Role of International Law in their Protection [1]*

by

Michèle MOREL** & Frank MAES***

KEYWORDS. — Climate Change; Migration; Legal Protection; Human Rights.
SUMMARY. — The phenomenon of 'climate refugees' catches increasing attention from organizations, academia and policy makers. This paper examines this phenomenon from a legal protection perspective and argues that the term 'climate refugees' is inadequate. It proposes to use the concept of 'survival migration' instead. After discussing conceptual issues, this paper examines the international legal protection framework for survival migrants. First the applicability of migration-related international instruments is looked at, then the question to what extent survival migrants can legally be sent back to their country of origin is discussed. This legal framework proves to be unclear and highly inadequate to protect survival migrants.

1. Introduction

No week passes without a newspaper article, television news or a documentary describing the plight of 'climate refugees'. This phenomenon of 'climate refugees' and its numerous variants such as 'environmentally displaced persons', 'environmental refugees' and 'environmental migrants' catch increasing attention from academia, policy makers and non- and intergovernmental organizations (MCADAM 2009, WESTRA 2009, IOM 2009). At the same time, confusion exists with regard to the meaning of those terms.

Although it is acknowledged that migration as a strategy for dealing with changes in the environment is as old as humanity, climate change is said to

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* The numbers in brackets [ ] refer to the notes, p. 192.

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lead to an increase in the intensity and scale of environmental disruptions and thus in migration/displacement. The Intergovernmental Panel on Climate Change (IPCC), which assesses the scientific, technical and socio-economic information relevant for the understanding of the risk of human-induced climate change, noted already in 1990 that the greatest impact of climate change may be on human migration with millions of people displaced by shoreline erosion, coastal flooding, agricultural disruption and severe drought (LONERGAN 1998). In its fourth Assessment Report of 2007, the IPCC informed the international community that global warming is speeding up and that human beings are primarily responsible (IPCC 2007).

Does the term 'climate refugees' accurately reflect the complexity of today's migration and displacement realities? This paper argues that this type of migration/displacement should rather be seen as belonging to a broader category of migration/displacement, *i.e.* 'survival migration/displacement', whereby climate change is often but a contributing element to migration/displacement alongside other environmental and socio-economic factors. The paper then examines the role of international law in the protection of survival migrants, *i.e.* those who have crossed an internationally recognized border. The existing international legal protection framework will be discussed and it is examined to what extent international human rights law provides protection to survival migrants against forced return to their country of origin. The paper will conclude by noting that the current legal framework is unclear and inadequate and fails to protect survival migrants.

2. From 'Climate Refugees' to 'Survival Migrants'

This part explains why, from a humanitarian and legal protection perspective, 'survival migrants' is considered to be a more adequate term than 'climate refugees'.

The frequently heard term 'climate refugees' is legally incorrect. To be a refugee in the sense of Article 1 of the 1951 Convention relating to the Status of Refugees (1951 Refugee Convention) it is required that a person fears persecution for reasons of race, religion, nationality, membership of a particular social group or political opinion. Although it is possible that a person fleeing climate-related events also fears persecution on one of the five grounds — for example, when a government intentionally refuses to offer relief to a minority group after a cyclone has affected the country —, this is rather the exception than the rule. It is therefore argued that it is preferable to use the term 'migrant' instead of 'refugee'.

Also the word 'climate' is preferred not to use. While this term might be useful for the purpose of advocating for climate change mitigation and adaptation, thus for the prevention of 'climate refugees', it is not an adequate term as regards humanitarian and legal protection questions. People usually flee for a complex mix of reasons and therefore it is in most cases very difficult, if not impossible, to isolate one factor, for example the climate factor, as the only cause of migration. There is no clear causal link between climate change and migration. Other elements that are intertwined with the climate factor are environmental problems other than climate change and socio-economic elements: air and water pollution, development projects, industrial accidents, deforestation, population pressure, lack of income, collapsing economies and physical insecurity are some examples.

Given this multi-causality of migration, the term 'climate refugees' or 'climate migrants' is in this paper abandoned and exchanged for the recently developed concept of 'survival migrants' by Alexander Betts (BETTS & KAYTAZ 2009). Survival migrants are defined as persons who are outside their country of origin as a result of an existential threat for which they have no access to a domestic remedy. The reasons for their flight have mainly been a combination of state fragility, livelihood failure and environmental disaster. Stated differently, a combination of social, economic and environmental factors. Survival migrants fall outside the traditional dichotomy of people fleeing persecution or conflict on the one hand, and voluntary economic migrants on the other.

The author considers the concept only in relation to cross-border movement, not in relation to internal displacement. The reason therefore lies in the fact that, from a legal protection perspective, it is not useful to distinguish between different groups of internally displaced persons based on the cause of displacement. Differently from migrants, internally displaced persons all have the same legal status: irrespective of their internal movement, they fall under the legal system of their country of origin or habitual residence. Therefore, the term 'survival displacement' does not serve a purpose from a legal protection point of view. Persons factually belonging to this category are thus incorporated in the category of internally displaced persons. Although later in this paper the international legal protection framework for internally displaced persons will briefly be touched upon, the emphasis lies on the legal protection of survival migrants, thus those who have crossed an internationally recognized border.

3. The International Legal Framework

As regards internal survival displacement, as said above belonging to the general category of internal displacement, the Guiding Principles on Internal Displacement have been developed in order to guide States on the protection of internally displaced persons. These Guiding Principles were developed in 1998 by the former Representative of the United Nations Secretary-General on internally displaced persons, Francis M. Deng, and have afterwards been adopted by the United Nations. Although the Guiding Principles as an international instrument are not legally binding on States (KÄLIN 2000, vii), the content of the Principles is to a large extent legally binding since they are mainly based on international human rights law and international humanitarian law (KALIN 2000, viii). The Principles are a powerful instrument for the promotion of the rights of internally displaced persons, particularly through the incorporation of the Principles in national policies. They list a number of rights of internally displaced persons and provide protection against arbitrary displacement, protection and assistance during displacement and during return or internal relocation or resettlement. Paragraph 2 of the Principles defines internally displaced persons as:

> "...persons or groups of persons who have been forced or obliged to flee or to leave their homes or places of habitual residence, *in particular* as a result of or in order to avoid the effects of armed conflict, situations of generalised violence, violations of human rights or natural or human-made disasters, and who have not crossed an internationally recognised State border." [Emphasis added.]

The words 'in particular' indicate that the list of causes of internal displacement is not exhaustive. Persecution, conflict, natural disasters, development projects, industrial accidents and socio-economic disasters and any other event leading to forced internal movement are included.

As regards survival migration, *i.e.* cross-border movement, international human rights law, applicable to each person without discrimination, applies to all migrants, including survival migrants [2]. Apart from this, the applicability of other, migration-related, international instruments needs to be examined.

As already mentioned earlier, the 1951 Refugee Convention is not automatically applicable in situations of survival migration. Much research has been done on the applicability of the 1951 Refugee Convention in situations of climate-related forced movement (*e.g.* COOPER 1998, FALSTROM 2002, ALEINIKOFF 2003, MCADAM 2007, WILLIAMS 2008) and there is now widespread agreement that the 1951 Refugee Convention is not automatically applicable: to meet the criteria of the 1951 Refugee Convention, a persecuting 'actor' is required and the persecution must be linked to one of the five convention grounds. Some have argued that climate-related migrants constitute a 'particular social group' — one of the five convention grounds — which is "composed of persons lacking political power to protect their own environment" (COOPER 1998). However, this interpretation is controversial and does not seem to be the right approach. Political powerlessness cannot be considered as a permanent characteristic that makes someone a member of a social group and in the same way persecution as such cannot define the social group (FALSTROM 2002, KOLMANNSKOG 2008).

The EU Temporary Protection Directive, offering temporary protection in the European Union in the event of a mass influx of displaced persons, defines those displaced persons in article 2(c) as:

> "...third-country nationals or stateless persons who have had to leave their country or region of origin ... and are unable to return in safe and durable conditions because of the situation prevailing in that country, who may fall within the scope of Article 1A of the Geneva Convention or other international or national instruments giving international protection, *in particular*: (i) persons who have fled areas of armed conflict or endemic violence; (ii) persons at serious risk of, or who have been the victims of, systematic or generalised violations of their human rights." [Emphasis added.]

The words 'in particular' indicate that other than the mentioned situations, such as situations of survival migration, may qualify for temporary protection (see also LOPEZ 2007). Temporary protection is defined in article 2(a) as:

> "...a procedure of exceptional character to provide, in the event of a mass influx or imminent mass influx of displaced persons from third countries ... immediate and temporary protection to such persons, in particular if there is also a risk that the asylum system will be unable to process this influx without adverse effects for its efficient operation, in the interests of the persons concerned and other persons requesting protection."

Persons enjoying temporary protection have the right, for a period not exceeding that of temporary protection, to engage in employment activities as well as in educational activities (article 12). The maximum possible duration of temporary protection is three years (article 4). As a result, no permanent protection is provided. A weakness of the Directive is the requirement of "mass influx". Consequently, the Directive is not applicable where an individual is in need of protection without finding him- or herself in a mass influx situation. Furthermore, the Directive does not contain a definition of this term: the existence of a mass influx should be established by a decision of the Council (recital 14).

The EU Qualification Directive provides subsidiary protection in the European Union for those who 'otherwise need international protection'. According to article 2(e), a person who is eligible for subsidiary protection is:

> "...a third-country national or a stateless person who does not qualify as a refugee but in respect of whom substantial grounds have been shown for believing that the person concerned, if returned to his or her country of origin ... would face a real risk of suffering serious harm as defined in Article 15, and to whom Article 17(1) and (2) do not apply, and is unable, or, owing to such risk, unwilling to avail himself or herself of the protection of that country."

Article 15 reads:

> "Serious harm consists of: (a) death penalty or execution; or (b) torture or inhuman or degrading treatment or punishment of an applicant in the country of origin; or (c) serious and individual threat to a civilian's life or person by reason of indiscriminate violence in situations of international or internal armed conflict."

This list of different types of 'serious harm' is exhaustive and does not include life threatening socio-economic and/or environmental conditions. However, the Directive might become relevant for survival migrants in the future, especially considering the ongoing amendment process of the Directive and the increased attention of the European Commission for the relationship between climate change and migration (European Commission 2008 (a) and 2008 (b)). Also, the question can be raised whether and to what extent life threatening socio-economic and/or environmental conditions constitute torture or inhuman or degrading treatment or punishment as meant in article 15 (b). The last part of this paper deals with this question.

The 1969 OAU Convention, dealing with refugee problems in Africa, states in article 1 (2), after reasserting the 1951 refugee definition in article 1 (1), that the term 'refugee' shall also apply to:

> "...every person who, owing to external aggression, occupation, foreign domination or *events seriously disturbing public order* in either part or the whole of his country of origin or nationality, is compelled to leave his place of habitual residence in order to seek refuge in another place outside his country of origin or nationality." [Emphasis added.]

Based on a plain reading, life threatening socio-economic and environmental circumstances may be included in this definition as those circumstances can be considered to constitute events that seriously disturb public order (RWELAMIRA 1989, COOPER 1998, LOPEZ 2007, NALDI 1999). However, the OAU refugee definition poses serious interpretive difficulties: there is few or no *travaux préparatoires*, case law and academic literature to rely on (SHACKNOVE 1995, OKOTH-OBBO 2001, RANKIN 2005). While it is probable that states will offer refuge to foreigners in situations that require temporary protection, this is much less evident where permanent or long-term protection is needed.

The last regional instrument that possibly offers protection to survival migrants is the 1984 OAS Cartagena Declaration. This Declaration provides in article 3 the following:

> "...the definition or concept of a refugee to be recommended for use in the region is one which, in addition to containing the elements of the 1951 Convention and the 1967 Protocol, includes among refugees persons who have fled their country because their lives, safety or freedom have been threatened by generalized violence, foreign aggression, internal conflicts, massive violation of human rights or *other circumstances* which have *seriously disturbed public order*." [Emphasis added.]

Again, it can reasonably be said that survival migration is implicitly included in this definition given the category of circumstances that seriously disturb public order. However, the 1984 OAS Cartagena Declaration is not legally binding upon State Parties to the Organisation of American States. Rather, it is a political document (MIRANDA 1990).

For ease of reference and for the purpose of comparison, table 1 indicates the applicable legal and normative instruments in three situations, *i.e.* persecution-induced movement, conflict-induced movement and survival movement. Both internal and cross-border movements are included.

Table 1

Applicable legal and normative instruments in the situation of persecution-induced movement, conflict-induced movement and survival movement

	Internal movement	Cross-border movement
Persecution-induced migration/ displacement	• International human rights law • Guiding Principles on Internal Displacement	• International human rights law • 1951 Refugee Convention • 1969 OAU Convention • 1984 OAS Declaration • EU Qualification Directive • EU Temporary Protection Directive
Conflict/ violence-induced migration/ displacement	• International human rights law • International humanitarian law • Guiding Principles on Internal Displacement	• International human rights law • International humanitarian law • 1969 OAU Convention • 1984 OAS Declaration • EU Qualification Directive • EU Temporary Protection Directive
Survival migration/ displacement	• International human rights law • Guiding Principles on Internal Displacement	• International human rights law • Other instruments: not applicable or unclear to what extent applicable.

It is clear from table 1 that survival migrants have a much weaker legal framework to rely on than the two other categories of migrants. However, a survival migrants' claim to international protection is as valid as the claim of the other types of migrants. Except for the cause of the existential threat, they all have the same features: they are outside their country of origin, they experience an existential threat and they have no access to a domestic remedy. The mere fact that the cause of the survival threat differs — persecution or conflict *versus* socio-economic and environmental problems — can by no means justify the current difference in legal protection.

4. The Right to be Protected against *Refoulement*

As said above, international human rights law applies to survival migrants. Within this framework of human rights law, the question can be raised to what extent the right to be protected against forced return to the country of origin or habitual residence applies to survival migrants. This right is known as the *non-refoulement* principle: no State is allowed to return, expel or extradite a person in any manner whatsoever to another State where that person risks being subjected to serious human rights violations (Wouters 2009).

The core question that arises here is what is understood by 'serious human rights violations'. Because there is no univocal prohibition of *refoulement* in international law — the concept has been developed under various treaties — it is necessary to examine the scope of the principle in each treaty separately.

The *non-refoulement* principle in both the 1951 Refugee Convention and the 1984 UN Convention against Torture and Other Cruel, Inhuman or Degrading Treatment or Punishment (UNCAT), respectively stipulated in Article 33 and Article 3, is not helpful for survival migrants given the requirements of respectively the risk of persecution on one of the five grounds and the strong link between the human actor inflicting the act of torture and the State. With regard to the International Covenant on Civil and Political Rights (ICCPR), although the Human Rights Committee — the body in charge of implementing the ICCPR — has interpreted the prohibition of torture and other cruel, inhuman or degrading treatment or punishment (Article 7) as implying the *non-refoulement* principle, there are no cases of survival migration where the Human Rights Committee has acknowledged a violation of Article 7.

As regards the 1950 European Convention on Human Rights (ECHR), Article 3 — stipulating the prohibition of torture and other inhuman or degrading treatment or punishment — implies, according to case law of the

European Court of Human Rights (the Court), the principle of *non-refoulement* (Soering v. the United Kingdom (1989) 11 EHRR 439, 91; Cruz Varas v. Sweden (1991) 14 EHRR 1, 70; Salah Sheekh v. the Netherlands (2007) 45 EHRR 50, 135). Although in most of the cases in which the Court has applied Article 3 the risk of being subjected to a proscribed form of treatment emanates from intentionally inflicted acts of public officials or non-State actors, we can observe that the Court does not exclude the application of Article 3 in other contexts. In other words, the source of the risk of proscribed treatment in Article 3 is in principle irrelevant and thus the harm may emanate from a situation instead of human activity. Two relevant cases in this context are D v. the United Kingdom ((1997) 24 EHRR 423) and N v. the United Kingdom ((2008) 47 EHRR 885). While in the first case, the Court decided that returning the applicant to St. Kitts would amount to a violation of Article 3, referring to the very exceptional circumstances of the case (the applicant suffered from HIV/AIDS and was in the advanced stage of this terminal and incurable illness), in the second case (where the applicant also suffered HIV/AIDS) the Court decided that expulsion would not constitute a breach of Article 3. In other words, except for very exceptional situations, the Court is reluctant to include socio-economic rights within the scope of Article 3.

As regards survival migrants, finding themselves on the territory of a State Party to the ECHR, it seems unlikely — though not necessarily excluded — that their expulsion to a country where they would face life threatening socio-economic and environmental conditions, in the absence of 'very exceptional circumstances' with regard to a severe illness, would in the future be considered by the Court as a violation of Article 3.

5. Conclusion

This paper argued that the term 'climate refugees' is not an appropriate term from a humanitarian and legal protection perspective, whereby it was explained why both 'climate' and 'refugees' pose problems. As an alternative to the term, the concept of 'survival migrants' was proposed. This concept, contrary to the term 'climate refugees', recognizes the multi-causality of human mobility and links social, economic and environmental factors as cause of certain migration. Moreover, it removes the legal incorrectness of using the term 'refugees' in the context of life threatening socio-economic and environmental conditions.

The examination of the applicability of several migration-related international instruments, *i.e.* the 1951 Refugee Convention, the EU Temporary

Protection Directive, the EU Qualification Directive, the 1969 OAU Convention and the 1984 OAS Cartagena Declaration leads to the conclusion that survival migrants currently have no clear legal framework to rely on for their protection. While the applicability of some of those instruments is not excluded, it cannot with certainty be said that they do apply. Using then the framework of international human rights law, instead of migration law, to examine whether survival migrants are protected against forced return to their country of origin, *i.e.* the principle of *non-refoulement*, this results in the conclusion that there is no sufficient legal basis for answering this question in the affirmative. More research is needed to determine whether international human rights law may in other ways offer protection to survival migrants.

NOTES

[1] This paper was presented in the way of a poster at the symposium "Developing Countries facing Global Warming: a Post-Kyoto Assessment", organized by the Royal Academy for Overseas Sciences (Brussels, 12-13 June, 2009). Parts of this paper are based on MOREL, M. & MAES, F. 2010. The Curious Phenomenon of "Environmental Migration/Displacement" & The Role of International Law in Cross-Border Protection. — *In*: FRENCH, D. (Ed.), Global Justice and Sustainable Development, Leiden, Martinus Nijhoff, pp. 273-288.

[2] The most relevant human rights instruments are the 1948 Universal Declaration of Human Rights, 10 December 1948, GA Res. 217 (III), UN GAOR, 3d Sess., Supp. No. 13, UN Doc. A/810 (1948) 71, which protects the freedom of movement and other social, cultural and economic rights; the 1966 International Covenant on Civil and Political Rights (ICCPR), 19 December 1966, 999 UNTS 171, stipulating in Article 6, 7 and 1(2) respectively the right to life, the right not to be subjected to cruel, inhuman or degrading treatment and the right not to be deprived of means of subsistence; and the 1966 International Covenant on Economic, Social and Cultural Rights (ICESCR), 19 December 1966, 993 UNTS 3, protecting amongst others the right to an adequate standard of living in its Article 11. Other relevant instruments, offering human rights protection to specific social groups, are the 1989 Convention on the Rights of the Child, 20 November 1989, 1577 UNTS 3, the 1979 Convention on the Elimination of All Forms of Discrimination against Women, 18 December 1979, 1249 UNTS 13 and the 1989 ILO Convention on the Rights of Indigenous People, 27 June 1989, 1650 UNTS 384.

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Integration of Climate Change Mitigation and Adaption Strategies in the South

by

Bart MUYS*, ** & Festus AKINNIFESI***

KEYWORDS. — Land Use; Land-Use Change; Agroforestry; Deforestation Avoidance; Biofuels.

SUMMARY. — For rural communities in the South the main challenges and opportunities originating from climate change are related to land use, land-use change and forestry. In many areas however the challenges for climate change adaptation are poorly understood and are so far seldom considered in development projects. The opportunities by climate change mitigation are somewhat better understood, but so far poorly implemented because of their complexity in the case of Clean Development Mechanism afforestation/reforestation in the framework of the Kyoto Protocol, or because of their non-eligibility so far in the case of credits from deforestation and devegetation avoidance.

In a near future all these initiatives seem to converge to an integrated vision on rural development in the south, where sustainable and climate-proofed projects need to integrate climate change adaptation and mitigation. Such projects would typically invest in increasing the resistance and resilience of a local community to climate change by introducing adapted crop systems and/or alternative income generating activities, meanwhile safeguarding existing forests and developing an essentially tree-based landscape adopting agroforestry techniques in their broadest sense, and including both subsistence and commercial, *e.g.* biofuel, crops.

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The Impact of Global Warming on Lake Victoria. A Case of East Africa

by

Alex NAKATO* & Eric DE DECKERE

KEYWORDS. — Global Warming; Water Scarcity; Water Management; Population Growth; Efficient Use.

SUMMARY. — Climate variability is affecting available water resources all around the world, but especially in countries in Africa. Lake Victoria in East Africa is such an example. Lake Victoria is a source of water supply, hydropower and transport among others. It is very important to the development of the Ugandan economy but increasing temperatures combined with changing water management practices have brought about a reduction in water levels in the lake. Todate water levels have decreased by 1,1 m, the lowest since 1961, a rate that is greatly affecting the water sector.

Available safe water is a great challenge, yet it is unlikely that the predicted increase in runoff will have any significant impact on water systems in Uganda, since the country is faced with high population growth rates and steadily increasing rates of urbanization. To enhance economic development and reduce the disease burden caused by inadequate and unsafe supplies, water of a sufficient amount and quality is needed. But with high poverty levels, focus should first of all be set on efficient water use and, later on, on harnessing water supplies using methods that adhere to ecosystem values and services.

With the increasing number of connections to a piped source of water, behaviour change to discourage wastage and poor waste water disposal practices is essential. This will ensure that the amount of waste water is reduced and that available amounts are either available to more people or for more hours and/or days. It is a big task, that requires a collectively big effort that draws all users' involvement. Whereas the level of adaptability to changes brought about by climate change is limited by monetary power, it should not be limited by manpower. Collective efforts could change atitudes that influence behaviour.

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Global Climate Model (GCM) based Perturbation Analysis over Katonga and Ruizi Catchments in Lake Victoria Basin

by

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KEYWORDS. — Climate Models; Hydrological Impacts; Perturbation Factors; Uncertainty.

SUMMARY. — Most climate models do not accurately reproduce present climate situation with similar statistics. This means that direct application of projected climate variables to hydrological models for impact analysis is implausible. In order to reach an adequate impact analysis of climate change, the support climate models should provide perturbation factors (PFs) or climate change signals that are consistent and account for the different aggregation dependency. This study uses the quantile perturbation analysis to explore the variation of PFs of rainfall intensities with respect to different aggregations, the model resolution and frequency, for three future IPCC emission scenarios (A2, A1B and B1) from eighteen Global Climate Models (GCMs). This approach ensures that the perturbations in the observed events are consistent with similarly ranked events in the climate model series. The GCM scenario quantiles are ranked from high to low values from current (1971-1990) conditions and compared to ranked data of GCM simulations for future (2049-2060 and 2081-2100) conditions. These ratios (PFs) were graphically analysed for consistency, uncertainty, and dependency on frequency (return period) for the different rainfall aggregations.

The PFs, derived from three GCMs (CGCM3.1t63, CM2.1U.H2 and CM2.0) outputs, are highly inconsistent with those derived from the other models for all the different rainfall aggregations considered and for both the 2050s and 2090s. Uncertainty in PFs, which depicts uncertainty in a given model, increases with increase in model temporal resolution. For most models, the PFs are above one and depend on the frequency for both the 2050s and 2090s and all three emission scenarios. For daily and monthly aggregations, the distributions of PFs tend to cluster around one for most

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models. The variation in PFs is higher for the lower quantiles for annual aggregation; but increases in the wet months than in the dry months for monthly aggregation. At daily aggregation, there are many outliers in the PFs for higher ranked quantiles for most of the GCMs. There is no evidence to suggest that the PFs are spatially dependent although CM4.1 model has shown significant variation from Katonga to Ruizi catchments. Models such as MK3.5, MK3.0 and ECHAM5, with higher spatial resolutions, tend to have PFs close to or lower than one. Future rainfall intensities will be frequently higher than the present rainfall events in Katonga and Ruizi catchments for both the 2050s and 2090s. Although PFs can easily be derived from annual and monthly aggregations, the challenge of deriving climate change signals from daily climate model series, especially for dry days, for application to observed series, is still big. The resulting uncertainty is carried to hydrological models; leading to uncertain impact analysis. However, perturbation analysis is important in assessing consistent models and uncertainty in climate projections as given by the different GCMs.

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Clean Development Mechanisms (CDM) and Sustainable Development in South Countries

by

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KEYWORDS. — Kyoto Protocol; Clean Development Mechanism; CO_2 Offset; Geographical Distribution; Africa.

SUMMARY. — The Clean Development Mechanism (CDM) allows emission-reduction (or emission removal) projects in developing countries to earn Certified Emission Reduction (CER) credits, each equivalent to one tonne of CO_2. These CERs can be traded and sold, and used by industrialized countries to meet a part of their emission reduction targets under the Kyoto Protocol.

The mechanism stimulates sustainable development and emission reductions, while giving industrialized countries some flexibility in how they meet their emission reduction limitation targets. Accepted projects must qualify through a rigorous and public registration and issuance process designed to ensure real, measurable and verifiable emission reductions that are additional to what would have occurred without the project.

Between November 2004 and May 2009, the mechanism has registered 1,653 projects and is anticipated to currently produce CERs amounting to 303 10^6 tonnes of CO_2 equivalent yearly. The mechanism is extremely interesting since it is the first global, environmental investment and credit scheme of its kind, providing a standardized emissions offset instrument. However the geographical distribution of the CDM projects is revealing very large differences in between developing countries since China, India, Brazil and South-Korea totalise 82 % of the CERs while Africa only represents 3,3% of the total.

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Urbanization and Climate Change in Vietnam: a Case Study of Hanoi

by

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KEYWORDS. — Hanoi; Red River Delta; Urbanization; Water Infrastructure; Climate Change.

SUMMARY. — Vietnam, a rapidly developing country in the context of a transitional free-market economic system, is predicted to be one of the most affected countries in the world with regards to climate change. The response of context-specific urbanization is urgent as the country is developing at an unprecedented scale, speed and scope. The nation's larger cities — located in the large river deltas (the northern Red River Delta and the southern Mekong River Delta) or strung along the low-lying coast — are bearing the grunt of the development pressures. The case study of Hanoi exemplifies a number of issues that urban planners and designers, urban and water managers and civil engineers must address if urban Vietnam is to reach any kind of "sustainable" development dealing with the new urban conditions.

Challenges of Climate Change in Vietnam

Vietnam has a tropical monsoon climate. The country's total annual rainfall averages between 1,400 and 2,400 mm. The wide range of latitudes and the marked variety of topographical relief means that the climate tends to vary considerably from region to region. Mean annual temperatures range from 18 to 29 °C and there is a distinct seasonal difference between the dry season (November to April) and the warm rainy season (May to September). Mean annual rainfall ranges from 600 to 5,000 mm and, in extreme cases, reaches

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8,000 mm; 75 to 85 % of this total is concentrated in the rainy season [1]*. The country's northern region is characterized by mountainous or hilly terrain, combined with the large Red River Delta with its coastal plain, which is extremely vulnerable to seasonal flooding. In central Vietnam, the western mountainous terrain and eastern coastal plains have rivers which are short and steep. This region is particularly prone to flash floods, which pose a serious hazard for the population concentrated within the alluvial flood plains. It also suffers from severe droughts in the annual dry season. The southern Mekong Delta region has a very flat terrain, which is nutrient-replenished with the monsoon floods (and accounting for the "rice basket"/aquaculture export-economy of the nation) and vulnerable to flooding from both inland and the Eastern Sea.

Its location and topography makes Vietnam one of the most disaster-prone countries in the world; it suffers from typhoons, tropical storms, floods, droughts, sea-water intrusions, landslides and forest fires. Typhoons and tropical storms bring about the most damage; and floods and droughts, which are increasing in frequency and severity, bring along devastating human and economic consequences. These altered conditions are predicted to continue as climate change is expected to alter the current storm system and precipitation regimes [2]. On average, four to six typhoons reach Vietnam every year. They raise sea levels, often by several metres, and cause extensive loss of land through wave-induced erosion. The resultant storm surges extend for considerable distances inland, flooding valuable land with saltwater and causing loss of life, damage to infrastructure, and disruption of livelihoods. The sea dikes constructed over most of the exposed length of coastline are themselves vulnerable to damage by wave action. Each year, several sections of dike are overwhelmed or destroyed by wave action during typhoons and floods.

Although Vietnam has an admirable history of coping with natural hazards and reducing their effects, the economic and human costs are still tremendous. Extreme consequences from nature's regimes — perhaps a revenge of nature to reckless human activities? — appear to be more widespread and dramatic as time passes. Flooding is a major water management problem in Vietnam. Every year, the monsoons' heavy rains result in the overflowing of rivers, causing death and devastation in many regions. In the decade between 1991 and 2000, for example, officials estimate that 8,000 people lost their lives as a result of storms, floods and landslides. Economic losses are said to have amounted to nearly three billion USD [3]. According to Cao Duc Phat,

* The numbers in brackets [ ] refer to the notes and references, pp. 218-220.

Minister of Agriculture and Rural Development, 75 % of Vietnam's population — mainly the poorer rural sector — is to be directly impacted from climate change [4]. A staggering 70 % of the country's population lives in areas subject to water-related natural disasters [5]. In 2008, according to the national statistic office, it was estimated that Vietnam lost approximately 11.5 billion VND, or 1 % of its GDP due to climate change impacts [6].

Vietnam is predicted to be one of the most vulnerable countries in the world due to climate change (and more specifically to sea-level rise). Its 3,000 km eastern coastal seaboard is extremely vulnerable, and so are the poorer inhabitants of the region (fig. 1, tab. 1) [7]. A recent World Bank study on the potential impacts of sea-level rise on eighty-four coastal developing countries shows that a one-metre rise in sea level would affect approximately 5 % of Vietnam's land area and 11 % of the population; it would have an impact on 7 % of the agriculture, and reduce the nation's GDP by 10 % [8]. According to a report by the IPCC (Intergovernmental Panel on Climate Change), such a rise would subject 17 million people to flooding and cause damages of up to USD 17 billion (80 % of the country's annual GDP), with substantial impacts penetrating inland beyond the coastal zone [9]. The projections for sea-level rise scenarios for Vietnam are described as potentially catastrophic. The study suggests that Vietnam would be ranked among the top five most affected countries, considering all sea-level rise impact indicators. Furthermore, vulnerability due to climate change extends beyond sea-level rise and includes extreme weather events, especially from tropical cyclones [10]. Effects will be most severe in the Red River Delta and the Mekong River Delta [11].

A rise in sea-water level will also worsen saline water intrusion in coastal zones, which is already a problem in some areas due to freshwater extraction for irrigation and drinking water. The construction of canals in the deltas and upstream dams exacerbates the problem. The Mekong River Delta will be the most affected region, with 1.77 million hectares of 'salinated' land, accounting for 45 % of the territory. A sea-level rise of 30 cm (a scenario for 2050) would increase the salinity of the main tributaries of the Mekong River as far as 10 km inland. Inundation and the resulting loss of land and saline water intrusion in the Mekong Delta and parts of the Red River Delta, the most important agricultural areas in Vietnam, will pose serious threats to farmers (accounting for approximately 60 % of the total number of Vietnamese workers) as well as to the amount of agricultural exports such as rice (Vietnam is the second largest exporter in the world), and possibly to national food security [12]. A net result will be the growth of so-called "climatic refugees", who will move to higher, safer and non-salinated lands, and thus substantially increasing the pressure on existing urbanized areas.

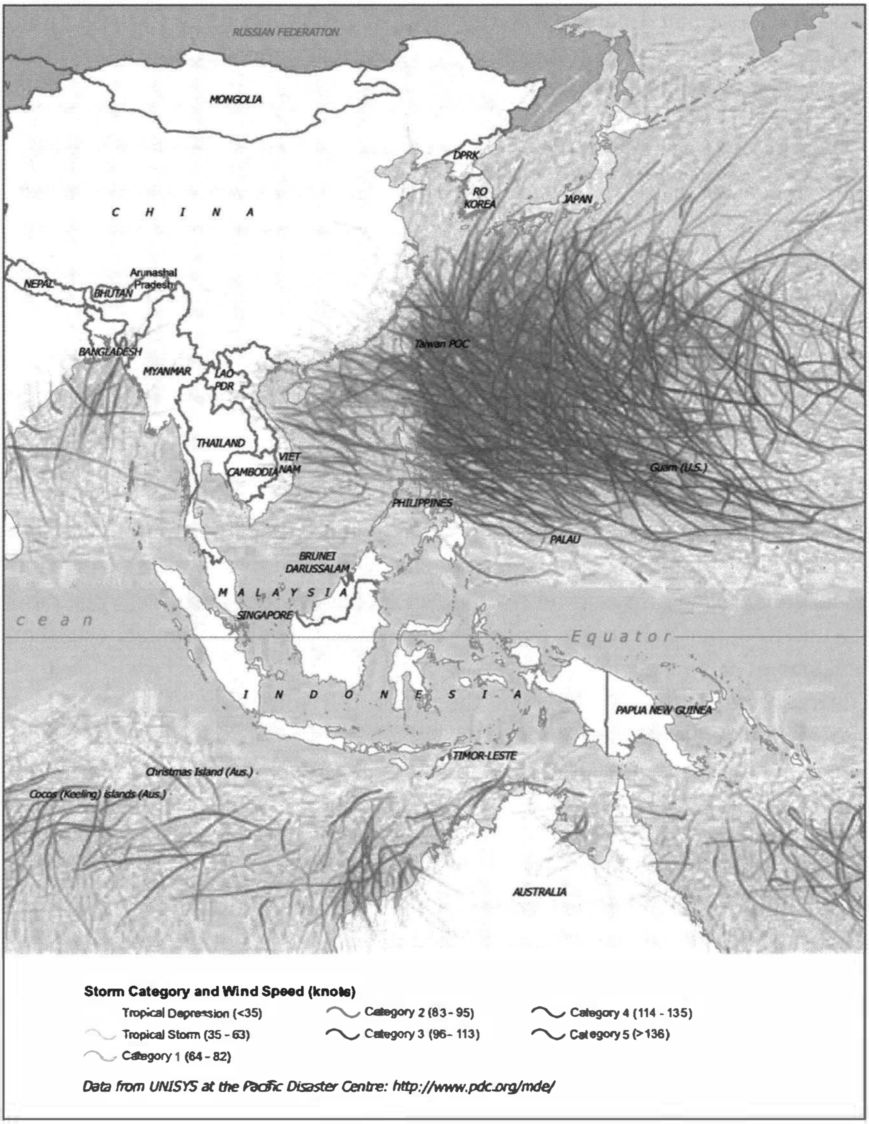


Fig. 1. — Typhoons in fifty years in the Asian Pacific.

Table 1
Ten countries most affected by a one-metre rise in sea level (percentage affected)

Rank	Population	GDP	Urban Areas	Wetlands
1	Vietnam (10.79)	Vietnam (10.21)	Vietnam (10.74)	Vietnam (28.67)
2	Egypt, Arab Rep. of (9.28)	Mauritania (9.35)	Guyana (10.02)	Jamaica (28.16)
3	Mauritania (7.95)	Egypt, Arab Rep. of (6.44)	French Guiana (7.76)	Belize (27.76)
4	Suriname (7.00)	Suriname (6.35)	Mauritania (7.50)	Qatar (21.75)
5	Guyana (6.30)	Benin (5.64)	Egypt, Arab Rep. of (5.52)	The Bahamas (17.75)
6	French (5.42)	Guiana (4.74)	The Bahamas (5.39)	Libya (15.83)
7	Tunisia (4.89)	Guyana (4.64)	United Arab Emirates (4.80)	Uruguay (15.14)
8	United Arab Emirates (4.59)	French Guiana (3.02)	Tunisia (4.50)	Mexico (14.85)
9	The Bahamas (4.56)	Tunisia (2.93)	Suriname (4.20)	Benin (13.78)
10	Benin (3.93)	Ecuador (2.66)	The Bahamas (3.99)	Taiwan, China (11.70)

Source: Global monitoring report 2008, World Bank.

Water resource management has become a central concern at the national scale. Line-ministries now have climate change departments, and researches into adaptation measures are underway. Of particular focus are urban areas and their water supply. The current average per capita of surface water availability from the total volume of water in rivers within Vietnam is about 3,840 m^3 per year, which is significantly lower than the world average [13]. If water inflows from outside the country are included, the average per capita river water availability is 10,240 m^3 per year. Taking population growth into consideration, the average per capita surface water availability will be 2,830 (internal) and 7,660 (internal and external) m^3 per year by 2025. However, the average annual water flow of all rivers in Vietnam reaches 830-840 billion m^3, of which the water flow generated from outside the country is 520-525 billion m^3, accounting for 63 % of the total water flow. Predicted global climate change will lead to a decline in water resources. Recent research has forecasted that the total volume of surface water in 2025, 2070 and 2100 will be approximately 96 %, 91 % and 86 % respectively of today's quantity. Vietnam is expected to have reached an inadequate water level by 2025 [14]. A great deal of the country's difficulty regarding water supply is due to dams and reservoir constructions upstream — especially those by China.

It is clear that the water challenges to Vietnam are immense and demand studied reflection and measured action across scales, and certainly across sectors. From here on, this paper will focus on the case of Hanoi and the water issues specifically related to the interplays between urbanization, landscape and infrastructure.

Hanoi: Origins as a Water-based City

Hanoi is structured by an interconnected network of natural and man-made lakes, rivers and a low-lying periphery. The city is often referred to as a "city of lakes and rivers". It is located in the Red River Delta, which has a total area of 169,020 km^2, 51.35 % — or 86,660 km^2 — of which situated in Vietnam [15]. The city and its larger territory have always been tied to the regime of the mighty Red River (1,149 km long, 510 km of which flow on Viettnamese territory). The 'red' of the Red River refers to the colour of the water, which is the result of the excessive amount of sediment it carries. There are 115 km of the river in Hanoi, where the level of water fluctuates from +1.5 to +14.13 m; in Hanoi itself, the river is 1.2 to 6.7 km wide. The city's and region's relative degree of safety is based upon an ancient, dense network of dikes and engineered water management systems built for both irrigation and flood control. Age-old traditions of cut-and-fill and dike building have been developed in parallel with densification of both the city and its dense rural hinterland.

Historically, Hanoi has been an important spiritual and symbolic centre of the agriculturally-based nation. In the pre-feudal era, the Red River Delta developed as a densely populated area and in the feudal period, Hanoi (then called the Tong Binh District) was its most important trade and economic centre. The Red River was an important component in the structure of the territory, serving as a transportation spine and with a number of craft villages developed along its banks. Temples and pagodas were also strategically located along the river's edges. In 1010, under Ly Cong Uan (Ly Thai To), the first emperor of the Ly Dynasty, Hanoi became the capital of the country. The territory was considered to be imbued with magical powers of the ascending dragon made by the relationship of land and water. In the feudal era (1010-1873), most of the settlements and activities were strongly tied to the natural water network.

The dynamics of the water was, in turn, controlled with a relatively simple soil dike system. In Hanoi itself, the first dike was constructed at Co Xa (today's Nghi Tam, Yen Phu (in Tay Ho District) to Luong Yen (in Hai Ba Trung District)) under the Ly Dynasty in 1108 [16]. This dike was built for both irrigation and flood control. In this period, the structure of Hanoi was primarily based on three settlement morphologies: the royal citadel, the "*ke cho*" market city (now known as '36 streets'), surrounding Hoan Kiem Lake and a series of craft villages around West Lake. The citadel was enclosed by a water system — Red River, To Lich River and Set River — and the market city was the connection between the citadel and the Red River, which was the most important transport conduit linking Hanoi to both its immediate hinterland and the Eastern Sea.

In Vietnam, the water system was vital not only for daily life activities and as a means of defense, but also for the spiritual and cultural understanding of the nation. The interdependency, yet autonomy, of "earth and water" (*dat nuo*) is woven into the mythology of mountain and water spirits. As well, it is the alluvium itself, torn away by erosion on the slopes of the mountains, that enriches the lowland plains — traditionally cultivated with wet rice — and allowed the Vietnamese culture to flourish. The water (and mountain) systems are also fundamental in the auspicious citing of houses and cities — as related to *feng-shui* (*Phong Thuy* in Vietnamese and meaning the "science of wind and water").

Hanoi: a Problematic Product of Colonial Exploitation

The French invaded Hanoi in 1873 as part of the assembling of their colonial Indochina. Geopolitically, the area was seen as of strategic importance in order to expand overland trade to China. The economic prerogatives to exploit natural resources and open up new markets for domestically manufactured goods led to the initiation of Vietnam's transition from an agricultural backwater towards a more internationally-linked, market-driven society. In Hanoi itself, the city was dramatically transformed through extensive land filling and consolidation of the relationship between the urban core and Red River. The French formalized the river-city threshold with an increased water transportation system, the construction of the city's first bridge and through a number of projects which developed and upgraded the flood control system. French engineers were responsible for the installation of new flood control gates, a reinforced and upgraded dike system and new pump stations. The existing hydraulic logic of the water system was radically restructured by the French — most notably evident in the severing of the connection between a number of smaller rivers and the Red River. The To Lich River, for instance, was cut off from the larger hydraulic network and canalized as well. A fundamental socio-cultural and ecological balance was disrupted.

Uncontrolled speculation by powerful corporations and industrialists was rapidly transforming Hanoi and its immediate countryside into a fragmented landscape. This was to change in 1922, when Ernest Hébrard was appointed the first director of urbanism for Indochina. Hébrard introduced land-use zoning in order to override the individualistic economic interests that heretofore determined growth patterns. According to Gwendolyn Wright, Hébrard by no means ignored economic development, he simply wanted to control it, civilizing the effect it had in urban settings. In the major cities of Indochina and at new industrial installations he envisioned vast arenas for productivity [17]. Cities were now planned with five spatially-distinct areas: an administrative centre, residential districts, recreational space, commercial districts and industrial sectors. By the beginning of the twentieth century, French Hanoi began to see itself as the "*Paris de l'Annam*" and Hébrard's arrival brought with it a focus on spaces and groups of buildings as opposed to architectural details of buildings or the engineering details of road and bridge construction [18]. Land-use planning was also utilized as a mechanism for social and racial control. Urban centres were developed as bi-polar, dual cities — the existing, and rarely improved, *ville indigène* (for locals) was separated by a buffer zone form the newly planned *ville moderne* (for foreigners).

The French destroyed the citadel, kept the commercial area and craft villages for their benefit, and moved the administrative and political centre to an area south of the Ancient Quarter. They established a new city area within grid of wide avenues and roads; the residential area was later expanded and large villas with gardens were constructed on small plots. Meanwhile, waterways were developed for both trade and military purposes. A number of the city's lakes — particularly ones of symbolic importance to the Vietnamese — were reclaimed as an expression of control over Vietnamese culture. The negative consequences of the loss of the city's permeable ground surfaces and areas for water retention remain evident today.

Hanoi: from a Colonial to a Socialist to a Free-market City

During the socialist era, Hanoi underwent limited structural changes in the first place due to a lack of financial resources (as the country was at war for its independence). Following the Second Indochina War (with the USA), a new master plan (1980-1984) was developed for the city with assistance of planners from Leningrad State University. The key features of this master plan included the development of new housing quarters to accommodate the growing urban population, and the transformation of the numerous public buildings constructed during the French colonial occupation. At the same time, there was the extreme canalization of small rivers and the creation of new lakes that exploited the collective physical labour regime, which was part of the socialist programme.

Frenzied urbanization in Hanoi took hold in the "*doi moi*" period (economic liberalization since 1986) and resulted in reckless and sprawling development both inside and outside of the city's dike system and on its immense low-land periphery. The informal housing along the city's eastern edge, between the protective dike and the Red River, has over time become more formal andhas, *post factum*, been recognized by the State. In the 1990s, Hanoi's urbanization rate dramatically increased due to a massive rural-to-urban migration. The area's already dense settlement pattern led to the transformation of permeable flood plains to hard surface, severely compromising the natural discharge for water and thereby increasing flood levels. Compounding the problem, in August 2008, the Prime Minister approved the expansion area of Greater Hanoi — effectively tripling the area of the city. The environmental balance of a large territory is slated for major upheavals. At the same time, however, Hanoi is now having a larger natural and artificial river network upon which to potentially graft its new urbanization.

In order to make this possible, Hanoi must change its business-as-usual attitude. The once water-based city has progressively shown little concern for the role of water spaces in the city and recent development has mostly turned its back to its once important water bodies. Over the past hundred years of urbanization, there has been the disappearance of 90 % of the city's lakes and uncontrolled encroachment along the city's rivers and canals in the old city [19]. More specifically, in the past fifteen years, there has been a disappearance of twenty-one of the forty lakes in Hanoi's centre, translating to a decrease of 850 to 547 ha of lakes' water surface [20]. Simultaneously, as the water bodies shrink, there has been an increase in road and railway infrastructure systems. Hanoi's transformation from water-based to road-based urbanity is rapid.

Hanoi and its Contemporary Water Challenges

Contemporary Hanoi is located in a landscape with a rich lake and river network and has an incredibly dense population (1,864 people/sq. km) estimated to expand to an astonishing 4,485 people/sq. km by 2025 [21]. In terms of geography, most of Hanoi's area lies in the flood plain of the Red River Basin. Only the part of the Dong Anh District and the south-western extents of the enlarged city are mountainous. In Hanoi, the Red River has three major tributary systems: the Da, Thao and Lo Rivers. The topography of Hanoi gradually slopes from northwest to southeast. Many areas in old Hanoi have an elevation of +5 m, which is significantly lower than the riverbed of the Red River (with an average elevation of 7-8 m). As a result, the city is quite prone to rainy season floods. In the Red River Delta, there have been twenty-six extreme flood events, especially in 1945 and 1971. There was a +14.13 m water level recorded in 1971, and the accompanying flood caused dike breaks at three locations and inundated 250,000 ha affecting the lives of 2.7 million people. The economic losses were estimated at around 78 million USD (1,170 billion VND) [22].

The risks of the predicted rising sea levels, coupled with higher river floods (due to stronger storms and heavy rainfall) include upstream dam and dike failure. Furthermore, during the time of floods, the dike system retains water that is loaded with sediment. The channeling of the water means that the sediment cannot flow over the delta (as is the case in the Mekong River Delta). Instead, the sediment tends to drift to the mouth of the rivers and settles in estuaries, blocking the free-flow discharge of water to the sea. Water is locked inside the dike system which, in turn, causes further rising of rivers' water levels. Besides, the predicted sea- level rise will inevitably reduce rivers' capacity for water discharge. Moreover, the rise of water levels increases the risk of dike failures. During heavy rains, the water that accumulates in the territory's expansive lowlands cannot naturally drain to the river due to the higher elevation of the river bed. Compounding this is the fact that the city's pump stations are beyond their capacity and Hanoi's underground sewage is rendered inoperative when rainfall is higher than 100 mm/hour. Due to climate change, there are increasing instances of rains heavier than 100 mm/hour. The severity and frequency of floods has been increasing, as witnessed in November 2008, with Hanoi's most extreme innercity floods to date. The death toll reached a devastating ninety-four, and damages were estimated at VND 7.3 trillion (USD 430 million) [23].

Today, with the liberalization of the economy and the subsequent massive rural-to-urban migration, Hanoi is rapidly urbanizing. Fragmented development is proving to be a challenge that is increasingly difficult to keep in-check. Land filling is substantially changing the overall permeability of the territory and asserting new pressures on the existing dike system. Meanwhile, the Red River continues to wield its might and has effectively become the backside of the city. At the same time, there has been an explosion of unauthorized settlement in areas outside the dike, in unsafe/flood areas which are also those most vulnerable to the impeding impacts of climate change. Such settlements, once built by the poorest sector in society, are now part of the speculative/corruption game of the rising entrepreneurial class. The estimated number of inhabitants living outside the dike system in Hanoi is about 41,176 [24]. The area's dense settlement has led to the transformation of permeable flood plains to hard surfaces, severely compromising the natural discharge for water and thereby increasing flood levels.

Also, in ancient times, the foundations and earth used for the filling of lowlands and creating dikes were neither carefully selected nor treated, and thus there are frequent problems of sand boiling, seepage and slides in dikes [25]. In some places, due to unauthorized earth excavations for aquaculture, the stability of the dike system is compromised. Changes of water flow inside the dike system during the rainy season and sand excavation activities increase bank erosion and threaten the structural integrity of the dikes. Riverbanks that are protected by revetments and levees are costly and their precise engineering standards have proven difficult to meet in Vietnam. Moreover, most of the sluices for water-level control of the rivers are damaged or do not operate properly during floods (due to technical problems). Although there is a committee responsible for dike protection and flood prevention, there is a lack of resources and equipment for dike monitoring and maintenance.

Floods in the Red River Delta often occur in July and August. However, due to the vast area of the basin, the floods rarely occur at the same time in the entire basin. Nonetheless, losses from floods are a serious annual event in northern Vietnam. In studies by the United Nations Development Program (UNDP), it was estimated that the average annual loss in the Red River Delta and along the central coast could reach more than 130 million USD. In a subsequent, more rigorous, Asian Development Bank study, it was found that the average annual damage from floods in the area protected by dikes amounted to well over 50 million USD per year around Hanoi alone (fig. 2).

Hanoi's drinking water source is mainly supplied from the Red River. There are two reservoirs, Hoa Binh and Thac Ba, which must be kept under the critical level of +13.30 m (since the dikes protecting the city are at 13.30 m). The changing amounts of water — particularly as evidenced by droughts in the dry season — are bringing new challenges to Hanoi's water supply. Moreover, reservoir construction further upstream — out of Vietnam's borders — cannot be controlled, yet has a tremendous effect upon the availability of the vital resource for the city and its surroundings. Many areas in Hanoi — such as the Nhue-Day River subbasin, which is to the west of the concentrated city of Hanoi and part of the planned extension area — will

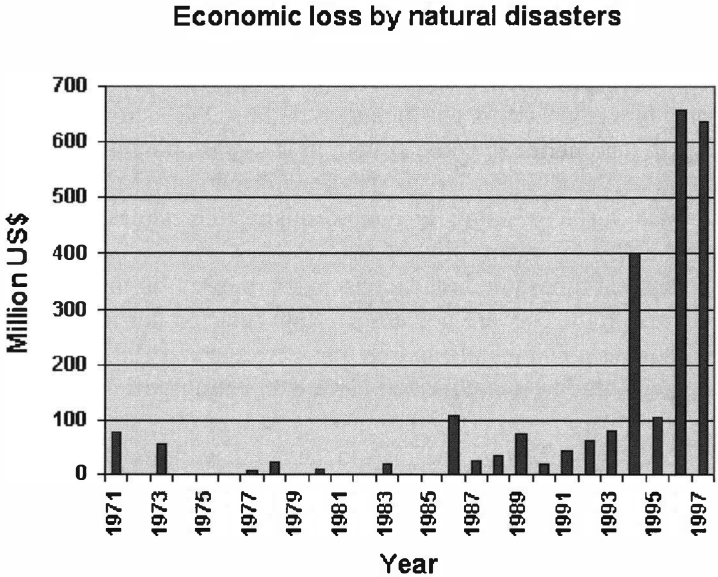
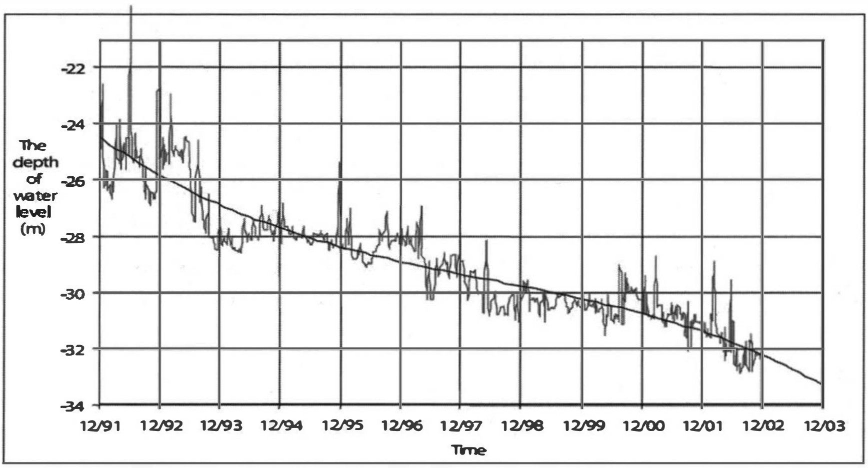


Fig. 2. — Increase of losses in Vietnam.

face a lack of water in the dry season. Today, as a barely urbanized area, its water availability measures 3,760 m^3 per capita per year [26], which is lower than the world water level standard. And further compounding the issue is the fact that the underground aquifer is not being adequately replenished, partially due to the massive covering of the territory with impermeable surfaces. In general, groundwater resources are abundant, but exploitation is intensive in and around Hanoi. As a consequence, the groundwater table is constantly declining and land subsidence is a problem (fig. 3). In the Hanoi area near Tuong Mai and Thuong Dinh bore-well fields, the land subsidence rate is 30-40 mm/year. A further consequence of groundwater exploitation is saltwater intrusion, which primarily affects the coastal parts of the delta.

A New Water Urbanism for Hanoi

According to De Meulder and Shannon, "Vietnam is on the verge of literally drowning in water. Vietnam is undergoing massive urbanization and is consequently on the lookout for less capital-intensive solutions that attempt to work with the forces of nature rather than articulating an antagonistic position towards water — which is both economically unsustainable and ecologically undesirable" [27]. The tremendous challenges of urbanization in Hanoi offer new opportunities for the development of a new paradigm. Hanoi needs to (re)develop and (re)balance the fragile relationship of land/water, culture/nature and heritage/modernity.



Source: Vietnam environment monitor 2003, Water.

Fig. 3. — Groundwater level decline in Hanoi area.

The city's and region's extensive water network (both artificial and natural bodies) can (and should) play a fundamental role in the (re)structuring of the territory. Cross-scalar and cross-sectoral thinking must replace the present land-use planning mechanism, and engineers, managers and designers must forge new coalitions to address the problem in new, creative manners. The creation of a water-adaptive and resilient city could bring about synergies with other urban functions: flood plains and water retention areas could double as public open space and ecological step-stones; road-based and water-based transport could complement one another and their interchange points could become new centers; waste water treatment areas could be developed as recreational areas, etc.

Amongst the urban design and planning strategies that could be developed are: waterfronts and their adjacent rural landscape could be synchronized as productive systems with public amenities and dynamic open spaces at the water's edge; urban riverbanks could be redesigned to reshape the city's relationship and structured by a series of terraced platforms, which accommodate different programmes; constructed wetlands and mangrove afforestation projects could deal with the increasing severity and frequency of flooding, to act as natural filters and remove pollutants, to mitigate natural disasters and, at the same time, to strengthen the vision of green and tropical city through interconnected public open spaces.

Recovery of the city's wetlands and water networks could be seen as going hand in hand with urban upgrading, new urbanization and development. The ecological corridor, as a mosaic pattern in the whole of the city, is recreated by the establishment of an interconnected system along the sides of rivers, canals, lakes, ponds,... On the other hand, the water system — a natural function as a sponge — is exploited and enhanced as a device system for flood protection and water purification as well as for drainage and urban structure delineation. Hence, it will contribute to a good condition for sufficient water supply and balance of water demand (domestic and industrial activities) because of the increasing ability of water restoration, water network and water table. It is more important for sustainable urban development. Because of the rapid urbanization, the total area covered by impermeable surfaces has increased dramatically. A vast network of underground water pipes, infrastructures and sewer systems is being constructed day by day; these problems will be considered as a major progress in the field of engineering urban designing and planning.

A "return of the rivers" could become a primary strategy for Hanoi's development. Following the city's swift growth, the urban structures of the city are increasingly dissociated from the organization of its hydraulic systems, and have thereby erased the visual and spatial logic of the territory's urban watersheds. Therefore, the restoration of the natural characteristics of rivers and canals is both a challenge and an opportunity for contemporary development. In addition to the restoration of the waterways, there should be upstream afforestation, the creation of artificial wetlands and lagoons, the reconnection of vegetal patterns and the re-establishment of biodiversity. Such systems would not only work as natural mechanisms of purification and flood control, but also provide the city with much needed open space for recreation. Landscape corridor systems along the rivers, in various dimensions, could be (re)constructed, with many landscape accesses connected to the city structure. A number of the city's rivers (the Day River and the Tich River, for example), which were severed by the French from the Red River, could be reconnected to the larger hydraulic system in order to increase flooding resilience for the Hanoi region. Evidently, a return of the rivers would require the urgent upgrading and expansion of the city's dike system, where some places must be readjusted for flood management and others for residential protection. Regarding this question, there exists an opportunity to rethink the pure-engineering solution of dike construction and to integrate landscape and urban design, enlarging the public realm by increasing recreational areas for the city and addressing water management issues.

In addition to re-establishing the importance of Hanoi's rivers, the cultural and hydrological meaning of the city's numerous lakes (and other water bodies such as ponds and reservoirs) needs to be recognized and revalued. Over the past decades, they have been disappearing from the urban landscape due to encroachment and even landfilling related to real estate speculation. These water bodies are critical elements in the hydraulic system, as they absorb water in the monsoon system, recharge the aquifers and provide places of relief in the dense urban fabric. The preservation of the existing lakes is essential and the recovery — if at all possible — of other water bodies is highly recommended.

Towards a Possible Integrated Approach of Water Design, Engineering and Management

"The (water)landscape can be designed to structure urbanism and thereby operate at the level of (infra)structure and strategic planning. Well-planned and designed large-scale hydrological infrastructural interventions offer the possibility to protect and enlarge the collective, public realm of rapidly urbanizing cities, while at the same time act as support for appropriation by unprogrammed activities, mobility/transport and as platforms for investment. Water urbanism is possible when urban planning and design, civil and sanitary engineering and landscape architecture are folded into another vision as concerns mobility, health, recreation and scenery" [28].

With the speed of development in Vietnam, there are significant challenges to the management and effective use of its natural resources. The changes require that, in particular, the effective management of water resources is vital. A synchronous action plan for Hanoi, to develop it as a resilient and adaptable city with regards to climate change, is necessary and requires innovation in design, engineering and management. Moreover, new stakeholder coalitions will become necessary. For instance, both small-scale irrigation works by local farmers and large-scale government-managed works of irrigation and flood control must be based on a deep understanding of water-related natural characteristic and ecosystem performances, in order to ensure survival in such unpredictable natural conditions [29]. And finally, given the imperative of designing a more sustainable water system, deeper knowledge of the landscape, its ecology and water technology is required [30].

The synchronous development of engineering, designing and planning activities could eventually create an urban waterscape with a clear structural interweaving of topography, hydrology and soil conditions and a new urban morphology that works with landscape for water retention, discharge and treatment. Strengthening the cooperation between hydraulic and civil engineers, ecologists, urban designers and landscape architects is very important in terms of moving towards a sustainable water-based urbanism. By reuniting engineered and natural processes, there may be new logics identified which point towards a more resilient development of an infrastructured landscape, which, in turn, could become a base for a new regional and urban form. "Through properly planned and projected space, a "soft engineering" approach could work with nature to reduce or mitigate the likely impacts of natural disasters, such as floods, typhoons and earthquakes. Mitigation can become proactive rather than reactive if urban design and planning anticipate risk and exposure — designing for resilience by remoulding landscape and [re]constructing settlements to bends from hazards, but not break" [31].

The development of a "water urbanism" for Hanoi requires more profound and practical knowledge about the interrelationships between ecological, infrastructure and urban systems. The natural hydrology and principles of hydraulic engineering can be developed hand in hand with urbanism. The ancient traditions and current challenges of Hanoi demonstrate the strengths and weaknesses of hydraulic engineering and territorial planning and highlight the potential of water infrastructure and its crucial role in urban development.

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An In-house Protocol for the Selection of Antimalarial Candidates interfering with the Heme Metabolism of the Parasite

by

Julie PILATE*, Delphine FORGE*, Daniel DIVE**, Jamal KJALIFE** & Jean Jacques VANDEN EYNDE*

KEYWORDS. — Malaria; Screening; Cell-free; Drug Candidates.

SUMMARY. — Although libraries of compounds can exhibit an antiplasmodial activity, most of them will remain laboratory curiosities. This can be due to the fact that the substances are toxic for the host of the parasite, are devoid of appropriate physico-chemical properties, or can hardly be prepared in large quantities.

In order to select drug candidates meriting a close attention, our laboratory is exploring a simple and not expensive protocol, which takes into account, as far as possible, the above-mentioned obstacles. That protocol uses:

— Values that can readily be calculated with free software (Lipinski's rule, ...);
— A **cell-free** evaluation [1] of the ability of the compounds to interfere with the heme detoxification pathway;
— An estimation of some physico-chemical properties;
— An *in vitro* cytotoxicity screening;
— A semi-quantitative tool to estimate economical and ecological parameters associated with the chemical syntheses.

Some bisbenzamidines [2, 3] and bisbenzimidazoles [4] derivatives have passed through those gates and therefore emerge now as interesting substances deserving to be tested for their antimalarial activity *in vitro* and *in vivo* for further consideration to potential development.

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Impacts of Global Warming on Mangroves: Some Preliminary Results

by

Katrien QUISTHOUDT* & Diana DI NITTO*

KEYWORDS. — Mangroves; Sea-level Rise; Hydrodynamics; Temperature; Range Limits.

SUMMARY. — The present rate of global warming threatens the survival of entire ecosystems worldwide. Inhabiting the interface between land and sea, mangroves are amongst the most at-risk ecosystems when the sea level rises. Although the effects of a sea-level rise are presumed to be more significant, other climate change components like a rise in temperature, CO_2 levels and precipitation will most likely have a major influence on mangrove productivity, phenology and distribution. This will consequently influence species-specific competition and adaptation to altered inundation conditions.

In this study we present two parts regarding the effect of global climate change on mangroves: (1) Can mangroves be resilient to sea-level rise? Case study in Gazi Bay (Kenya); and (2) temperature increase: what will happen at the latitudinal mangrove range limits in South-Africa and Brazil?

Part (1) mainly focuses on the tidal range in order to forecast what will happen to mangrove vegetation assemblages under different 'Intergovernmental Panel for Climate Change (IPCC)' scenarios of sea-level rise. Using experimental digital terrain modelling combined with water level simulations in a GIS environment and based on a detailed vegetation map, preliminary results are generated regarding the effect of a sea-level rise in the study site in Gazi Bay (Kenya). We adopt a reductionistic approach by taking abstraction of alterations in sedimentation and elevation and to other consequences of global change such as increases in temperature, in CO_2 concentration and in storm frequency.

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Modelling of the different IPCC scenarios (whole bay) gave the overall trend of an area increase for all species (incl. the most typical and economically important *Rhizophora* assemblage, excl. *Avicennia marina* on the landward side) for the minimun, relative and average scenario. Under a sea-level rise scenario of +88 cm by the year 2100, the highest intertidal inundation class strongly decreases due to the topographical settings at the edge of the inhabited area. Consequently, the landward *Avicennia*-dominated assemblages will decrease if they fail to adapt to a more frequent inundation.

Part (2) focuses on the latitudinal mangrove range limits in order to forecast what will happen to the limits under different IPCC scenarios of temperature increase. We focus on latitudinal range limits of *Avicennia* and *Rhizophora* genera. First of all, we look at the current temperature requirements of latitudinal mangrove range limits. Two limits in Brazil and South-Africa, where humidity is high yet not limiting, are chosen as case studies. By combining the current temperature requirements with the different IPCC temperature scenarios for those regions, we predict the future mangrove limits. This is again a reductionistic approach by taking abstraction of mangrove dispersal requirements and all other consequences of global change (like sea-level rise).

Global warming will influence mangroves in many ways. There is a lack of data to study the total impact of all those factors on mangroves. In this poster we try to combine two major factors, namely sea-level rise and temperature increase. Sea-level rise will change the position and composition of mangrove forests, while temperature increase will change the mangrove range limits.

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A New Meteorological Drought Assessment in Water Resource Management: a Case Study in Semi-arid Shahrekord (Iran)

by

Mahdi RADFAR* & Kristine WALRAEVENS**

KEYWORDS. — Global Warming; Meteorological Drought; Water Resource Management; Shahrekord.

SUMMARY. — Nowadays one of the most important research subjects is climate change, drought and its impact on water resources. Global warming of the surface temperature resulted in increasing evapotranspiration and water demand, and decreasing precipitation and water resources. Perhaps the most general of the proposed definitions of drought is the one formulated by BERNAN & RODIER (1985) 'drought is a decrease of water availability in a particular period and over a particular area' (TSAKIRIS & VANGELIS 2004). Identifying drought conditions is necessary for water resource management, especially in arid and semi-arid areas such as Shahrekord region. Several methods were used to recognize drought in a catchment like meteorological and hydrological methods. In most of the methods different effective climate and hydrological factors are applied to define an index. By comparison of the index on the long term, the evaluation of climate changes and drought occurrence in any region is possible. In arid and semi-arid regions precipitation is zero in several months, while evapotranspiration is very high. This research has adopted P/PET as a drought index, which has been assessed by several methods: yearly P/PET, monthly P/PET, P/PET for wet and dry season, sum of all monthly P/PET values over a hydrologic year. Meteorological parameters, including monthly precipitation and evapotranspiration on the long term, are used. The different drought indices obtained were compared to long-term fluctuations of the groundwater level.

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Climate-related Natural Hazards in Bukavu (DRC)

by

Stéphane SADIKI NDYANABO*, Ine VANDECASTEELE**,
Jan MOEYERSONS** & Philippe TREFOIS**

KEYWORDS. — Bukavu; Natural Hazards; Climate Change; Landslides; Vulnerability.

SUMMARY. — The aim of this study was to investigate the relationship between the climate and the occurrence of (non-seismic) natural hazards in Bukavu. Precipitation data dating from 1931 to 2003 were analysed and compared to the frequency of natural hazards in the region for the same period.

There has been no significant change in the absolute amount of annual rainfall over time. There has, however, been an increase in the variability of rainfall, and a change in the monthly distribution thereof, over the last two decades. This corresponds to an increase in frequency of natural hazards in the region (mass movements, flooding, storms).

Climate change is not the only factor leading to a higher frequency of hazardous events. Rapid urbanization and deforestation has increased the vulnerability of the population to natural hazards. The frequency of events as well as the vulnerability of the people can be reduced by applying appropriate urban planning, soil and water conservation techniques, and encouraging further research.

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Drought Stress Profiling for Improved Phenotyping: targeting Best Performing Crop Varieties to Small Farmers in Developing Countries

by

Nirman SHRESTHA*, Sam GEERTS*, Glenn HYMAN** & Dirk RAES*

KEYWORDS. — Soil Water Balance; Modelling; Climate Change; Breeding; Drought Tolerance.

SUMMARY. — Farmers in the developing world face agricultural challenges far different from farmers in industrialized countries. Drought, low soil fertility, pests and diseases threaten each season's harvest and lack of resources keep irrigation, pesticides and fertilizers beyond their reach. Decades of advances in plant science and crop breeding have had only marginal effect on mitigating these constraints. Now the global climate change models predict that the effect of climatic extremes will only intensify for crops in most fragile land. Indeed with climate change, water scarcity is becoming more pronounced with increases in intra seasonal dry spells in specific regions around the world. To meet the needs of growing population more food must be produced using less water. For an improved phenotyping of the crop varieties that perform under drought, improved drought stress profiling for specific crops is necessary.

Monthly climatic data of different locations around the world were extracted using the New-LocClim software developed by FAO. Frequency analysis was performed on the extracted climatic data for each location using RAINBOW software and monthly rainfall and reference evapotranspiration (ETo) was calculated for dry, normal and wet years. Using the statistically analysed climatic data, simulations were performed for different crop common for the region to calculate the soil water balance during the crop growing period using the BUDGET software. The simulations were performed for three time frames each starting at a difference of two weeks within the season. 1-ETa/ETc was used as indicator of water stress, where ETa is the actual evapotranspiration and ETc is the crop evapotranspiration under the same conditions but for non-limiting water conditions. The calculation of ETa and ETc includes crop coefficients (Kc) and water stress factors (Ks), which are crop specific. The ETa and ETc

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obtained from BUDGET simulations were used to calculate the drought stress indicators and the results were plotted for dry, normal and wet conditions.

The amount of daily drought stress strongly varied for the various sowing dates. For a location at Cali in Colombia, for example, the average water stress in midstage ranged from 7 to 62 % of maximum drought stress for different sowing dates. The water stress was calculated for different regions around the world and sites were categorized based on similarity in midseason drought stress.

The drought stress profiling is performed for developing countries around the world. It is the basis for setting up different experiments to test more drought tolerant varieties and to target them to small farmers in developing countries. The improved varieties can be used in locations around the world that are similar in climate.

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Micrograzers in Lake Tanganyika: which Part will They play in a Global Warming Context?

by

A. TARBE, S. STENUITE, R. MASSANA & JEAN-PIERRE DESCY*

KEYWORDS. — Microbial Food Web; Protists; Grazing; Lake Tanganyika.

SUMMARY. — Recent studies have shown that picocyanobacteria (*Synechococcus* spp.) are extremely abundant in Lake Tanganyika, where they contribute to a substantial fraction of the pelagic primary production (STENUITE *et al.* 2007). An increase in temperature, as shown during the last decades, should favour these small algae at the expense of some bigger phytoplankton. As the most important grazers of picocyanobacteria, protozooplankton will surely play a crucial part in the ecological response of Lake Tanganyika to global warming. But so far, grazing and diversity of those ciliates and heterotrophic nanoflagellates have not been studied in detail. Our objective was thus to identify the key micrograzers of Lake Tanganyika, combining cell counts, complementary grazing measurements and culture-independent approaches. It appeared that protozooplankton contributed to a great part of picocyanobacterial mortality and that functional diversity of eukaryotic microbes might be more diverse than expected.

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Development of Decentralized Jatropha Oil Production and Marketing Chains in Senegal: a Promising Way to combine CO_2 Emission Reduction and Rural Poverty Alleviation

by

Marieke TERREN*, **, S. SAVERYS*, P. JACQUET DE HAVESKERCKE*, A. TOUSSAINT**, J.-P. BAUDOIN**, F. LOCHT*** & GUY MERGEAI**, ***

KEYWORDS. — *Jatropha curcas*; Senegal; Rural Poverty Alleviation; CO_2 Emission Reduction; Pilot Projects.

SUMMARY. — *Jatropha curcas* L. (JCL) is a multi-purpose hardy shrub that belongs to the *Euphorbiaceae* family. Originating from Central America it is now widely distributed in almost all tropical and subtropical regions of the world. Recent investigations have demonstrated that JCL could contribute to alleviate the consequences of global warming and improve the living conditions of rural populations in the least developed countries. Primary characteristics favouring *Jatropha* over other agrofuel feedstock crops are its non-food nature, multiple uses (oil production, plot delimitation, traditional medicine, pest control, etc.), reported ability to grow on marginal land and the need for limited rainfall. There are also claims of *Jatropha* interest in preventing deforestation and desertification, and improving soil fertility.

However, for several reasons, both technical and socio-economic, the full potential of JCL is far from being realized. The variation of the plant behaviour according to the agro-ecological conditions is insufficiently documented and management recommendations adapted to the existing farming systems have not been yet developed. Besides the quantification of the real yield potential of the crop in the existing agro-ecological conditions, and the determination of the most sustainable and profitable production practices suited to pure stand cultivation and intercropping systems involving JCL, it is of utmost importance to develop sustainable organizational models of local production chains that can be mastered by small-scale growers in order to allow them to fully benefit of the potential of the crop. In these decentralized JCL chains, the oil extracted from the seed is the main output. It can be used (i) directly in unsophisticated

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diesel engines that can power various tools (cereal mill, husker, alternator, etc.), (ii) in adapted stove, (iii) to produce soap or (iv) as biopesticide.

Four pilot actions have been launched in different regions of Senegal during the last two years to overcome the constraints that limit the full exploitation of JCL potentialities. These projects are carried out by Durabilis Foundation, with the scientific support of GAU, Aide au Développement Gembloux NGO, EESF programme, and SBE – Senegal Company, and located in the departments of Dagana, Tivaouane, Foundiougne and Tambacounda respectively. These areas are representative of most of the different agro-ecological regions of Senegal. Each pilot project tests different production practices (under rain-fed or irrigated production conditions) and organizational models (cooperatives, local company involving growers, informal producer groups) adapted to the local environments for the production, transformation and marketing of Jatropha oil. The preliminary results obtained so far highlight the following points: a good tending of the crop during the first months after direct sowing or planting is important because JCL is sensitive to the concurrence of weeds or of companion crop with large vegetative development (sorghum, millet, maize). JCL is not immune to pest infestation and adequate protection methods need to be implemented to avoid the total destruction of the crop in its early development stages. Protection against divagating animals after planting (especially during the dry season) is absolutely necessary.

These action-research initiatives should allow identifying the adequate solutions for the implementation of decentralized production and marketing chains of JCL in Senegal and quantify their exact potential for CO_2 emission reduction and rural poverty alleviation.

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Biofuels in Developing Countries: Situation and Prospects

by

Eric TOLLENS*

KEYWORDS. — Biofuels; Climate Change; Energy Security; Trade-off Biofuels-food; Environmental Impact.

SUMMARY. — Governments support biofuels because of concerns over climate change, energy security as well as a desire to support the agricultural sector. Actually, most plants in operation in developed countries have difficulties surviving, despite government subsidies. Below 50 US$/barrel crude oil price, most biofuel production is not profitable, except for bioethanol from sugar cane in Brazil. Second-generation biofuels based on lignocellulosic feedstocks offer the most prospects, because they do not compete for land with food crops, but profitable commercial production is years away. It does not make sense for developing countries that are net importers of food to promote biofuel production. The same constraints that hamper food production will operate on biofuel feedstock production. Moreover, there is such a trade-off with producing food that the price of locally produced food will increase as well as food imports. Only when biofuel crops can grow on marginal land not suitable for food crop production, such as jatropha, is there no competition. In countries that are already major exporters of agricultural products, where land is abundant and productivity high, biofuel production can offer a new source of employment and income for rural areas. Environmental impacts of biofuels vary widely across feedstocks, production practices and locations. If land-use changes are involved, directly or indirectly with land clearing, particularly in tropical countries, the Kyoto effects are always largely negative.

1. Introduction

Bioenergy covers approximately 10 % of the total world energy supply, but traditional unprocessed biomass, such as wood and charcoal, accounts for

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most of this. It is only recently that commercial bioenergy has been assuming greater importance. Liquid biofuels for transport cover only 1 % of the total transport fuel consumption.

Biofuels are a complex issue. They comprise a very large diversity of products from organic origin that can be used to produce energy. They include (bio)gas from the fermentation of organic wastes, wood products, bioethanol, biodiesel, energy produced from algae, etc. The focus will be on what is called first-generation biofuels, which comprise bioethanol produced from biomass with high starch and/or sugar content and biodiesel produced from vegetable oils (palm oil, rapeseed oil, soybean oil, etc.). There is a lot of speculation about second-generation biofuels, because they have no competition with food crops as they are derived from cellulose and lignin, like straw and wood, low value byproducts or waste, but the truth of the matter is that they are still years away from profitable, industrial scale production. The focus is thus on first-generation biofuels, as we know them today, which are controversial for two reasons: their competition with food crops, and as a result, their price-increasing effect on the cost of food, which is particularly undesirable for poor, food-deficit and food-insecure countries, and their questionable Kyoto effects in terms of savings on greenhouse gases (GHG).

2. First-Generation Liquid Biofuels

Under this heading, we have biofuels, derived from food crops. Two products can be distinguished: bioethanol and biodiesel. Bioethanol is either derived from sugar, sugar-cane or sugar beet, or sugary products such as molasses, the fraction in the sugar-producing process that does not crystallize, or from starch rich products such as maize or sweet sorghum, which through fermentation produce glucose, which is easily converted into ethanol. To make the process profitable, it is important how the byproducts are used as they are important to make the process profitable. In the case of sugar cane, the bagasse or fibrous mass that is left over after the sugar is extracted, is also rich in (cellulosic, lignin) energy and is burnt in boilers, whereby the steam generated not only can be used in the process for cooking and distillation, but also for electricity generation. Most sugar-cane factories thus have a net surplus of electricity which is sold to the grid. Sugar-cane-based ethanol production in Brazil is currently economically viable without subsidies. For sugar beet, the pulp, which is the equivalent of the bagasse, is relatively rich in protein and is a valuable animal feed. For bioethanol derived from maize (in the USA) or wheat (in Europe), the fraction that is not fermented is rich in protein and is used as animal feed as (dried) distiller's grain. Thus, most bioethanol plants in the USA deliver animal feed for cattle fattening, which for this reason is clustering more and more around these plants.

Regarding liquid biofuels produced in developed countries, particularly North America, the subsidy in the USA is now € 0.33 per gallon (3,785 l), and the tax on imports is € 0.35 per gallon of ethanol. The EU import tariff for bioethanol is 10.2 %. They are subsidized, directly and/or indirectly, with the usual import protection (against cheap bioethanol from Brazil), and with, in addition, mandatory mix-in regulations such that petroleum companies and fuel distributors have an obligation to use a certain percentage. Nevertheless, early in 2009, with the oil price below 50 $/barrel, the bioethanol market in the USA and in Europe was crashing. In the USA, it is expected that at least forty ethanol plants will be closed. Already in November 2008, VeraSun, the second-largest bioethanol producer in the USA, had closed down.

As for developing countries, most if not all of the poor countries are in fact net importers of food, particularly cereals. Even the large petroleum producers, such as Nigeria, Angola, Congo (Brazzaville), etc., import sizeable quantities of cereals (wheat and rice) and vegetable oils. For those countries, producing biofuels implies a trade-off with producing food. Using local food crops for biofuels — *ceteris paribus* — will increase the price of locally produced food and result in more food imports. Only when biofuel crops can grow on marginal land not suitable for food crop production, such as jatropha, is there no competition. But there may still be a trade-off in terms of labour and other resources used for jatropha production. While jatropha still produces some oil on poor, marginal soils, of course its production is higher on better soils. In fact, many developing countries, such as South Africa, Namibia, DRC, etc., are planting jatropha on good land, and so this crop also competes with food crops.

3. The Kyoto Gains of Biofuels

The Kyoto gains — reduction in CO_2 production — are one of the main drivers in planting biofuel crops, at least from a public perspective. The GHG emission reductions compared to petrol or diesel vary widely from author to author, depending on how far fossil fuel inputs throughout the production and processing of feedstocks are accounted for. In principle, a full life-cycle analysis needs to be done, but this is difficult. In most cases, the use of biofuels results in some reductions in GHG emissions, compared to petroleum fuels. However, these results hold only if there is no clearing of forest land or virgin cerrado or, worse, peat lands in order to grow these biofuel feedstocks.

In terms of the mitigation of carbon dioxide-driven global warming, over the next thirty years it is more advisable to focus on increasing the efficiency of fossil fuel use and to preserve existing forests and savannahs. Forestation of an equivalent area of land to that used for biofuel crops would sequester two to nine times more carbon than the emissions avoided by the use of biofuel, at least over a thirty-year period (USAID 2008, RIGHELATO & SPRACKLEN 2007). In any case, ethanol from maize yields only a GHG reduction compared to petrol of + 30 to 40 %, while ethanol from sugar cane yields 80 to 85 %. Ethanol derived from wheat, as is the case in Europe, is not better than maize. In terms of biodiesel, GHG emission reduction is in the order of 70-80 %, if the effect of land clearing/land-use change is not taken into account. Moreover, the GHG emission reductions vary widely according to the methodology used and the authors (USAID 2008).

According to RYAN *et al.* (2006), 1,000 l of European biodiesel save 1.3 tons of GHG. With a European Emissions Trading Scheme price for carbon of 30 € per ton, this yields a total of 39.0 € worth of abatement savings. This is only 0.039 €, say 4 eurocent per litre abatement saving, far lower than the tax exemptions presently accorded to biodiesel in Europe and far lower than the production-cost differential between biodiesel and its fossil counterpart. In terms of the economics of biodiesel in Europe, the value of the abated GHG emissions justifies a tax credit on biodiesel, but as can be seen, this is far lower than the tax exemptions presently accorded (RYAN *et al.* 2006).

The conclusion is that for most countries, with the exception of Brazil where ethanol from sugar cane is competitive with petrol prices, biofuels are currently a relatively expensive way to reduce GHG emissions. Purchasing carbon in the European Climate Exchange is always cheaper and more effective, particularly if the money is spent on reforestation. If land has to be cleared from forest or woody savannah for biofuel production, the GHG picture is always negative for at least thirty to fifty years, and on peat soils, for hundreds of years (VANDENBEMPT 2008).

4. Biofuels and Food Price Increases

According to Donald MITCHELL (2008) of the World Bank, the contribution of biofuels to the rise in food prices in 2007-08 is estimated at 70-75 % in addition to the related consequences of low grain stocks, large land-use shifts, speculative activity and export bans. Higher energy prices and related increases in fertilizer prices and transport costs, and dollar weakness explain only 25-30 % of the total price increase. Other studies put Mitchell's analysis in doubt and attribute only about 20-40 % of the food price increases to biofuels (*Agricultural Economics* 2008). Today, about one-third of the corn produced in the USA is converted into bioethanol, replacing about 4 % petrol. Thus, if all corn produced in the USA was used for biofuel, that would replace only 12 % of petrol presently used (USAID 2008). Biofuels cannot be considered a replacement for fossil fuels. Only in Brazil is ethanol replacing about half of petrol use.

For developing countries that have chronic food shortages and import a lot of food, particularly cereals and vegetable oil, converting presently used land into biofuels will drive up the price of locally produced food, *ceteris paribus*, and lead to increased food imports. Both are likely to hurt poor households. The constraints that are now hampering agricultural growth, poverty reduction and food security in developing countries will also prevent biofuel production development. Developing countries that are not economically efficient producers of agricultural commodities are unlikely to become efficient producers of biofuels (PINGALI *et al.* 2008).

It all depends on whether productivity can be enhanced as agricultural productivity growth is essential to prevent a conflict between food and fuel. As for food security, addressing the many constraints to the technology adoption and market participation by the poorest developing countries is essential. There may be some economic justification for import substitution for petroleum products, but the fallacy of energy self-sufficiency may be just as misleading as food self-sufficiency.

In countries that already are major exporters of agricultural products, where land is abundant and productivity high, biofuels and biofuel feedstock production can offer a new source of employment and income for rural areas. This is the case for ACP sugar-exporting countries affected by the European Union sugar reforms which came into force in July 2006. With the compensation received for restructuring, they can convert to energy production. This is the case for Mauritius, Jamaica, Barbados, etc.

Regarding the "food-versus-fuel" trade-off, agricultural productivity growth is essential to prevent a food-fuel conflict. Countries that fail to make gains in agricultural productivity — and most poor, net food-importing countries are in this case — should not embark on a biofuel development policy, as poverty alleviation and food security may suffer. Also, basic market institutions and infrastructure are essential for a biofuel development policy to succeed. Of course, biofuels are locally relevant in isolated areas with poor market access for local use, *e.g.* electricity generation, as is happening in many isolated places in the Democratic Republic of Congo, where palm oil is used for electricity generation.

5. Conclusions

New and renewable energy systems will play an important role in the sustainable development of a future energy strategy. Most governments now see the promotion of renewable energy sources as of high priority, for security and diversification of energy supply, environmental protection and sustainable economic development.

For the first time in history, energy markets are now linked with agricultural markets, and because the former are large compared to the latter, energy prices will tend to drive the prices of biofuels, their agricultural feedstocks and thus agricultural markets.

Governments support biofuels because of concerns over climate change, energy security as well as a desire to support the agricultural sector through increased demand for agricultural products. Environment impacts of biofuels vary widely across feedstocks, production practices and locations. If land-use changes are involved, directly or indirectly with land clearing, particularly in tropical countries, quantities of GHG that far exceed potential annual savings from biofuels for many decades, if not centuries (for peat soils), will be released.

Poor urban consumers and poor net food buyers in rural areas, who tend also to be the majority of the rural poor, are particularly at risk of higher agricultural commodity prices, partly because of growing demand for biofuels.

Biofuels strengthen the case for focusing on agriculture as an engine of growth for poverty alleviation. This requires strong government commitment to enhancing agricultural productivity, for which public investments are crucial. But accelerated biofuel production, pushed by policy support, strongly enhances the risk of large-scale land-use changes and the associated environmental threats.

Production of biofuel feedstocks as cash crops may offer income-generating opportunities for farmers in developing countries, which does not necessarily come at the expense of food crops and which may improve food security (FAO 2008).

There is a case for directing expenditure on biofuels more towards research and development, especially on second-generation technologies based on lignocellulosic feedstock, which hold more promise in terms of reductions in greenhouse gas emissions with less pressure on the natural resource base and less impact on food prices.

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Challenges of Climate Change to Surface Water Quality in Vietnam

by

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KEYWORDS. — Climate Change; Surface Water Quality; Vietnam.

SUMMARY. — It has been noted that Vietnam is one of the countries that are most suffering from climate change. At the end of this century, the annual temperature in Vietnam is projected at about 2.3 °C higher, and the sea level is estimated to rise 75 cm compared to the period 1980-1999. In order to assist scientists and policy makers to clarify impacts of climate change to surface water quality in Vietnam and to develop action plans to respond to climate change, this paper gives a picture of potential challenges of climate change (temperature rise, rainfall change and sea-level rise) to surface water quality and appropriate recommendations for integrating climate change issues into the action plan toward sustainable development.

1. Introduction

Vietnam has a complex and dense river network, including thirteen large-river systems, with more than 10,000 km^2 of catchment. Nine of them (Red, Thai Binh, Bang Giang-Ky Cung, Ma, Ca-La, Thu Bon, Ba, Dong Nai, and Mekong river) contribute to 93 % of the total river basin area in the whole country. The Red and the Mekong river systems have the largest basin areas (155,000 and 795,000 km^2 respectively) as well as the highest total volume of water flow (126.5 mil. and 500 mil. m^3/year). Besides, there are also many natural lakes, ponds, lagoons and pools with a total area of about 150,000 ha. Examples of major lakes are: Lak (about 10 km^2), Ba Be (5 km^2) and West Lake (4.46 km^2).

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As reported by the Ministry of Natural Resources and Environment (MONRE), the quality of the surface water in these river basins and lakes is highly polluted, especially in Cau, Nhue-Day and Dong Nai river basins. The surface water of the Cau river (part of the Red river basin) is locally polluted by organic pollutants, suspended solids and oil waste. Especially, BOD and COD concentrations are about two to three times higher than the national standard, even ten times higher downstream. In addition, downstream of Sai Gon and Dong Nai rivers the water is heavily polluted with organic, suspended solid substances, and has lead concentrations few times higher than the permitted limits. The water downstream of Dong Nai river is also seriously salinized and cannot be used for domestic or agricultural purposes (MONRE 2006). In the part of Sai Gon river system, rivers are severely polluted with organic pollutants, coliforms and heavy metals. The most critical case is Thi Vai river, which is highly contaminated with mercury, zinc, organic compounds, etc. With this severe pollution, almost all species are unable to survive and the river is now a dead river. In cities, lakes, streams and canals increasingly serve as sinks for domestic sewage, municipal and industrial wastes.

It is clearly seen that increasing water-quality degradation depends on both anthropogenic and climate change impacts. In fact, the former one includes major factors of excessive water exploitation and uncontrolled waste-water discharge. The latter is considered as changes of rainfall frequency and intensity, temperature and sea-level rise. As recorded by the Ministry of Natural Resources and Environment, over the past fifty years (1958-2007), the annual temperature has increased about 0.5 °C, the sea level has risen by 20 cm and the frequency and intensiveness of natural disasters, such as typhoons, heavy rains, floods and droughts, have increased in many regions of Vietnam. At the end of this century, annual temperature is projected at about 2.3 °C higher and the sea level is estimated to rise 75 cm compared to the period 1980-1999 (MONRE 2009).

In addition, it has been noted that DOC concentrations in lake and stream waters have increased during the last thirty years across many parts of Europe and North America. The potential reasons for this increase include increasing atmospheric CO_2 concentration, climate warming, continued N deposition, decreased sulfate deposition, and hydrological changes due to increased precipitation, droughts, and land-use changes. Any change in DOC concentrations and properties in lakes and streams will also impact the acid-base chemistry of these waters and, presumably, the biological, chemical, and photochemical reactions that take place (PORCAL *et al.* 2009).

Being aware of the impacts of climate change, the Government of Vietnam has taken part in and approved the Framework Convention of the United

Nations on Climate Change and the Kyoto Protocol. Recently, on 2 December 2008, the Prime Minister of Vietnam approved the "National Target Programme to Respond to Climate Change" (referred to as the NTP) in Decision No.158/2008/Qd-TTg (Prime Minister 2008). One of the strategic objectives of the NTP is to assess climate change impacts on sectors and regions in specific periods and to develop feasible action plans to effectively respond to climate change in the short term and the long term to ensure the sustainable development of Vietnam. In order to assist scientists and policy makers to clarify the impacts of climate change to surface water quality in Vietnam and to develop action plans to respond to climate change, the authors would like to contribute with a picture of potential challenges of climate change to surface water quality and appropriate recommendations for integrating climate change issues into the action plan toward sustainable development.

2. Challenges of Climate Change to Surface Water Quality in Vietnam

Surface water naturally contains many dissolved materials, depending on atmospheric inputs, geological conditions, and climate. These materials define the water's chemical characteristics, and water "quality" is a function of chemical, physical, and biological characteristics. Pollution can be broadly defined as deterioration of some aspects of the chemical, physical, or biological characteristics of water. Major water pollutants include organic material, nutrients, toxic heavy metals and organic compounds. Water pollution can be governed by the intensity of pollutants and the assimilation capacity of water bodies, but not all pollutants can be degraded. Along with alarming climate change, its indirect and direct effects might play an important role in increasing water quality pollution (fig. 1).

2.1. Temperature Rising

According to MONRE, during the last fifty years (1958-2007), the annual average temperature in Vietnam increased about 0.5 to 0.7 °C. Winter temperatures increased faster than those of summer and temperatures in northern climate zones increased faster than those of southern climate zones. The annual average temperature for the last four decades (1961-2000) was higher than that of the three previous decades (1931-1960). Annual average temperatures for 1991 to 2000 in Ha Noi, Da Nang and Ho Chi Minh City were all higher than the average for 1931-1940 (0.8, 0.4 and 0.6 °C respectively).

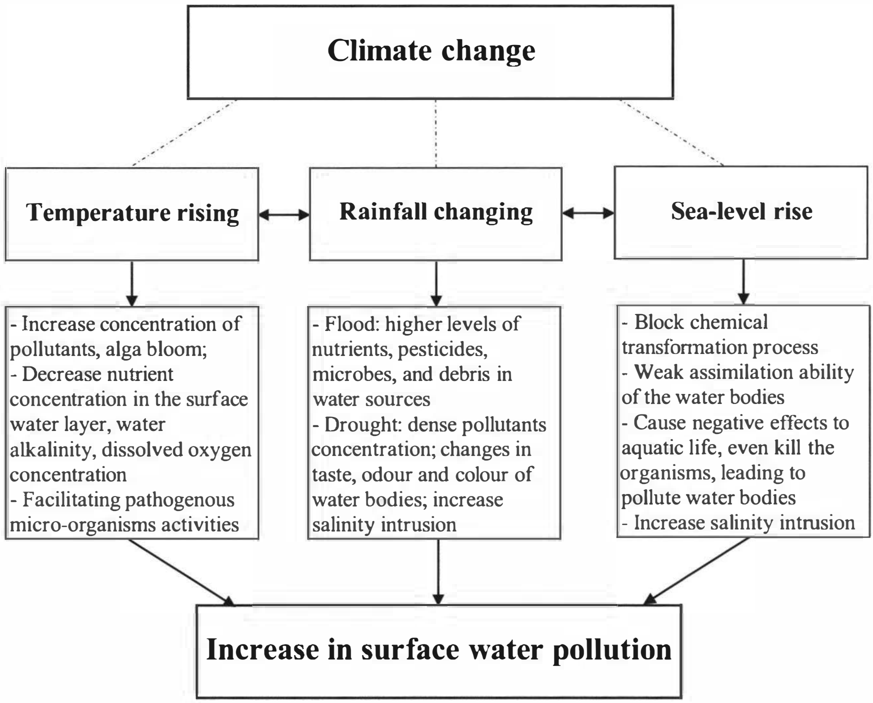

Fig. 1. — Outline of challenges of climate change to surface water quality in Vietnam.

In 2007, the annual average temperatures at these three locations were all higher than the average for 1931-1940 (0.8 - 1.3 °C), and similarly higher than the average for 1991-2000 (0.4 - 0.5 °C) (MONRE 2008).

In an attempt to find the possible impacts of temperature increase on surface water quality, many case studies have been carried out, such as in Australia, Canada, Czech Republic, Me Kong basin, Netherlands, United States of America, Norway, Scandinavia, Sweden, United Kingdom, etc. (DELPLA *et al.* 2009). These studies commented that the increase in temperature will lead to an increase in pH (BATES *et al.* 2008), DOC (MONTEITH *et al.* 2007, EVANS *et al.* 2005, WORRAL *et al.* 2004, HEJZLAR *et al.* 2003), N river loading (KASTE *et al.* 2006), N and P (DUCHARNE *et al.* 2007), nutrients loading (ARHEIMER *et al.* 2005, ZHU *et al.* 2005), micropollutants (THIES *et al.* 2007), pollutants uptake due to an increase in metabolic rate and decrease in oxygen solubility (DAUFRESNE *et al.* 2003, DAUFRESNE & BOET 2007), enzymatic activity (SARDANS *et al.* 2008), and development of Cyanobacteria blooms (ARHEIMER *et al.* 2005, JOHNK *et al.* 2008, HUNTER 2003].

By the end of the 21st century, temperatures in Vietnam would raise 2.3 °C compared to the average of 1980-1999. The increase in temperature would be in the range of 1.6 to 2.8 °C in different climate zones. Temperatures in northern and northern-central climate zones of Vietnam would increase faster than those in southern zones. In each climate zone, winter temperatures would increase faster than summer temperatures (MONRE 2009). These are projected at leading to pollute the surface water by increasing the concentration of pollutants, alga bloom; decreasing nutrient concentration in the surface water layer, water alkalinity, dissolved oxygen concentration; and facilitating pathogenous micro-organism activities.

2.2. Rainfall Changing

In Vietnam, in every location, the change of annual average rainfall for the last nine decades (1911-2000) was not distinct and not consistent with each other. The annual rainfall decreased in northern climate zones and increased in southern ones. On average for the whole country, the rainfall over the past fifty years (1958-2007) decreased by about 2 % (MONRE 2008). In a recent announcement, MONRE projected that both annual rainfall and rainy season's rainfall would increase, while dry season's rainfall tends to decrease, especially in southern climate zones. For the whole country, annual rainfall by the end of the 21st century would increase by 5 % compared to that of the period 1980-1999. In northern climate zones, rainfall increasing rate would be more than that of southern ones (MONRE 2009).

The projection of increasing rainfall in the rainy season would draw the attention to the increase in frequency and the intensity of heavy rainfall. These tend to affect adversely water quality by increasing pollutant loads flushed into rivers and possibly by causing overflows of sewers and waste storage facilities. Pollutants are washed and transported into water bodies due to inundation in solid waste dispose sides; waste water treatment plants, waste water drainage culverts; sanitary construction, agricultural land and breeding areas; plants and animals; chemistry and pesticide depot. Therefore, there are higher levels of nutrients, pesticides, microbes, and debris in water resources.

In a study of water quality degradation in paddy fields after long-term flooding in the irrigated area of the Chao Phraya river basin, the water quality measured in terms of DO, BOD, NH_3, NO_3 and PO_4 was degraded due to long-term flooding (Hungspreug *et al.* 2007). The flood in the Oder river in 1997 caused — regarding priority pollutants like heavy metals, nutrients and organic matter — a flood load estimated to be one third of the annual load. The flood loads of other harmful substances were significantly higher than the corresponding monthly loads in 1996 (MULLER 1998). A study by Senhorst on relationships between climate change and water quality of Dutch surface waters indicated that the impact of climate change on water quality cannot be generalized and should be assessed on a case-by-case basis. However, the impact on extreme situations (floods and droughts) seems to be largest, whilst water quality under average discharge conditions appears to be relatively unchanged (SENHORST & ZWOLSMAN 2005).

Recently, a study on environment after floods in five provinces of Vietnam, including Ninh Binh, Thanh Hoa, Nghe An, Ha Tinh and Quang Binh, showed that the concentration of BOD and COD in water environment during and after the flood is much higher than before (fig. 2). For example, in Hoang Long river, the COD level increased from 28.2 to 43.1 mg/l and the BOD level from 15.3 to 36.7 mg/l, as compared between the periods before and after the flood year 2007. These levels during and after the flood are much higher than the national standard level B for irrigation.

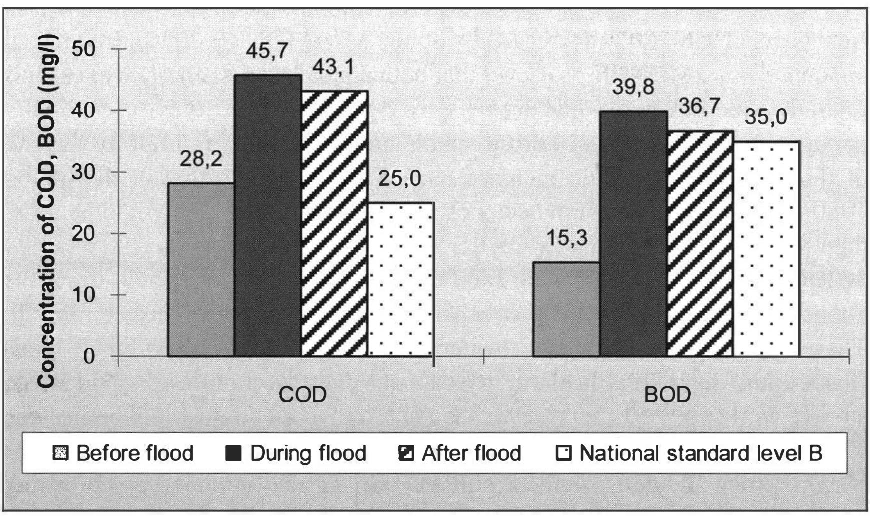

Fig. 2. — Concentration of COD and BOD in Hoang Long river before, during and after the flood (2007), relative to the national standard level B for irrigation.

In terms of droughts, these caused seriously lower dissolved oxygen solubility and concentration in rivers and lakes; warming of the water column; sediment release and ammonium increase; selenium, baryum, mercury, zinc, cadmium, lead and nickel increase (BATES *et al.* 2008, DUCHARNE *et al.* 2007, KOMATSU *et al.* 2007, VAN VLIET & ZWOLSMAN 2008, ZWOLSMAN & VAN

BOKHOVEN 2007). In order to simulate water quality downstream of a point source under current and climatically changed conditions, a new model (R-Qual) — developed in the stream — is applied with simulated parameters including monthly concentrations of BOD, DO and NH_4. Both scenarios suggest increase of temperature and decrease of precipitation in the study region. Those changes result in a significant decrease of mean monthly run-off for almost all months, with a considerable negative impact on summer drought. Moreover, quality simulations under future climatic conditions entail significant impairments of water quality because of decreased stream flows (MIMIKOU *et al.* 2000).

Therefore, it is considered that prolonged drought causes decrease in surface water level. The lack of precipitation during a drought allows the accumulation of these materials on the roads and land surfaces. Low water levels due to higher water temperatures, that have an impact on water resources in many ways such as an increase in the concentration of salts, nutrients and suspended solids within the body of water, or warm, shallow water, stimulate the growth of algae. All these factors may contribute to changes in the taste and odour of the water. The problems do not stop there. Exposed lake sediments in larger beach areas that are normally under water, may develop rooted vegetative growth, but when the lake levels come back after the drought, the vegetation is inundated and dies. Dead and declaying plants release chemical compounds that, even at very low levels, make the water taste musty or fishy. Taste and odour are not harmful, but can be aesthetically displeasing.

2.3. SEA-LEVEL RISE

Historical data, provided by MONRE, of sea level from tidal gauges along the Vietnam coasts show that the sea level rose at a rate of about 3mm/year during the period of 1993-2008, which is comparable with the global tendency (MONRE 2008). According to a recent study of the World Bank among eighty-four developing countries, Vietnam and Bangladesh are considered to suffer most from the impacts of sea-level rise (DASGUPTA *et al.* 2007). By mid of the 21st century, sea level is expected to increase about 30 cm and sea level would rise about 75 cm by the end of the 21st century compared to the period of 1980-1999 (MONRE 2009). Sea-level rise will have an overwhelming impact on the low-lying Mekong River Delta, and it is estimated that about 45 % of the total area will suffer from extreme salinity intrusion.

Climate change increases the risk of salinization in Vietnam in two ways. Firstly, low-river discharges, in combination with strong winds from the East, increase the intrusion of sea water through river mouths. Secondly, the ongoing increase in sea level leads to upcoming of salt water from deeper marine aquifers. Sea-level rise would increase salinity in open bays because the increased cross-sectional area would slow the average speed at which freshwater flows to the ocean. As recorded by Thanh, in recent decades, the 1 ‰ salinity contour (isohaline) has moved landward by 4-10 km in the northeastern part of the Red River Delta (THANH *et al.* 2004).

As a result, a high concentration of salt will block the chemical transformation process and reduce the development of aquatic ecosystems; it also causes the weak assimilation of the water accumulation body. Salinity increases in estuaries can also harm aquatic plants and animals that do not tolerate high salinity, especially mangrove forest. Salinity is one of the most important determinants of mangrove forest growth and distribution. Too high a salt concentration in water (40-80 %) diminishes the number of species and their size. In places where the salt concentration reaches 90 %, only a few species can exist and even then they grow slowly. However, mangrove do need a certain amount of freshwater during their growth. Freshwater from rivers, channels and rain dilutes the salinity of sea water, creating brackish water suited to many species during specific stages of their growth. As the sea level rises and the river flow alters, the distribution of salinity and freshwater in mangrove areas will change. These changes will likely modify fish, shrimp, crab and wildlife populations living in mangrove forests. The loss of mangrove forests at muddy coasts of Red River Delta is very serious since without mangrove forests, coastal protection in this area is almost impossible (HANH & FURUKAWA 2007).

According to sea-level rise scenarios simulated by the Vietnam Institute of Meteorology, Hydrology and Environment, and salinity intrusion downstream Sai Gon and Dong Nai rivers i) the maximum distance of salt water intrusion into the mouth increases; ii) the 4 g/l salinity front moves further inland 2 km from the base scenario, the 10 g/l salinity front (brackish water) even expands further about 5 km; and iii) number of days in dry season with salinity concentration greater than 4g/l increases (figs. 3, 4).

3. Adaptation Measures to Respond to Climate Change

Within the context of climate change, water resources in Vietnam are projected to become one of the sectors that are most suffering from impacts of temperature rising, rainfall changing and sea-level rise. As mentioned above, all these climatic changes will finally result in an increase of surface

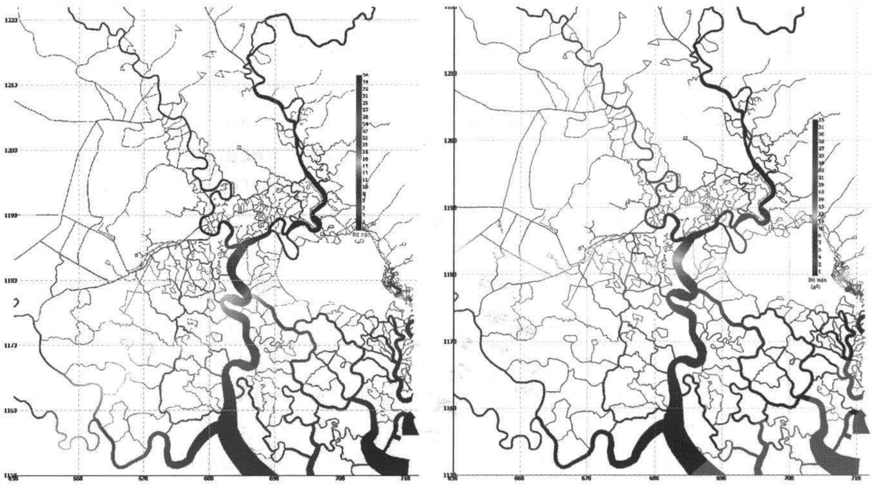

Fig. 3. — Mean salinity concentrations in April (dry season) downstream Sai Gon-Dong Nai rivers.

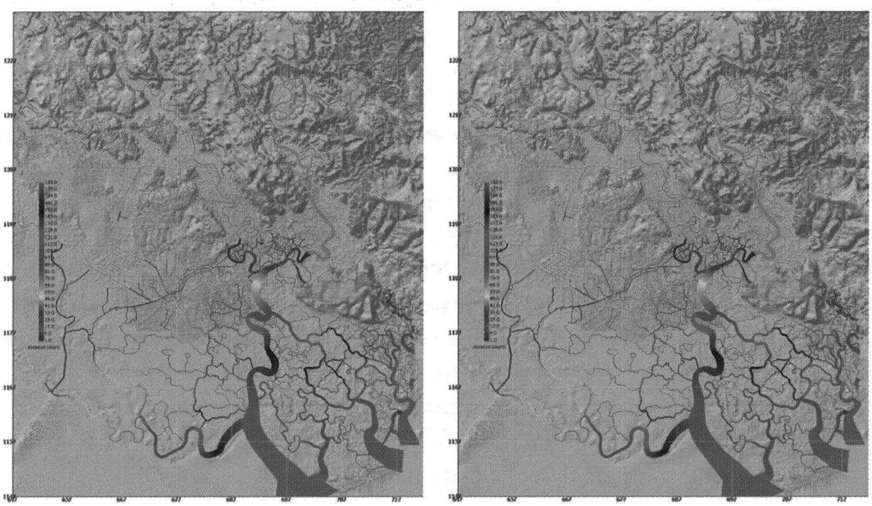

Fig. 4. — Number of days in the dry season with salinity concentrations greater than 4 g/l downstream Sai Gon-Dong Nai rivers.

water pollution. Therefore, protecting the river basins and lakes is a crucial part in water resource management.

In the light of the National Target Programme to Respond to Climate Change (Prime Minister 2008), based on the assessment of climate change variability, agreed climate change scenarios, the assessment of climate change impacts, relevant ministries, sectors, and localities should take initiative in developing their own action plans to respond to climate change. Emphasis is put on those sectors that are region sensitive and vulnerable to climate change, such as: (1) water resources, land use, ecosystem; (2) agriculture, forestry, aquaculture; energy; construction; transportation; public health, tourism, likelihood; (3) Mekong Delta, Red River Delta, and coastal zones. Action plans to respond to climate change for the water resources sector should therefore include:

— Scientific studies on the impacts of climate change on water resources, especially water quality in specific river basins and lakes: adequate assess of extreme events of precipitation (droughts, heavy rainfall, and typhoons) should be recognized to predict watershed hydro-biogeochemical responses to climate change. It is also very important to isolate the short-term impacts on water quality by humans from the effects of climate change that can potentially have indirect effects on the water quality.
— Identifying suitable scientific and technical solutions, such as overall plans for river basins, change specifications for water use and exploitation projects, methods for cost-effective use of water sources, protection and preservation of water sources, water pollution control.
— Reviewing existing laws and regulations on water resources protection and environment before taking steps of revising, developing and improving a legal framework: although the Vietnamese government adopted the water resources law (1998), land law (2003), environmental protection law (2005), river basin management decree (2008) and national standards for surface water quality, water quality management in Vietnam still meets many difficulties. These are considered as the unclear definition of responsibilities and competences among ministries and sectors, and the lack of mechanisms to acquire resources from private, non-governmental, international organizations and communities in water resource protection. It is a fact that the environmental legislation has provided the activities of water resource protection as a legal basic; application and implementation of those laws are still limited and inadequate.
— Building a management mechanism for cooperating with other sectors to protect the environment in the context of climate change.
— Strengthening monitoring network of surface water quality.
— Raising community awareness on methods for water use and protection in response to climate change.

— Developing implementation plans, programmes to respond to climate change in the field of water resources in all sectors and at all levels.
— Promoting international cooperation in scientific and technological activities, effectively apply and transfer climate-friendly technologies.

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Impacts of Climate Change on Salinity Intrusion in Vietnam

by

Van TRAN THI*, Ngoc TRAN THI BICH* & Thuc TRAN*

KEYWORDS. — Climate Change; Salinity Intrusion.

SUMMARY. — According to the World Bank, Vietnam is ranked in the list of the ten highest at-risk countries hit by climate change (CC). With a coastline of approximately 3,260 km and three fourth of the population living in a coastal area, Vietnam tends to considerably be affected by salinity intrusion (SI) — one of the highlighted impacts that has been intensified by CC. The two critical areas which are salinized in Vietnam are Mekong River Delta and low-lying Deltas. SI has been claimed as a disaster due to its no less serious damage than drought or flood on life and production. SI damage can be displayed as follows:

SI brings about shortage of domestic and agricultural water supply: in the dry season, water in rivers and canal systems has high salinity so that it cannot be taken to irrigate fields or hicks. Even to salt marsh, high-salinity water is harmful for raising aquatic organisms. In such main streams of Mekong River Delta as Tien, Hau, Vam Co Tay and Vam Co Dong, the range of salinity that may encroach on inland area varies from 60 to 120 km. As to fresh water in rivers, SI makes it contaminated and obviously cuts down the quantity of water supply. In the rainy season, consequence of flood is the wide spread of fertilizers, pesticides, disposal from water closets and breeding facilities as well as infectious diseases. People in those areas lack water, especially the poor who have to buy domestic water at a cost three to ten times higher than others. Besides, the constructions on river systems are ruined when salt attacks and undermines building materials, causing a huge amount of money for the government budget and the people taxes.

SI contributes to land salinization: two significant harmful actions of SI to the soil can be: (i) widening alkalium land that cannot be used for agriculture and (ii) salinizing ground water in coastal zones. In Mekong River Delta, in March 2008, a high salinity of 4 ‰ resulted in an emergency threat to tens of thousands of ha farming land, million of people and 45 million USD damage.

SI is related to harmful effects on coastal ecosystem: international and national studies all point out the impacts of CC on SI that affect the ecosystem. Sea-level rise

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makes physical, chemical and biological conditions of sea water worse, therefore affect food chain of fisheries and other marine animals. This is the main reason why organisms emigrate to another sea and partly/completely destroy marine populations.

As to complicated effects of CC in general and SI in particular, Vietnam needs to develop active responses such as:

In the short term: regularly monitor SI situation; build temporary dams and complete anti-salt dykes across river systems; save fresh water, especially in dry season; transfer the cultivated plant mechanism.

In the long term: according to the National Target Program to Respond to Climate Change, major activities should be implemented including: assess CC impacts in Vietnam; identify measures to respond to CC; develop a scientific-technological programme; strengthen the capacity in the organization, institution and policy; raise awareness and develop human resources; enhance international cooperation.

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Climate Change and Vector-borne Diseases of Livestock in the Tropics

by

Peter VAN DEN BOSSCHE*† & Tanguy MARCOTTY*

KEYWORDS. — Climate Change; Vector-borne Diseases; Tropical; Animal Health.
SUMMARY. — Despite the large degree of uncertainty associated with the impact of climate change on animal diseases in the tropics, there is a general consensus that vector-borne diseases will be affected most. The expected impacts of climate change on the epidemiology of vector-borne diseases are attributed to the direct effects of climate on the distribution and density of vectors and, indirectly, on the effects of climatic factors on the vector's susceptibility to infection and the ease with which the pathogen develops in the vector. Considering its complex nature and unpredictability it is suggested that the development of an effective and sustainable animal health service is perhaps the most important strategy in many African countries to safeguard livestock populations from the threats of climate change and its impacts on animal health, in general, and vector-borne diseases, in particular.

Introduction

The African climate has, during the 20th century, experienced wetter and drier intervals. Projections for the rates of change in temperature and precipitation for the 21st century vary but, irrespective of this uncertainty, future annual warming is expected to be highest in the interior of the semi-arid regions of Saharan and central southern Africa, resulting in desertification. Future changes in rainfall are more uncertain (CARTER *et al.* 2000, HULME *et al.* 2001). Despite this, there is general consensus that East Africa will become

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wetter, South-East Africa will become drier and there is a poorly specified outcome for the Sahel region (HULME *et al.* 2001).

Although climate change is a fact, there remains great uncertainty about how climate might change at the subregional level in parts of Africa and, especially, how this might be influenced by human-associated and other factors (KURUKULASURIYA *et al.* 2006). Moreover, the size and geographical diversity of sub-Saharan Africa make climate change predictions particularly challenging. Nevertheless, observations show that the African continent is warmer than twenty years ago, with an average rate of warming of about 0.05 °C per decade (Intergovernmental Panel on Climate Change 2001).

Climate Change and Vulnerability

Although the African continent's minimal contribution to climate change, the impact of climate change on the African population is expected to be high. This is because the direct and indirect impacts of climate change on, for example, livestock production and health are important additions to the already impressive list of constraints that impede African livestock development. Moreover, African livestock production systems are susceptible to, or unable to cope with, the adverse effects of climate change, including climate variability and weather extremes. This vulnerability is attributed to the heavy reliance on natural resources, the poor development status, the political and social instability, the institutional weakness and the associated weaknesses in its science and technology infrastructure. Moreover, the diversity of climate, vegetation, culture, economic circumstances and livestock production systems makes it very difficult to develop a generic response to adapt to the adverse effects of climate change. Furthermore, the vulnerability of the livestock production sector is aggravated by the risk averseness of most livestock owners and ineffective private and public animal health and laboratory services making it difficult to cope with the effects of climate change on animal health.

Climate Change and Animal Health

Changes in climate can have direct effects on the health of animals. An increase in ambient temperature may cause heat stress especially in less-adapted imported livestock breeds. Moreover, extreme events such as droughts or flooding may result in a substantial increase in livestock mortality. Probably more important are the indirect impacts the effects of climate change can have on livestock. Of particular importance are the effects of a changing environment as a result of a changing climate on the epidemiology of livestock diseases, in general, and on vector-borne diseases, in particular.

Vector-borne Diseases

Vector-borne diseases are a range of diseases in which pathogens are transmitted cyclically or mechanically between host(s) by insects or ticks. In Africa, most vector-borne livestock diseases fall into three main categories, *i.e.* the arboviral diseases transmitted by mosquitoes, midges or biting flies, tsetse-transmitted trypanosomiasis and tick-borne diseases.

The distribution and prevalence of vector-borne diseases is affected by the often complex interaction between the pathogen, the vector and the host. Any climate-related factor that affects this interaction will have an effect on the epidemiology of the vector-borne disease. Of particular importance are climate-related effects on (i) the survival of the vector, its reproduction and, hence, its distribution and density, (ii) the biting rate of the vector and (iii) the maturation and the survival of the pathogen within the vector.

Heat and aridity are known to reduce the life span of arthropods and, as a consequence, their abundance and sometimes even their capacity to maintain themselves in a particular area. Yet a dryer and warmer climate may favour some species compared to others. For example, *Hyalomma* ticks and *Aedes* mosquitoes are highly adapted to dry and warm climates. In an environment where livestock is highly mobile, such vectors can be introduced into areas that, as a result of climate change, now have become more suitable for their development. A warm and humid climate is likely to increase the transmission of insect-borne pathogens for two reasons: (i) increased blood meal frequency and (ii) increased life span. For instance, the frequency with which tsetse flies (*Glossina* spp., the vector of African trypanosomes) take a blood meal from a host animal increases with increasing temperature. This is because, being poikilotherm creatures, an increase in the ambient temperature increases the tsetse's basic metabolism and hence the fly's requirements for nutrients and energy (Hargrove & Coates 1990). Although the tsetes's survival depends on a species specific range of climatic conditions, an increase in humidity usually increases the fly's survival (Terblanche *et al.* 2008). This is clearly reflected in the significant increase in the average age of a tsetse population during the rainy season. Hence, changes in temperature and humidity (for example as a result of climate change) will have repercussions for the tsetse's feeding behaviour and survival with concomitant repercussions on the epidemiology of human and animal trypanosomiasis.

Climatic conditions can also affect significantly the development of the pathogen in its arthropod host. For example, stressed tsetse flies and their offsprings (as a result of unfavourable climatic conditions) are more susceptible to trypanosomal infections and, thus, have a higher vectorial competence. Indeed, whereas unstressed flies are mostly infected during the course of their first blood meal, stressed flies remain susceptible to infection throughout their adult life (KUBI *et al.* 2006, AKODA *et al.* 2009). Climatic conditions are also known to have an effect on the maturation of *Theileria parva* in its vector ticks. The optimal temperature for *T. parva* development in its vector tick ranges, depending on the strain, between 22 and 28 °C (YOUNG & LEITCH 1981, BUSCHER & TANGUS 1986). Lower and higher temperatures result in lower infection rates in ticks. Moreover, the transmission of *T. parva* is affected by another interesting feature that is influenced by climate. In equatorial areas, the vector tick (*Rhipicephalus appendiculatus*) cycles throughout the year (three or four cycles in a year). In areas where the dry season is more pronounced, only two or even one single generation is observed in a year: the adult ticks feed at the onset of the rains, followed a few weeks later by the larvae and, finally, the nymphs. If the meteorological conditions are not favourable, newly emerged adult ticks enter a period of quiescence and wait for the rainy season of the following year to feed (BILLIOUW *et al.* 1999, MADDER *et al.* 2002). When a single annual generation is observed, the interval between an individual's blood meal taken as a nymph and that taken as an adult might be as long as six to eight months. Different authors indicated that such intervals were particularly detrimental to the survival of *T. parva* picked up by a nymph (MARTIN *et al.* 1964, MARCOTTY *et al.* 2002) and affected significantly the epidemiology of the disease, East Coast Fever (BILLIOUW *et al.* 1999). Similar to what has been observed in parasites, climate can also affect the development of viruses in their arthropod hosts (*e.g.* MULLENS *et al.* 1995).

EXAMPLES OF VECTOR-BORNE DISEASES ASSOCIATED WITH CLIMATE CHANGE

Rift Valley Fever

Rift Valley fever (RVF), an important arboviral disease transmitted by mosquitoes, is already associated with climate change. The disease is most severe in sheep and goats, resulting particularly in mortality in new-born animals and abortion in pregnant animals and occurs mainly in eastern and southern Africa (SWAENEPOEL & COETZER 2004). Outbreaks of RVF are associated with excessive rainfall and the flooding of shallow, seasonally inundated wetlands that contain dormant drought-resistant, infected eggs of the mosquito (*Aedes*). As a result of the flooding the eggs hatch and the emerging infected mosquitoes infect an amplifying host (ruminant), which serves as a source of infection for many other genera of mosquitoes that rapidly spread the disease. Outbreaks of RVF are thus associated with sudden heavy rains and floods, often triggered by El Niño (LINTHICUM *et al.* 1999).

African Horse Sickness and Bluetongue

African horse sickness (AHS) and bluetongue (BT) are caused by viruses transmitted by Culicoides biting midges. The distribution of both diseases is thus very much affected by the presence of favourable conditions for the breeding and spread of midges. In South Africa, large outbreaks of AHS have been associated with the succession of drought and heavy rainfall caused by the warm phase of ENSO (BAYLIS *et al.* 1999). Since some global climate models predict that ENSO will occur more frequently in the future, epidemics of these vector-borne diseases may become more frequent.

Tsetse-transmitted Trypanosomiasis

The direct and indirect effects of climate change on the distribution and density of tsetse flies will largely determine the future distribution and prevalence of livestock trypanosomiasis. However, a recent study modelling the expected impact of climate change on the distribution of tsetse flies suggested that the influence of climate change is limited, compared to the effects of population growth and the concomitant changes in land use and the natural habitat of the tsetse (THORNTON *et al.* 2006). The largest changes in the distribution of the tsetse fly are expected in the drier areas of West, East and southern Africa. Humid areas of the African tsetse belt will be less affected by climate change. However, the possible effects of increased temperatures and changes in habitat suitability on the vector capacity of the tsetse fly are not known and require further investigation.

Tick-borne Diseases

Ticks spend a large part of their life living off their host(s) and are thus subject to ambient temperature and humidity. Climatic conditions and vegetation influence the ecosystem and largely determine the distribution of ticks and their density. Increasing temperature, as a result of climate change, may shorten their life cycle and increase their reproductive rate. On the other hand, a warmer climate might be detrimental for some species. A model developed for the brown-ear tick (*R. appendiculatus*), the primary vector of East Coast Fever, predicts that, by the 2050s, suitable habitats for the tick will have disappeared in most of the south-eastern part of its range. This is because this species is particularly susceptible to warm and dry climate. Conversely, more suitable areas for tick survival will appear in the western and central parts of southern Africa (ROGERS 1996). In southern Zambia, a positive association was found between El Niño events and an increased *T. parva* seroprevalence, as a result of the increased survival of the tick vector (FANDAMU *et al.* 2005). Hence, climate clearly influences the dynamics of the tick population and the diseases they transmit by affecting the distribution of ticks and their seasonal occurrence.

In large areas of Africa, the control of major tick-borne diseases is based on the maintenance of an endemic stable situation. Endemic stability is the epidemiological state of a population in which clinical disease is rare, despite high levels of infection (COLEMAN *et al.* 2001). It can develop in circumstances where young animals are exposed to infection but do not become diseased because of maternal or age resistance. As a result of this infection, they develop a long-lasting immunity. In the event that animals are not exposed to the disease agent during the 'protected' period, they will become susceptible to infection and may develop severe disease when challenged. Endemic stable situations are known to occur in the cases of heartwater, babesiosis and anaplasmosis. In endemic East Coast Fever situations, only calves suffer from the disease. The development and maintenance of endemic stability for tick-borne diseases in cattle is thus dependent on an optimal relationship between livestock, the parasite and ticks. Disruption of this relationship, as a result of climate changes and subsequent alterations in the distribution and density of certain tick species, is likely to affect endemic stability and may result in outbreaks of disease.

Conclusion

Despite the expected impacts of climate change on African livestock in general, and on a number of vector-borne diseases in particular, there are few reports on the effect of long-term climate change on animal health in Africa. Monitoring its impact is a challenging task. Indeed, changes in livestock health due to climate are often difficult to distinguish from other confounding influences. This is of particular importance in vector-borne diseases where the distribution of the vector may be attributed to changes in the climate and/or other changes in environmental conditions (*e.g.* suitable habitat). Hence, any assessment of climate change impact on the epidemiology of these diseases should also attempt to integrate any physical, biological and societal confounding factors.

The effects of climate changes on the epidemiology of vector-borne diseases are influenced by numerous, sometimes contradictory, factors. Whereas a sound understanding of how climate change affects livestock health is crucial in making recommendations on how to reduce its potential impact, it is important to collect objective evidences of epidemiological changes and avoid undocumented postulations. The current knowledge and experience acquired in different places could prove useful to envisage and model different scenarios and, ultimately, better anticipate epidemiological changes but can by no means replace disease and vector surveillance in the field. In addition, the determinants of resilience and adaptation that already reduce this impact are also often poorly understood. Lessons can be learned from case studies of past and present responses and adaptations, or from livestock production systems in regions that already experience similar climatic conditions (*e.g.* THORNTON *et al.* 2006). In some cases, it is also useful to see how policy has been influenced by these experiences.

Many possible adaptive measures are not unique to climate change but are needed regardless, and indeed benefit the livestock sector as a whole (SCHERAGA *et al.* 2003). For example, adaptive capacity could be increased in the broader context of developing appropriate policy measures and institutional support to help the African livestock owner cope with all animal health problems. In fact, the development of an effective and sustainable animal health service, with associated surveillance and emergency preparedness systems and sustainable animal disease control and prevention programmes (*e.g.* vaccination campaigns), is perhaps the most important and most needed adaptive strategy in many African countries, and may, to a considerable extent, safeguard livestock populations from the threats of climate change and climate variability. Such a holistic approach is likely to be more acceptable, and probably more sustainable, since it is consistent with or can be integrated into programmes that address wider livestock production and rural development issues in Africa.

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Effects of Elevated Atmospheric CO_2 Concentrations on Crop Growth and Production: a Metastudy for Implementation in the Water Productivity Model AquaCrop

by

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KEYWORDS. — Climate Change; Elevated CO_2; AquaCrop Model; Crop Growth; Water Balance.

SUMMARY. — Elevated atmospheric CO_2 concentrations can affect crop development, transpiration and water productivity, which involves consequences for yield production and the soil water balance. This impels to adjust crop productivity models as to predict crop growth and yield under changed climatic conditions. The effect of elevated CO_2 concentrations was considered by means of an exhaustive metastudy of peer-reviewed literature on free-air CO_2 enrichment (FACE) experiments. The study revealed slightly accelerated crop growth, improved water use efficiency and enhanced yield production. As emphasis was placed on processes and parameters crucial in AquaCrop, the crop water productivity model of FAO, the results of this study will serve to incorporate the CO_2 effect in AquaCrop. This will make the model suitable to predict and analyse risks related to food security, droughts and floods in developing countries under future climatic conditions.

Introduction

Global warming and the forthcoming climate change are unequivocal (IPCC 2007). Elevated atmospheric CO_2 concentrations ([CO_2]), risen air temperatures and altered rainfall patterns constitute a fundamental trio of

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climatic changes. The Intergovernmental Panel on Climate Change (IPCC) expects an increase in air temperature of 0.2 °C per decade, leading to an absolute temperature increase between 1.1 and 5.4 °C at the end of the century. The concurrent change in precipitation amount and pattern will cause less predictable and more extreme droughts and floods. The anticipated rise of [CO_2] of about 2 ppm per year will level up the [CO_2] in 2100 to 560 ppm.

Inevitably, those changes affect water resources and the agricultural productivity in regions at mid and low latitudes (IPCC 2007). Increases in mean seasonal temperature of only 2 to 4 °C and episodes of extreme hot temperatures can reduce crop yield when optimal temperature levels are exceeded (ADAMS *et al.* 1998, WHEELER *et al.* 2000, BATTISTI & NAYLOR 2009). Changed rainfall patterns can alter the moisture availability for crops dramatically. In drought-prone areas, increased precipitation can improve the soil water balance, but crops may as well be confronted with damaging floods resulting in yield decline (EASTERLING & APPS 2005, LOBELL *et al.* 2008). In areas with rainfall decline, water stress challenges agricultural productivity (GEERTS & RAES 2009). The negative impact of the mentioned climatic modifications can however be tempered by the growth stimulating effect of elevated [CO_2] (MORISON & LAWLOR 1999, AINSWORTH *et al.* 2007).

Adequate predictions of crop production and the soil water balance under future climatic conditions are essential to analyse and tackle risks related to food security, droughts and floods, especially in developing countries. Crop models are therefore indispensable, but existing models need to be adapted. Future scenarios for precipitation and temperature generated by climatic models can directly serve as changed input. To account for the effects of elevated [CO_2] in contrast, models require a thorough adjustment (EASTERLING *et al.* 1996, TUBIELLO & EWERT 2002, LONG *et al.* 2006).

AquaCrop, the recently released crop water productivity model of the Food and Agriculture Organization of the United Nations (FAO), aims to be a robust, accurate and easy-to-use crop model (STEDUTO *et al.* 2009, RAES *et al.* 2009). The growth engine of the model is water-driven and assumes a linear and conservative relationship between crop transpiration and biomass growth through a water productivity parameter (WP). The possibility to normalize WP for climate (*i.e.* evapotranspiration and [CO_2]) implies the applicability of the model in wide perspectives of space and time (STEDUTO *et al.* 2007, STEDUTO *et al.* 2009). Although simulations are based on elementary and complex biophysical processes, AquaCrop requires limited and easy-to-achieve input parameters. This makes it a suitable modelling tool to predict crop growth and yield, assess soil water balances and optimize water use efficiency for a broad range of crops (STEDUTO *et al.* 2009, RAES *et al.* 2009). To assess the impact of climate change, AquaCrop requires an adjustment to account for elevated [CO_2] that goes beyond merely normalizing WP for [CO_2].

Several field trials have been carried out in different places in the world to establish knowledge on different, either opposing or intensifying, effects of elevated [CO_2] on crop development (*e.g.* IDSO & IDSO 1994, KIMBALL *et al.* 2002). Among these, free-air CO_2 enrichment (FACE) experiments enable to study the influence of elevated [CO_2] on crop growth in a near-natural environment. A FACE experiment consists of several plots (8 - 30 m diameter) where CO_2 is released in and above the crop surface via blowers around the individual plots. The CO_2 release is automatically and instantaneously adjusted in accordance with the monitored [CO_2], wind direction and velocity at the site. FACE installations reach in general 10 % of the target [CO_2] for more than 90 % of the time (LONG *et al.* 2006, AINSWORTH *et al.* 2008). Large-scale qualities and minimal perturbation of the natural environment are often mentioned as main advantages. Drawbacks consist in the relatively high operational costs, the isolation of the CO_2 effect from other environmental changes, and possible side-effects caused by the blower system (LONG *et al.* 2006, AINSWORTH *et al.* 2008).

The objective of this work is to assess the impact of CO_2 on important crop parameters and output variables of AquaCrop by means of a metastudy as a first step in the process to incorporate the CO_2 effect in the crop productivity model AquaCrop.

Materials and Methods

METASTUDY

Development of the Database

To gain a clear understanding of the effect of elevated [CO_2] on different aspects of crop development and yield production, an exhaustive metastudy of peer-reviewed literature on FACE experiments was carried out. Crucial crop attributes of AquaCrop, elaborated below and listed in table 1, embodied the base for the metastudy. The CO_2 effect was quantified through a response ratio (R). R was determined for different crop attributes as the ratio between the attribute value under elevated [CO_2] and the value under ambient [CO_2]. For attributes related to phenological development, an alternative indicator was established, which expresses the difference between the attribute value under elevated [CO_2] and under ambient [CO_2] in days.

Table 1
Crop attributes (parameters ^{p} and output variables ^{o} of AquaCrop) analysed in the metastudy

Process	Crop Attribute	Abbreviation
Canopy expansion	Canopy growth coefficient ^{p}	CGC
Root growth	Maximum rooting depth ^{p}	Z_r
Phenological development	Onset of anthesis ^{p}	A_o
	Onset of senescence ^{p}	S_o
	Crop maturity ^{p}	M_o
Transpiration	Actual crop transpiration ^{o}	Tr
Biomass production	Water productivity ^{p}	WP
	Biomass ^{o}	B
	Root:shoot ratio ^{p}	R:S
Yield formation	Harvest index ^{p}	HI
	Yield ^{o}	Y

Attribute values were withdrawn from primary research published in peer-reviewed journal articles. The ISI Web of Science citation database (ISI, Thomson Inc., Philadelphia, USA) and the ScienceDirect citation database (Elsevier B.V., Amsterdam, The Netherlands) were searched for all primary FACE research. The literature survey was intended to be comprehensive, with all published studies conducted on relevant agricultural crops and pasture grasses available in June 2009 included. Only experiments in open air conditions, with unrestricted root growth and elevated [CO_2] attained via blowers were included. All published accounts of FACE experiments were selected if they provided, either in tables or in charts, values of at least one crop attribute mentioned in table 1. No consideration was made as to the outcome of the CO_2 exposure, be it negative or positive, significant or non-significant, or as to the length of exposure time to CO_2, to possible interruptions during night time, or to the size of the experimental plots. In general, the elevated CO_2 levels were environmentally relevant and ranged between 450 and 600 ppm, which are consistent with predictions for the coming 50 to 100 years. Yet, occasional studies with higher or lower exposure values were not banned from the metastudy. No crop attribute values were corrected for the level of CO_2 enrichment. The generated database incorporated 144 independent trials with C_3 crops *Triticum aestivum* L. (wheat), *Hordeum vulgare* L. (barley), *Oryza sativa* L. (rice), *Brassica napus* L. (oilseed rape), *Lolium perenne* L. (perennial ryegrass), *Glycine max* (L.) *Merr.* (soybean), *Trifolium repens* L.

(white clover), *Solanum tuberosum* L. (potato), *Gossypium hirsutum* L. (cotton), *Vitis vinifera* L. (grapevine), and C_4 crops *Zea mays* L. (maize) and *Sorghum bicolor* (L.) *Moench* (sorghum). Within an individual study, each experiment was considered independent if it differed in experimental year, site, nutrient or water availability, or crop species from another experiment. Relative responses to elevated [CO_2] were computed for the attributes in table 1, directly from values in tables or after digitizing charts using the software package Engauge Digitizer (Free Software Foundation Inc., Boston, USA).

Crop Water Productivity Model AquaCrop

Selection of Crop Attributes

The internal structure of the crop water productivity model AquaCrop guided the selection of crop attributes to be investigated in the metastudy.

AquaCrop comprises a growth engine, which relies on the conservative relationship between biomass (B) and crop transpiration (Tr) (Steduto *et al.* 2007):

$$B = WP \cdot \sum Tr \qquad \text{(Equation 1)}$$

with B = biomass (kg/m²)
Tr = crop transpiration (mm)
WP = water productivity (kg biomass per m² and per mm cumulated water transpired over the time period in which the biomass is produced)

The growth engine is coupled with other model components in a structure that imitates the soil-plant-atmosphere system (fig. 1). The soil component includes a soil water balance that can trigger crop responses to possible water stress. For the climate component, air temperature, rainfall, evaporative demand and [CO_2] are the essential elements. As rainfall and reference evapotranspiration affect soil water balances, temperature and atmospheric [CO_2] govern crop development, involving phenology, growth rate and WP. The crop component includes phenology, crop canopy, rooting depth, biomass production and harvestable yield, which are coupled via dynamic responses. The crop develops by expanding its canopy and deepening its roots while simultaneously evolving through the main phenological stages. An indirect mutual linkage between canopy development and root deepening through

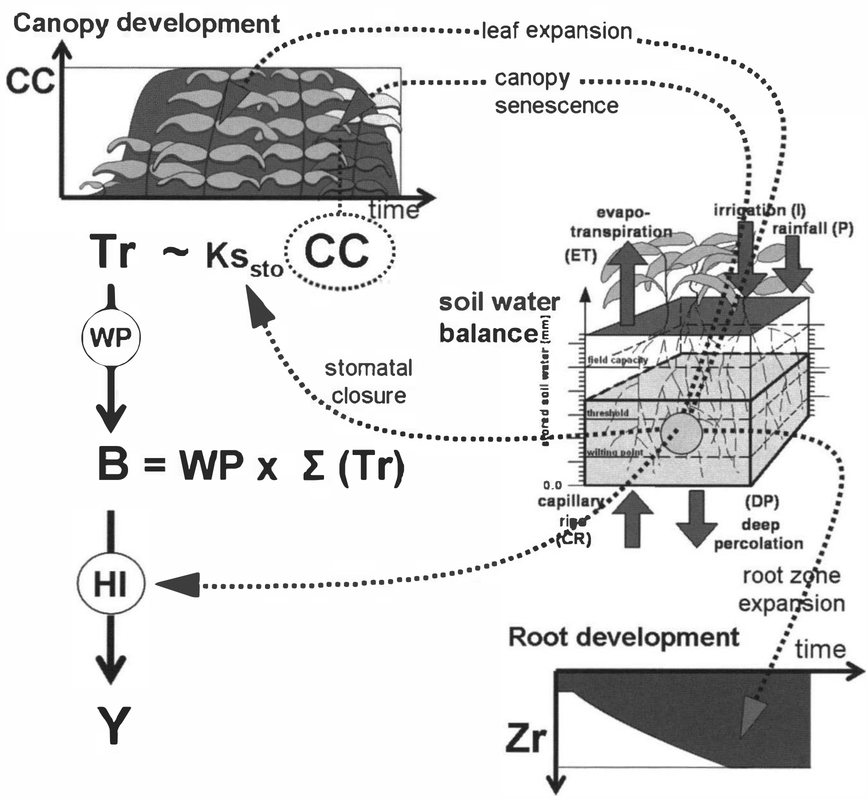

Fig. 1. — Schematic representation of the AquaCrop model.

stress factors maintains the root:shoot ratio in the model. The crop canopy determines Tr, which in turn establishes the proportional amount of produced B through the WP parameter (Equation 1). The proportion of total B that is harvestable yield (Y) is determined by a harvest index (HI) (STEDUTO *et al.* 2009):

$$Y = B \cdot HI \qquad \text{(Equation 2)}$$

The fundamental processes described above reveal eight crop parameters crucial for crop development and three output variables of AquaCrop that may be subject to the impact of elevated [CO_2]. The parameters and output variables (crop attributes) are summarized in table 1 and embody the base of the metastudy.

Determination of Crop Attributes

The Canopy Growth Coefficient (CGC) was determined directly from the evolution of canopy cover (CC) within the growing season or indirectly from the evolution of Leaf Area Index (LAI) over time. The analysis of Z_r, A_o, S_o, M_o, Tr, B and Y was performed with direct attribute values. Values for R:S, WP and HI were collected and directly analysed if given, or first calculated as the ratio of below-ground B over above-ground B, above-ground B over Tr, or harvestable Y over above-ground B, respectively. If information about Tr was not available, actual crop evapotranspiration (ET_a) was analysed as a substitute for actual crop water use. Water Use Efficiency (WUE), defined as the ratio between above-ground B and ET_a, was studied as a substitute for WP if Tr was not measured. Given the particular features of tuber crops, WP and WUE of potato crops were exceptionally calculated including below-ground biomass.

Results and Discussion

Crop responses [1]*

Canopy Expansion

Under elevated [CO_2] of 540-600 ppm, crop growth accelerated lightly. Averaged for all crops, CGC augmented with 6 % (4 % standard deviation (sd)) in optimal conditions. With suboptimal water or nitrogen availability, CGC augmented 3 % (5 % sd) (*e.g.* Kimball *et al.* 1995, Ottman *et al.* 2001).

Root Growth

Few studies explicitly examined the maximum rooting depth of crops under elevated [CO_2]. Wall *et al.* (2001) estimated the root penetration for sorghum and found a CO_2 induced increase of 6 % in well watered and 8 % in water stress conditions. For cotton, Prior *et al.* (1995) reported the taproot length to be extended by 9 to 11 %. Jongen *et al.* (1995) registered an increase in total root length of 32 to 40 % for white clover, under high and normal nitrogen fertilization respectively.

* The number in brackets [ ] refers to the note p. 282.

Mostly, elevated [CO_2] triggered root biomass, R:S and root volume to increase, which involves an improvement of the root capability to explore the soil for nutrients and water resources (PRIOR *et al.* 1994, SUTER *et al.* 2002). R:S increased 4 % (6 % sd) in optimal conditions for all but tuber crops under [CO_2] between 540 and 600 ppm. Water stress and nutrient deficiency increased the R:S response to elevated [CO_2] to 32 % (31 % sd) and 7 % (8 % sd), respectively (*e.g.* MAUNEY *et al.* 1994, HEBEISEN *et al.* 1997). Tuber crops showed a more pronounced effect than other crops with an increase of R:S of 60 % (59 % sd) in well watered conditions (MAGLIULO *et al.* 2003).

Phenological Development

Elevated [CO_2] can affect the phenological development of crops. The metastudy revealed A_o, S_o and M_o of C_3 crops to be advanced with on average two days (three days sd) under [CO_2] between 540 and 600 ppm. Yet, a few studies revealed a status quo or delay of A_o, S_o and M_o (*e.g.* MIGLIETTA *et al.* 1998, ROGERS *et al.* 2006). C_4 crops in contrast often postponed their phenological development (OTTMAN *et al.* 2001, LEAKEY *et al.* 2004). Doubts exist, however, about the causal factor of the phenological change. Stomatal closure, triggered by elevated [CO_2], can diminish leaf transpiration and increase canopy temperature, which can fasten phenological development (*e.g.* MAGLIULO *et al.* 2003). On the other hand, accelerated phenology can be an indirect effect of increased crop growth under elevated [CO_2] in so-called determinate crops (*e.g.* DERMODY *et al.* 2008, GEERTS *et al.* 2008). Yet, other authors blame the microclimate created by FACE blowers to artificially induce (supplemental) phenological fastening (*e.g.* PINTER *et al.* 2000).

It should be kept in mind that changes in phenological development are often mentioned in studies, while a status quo of the phenology more often fails to be reported. This can possibly bias the conclusions of this metastudy and slightly overestimate the change in phenological development.

Crop Transpiration

Averaged for different crops, Tr reduced 13 % (13 % sd) in well watered and 8 % (8 % sd) in water stress conditions when [CO_2] was raised to 540-600 ppm (*e.g.* DUGAS *et al.* 1994, WALL *et al.* 2006). The actual evapotranspiration (ET_a) reduced less: on average 6 % (4 % sd) when water was a non-limiting factor. In water limited conditions, ET_a showed less evidence to decline: an average reduction of 4 % (7 % sd) was registered (*e.g.* SENOCK *et al.* 1996, BERNACCHI *et al.* 2007). In general, the CO_2 effect on ET_a was more pronounced in tuber or C_4 crops than in C_3 plants (*e.g.* CONLEY *et al.* 2001, MAGLIULO *et al.* 2003). Although elevated [CO_2] triggers stomatal closure, smaller than expected declines in Tr and ET_a are reported. An explanation lies in the combined effect of an increased vapour pressure deficit, caused by the rise in leaf temperature following stomatal closure, and enhanced leaf area and B growth. Both effects increase total Tr, apart from whether or not the transpiration per leaf area decreases (*e.g.* BERNACCHI *et al.* 2007). The limited reduction of ET_a and Tr in dry conditions can probably be ascribed to amplified root growth under elevated [CO_2], which enables to exploit deeper water reservoirs and sometimes prolongs the growing cycle of water stressed crops (CONLEY *et al.* 2001). Specifically for C_4 crops, limited growth and leaf area responses to elevated [CO_2], but a strong decrease in stomatal conductance explains the higher reduction of Tr in C_4 crops (TRIGGS *et al.* 2004).

Water Use Efficiency and Biomass Production

Only one study determined WP and reported the increase under elevated [CO_2] (560 ppm) to be 19 % (YOSHIMOTO *et al.* 2005). The rise of WUE, which was more frequently measured, averaged 24 % (13 % sd) for all but tuber crops and is visualized in figure 2 (*e.g.* HUNSAKER *et al.* 2000, CONLEY *et al.* 2001, YOSHIMOTO *et al.* 2005). Trend lines are given in the figure to visualize the positive impact of elevated [CO_2] on WUE, but must be considered with reservations. Individual responses are scattered around the average response and lack of responses for a broad range of elevated [CO_2] levels prevents to estimate the impact for various [CO_2], both reducing the validity of the trend lines.

For potato, a tuber crop, WUE increased 53 % (14 % sd) (MAGLIULO *et al.* 2003). The rise in WUE of C_3 crops is primarily related to B increase, and less to the minor decrease in water consumption (*e.g.* HUNSAKER *et al.* 2000). MAGLIULO *et al.* (2003) explain the explosive WUE gain for tuber crops partly by the higher water savings, although the benefit in efficiency remains mainly due to B increase. C_4 crops in contrast take limited advantage of elevated [CO_2] for B production. Increased WUE is here primarily due to water savings (CONLEY *et al.* 2001).

In well watered conditions, B of C_3 crops increased on average 17 % (sd 7 %) when [CO_2] was raised to 470-600 ppm. With water stress, the CO_2 effect on B production was higher: 28 % (31 % sd) (*e.g.* MORGAN *et al.* 2005, MA *et al.* 2007). The combination of water stress and nitrogen deficiency hindered however elevated [CO_2] to stimulate B production of pasture grasses (*e.g.* SCHNEIDER *et al.* 2004). C_4 crops only benefitted from elevated [CO_2] when

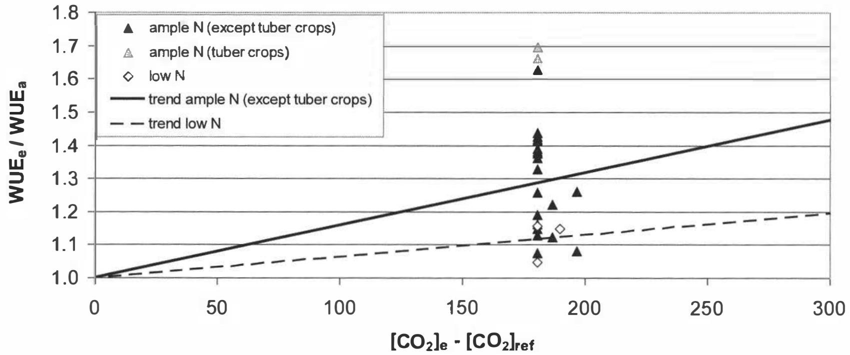

Fig. 2. — Effect of elevated $[CO_2]$ on WUE (e = under elevated $[CO_2]$; a = under ambient $[CO_2]$; $[CO_2]_{ref}$ = 369.61 ppm).

crops experienced water stress: B production increased with 16 % (4 % sd). CO_2 does not stimulate B production of C_4 crops photosynthetically, but can only increase it by alleviating drought stress (*e.g.* OTTMAN *et al.* 2001).

Yield Production

Changes of HI due to elevated $[CO_2]$ were small or non-existing. The average response ratio equalled 1 (5 % sd) (*e.g.* MORGAN *et al.* 2005, MANDERSCHEID *et al.* 2009). Y stimulation under elevated $[CO_2]$ is therefore almost identical to B stimulation.

In optimal conditions, Y production of C_3 crops increased under elevated $[CO_2]$ on average 22 % (15 % sd) (*e.g.* YANG *et al.* 2006, MANDERSCHEID *et al.* 2009). Water shortage increased Y gain to 31 % (16 % sd), while sub- or superoptimal nitrogen levels decreased the gain to 17 % (13 % sd) and 16 % (4 % sd), respectively. Whereas drought stress can be partly alleviated by enhanced WP under elevated $[CO_2]$, Y formation is impeded by nutrient shortage (*e.g.* KIM *et al.* 2003, WALL *et al.* 2006). C_4 crops only benefitted from high $[CO_2]$ in water stress conditions. Final Y of stressed crops was 26 % (12 % sd) higher under elevated $[CO_2]$, while if water was not limited, Y production decreased on average 3 % (7 % sd). As for B, CO_2 does not stimulate Y production of C_4 crops photosynthetically, but can increase Y by tempering drought stress (*e.g.* OTTMAN *et al.* 2001). Figure 3 visualizes the effect of elevated $[CO_2]$ on yield for crop grown with ample N in well watered and water stress conditions. The same reservations that apply to figure 2 must be considered for figure 3.

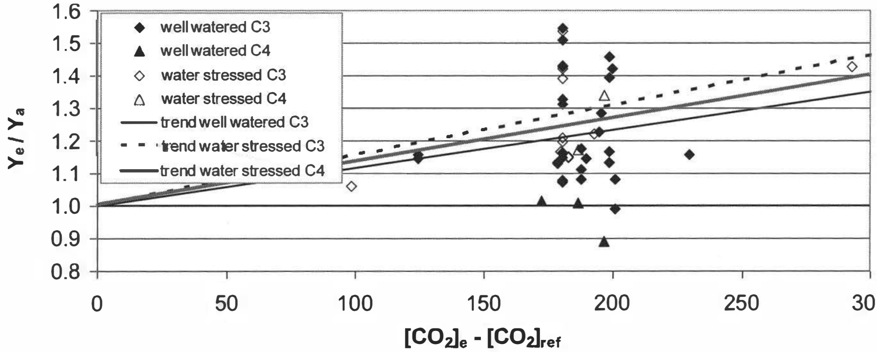

Fig. 3. — Effect of elevated $[CO_2]$ on Y (e = under elevated $[CO_2]$; a = under ambient $[CO_2]$; $[CO_2]_{ref}$ = 369.61 ppm).

General Overview

Table 2 summarizes the effect of elevated $[CO_2]$ between 500-600 ppm on different crop processes and parameters in optimal conditions, as evidenced by this meta-study. Representative symbols are given instead of specific values since response ratios differ according to elevated $[CO_2]$ level and crop species. Nevertheless, this overview can give a good indication of the general effect of elevated $[CO_2]$. Caution is called for interpretation of the results for C_4 crops. This functional crop type is underrepresented in field experiments and therefore conclusions are less robust than for C_3 crops.

The significance of the difference of response ratios under different levels of water or nutrient stresses was not addressed in this study, but will be considered in a statistical meta-analysis supplementary to this review. Differentiation between stressed and unstressed conditions was made here for crop modelling purposes for which results for non-stressed crops are essential to describe the isolated effect of elevated $[CO_2]$. Once able to simulate the effect of elevated $[CO_2]$, crop modellers can investigate the interaction with other climatic factors (*e.g.* temperature, rainfall, evaporative demand of the atmosphere) and come to well-founded estimates of food production.

Adjustment of AquaCrop

The outcome of the meta-study suggests adapting AquaCrop for the influence of elevated $[CO_2]$. In ongoing research, meta-analytical techniques will be used to update the calculation procedures for important model parameters under elevated $[CO_2]$.

Table 2
Schematic overview of the effect of elevated [CO_2] on different crop attributes

Crop Attributes	**Effect**	
	C_3 crops	**C_4 crops**
CGC	↑	↑
Zr	↑	↑
Time to A_o, S_o, M_o	↓	↑
Tr, ET_a	↓	↓↓
WP, WUE	↑↑	↑↑
B	↑↑	x
R:S	↑↑	↑↑
HI	x	x
Y	↑↑	x

↑ = increase; ↓ = decrease; x = no or negligible effect.
Double arrows indicate more pronounced effects (≥ 15 %).

Conclusion

An extended metastudy of FACE experiments revealed an undeniable impact of elevated [CO_2] on several crop parameters and output variables of the water productivity model AquaCrop. To simulate crop development, yield production and soil water balances in the coming decades, AquaCrop has to be adapted for the effect of [CO_2]. The incorporation of the effect will enable to understand the combined effect of risen air temperatures, altered rainfall patterns and elevated [CO_2]. In addition, it will make the model suitable to predict and analyse risks related to food security, droughts and floods in developing countries where early risk assessment remains indispensable in the future.

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NOTE

[1] An exhaustive list of primary research literature used in the metastudy is not included in the reference list, but remains available from E. Vanuytrecht.

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International Symposium
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a Post-Kyoto Assessment
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p. 287.

Global Warming, Kyoto and Developing Countries

by

Jean-Pascal VAN YPERSELE*

KEYWORDS. — Climatic Change; Climate Impacts; Sustainable Development; North-South Relations.

SUMMARY. — Climate warming has now been qualified by the IPCC as unequivocal. The main factor for the warming since 1950 has been identified: greenhouse gases (GHGs) from human activities. The habitability of the planet is at stake, with impacts felt or projected on about every ecosystem or human activity. There will be significant, often adverse, impacts on many ecological systems and socio-economic sectors, including food supply and water resources, and on human health. Developing countries have the least contributed to the accumulation of GHGs, but they will bear the most severe impacts, particularly their poor populations. One can adapt but only up to a point. The Kyoto Protocol commits industrialized countries to a small reduction of their emissions over the period 1990-2012, and allows them to offset some of their emissions by funding "Clean development Mechanism" projects in developing countries. The first commitment period of the Kyoto Protocol expires soon, and the international community is presently negotiating a new agreement to reinforce and complement the Kyoto Protocol. The main issues and challenges ahead of the Copenhagen Conference (December 2009) will be reviewed, in the light of the IPCC reports, with a view on their implications for the sustainable development of North and South countries.

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Deforestation or Climate Change: what is Changing the Flow Regime of the Besai River? [1]

by

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Meine VAN NOORDWIJK*** & Bart MUYS*, **

KEYWORDS. — Climate Change; Deforestation; Hydrology; Sea Surface Temperature; Rainfall Patterns.

SUMMARY. — Deforestation is often perceived to be the cause of loss of watershed functions. The strong association of "forest" and "water" in public perception has very frequently led to conflicts when forest areas were converted to other productive systems. The Way Besai watershed (Sumberjaya) is an example of this, where conversion of forest to coffee gardens on slopes was considered to have led to a reduction of discharge of the Way Besai river, thus reducing the functionality of the hydropower plant. Analysis of the long-term data records (30 years) of flow of the Besai river and rainfall in the area illustrated that, in contrast with public perception, there was no decreasing trend in annual discharge; relative to annual rainfall there was in fact an increase. Variability in annual discharge is in the order of 1,200 mm, due to the variability of rainfall. This is four times more than the range that can possibly be attributed to land-use change (300 mm). Dry season flows, however, did decrease over the years and became more frequent. Parsimonious modelling illustrated that this had to be entirely attributed to changes in rainfall patterns and not to local land use changes. These changes in rainfall patterns correlated very well with changes in sea surface temperature in the Pacific, the well known El Niño, but also with the perhaps lesser known Indian Ocean Dipole. Time series analysis beyond thirty years is needed to investigate if these changes in sea surface temperatures are due to climate change or to natural cycli spanning a few decennia.

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Round-table Debate
Towards a New Protocol

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pp. 293-294.

Participants

Moderator

Morgan De Dapper, president of the "Environment and Development" Commission of the Royal Academy for Overseas Sciences; professor Universiteit Gent (Belgium)

Rapporteur

Pierre Ozer, member of the "Environment and Development" Commission of the Royal Academy for Overseas Sciences; *chargé de recherches* Université de Liège (Belgium)

Introduction

Yvan Biot, member of the Royal Academy for Overseas Sciences; Head Climate Change and Environment Research, Research and Evidence Division, Department for International Development (DFID), London (UK)

Discussants

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Towards a Strengthened Climate Deal. A Brief Scientific and Historical Context of the Global Policy Response to Climate Change

by

Yvan BIOT*

SUMMARY. — The Copenhagen conference in December 2009 represents a significant moment in climate politics. The attendance by one hundred and thirty Heads of State bears testimony to the fact that climate change has graduated from the relative backwaters of the Ministries of Environment to the highest offices in the land. Conditions are now in place for some tough decisions at the heart of national and international policy making. This paper summarizes the growing consensus on what actions need to be taken to avoid dangerous climate change, against the backdrop of the current state of knowledge on the extent of the problem. A brief assessment of what has already been achieved concludes that much still needs to be done to incentivize further reductions in greenhouse gas emissions and provide additional support to developing countries. The Bali Action Plan, agreed in 2007, and the Copenhagen Accord, issued in December 2009, contain the main elements of a new climate deal which Parties remain to finalize in the year(s) to come. The road ahead faces three core challenges: to get the science right, to get the policies right and to get the politics right. Climate change represents a very exciting arena for increased scientific, technical and development cooperation amongst nations and is showing the way for how the peoples of the world can co-manage an increasingly stretched earth. The paper concludes with some recommendations about what individual countries may wish to focus on to prepare for an uncertain climate future**.

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** The paper refers to the situation from the time of the Conference; some parts (*e.g.* funding) may have changed since!

Introduction

The last five years have seen a dramatic rise in public awareness of the importance of climate change, which has become a major issue in national and global policy. The 2009 meeting in Copenhagen witnessed a dramatic shift in the political process. The Copenhagen Accord represents a concrete proposal by the major emitting countries for scaled-up action following the realization by negotiating parties in Bali in December 2007 that such enhanced action is urgently needed.

The aim of this paper is to situate the political process leading up to an enhanced deal on climate change in its scientific and historical context, and to describe the major challenges and opportunities ahead.

The paper starts with a review of the current state of knowledge on climate change, its probable causes and likely consequences, as generally understood by policy makers and negotiators. We present the current consensus on what actions are required to avoid dangerous levels of climate change and describe the main elements of the global policy response. We provide a brief assessment of where we currently are and describe the process towards a new international agreement on enhanced action. We conclude with a brief discussion of the major challenges and opportunities and what countries may wish to focus on to take account of an increasingly uncertain climate in their national development plans.

Climate Change and Impacts — The Current Narrative

There now exists a wide-ranging consensus that temperatures across the world are rising and that this is largely caused by the radiative forcing associated with increases in greenhouse gas emissions since the beginning of the industrial revolution (fig. 1). If greenhouse gas emissions are not curtailed on a precautionary principle, we may have to plan for the possibility of global temperatures by the end of the century reaching 4 °C and higher above the global mean temperature for 1980-1990, causing sea-level rises of up to about 60 cm (tab. 1).

Models of the climate system, which simulate the effects of greenhouse gas emissions and other global climate drivers, predict that the amount of precipitation in high latitudes will increase, while decreases are likely in most subtropical land regions (fig. 2). Studies also show that it is likely that heavy precipitation events will become more frequent and that future tropical cyclones will become more intense (Solomon *et al.* 2007).

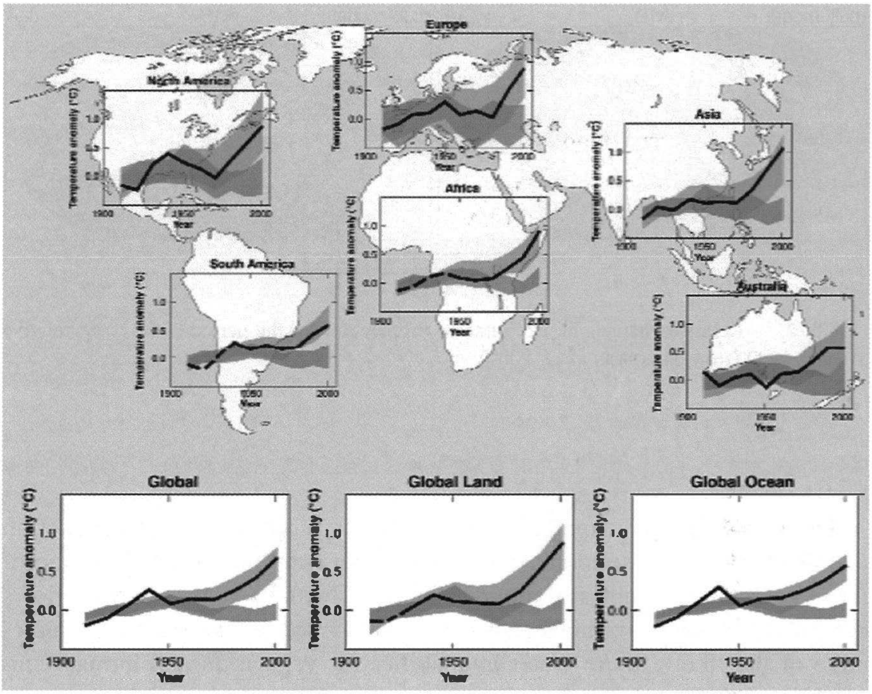

Fig. 1. — Comparison of observed continental and global-scale changes in surface temperature (black line) with results simulated by climate models using either natural (blue) or both natural and anthropogenic (pink) forcings (from Solomon *et al.* 2007).

Table 1

Assumed stabilization level of atmospheric CO_{2e} [1]* and associated increases in mean global temperature and sea-level rise for different emission scenarios (according to Metz *et al.* 2007)

Emission scenario [2]	**Stabilization CO_{2e}**	**Temperature change** (°C above 1980-90 level)	**Sea-level Rise** (m above 1980-90 level)
A1F	No stabilization	4.0 (2.4-6.4)	0.26-0.59
A2	No stabilization	3.4 (2.0-5.4)	0.23-0.51
B1	550 ppm	1.8 (1.1-2.9)	0.18-0.38
B2	650 ppm	2.4 (1.4-3.8)	0.20-0.43

* Numbers in brackets refer to the notes, pp. 322-323.

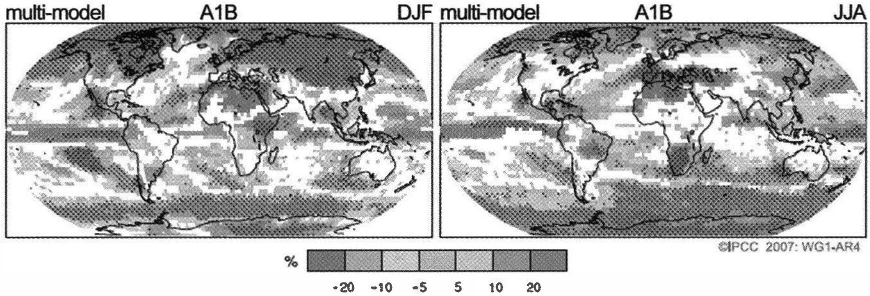

Fig. 2. — Relative changes in precipitation (in percent) for the period 2090-2099, relative to 1980-1999 (from SOLOMON *et al.* 2007).

These changes are expected to affect water supply and food production and are likely to cause increasing threats from extreme events. The map of mean percentage changes of annual runoff by NOHARA *et al.* (2006) follows closely the projected rainfall anomalies represented in figure 2 and is indicative of the likely future water availability for vegetation and human consumption. Moderate warming in mid- to high-latitude regions is generally believed to benefit crop and pasture yields, but even a slight warming could decrease yields in seasonally dry and low latitudes. The latter could cause an increase in the number of people at risk of hunger compared to numbers that would be achieved if the world economy were continuing to grow in the absence of climate change (range from 0 to 550 m people at risk from hunger by 2080, depending on emission scenario and assumed CO_2 fertilization effects (PARRY *et al.* 2007).

Climate change will likely have wider environmental impacts, some of which could accelerate the process even further, lead to irreversible impacts and cause massive disruption to the global and local economy. The higher the global temperature is allowed to rise above current levels, the higher the risk of reaching 'dangerous' levels of climate change. The main threats include: the decline of the great ice sheets and associated sea-level rise; dieback of the Amazon forest; the potential release of large quantities of naturally stored greenhouse gases and acidification of the world's oceans.

Figure 3 summarizes the main expected climate impacts associated with varying degrees of warming. The degree to which these impacts could affect human well-being is summarized in table 2.

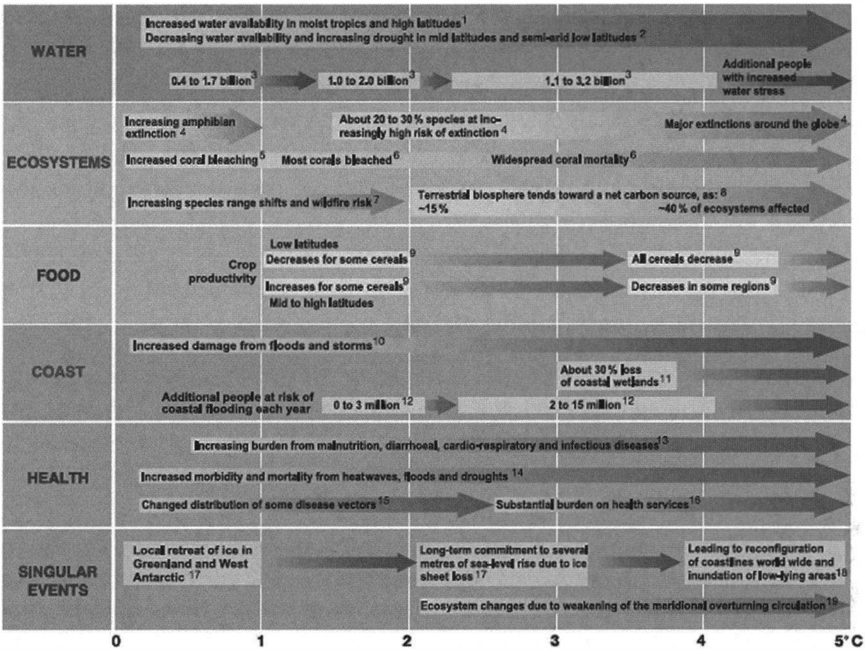

Fig. 3. — Examples of global impacts projected for changes in climate (and sea level and atmospheric CO_2 where relevant) associated with different amounts of increase in global average surface temperature in the 21st century (from PARRY *et al.* 2007).

Table 2

Global-scale impacts under unmitigated and stabilization pathways
(from PARRY *et al.* 2007, after ARNELL *et al.* 2002)

	2050 Scenario:			2050 Scenario:		
	Unmitigated	**S750**	**S550**	**Unmitigated**	**S750**	**S550**
Approximate equivalent CO_2 concentration (ppm)	520	485	458	630	565	493
Approximate global temperature change (°C difference from 1961 to 1990)	2.0	1.3	1.1	2.9	1.7	1.2
Area potentially experiencing vegetation dieback (million km²)	1.5 to 2.7	2	0.7	6.2 to 8	3.5	1.3
Millions of people exposed to increased water stress	200 to 3,200	2,100	1,700	2,830 to 3,440	2,920	760
Additional people flooded in coastal floods (millions/year)	20	13	10	79 to 81	21	5
Population at increased risk of hunger (millions)	-3 to 9	7	5	69 to 91	16	43

The Stern Review (STERN 2007), which assessed the likely global economic losses from climate change, concluded that unmitigated climate change could potentially cause a reduction in welfare equivalent to a persistent average reduction in global per capita consumption of between 5 and 14 %, depending on the climate system's sensitivity to greenhouse gas emissions and whether environmental and health effects are included. For poor countries alone, the reduction could amount to 20 %.

Climate change threatens human development in a variety of ways. The UNDP Human Development Report on Climate Change (WATKINS 2007) mentions the following possible extreme impacts:

— The breakdown of agricultural systems as a result of increased exposure to drought, rising temperature and more erratic rainfall. Semi-arid areas of sub-Saharan Africa face a danger of potential productivity losses of 26 % by 2060.
— An additional 1.8 billion people facing water stress by 2080.
— Displacement through flooding and tropical storm activity of up to 332 million people in coastal and low-lying areas.
— Emerging health risks, with an additional population of up to 400 million people facing the risk of malaria.

While the majority of these impacts are still subject to hotly debated scientific analysis (LOMBORG 2007), they start to give a picture of where and how climate change is likely to affect developing countries and assist targeting of international support. The extent to which developing countries are at risk from climate change, however, does not depend only on the likelihood and size of specific climate signals but also, and more importantly, on the country's *sensitivity* (*i.e.* the extent to which the main sectors of the economy are sensitive to changes in climate), *exposure* (*i.e.* the total population at risk) and *adaptive capacity* (*i.e.* the level of human development as estimated by GDP or allied measure of economic performance). Table 3 lists the developing countries that are most vulnerable to climate change, according to the World Bank.

Mitigating and Adapting to Climate Change

Policy interventions to minimize the risk from climate change are aimed at (a) reducing the net rate of increase in greenhouse gas concentrations in the atmosphere and (b) finding ways to adapt livelihood systems and growth strategies to its unavoidable consequences.

Table 3
Countries most at risk (from World Bank 2010a)

Drought	Flood	Storm	Coastal 1m	Agriculture
Malawi	Bangladesh	Philippines	All low-lying Island States	Sudan
Ethiopia	China	Bangladesh	Vietnam	Senegal
Zimbabwe	India	Madagascar	Egypt	Zimbabwe
India	Cambodia	Vietnam	Tunisia	Mali
Mozambique	Mozambique	Moldova	Indonesia	Zambia
Niger	Laos	Mongolia	Mauritania	Morocco
Mauritania	Pakistan	Haiti	China	Niger
Eritrea	Sri Lanka	Samoa	Mexico	India
Sudan	Thailand	Tonga	Myanmar	Malawi
Chad	Vietnam	China	Bangladesh	Algeria
Kenya	Benim	Honduras	Senegal	Ethiopia
Iran	Rwanda	Fiji	Libya	Pakistan

Despite the high degrees of uncertainty around both the level of impact (as summarized in fig. 3) and the risk from dangerous climate change, there is a growing political consensus that the Earth should not be allowed to get more than 2 °C warmer than it was in the 1980-1990 period. The scientific literature reviewed in the fourth assessment report of the IPCC indicates that such target would require a 50 to 85 % reduction in global CO_2 emissions by 2050 with CO_2 emissions peaking between 2000 and 2015 (METZ *et al.* 2007).

MITIGATION

MCKINSEY & COMPANY (2009) listed three main approaches to reduce net emissions: (i) increase energy efficiencies, (ii) move to low-C energy supplies, and (iii) manage terrestrial Carbon in such a way as to reduce emissions and increase sequestration. The latter includes the promotion of 'Reduced Emissions from Deforestation and Forest Degradation (REDD)'. Their estimate of the potential of a wide range of interventions to achieve a 35 % emission reduction by 2030, necessary to avoid overshooting a 2 °C temperature increase compared to the 1980-1990 average, is summarized in table 4.

Table 4
Possible greenhouse gas emission reductions across a range of technological and behavioural options (McKinsey & Company 2009)

Approach	**Gt CO_2 by 2030**
Cost: < €60/t CO_2	
Energy efficiency	14
Low-C energy supply	12
Manage terrestrial C	12
Promote behavioural change	4
Cost: between €60 and 100/t CO_2	
Additional technological options	5

The IPCC's assessment of the existing scientific evidence for the global cost of achieving a 2 °C target indicates that this would be equivalent to a less than 3 % GDP loss compared to a without climate change baseline (Metz *et al.* 2007). Stern (2007) estimates the upper boundary for expected annual costs of emission reductions consistent with a 550 ppm greenhouse gas concentration to be equivalent to about 1 % of global GDP by 2050.

McKinsey & Company (2009) calculated the abatement costs of a range of mitigation options. Their widely cited abatement cost curve includes a number of mitigation options with negative costs (*i.e.* options that achieve net economic benefits — mainly those options that achieve increased energy efficiencies) and others with increasing net costs. The estimated net cost of the full combination of mitigation options to achieve a 35 % emission reduction by 2030 amounts to € 200-350bn by 2030, equivalent to < 1 % of global GDP, but requiring an initial investment of € 530bn by 2020, equivalent to 5-6 % of estimated 'Business As Usual' (BAU) investments in fixed assets for that year.

Adaptation

The IPCC (Parry *et al.* 2007) define adaptation as "adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderate harm or exploit beneficial opportunities". It may be anticipatory (*i.e.* take place before impacts of climate change are observed), autonomous (*i.e.* triggered by changes in natural or human systems) or planned (the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change). The main aim of adaptation action in relation to the 2 °C target mentioned above is to address the residual damage to the natural and human systems caused by this increase in global temperature.

Effective adaptation targets one or more causes of vulnerability (sensitivity, exposure or adaptive capacity — see above) depending on their importance, effectiveness and availability of resources. If there is sufficient confidence that a hazard will occur and sufficient resources are available (*i.e.* high adaptive capacity), then it may be appropriate to tackle the hazard directly. If there is a low probability (or an inability to assess the probability) that a hazard may occur and poor adaptive capacity, then the most appropriate action may be to concentrate on reducing sensitivity and/or exposure.

Many actions that are aimed at improving adaptive capacity and reducing the vulnerability of affected populations also contribute to development. Such actions are referred to as "no regret" — they are particularly attractive where evidence about the size of the risk from climate change is weak.

Many "mainstream" development activities contribute to enhanced adaptive capacities and decreased sensitivities and exposure. Box 1 illustrates the range of approaches to adaptation, starting from pure development, which focuses on adaptive capacity, sensitivity and exposure (vulnerability focus) to interventions that tackle climate hazards directly (impact focus).

Box 1

Characterization of development intervention by adaptation type
(after McGRAY *et al.* 2007)

a) Addressing drivers of vulnerability. Bolstering human development, focus on reducing poverty and addressing other fundamental shortages of capability that make people vulnerable to harm, regardless of whether the stressors that can lead to harm are related to climate change.

b) Building response capacity. Focuses on building robust systems for problem solving. These capacity-building efforts lay the foundation for more targeted actions and frequently entail institution-building and technological approaches familiar to the development community.

c) Managing climate risk. Adaptation efforts that focus specifically on hazards and impacts, and the framework for action is provided by Climate Risk Management (CRM). This refers to the process of incorporating climate information into decisions to reduce negative changes to resources and livelihoods. Use of climate information distinguishes the CRM approach from typical development efforts, though the success of CRM may have strong development implications and vice versa. Many disaster-response planning activities fall into the CRM category, as do many technological approaches (e.g., drought-resistant crops). The success of CRM depends heavily upon the availability of climate information, and is enhanced when climate change predictions can be made with relatively high certainty and precision. If adaptation initiatives are rigidly based on risk assessments that later turn out to have been inaccurate, investments may be wasted, and maladaptation could result.

d) Confronting climate change. Actions taken focus almost exclusively on addressing impacts associated with climate change. Typically, these actions target climate risks that are clearly outside of historic climate variability, and have little bearing on risks that stem from anything other than anthropogenic climate change.

PARRY *et al.* (2009) have reviewed a range of estimates of the likely global cost of adaptation based on the expected increased costs of maintaining growth equivalent to what would be achieved in a world without climate change. Sources quoted include World Bank (2006), Oxfam (2007), STERN (2007), UNDP (2007), UNFCCC (2007) and a more recent report by the World Bank (2010b). These estimates range from a low annual cost of US$ 5-10bn for the 2010-2015 period to a high of US$ 100bn by 2050. The latter study by the World Bank, which represents the currently most thorough analysis, estimates high costs in the order of 0.5-0.8 % GDP for sub-Saharan Africa by 2050, with absolute costs being the highest for East Asia and the Pacific, because of a higher expected infrastructure asset base in that region.

The wide range of adaptation cost estimates reflects a wide range of what is, and what is not included in the calculations. PARRY *et al.* (2009) have observed that if an assessment of the cost to ecosystems, energy, manufacturing, retailing and tourism as well as the adaptation deficit and the costs of residual damages were to be added, the full cost of adaptation would probably amount to about twice to three times the values that have been quoted so far.

International Policy Response

In the sections above we outlined the main elements of the current consensus on climate change, what needs to be done about it and how much it could cost to do so. This section lays out the main components of the current international policy process.

A 'TRAGEDY OF THE (GLOBAL) COMMONS'

The core challenge of climate change is that the benefits individuals accrue from dumping greenhouse gases 'freely' into the atmosphere come at a cost which is borne by the entire global community. This is similar to the fate of many common properties, where individual benefits from 'over-harvesting' [3] a commonly owned/accessed resource, such as a forest or rangeland, can lead to a disproportionate cost borne by society as a whole (*e.g.*, from soil erosion, downstream impacts, long-term loss in productivity, loss in biodiversity, ...).

The process of common property resource degradation from over-harvesting (or dumping greenhouse gases in the atmosphere over and above its safe adsorptive capacity, *i.e.* the greenhouse gas concentration associated with a mean temperature rise of 2 °C) was described by HARDIN (1968) as a "Tragedy of the (unmanaged) Commons". Until incentives are introduced to make individuals bear the cost of over-harvesting (or in the case of climate change: dumping more greenhouse gases in the atmosphere than it is safe to do), the damage to the resource will continue to be shared by the entire community, including those who contribute very little to the problem.

The tragedy of the commons is a well-known market failure, which requires some agreement at the level of the community to 'internalize' the hidden 'external' cost of individual action. The current elements of the international community's attempts at addressing this market failure include:

- A mechanism to agree the nature and size of the problem: the International Panel for Climate Change (IPCC);
- A mechanism to discuss and agree the necessary international policy response to the problem: the United Nations Framework Convention for Climate Change (UNFCCC);
- A mechanism to agree and enforce 'caps' to greenhouse gas emissions with associated market regulations to allow greenhouse gas emission trading (hence: 'cap and trade'): the Kyoto Protocol (KP);
- A mechanism to support those members of the community who are most at risk from the impacts of climate change and least able to address them using their own resources: the financial mechanism of the UNFCCC.

THE IPCC AND THE INTERNATIONAL KNOWLEDGE ARCHITECTURE

The Intergovernmental Panel on Climate Change was established in 1988 by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) to provide the world with a clear scientific view on the current state of climate change and its potential impacts.

The IPCC reviews and assesses the most recent scientific, technical and socio-economic information produced worldwide and produces Assessment Reports (ARs) every six to seven years. The IPCC's most recent, Fourth Assessment Report (AR4) was published in 2007, and work is on-going for the next, Fifth Assessment Report, to be released in 2013-2014. The Panel's reports are drafted by scientists who work on a voluntary basis.

The IPCC is an intergovernmental body, open to all member countries of the UN and WMO. Governments participate in plenary sessions, where main decisions about the work programme are taken and reports are adopted and approved. By endorsing the IPCC reports governments acknowledge the authority of their scientific content — thereby sealing their agreement, in essence, on the nature and size of the problem to be addressed through international agreements and accords.

The IPCC represents the 'apex' of a growing international knowledge 'architecture', which includes a range of intergovernmental bodies that coordinate the collection and sharing of essential data, climate projections and the scientific assessment of their impacts. This 'architecture' is complex and dynamic and includes a growing number of both government and non-government agents [4] and initiatives [5].

The UNFCCC and Other Forums for Political Negotiations

The establishment of the UN Framework Convention on Climate Change (UNFCCC) in 1994 represents the global community's formal acknowledgement that there are physical limits to the atmosphere's capacity to store greenhouse gases. It also, crucially, represents a unique attempt by the global community to remedy this through a global decision-making process leading to global agreements and accords of various kinds.

The main objective of the Convention is to "stabilize greenhouse gas concentrations at a level that prevents dangerous interference with the climate system; and to achieve these reductions within a time frame that allows ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner" (UNFCCC 1994). A core element of the Convention is its acknowledgement that this 'burden' has to be shared equitably, or "in accordance with (Parties) common but differentiated responsibilities and respective capabilities".

The UNFCCC is an international treaty with one hundred ninety-four member countries (Parties) classified as:

- Annex I: developed countries that have committed themselves to adopting and communicating national policies and taking corresponding measures on the mitigation of climate change, by limiting their greenhouse gas (GHG) emissions and protecting and enhancing their greenhouse gas sinks and reservoirs;
- Annex II: developed countries that have committed themselves to providing new and additional financial resources to meet the costs incurred by developing countries;

— Developing countries: countries which are not required to reduce gas emissions unless developed countries provide funding and technology.

Parties to the Convention meet annually on the occasion of the Conferences Of the Parties (COP) to discuss and elaborate policy instruments in support of the implementation of the Convention. The major milestones in the Convention's history include:

— COP 3 (1997): The Kyoto Protocol: agreement by Annex I countries to legally binding restrictions in GHG emissions for the 2008-2012 period.
— COP 7 (2001): The Marrakech Accords:
  — Agreement on operational rules for international emissions trading and the Clean Development Mechanism (CDM);
  — Set up of three new funds to provide assistance to developing countries, including adaptation: the Special Climate Change Fund (SCCF), the Least Developed Countries Fund (LDCF) for support to (the elaboration of) National Adaptation Plans of Action (NAPA), and the Adaptation Fund under the Kyoto Protocol (AF).
— COP13/CMP3 (2007): The Bali Action Plan (BAP – see also below) and set up of the Ad Hoc Working Group on Long-Term Cooperative Action (AWG-LCA), *i.e.* to define the arrangements for enhanced action on mitigation and adaptation after termination of the Kyoto Protocol's commitment period in 2012.
— COP 15/CMP5 (2009): The Copenhagen Accord, which sets out voluntary actions and rules for their monitoring, verification and reporting, by a number of Parties intent on stabilizing "greenhouse gas concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system (...) recognizing the scientific view that the increase in global temperature should be below two degrees Celsius".

The Conferences of the Parties are advised by the deliberations of a Subsidiary Body on Implementation (SBI), which focuses on matters of implementation and policy and a Subsidiary Body on Scientific and Technological Advice (SBSTA), which links information and assessment provided by expert sources, including the IPCC, with the COP. Other deliberation mechanisms include Ad Hoc Working Groups, of which the AWG-LCA is the most recent.

The UNFCCC represents the main, formal multilateral forum where international agreements on climate action are sought and sealed. Other important forums in which positions of major political groups are discussed and agreed include:

— The G8 (Canada, France, Germany, Italy, Japan, Russia, UK and US), which meet once every year in June/July, where they issue a joint statement on issues of global concern, including health, law enforcement, labour, economic and social development, energy, environment (and climate change), foreign affairs, justice and interior, terrorism, and trade. Since their summit meeting in Gleneagles (2005), they have expanded discussions on a range of topics, including climate change, to an additional five large economies, *i.e.* Brazil, China, India, Mexico and South Africa.
— The G20: a forum established in 1999 to promote discussions between industrial and emerging-market countries on key issues related to global economic stability. Countries in this group include those already mentioned under the G8 + five group above, as well as: Argentina, Australia, Indonesia, Republic of Korea, Saudi Arabia, Turkey and the European Union.

The Kyoto Protocol

The Kyoto Protocol is an international agreement that sets *binding targets* for thirty-seven industrialized countries and the European Community for reducing GHG emissions amounting to an average of five per cent against 1990 levels over the five-year period 2008-2012. The Protocol came into force in February 2005.

Under this treaty, countries must meet their targets primarily through national measures. However, the Kyoto Protocol offers its signatories additional means of meeting their targets by way of market-based mechanisms:

— Emissions trading of Assigned Amount Units (AAUs) of greenhouse gas emission allowances.
— The Clean Development Mechanism (CDM), allowing a country with an emission-reduction or emission-limitation commitments under the Kyoto Protocol (Annex B country) to implement an emission-reduction project in developing countries. Such projects can earn saleable Certified Emission Reduction (CER) credits that can be counted towards meeting Kyoto targets.
— The Joint Implementation (JI) mechanism allowing an Annex B country to earn emission reduction units from an emission-reduction or removal project in another Annex B Party.

Emissions of countries under the Protocol are monitored and precise records are kept of the trades carried out in registry systems that track and record transactions by Parties under the mechanisms. The Secretariat of the UNFCCC, based in Bonn (Germany), keeps an international transaction log to verify that transactions are consistent with the rules of the Protocol.

The Climate Convention makes provision for greenhouse gas emission reductions achieved in land use, land-use change and forestry (LULUCF). A special mechanism is currently being designed and tested to allow emission reductions to be obtained and traded by Reducing Emissions from Deforestation and forest Degradation (REDD). This involves designing and testing methods for the establishment of baseline deforestation rates for target countries and regions, and ways of monitoring, verifying and reporting reductions in the rates of deforestation that could be translated into CER's.

The latest compilation by the UNFCCC secretariat [6] assessment of GHG emission reductions by countries that have commitments under the KP shows that, while the sum of the emission reductions of Annex B countries was already above the desired 5 % level (*i.e.* 5.3 %, including contributions from LULUCF) by the end of 2007, most of this reduction could be attributed to the reductions in greenhouse gas emissions by economies in transition (- 42.2 %), *i.e.* mainly eastern European countries whose industrial production levels decreased after the collapse of the Soviet Union, and that other countries (mainly OECD) had experienced a 12.8 % increase in greenhouse gas emissions.

The latest figures published by the UNEP-RISOE centre's CDM/JI pipeline analysis and database [7] show that almost 50 % of CERs issued to date originated from CDM investments in China and that China, India, Brazil and Mexico housed 80 % of all CDM investments. Sectors which most contributed to CERs included: HFC, PFC and N_2O reduction (76 %); renewables (13 %) and projects aimed at reducing emissions associated with methane production, cement and coal mining (6 %).

Assistance to Developing Countries

The Marrakech Accords in 2001 set up three funds to support developing countries to meet the costs of dealing with climate change impacts and policies. Estimates of these costs have been discussed above.

Table 5 summarises the funding available in December 2009 to support adaptation in developing countries. The total funding available/pledged to date varies between slightly less than $1bn to slightly over 1.77bn, depending on whether the expected revenues from the CER levy to 2012 into the AF are included or not.

Table 5
Funding available to support adaptation actions in developing countries
(major funds only – as per end of 2009 [8])

	Funds available / (pledged) US$ m	**Committed**
LDCF [9]	135.4 (176.5)	99.7
SCCF	100.5 (121)	67.5
AF [10]	28 m (560-850)	0
PPCR [11]	n/a (627)	n/a
Total	952.5 (1,484.5-1,774.5)	167.2

The sources of funding to finance low C energy projects in developing countries include the World Bank-managed Climate Investment Funds (especially the Clean Technology Fund (CTF), the Scaling-up Renewable Energies Fund (SREF)) and private finance available through various carbon investment funds. Totals available at the end of 2009 are summarized in table 6.

Table 6
Funding available to support mitigation actions in developing countries
(major funds only – as per 2009 [12])

	Funds pledged US$ m
CTF [13]	4,855
Renewables	351
Private C finance [14]	> 15,000
Total	> 20,206

Funding sources to support activities that enhance developing countries' preparedness for REDD are listed in table 7.

Table 7
Funding available to support REDD-related activities in developing countries
(major funds only – as per 2009)

	Funds pledged US$ m
Forest Investment Programme (FIP) [15]	351
Forest Carbon Partnership Facility (FCPF) [16]	115
UN-REDD [17]	20
Congo Basin Forest Fund [18]	160 [19]
Total	646

Scaling-up – The Bali Action Plan and the Copenhagen Accord

Data on atmospheric greenhouse gases and emissions from the major economies over the last thirty years show that action will need to be scaled up if emissions are to peak some time between 2010-2015 and decrease somewhere between 50-85 % by 2050.

Figure 4 summarizes the latest trends (up to 2008) in atmospheric concentration of the major greenhouse gases. The figure shows a steady rise in carbon dioxide and nitrous oxide from 1979 onwards, averaging 1.65 ppm/yr for carbon dioxide and 0.8 ppb/year for nitrous oxide. Methane concentrations started rising in 2006 after having reached a steady state. Concentrations in CFCs have started a gradual decline in response to the Montreal Protocol. The steady rise in the main greenhouse gas concentrations has been accompanied by a 28 % rise in the total atmospheric radiative forcing between 1990 and 2008.

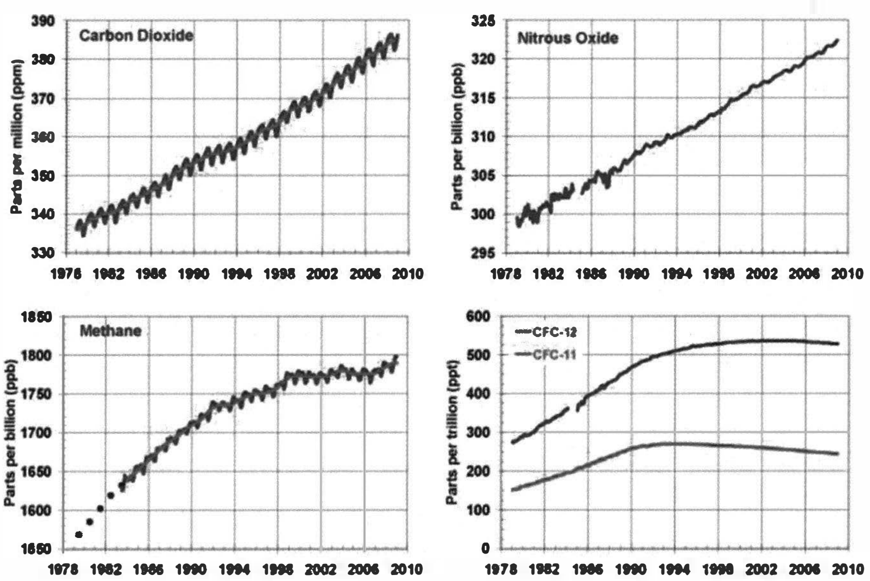

Fig. 4. — Latest trends in atmospheric concentrations of the main greenhouse gases (*source*: BUTLER 2009).

Carbon dioxide emissions from the main greenhouse gas emitters are summarized in table 8. Of those emitters, only the Kyoto Protocol countries have witnessed a decrease in emissions by around 5.3 % compared with 1990; however, this decrease is largely due to decreased emissions in eastern European countries following the collapse of the Soviet Union.

Table 8
2006 CO_2 emissions from main greenhouse gas emitters

Region	GT CO_2	% of global emissions	% increase since 1990
World	28.4	100	30.7
KP Annex B countries	8.1	28.6	– 5.3
China	6.1	21.5	152.8
US	5.7	20.2	18.2
EU	3.9	13.8	– 1.4
Russia	1.6	5.5	– 24.6
India	1.5	5.3	118.7

Source: UN Statistics Division 2010.

Estimates of the financial support by rich countries by the end of 2009 fall well short of estimated needs. The total annual financing needs to support adaptation by developing countries have been estimated between US$ 5-10bn for 2010-2015 and a high of US$ 100bn by 2050 (see above). The total pledges recorded in table 6 represent about 18-35 % of the estimated financing needs for 2010-15 or 1.8 % of the estimated annual financing needs for 2050.

The Road to Copenhagen

The realization that much more needs to be done to reduce greenhouse gas emissions and assist developing countries prompted negotiating Parties to look for an enhanced global agreement to take over from the Kyoto Protocol after termination of its commitment period in 2012. The negotiation process to design this 'enhanced' 'post-Kyoto' or 'post-2012' climate change deal was agreed in Bali in December 2007. This was followed by a two-year period of intense negotiations which eventually led to the presentation of the 'Copenhagen Accord' in December 2009.

The road map for the 2007-2009 negotiation cycle is known as the Bali Action Plan [20] (BAP), which was agreed by Parties in December 2007. The BAP's main objectives are to define concrete actions towards:

— A long-term global goal for emission reductions;
— Enhanced national and international action on mitigation;
— Enhanced action on adaptation;
— Enhanced action on technology to support mitigation and adaptation;
— Enhanced provision of financial resources and investment.

The BAP also set up an Ad Hoc Working Group on Long-term Cooperative Action (AWG-LCA) and set out the process and frequency of meetings under this working group. Proposals submitted and debated by Parties during the two-year negotiation process to Copenhagen include the following.

On Achieving a Shared Vision

— Statements of principles: equity, common but differentiated responsibility and adherence to the precautionary principle;
— Goals: in terms of greenhouse gas concentrations (350-450 ppm), maximum temperature rise (1.5-2 °C) or per capita emissions (2tCO_2);
— Pathways for Annex I countries: reduction targets for 2020 ranging from 25-45 % and for 2050 from 75-95 %;
— Pathways for non-Annex I countries: 'significant reductions' — up to 25 % by 2050.

On Enhanced Action in Support of Adaptation

— Statements of principles: frameworks, responsibilities, legal context;
— Approaches: national adaptation plans, mainstreaming, programme-based approaches;
— Impacts: monitoring, reporting and verification (MRV).

On Enhanced Action in Support of Mitigation

— Developed countries: binding commitments, buying credits, compliance and MRV;
— Developing countries: voluntary commitments, nationally appropriate mitigation actions (NAMAs), financial and technical support, MRV;
— REDD: baseline, accounting, financial and technical assistance, MRV;
— Approaches: sectoral, cost-effectiveness, co-benefits, crediting, market-based.

On Finance, Technology and Capacity Building

— Principles: additionality;
— Approaches: targeting, direct access, programme-based, grants and loans, accountability, public/market-based;
— Sources: 0.5-2 % of GDP, auctioning AAUs, CO_2 tax, aviation tax, CDM and JI levy, Tobin tax, fines;

- Architecture: single and multiple funds, governance structure, treatment of funding originating from outside the Convention;
- Technology: research and development, technology action plans, intellectual property rights (IPR), cooperation, knowledge platforms (regional networks);
- Capacity building.

The Copenhagen Accord

The Copenhagen Accord, drafted at a meeting of Heads of State of large emitting countries during the last hours of the Copenhagen COP, sets out the main elements of an enhanced climate deal. It is generally expected that this accord will form the backbone for a new treaty, to be agreed at the 2010 COP in Mexico. The main elements of the Accord include:

Principles and Goal Statement

- A reiteration of the principle of common but differentiated responsibilities and respective capabilities;
- An acknowledgement that deep cuts in global emissions will be needed to stabilize greenhouse gases below 2 °C;
- An acknowledgement that international support will be needed to support adaptation by developing countries.

Statements on Adaptation

- A statement of urgency of action and international cooperation;
- Special reference to the needs of the particularly vulnerable countries;
- A reiteration of the need for developed countries to provide financial resources, technology and capacity building.

Statements on Mitigation by Annex I Countries

- A request to Annex I countries to declare their commitments to implement quantified emission targets for 2020 [21];
- A commitment to subject commitments on targets and finance to international measurement, reporting and verification.

Statements on Mitigation by Non-Annex I Countries

- A request to non-Annex I countries to declare mitigation actions in Annex II of the Accord;

— A requirement for mitigation actions by non-Annex I countries to be subject to domestic measurement, reporting and verification;
— A requirement for national mitigation actions supported by international support to be subject to international MRV.

REDD

— A recognition of the crucial role of REDD;
— An agreement to provide positive incentives to mobilize financial resources from developed countries.

Incentives and Funding

— An acceptance of the role of markets;
— An acceptance that a variety of funding sources will be needed, including public and private, bilateral and multilateral, and alternative sources of finance;
— A request to developed countries to provide additional resources approaching US$ 30 billion for the period 2010-2012;
— A request to developed countries to commit to a goal of mobilizing US$ 100 billion a year by 2020.

Institutional Arrangements or Architecture

— A request for equal representation of developed and developing countries in the international governance structure;
— A request to establish a Copenhagen Green Climate Fund to act as financial mechanism of the Convention;
— A request to establish a Technology Mechanism to accelerate technology development and transfer.

The Road Ahead: Opportunities and Challenges

The climate change negotiations represent much more than an international meeting of scientists and policy makers discussing the management of a relatively minor environmental problem associated with rapid economic growth. They have grown into an important global policy forum where the nations of the world are jointly seeking to address a major challenge to future human well-being. Seen in this light, climate change is a strong force for international cooperation and peace building.

The presence of one hundred and thirty Heads of State at the COP in Copenhagen proves that climate change has risen to the attention of the highest authority in most nations. The agenda has definitely shifted from the relative backwaters of the Multilateral Environmental Agreements (MEA), to take centre-stage in international politics, at a level equivalent to trade negotiations. The pre-eminence of climate negotiations, under the umbrellas of the UN (UNFCCC and General Assembly) G8 and G20, reflects a desire and real effort by the global community to collaborate on finding effective and equitable solutions. The primary role of science in this policy arena is a pioneering example of an attempt at evidence-based policy making. In discussing the institutional implications of putting the political agenda to work, there are real opportunities for making progress on effectiveness and equity issues.

The road ahead, however, will need to address a number of challenges, highlighted by the difficult birth of the Copenhagen Accord. These include: growing questions about the robustness of the scientific foundations for action and the nature and size of the policy response, as well as the effectiveness of the international political process.

Challenging the Science

The awareness of the nature and size of the required policy response and of possible international commitments has prompted some to question the solidity of the historical temperature records constructed by researchers, such as at the Climatic Research Unit of the University of East Anglia (Pearce 2009). The validity of some claims in the Working Group II section of the AR4 has also been questioned, especially that glaciers in the Himalayas could disappear as early as 2035 (Pearce 2010), that there is an observable climate signal in increased damages from extreme weather events and that even slight changes in rainfall could see swathes of the rainforest rapidly replaced by savannah in the Amazon.

The response by the IPCC and the researchers involved in these controversies has revealed that, while the science reviewed by the IPCC is generally robust, insufficient references may have been made in the summaries for policy makers of the wide error margins that are associated with many scientific findings. Although the current challenges have not affected the core script concerning human-induced climate change, they have damaged the reputation of the IPCC as a solid basis for policy-making.

Challenges to the scientific foundations of environmental policy are not new. A similar discourse about the causes and seriousness of soil erosion in the 1980s, for instance, resulted in a shift in approaches to soil conservation from costly physical interventions to more cost-effective land husbandry approaches (Biot *et al.* 1992, Shaxson *et al.* 1989). A re-appraisal of semi-arid rangeland science in the 1980s led to a shift in approaches to management based on equilibrium models of grassland behaviour to approaches that acknowledge that grasslands rarely (if ever) assume equilibrium states (Behnke *et al.* 1991). Similar stories about the science – policy interface exist in the discourse on tropical forest (land) management.

The contestation of scientific facts in many environmental issues is partly due to the complexity of the systems under scrutiny and compounded further by (i) limits to the *observable* part of physical reality; (ii) limits to *experimentation* and the application of the *scientific method of enquiry*; and (iii) the *incentive structures* that shape research agendas, scientists' enquiries and the level of scrutiny in peer-reviewed publications (Mearns 1991, Biot *et al.* 1991). The result is that environmental 'narratives' are often 'contested', leading some to believe that "scientific truths (...) (are) socially negotiated rather than universal (...)" (Blaikie 1996).

The points above highlight the importance of rigorous peer review and an honest and open contestation on the basis of facts that are established through widely accepted scientific methodologies. The recent challenges to the IPCC are an indication that this process of contestation is alive and kicking. This is healthy. The independent review of IPCC procedures on behalf of the UN's Secretary General, which was on-going at the time of drafting this manuscript, is further proof that the principles of due diligence are taken very seriously in international climate change science and policy circles.

Challenging the Policies

While some authors contest the nature and size of the problem, others acknowledge the importance of the issue, but contest the assessment of its impacts and the policies that are designed to address them.

Some authors doubt that the carbon emission reductions necessary to avoid dangerous climate change are possible without challenging the global economic orthodoxy. Anderson & Bows (2008), for instance, consider the implications of a 2 °C threshold on a range of post-peak emission reduction rates for global emission pathways and cumulative emission budgets. Their analysis, which took into account likely scenarios and behaviour of six GHGs and incorporated the latest understanding of C-cycle feedbacks, demonstrates that:

- If emissions peak in 2015, stabilization at 450 ppmv CO_{2e} requires subsequent annual reductions of 4 % in CO_{2e} and 6.5 % in energy and process emissions;
- If emissions peak in 2020, stabilization at 550 ppmv CO_{2e} requires subsequent annual reductions of 6 % in CO_{2e} and 9 % in energy and process emissions;
- If emissions peak in 2020, stabilization at 650 ppmv CO_{2e} requires subsequent annual reductions of 3 % in CO_{2e} and 3.5 % in energy and process emissions.

The authors conclude that "there are serious questions as to whether the global economic orthodoxy is sufficiently robust to absorb the scale of the challenge faced" and that "Ultimately, the latest scientific understanding of climate change allied with current emission trends and a commitment to 'limiting average global temperature increases to below 4 °C above pre-industrial levels', demands a radical reframing of both the climate change agenda, and the economic characterization of contemporary society".

At the other end of the spectrum, some argue that climate change impacts have been exaggerated and that the policies that are designed to address those are too costly and will do very little 'good'. In his book, aptly titled 'Cool It', LOMBORG (2007) argues that scientists and policy makers have chosen worse case scenarios (at best) and relied on weak science (at worst) to define targets for emission reductions that are not only very unlikely to be politically achievable, but will also be much less effective at helping developing countries prepare for the future. His suggestion is that, instead of focusing on heavy de-carbonization of the economy through strict emission targets, international assistance is focused instead on accelerating development to make people more able to deal with climate change impacts and free up resources to support research and innovation.

Another challenge concerns gearing up the C-trade to a level that will have a significant impact on C-emissions. By the end of 2009, the annual projections of CERs were estimated by the UNEP-Risoe [22] analysis and database at 716 m t CO_{2e}, or the equivalent of 2.5 % of global CO_{2e} emissions in 2006 — a very small proportion of what will eventually need to be achieved in terms of overall emission reductions. Most CERs are produced in China, India, Brazil and Mexico and very few poor developing countries benefit from the C market. Only a small proportion of CERs come from the production of energy from renewable sources.

Moves to scale up the C-market through sector-wide approaches face difficulties in the negotiations. There has been significant progress on agreeing the role of REDD+ (Reduced Emissions from Deforestation and forest Degradation and tree plantations) in land-use related carbon management and there are some serious efforts at helping developing countries get ready for REDD+. However, it remains to be seen whether institutional arrangements for REDD+ will be effective at avoiding the transfer of forest destruction to alternative sites (C-leakage), whether real amounts of C sequestration can be measured and reported on effectively and whether the financial benefits originating from selling C credits earned through this scheme will accrue to the people who depend on forests for a living. In short, it remains to be seen whether REDD+ will manage to tackle the difficult issues of forest governance that have challenged foresters for years (BIOT 2004), and become a driver for positive change rather than a financial reward for actors who have been harvesting forest products, often illegally, for many years.

The Copenhagen Accord calls for financial assistance to developing countries of the order of $100bn/year from 2020 onwards. This is of the same order of magnitude as current levels of official development assistance, which raises a number of issues. International assistance to adaptation could potentially cause moral hazard, and lead developing countries to implement adaptation actions that are not cost-effective. Thematic funds aimed at assisting developing countries can take away and even undermine the process of prioritization of budgetary expenditure by national policy makers.

There is a serious risk that the 'additionality' principle of adaptation finance will narrow the scope of adaptation projects to actions that are demonstrably not focused on development, irrespective of whether this is appropriate or not (see box 1 for a definition of what constitutes effective adaptation action). Calls have been made for the principles enshrined in the 'Paris Declaration on Aid Effectiveness' [23] to be applied in climate change finance; however, this is resisted by developing country Parties who claim that climate change finance represents compensation to developing countries for harm done by developed countries and should therefore not be bound by conditions that apply to donor assistance.

CHALLENGING THE POLITICS

We described the UNFCCC above in terms of a global level decision-making forum to address the market failures that occur in the global atmospheric commons. Its main aims are to identify ways to internalize the external costs associated with dumping GHGs into the atmosphere and to assist poorer countries to deal with the consequences of irreversible climate change.

If the Copenhagen COP did show a dramatic shift in the climate negotiations, it also revealed some major issues with the way in which such negotiations are conducted. While the process adopted by the Convention did manage to design and enact the Kyoto Protocol and to establish and regulate the use of funds in support of adaptation by developing countries, the two-year negotiation process leading up to the COP in Copenhagen was fraught with serious difficulty. The final negotiation text going into the Conference Hall in December 2009 contained a very large number of unresolved issues, which could not possibly be addressed in full in the allotted time. While earlier assessments at the level of the UN and key negotiators had already indicated that it would not be possible to agree a treaty in Copenhagen, and that the aim was to get a high-level ministerial declaration instead, there was no agreed format on how to take this forward. The Copenhagen Accord eventually came about through the personal initiative of the heads of states of the major global economies, a process which caused much controversy and contestation.

While the Copenhagen Accord unquestionably raises the stakes on climate change action, it is, at the time of drafting this paper, not clear how this will be taken forward in the formal Convention negotiations. Many developing country actors are worried that the Copenhagen Accord has disenfranchised them from the negotiation process, and effectively defined a twin track approach with major economies and emitters setting the agenda.

So, Where do We go from Here?

At the heart of the climate change debate is a realization that 'business as usual' development is not an option for medium- to long-term development. The main issue is energy, its role in growth and how it is produced and distributed. The increasing costs of using fossil fuels associated with climate change policies, it is hoped, will trigger innovation and the rapid development of alternative sources of energy that will guarantee growth for developing countries and continued well-being for rich nations.

There is an increasing realization by the private sector of the opportunities for innovation and there are very clear signs that it is starting to engage substantial resources in this area. A key question is the extent to which the pace of innovation will keep up with the demand for rapid decarbonization of the economy. Another is what the state can do to accelerate this process without affecting the competitive process which lies at the heart of successful technology development.

Much can be done to improve the way in which the market failures that have caused the *'tragedy of the global climate commons'* are addressed.

First of all, there is a need for better science, especially about the climate system itself and its likely future trends. Key questions concern the likelihood of occurrence of dangerous tipping points that could project the global climate system onto dangerous and irreversible trajectories. Recent doubts about the robustness of some climate science facts necessitate a re-examination of the role and process of research and its communication to policy and the wider public. There is no real alternative to promoting honest and open debate and contestation as a means of ensuring high quality research and ways will have to be found to guarantee this.

Secondly, there is a case for a re-examination of the full scope of policy responses, including the prospects of geo-engineering (and the ethics of doing research on this) and ways of incentivizing citizens and the private sector to develop and adopt low-C energy sources and to protect themselves from the possible harms from climate impacts. Climate change will not affect all in the same way — climate change provides opportunities to change the way citizens derive a living and economies grow. There is a case to be made for moving the current climate change 'gloom and doom' discourse to an alternative narrative about opportunities for enhanced local, regional and global cooperation and more sustainable well being for all.

Thirdly, the international negotiation process may need to be improved to take better account of some important differences of opinion about the way forward. The political crisis at the Copenhagen COP represents a serious challenge to the underlying idealism that shaped the design of the global negotiation processes to implement the Multilateral Environmental Agreements (MEA's) that were launched at the World Summit on Sustainable Development (WSSD) in Rio de Janeiro in 1992. It is time to look again at how the UNFCCC itself operates and what the potential role is of other important UN forums, the G8 and the G20.

In the meantime, nations need to prepare and enact new national policies, strategies and programmes to help move their economies in ways that take account of a progression towards low-C energy sources and increasingly uncertain climatic conditions. Knowledge generation and dissemination about what could happen and what options there are for making adjustments, or even exploit, future scenarios is probably the most important first step. In some parts of the world where critical mass will be difficult to obtain nationally, this will require working with neighbouring countries, via regional centres.

Developing countries need assistance, and will need to put in place the structures and processes that will ensure international climate finance will be 'woven' effectively into national budgets for development and are targeted at assisting the poor and vulnerable while not threatening the driving function of the private sector. The KP Adaptation Fund's [24] call to Developing Country Parties to nominate 'National Implementing Entities' to function as national gateways for its funds represents a major step towards the establishment of national coordinating and fiduciary control mechanisms for international climate and development finance. These could be replicated elsewhere, including in the mechanisms that will be established in response to the Copenhagen Accord's call to establish a Green Fund.

Climate change challenges our common understanding of how we can build and maintain human well-being. It challenges the core economic and geopolitical underpinnings of our current global development trajectory. It has motivated the largest and deepest effort at global cooperation human history has witnessed so far. While recent events in Copenhagen have somewhat rocked the (climate) boat, Climate Change will probably continue to represent a very exciting arena for increasing scientific, technical and development cooperation amongst all nations. And as such it is showing the way in which the nations of the world can co-manage an increasingly stretched earth.

NOTES

[1] Carbon dioxide equivalent, *i.e.* sum of all greenhouse gases (GHG), corrected for their equivalent radiative forcing expressed in relation to the radiative forcing of CO_2.
[2] After Nakicenovics *et al.* (2000): A1F: global economy, fossil fuel intensive; A2: regional economy with emphasis on self-reliance; B1: global economy with sustainable growth policies; B2: regional economy with local sustainable growth policies.
[3] Harvesting a resource such as timber over and above a 'safe' threshold.
[4] For example: World Meteorological Organization (WMO), United Nations Environment Programme (UNEP), Global Climate Observation System (GCOS), Global Earth Observation System of Systems (GEOSS), African Centre for Meteorological Application for Development (ACMAD), Caribbean Community Climate Change Centre (CCCCC), ...
[5] For example: Earth System Science Programme (ESSP), World Climate Research Project (WCRP), Climate and Development Knowledge Network (CDKN), ...
[6] http://unfccc.int/ghg_data/ghg_data_unfccc/items/4146.php
[7] UNEP Risoe CDM/JI Pipleine Analysis and Database – January 1, 2010: http://cdmpipeline.org/index.htm
[8] Does not include dedicated bilateral funds.
[9] SCCF and LDCF: as by June 2009.
[10] As by November 2009; committed: estimated revenue from 2 % CDM levee on basis of total estimated CERs issued from UNEP Risoe and US$10-15 /CER.

[11] Includes about 50 % in the form of concessional lending; data on total committed not available at time of writing this paper. Source: http://www.climateinvestmentfunds.org/cif/sites/climateinvestmentfunds.org/files/CIF%20pledges%20as%20of%20Dec%2031%202009.pdf
[12] Does not include support to preparing developing countries for REDD.
[13] CTF and SREF. Source: http://www.climateinvestmentfunds.org/cif/sites/climateinvestmentfunds.org/files/CIF%20pledges%20as%20of%20Dec%2031%202009.pdf
[14] *Source*: http://www.environmental-finance.com/envfin/books.htm
[15] http://www.climatefundsupdate.org/listing/forest-investment-program
[16] http://www.forestcarbonpartnership.org/fcp/
[17] http://www.un-redd.org/Home/tabid/565/language/en-US/Default.aspx
[18] http://www.cbf-fund.org/
[19] Equivalent to £100 m.
[20] http://unfccc.int/resource/docs/2007/cop13/eng/06a01.pdf#page=3
[21] To be submitted by 31 January 2010.
[22] UNEP Risoe CDM/JI Pipleine Analysis and Database – January 1, 2010: http://cdmpipeline.org/index.htm
[23] http://www.oecd.org/dataoecd/11/41/34428351.pdf
[24] http://afboard.org/index.html

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Developing Countries facing Global Warming: a Post-Kyoto Assessment. Round-table Debate

by

Pierre OZER*

KEYWORDS. — Global Warming; Developing Countries; GHG Emissions; Common but Differentiated Responsibility; Adaptation; Mitigation.

SUMMARY. — This paper reports the results of a round-table debate organized by the Royal Academy for Overseas Sciences (RAOS) on *Developing Countries facing Global Warming: a Post-Kyoto Assessment* (Brussels, 13 June, 2009) to highlight the view of developing countries on adaptation to and mitigation of climate change. The participants convened to discuss the various aspects of climate change impacts and adaptation in developing countries preceding the Copenhagen Conference (UNFCCC COP 15) in December 2009. Here, we summarize the point of view of the two invited speakers representing developing countries.

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The discussion, chaired by Morgan De Dapper, President of the "Environment and Development" Commission of the Royal Academy for Overseas Sciences, focused on various developing countries considerations regarding the forthcoming climate change negotiations (Copenhagen in 2009, Cancun in 2010, Cape Town in 2011, ...), including their role in reducing greenhouse gas emissions, their weak position in international talks and their difficulties to adapt to forced climate change.

Speakers representing developing countries were Karimou Ambouta (RAOS; Université Abdou Moumouni, Niamey, Niger) for least developed countries, and Rais Akhtar (RAOS; Jawaharlal Nehru University, New Delhi, India) for emerging economies countries. The Vice-Chair of the *Intergovernmental*

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Panel on Climate Change (*IPCC*), Jean-Pascal van Ypersele (Université catholique de Louvain, Belgium), joined the round table together with Yvan Biot (RAOS; Research and Evidence Division, Department for International Development, London, UK), who also prefaced the debate. Also participated in the debate: Samy Mankoto (RAOS; UNESCO Paris, France), Bernard Mazijn (Universiteit Gent, Belgium), Bart Muys (Katholieke Universiteit Leuven, Belgium), Jean-Jacques Peters (RAOS; river specialist), Eric Tollens (RAOS; Katholieke Universiteit Leuven, Belgium), Philippe Tulkens (European Commission, Brussels, Belgium), and Marc Van Montagu (RAOS; Universiteit Gent, Belgium).

Developing countries are least responsible for causing climate change but are very likely to face disproportionate impacts in terms of natural disasters, agriculture, health effects and food security since already existing stresses on health, well-being, limited financial, institutional and human resources leave the poor most vulnerable and least able to adapt to the impacts of negative rapid changes, including climate change. Consequently, climate change may undermine the ability of developing countries, particularly least developed countries in Africa, to meet some targets of the Millennium Development Goals (MDGs), thereby slowing progress towards sustainable development. Yet, climate change poses a particular threat to those marginalized from development and global adaptation cost estimates are extremely important as shown in table 1.

Table 1

Estimates of adaptation costs in developing countries, for 2010-2015 (after PARRY *et al.* 2009)

Source	US$ billion per year
World Bank (2006)	9-41
Stern (2006)	4-37
Oxfam (2007)	> 50
UNDP (2007)	86-109
UNFCCC (2007)	27-66

CO_2 emissions from the burning of fossil fuels are considered to be the primary cause of global warming. Special attention has been focused on the CO_2 directly emitted by each country. Top ten emitters in 2007 are presented in table 2, with comparison values for 1971 and 1990. It shows that twenty-nine gigatonnes of CO_2 from fuel combustion were globally emitted in 2007. Between 1971 and 2007, global emissions doubled, with industrialized countries dominating historical totals. However, the share of developed countries progressively shrank as developing countries, led by emerging economies such as China and India (with respectively + 650 % and + 565 %), increased at a much faster rate (+ 243 % for non-OECD (Organization for Economic Co-operation and Development) countries). Yet, OECD countries show a 41 % increase during the 1971-2007 period, while representing 69 % of global CO_2 emissions in 1971, 54 % in 1990, and 'only' 47 % in 2007.

Table 2

Estimation of CO_2 emissions from fuel combustion (in 10^6 tons) and their evolution at the global and regional levels, and top 10 emitting countries in 2007 (accounting for 65 % of the world CO_2 emissions) (adapted from IEA 2009)

Region/Country	CO_2 emissions (1971)	CO_2 emissions (1990)	CO_2 emissions (2007)	Evolution (1971-1990)	Evolution (1990-2007)	Evolution (1971-2007)
World	**14,095**	**20,981**	**28,962**	**+ 49 %**	**+ 38 %**	**+ 106 %**
OECD	**9,604**	**11,440**	**13,565**	**+ 19 %**	**+ 19 %**	**+ 41 %**
Non-OECD	**4,491**	**9,541**	**15,397**	**+ 112 %**	**+ 61 %**	**+ 243 %**
1. China	810	2,244	6,071	+ 177 %	+ 171 %	+ 650 %
2. USA	4,291	4,863	5,769	+ 13 %	+ 19 %	+ 34 %
3. Russian Fed.	1,191	2,180	1,587	+ 83 %	– 27 %	+ 33 %
4. India	199	589	1,324	+ 196 %	+ 125 %	+ 565 %
5. Japan	759	1,065	1,236	+ 40 %	+ 16 %	+ 63 %
6. Germany	979	950	798	– 3 %	– 16 %	– 19 %
7. Canada	339	432	573	+ 27 %	+ 33 %	+ 69 %
8. United Kingdom	624	553	523	– 11 %	– 5 %	– 16 %
9. Korea	52	229	489	+ 340 %	+ 114 %	+ 840 %
10. Iran	41	175	466	+ 327 %	+ 166 %	+ 1,037 %

These recent trends make Rais Akhtar uncomfortable since many observers commented that China overtook the United States in 2007 to become the world's largest emitter of CO_2 emissions from fuel combustion, and that India is about to take the third ranking position. He deplores that most messages stop there without detailing the existing gap between per capita CO_2 emissions (tab. 3). It would then clearly appear that per capita CO_2 emissions are four times higher in developed countries (11 tons per year) than in developing countries (2.7 tons), with an average of 4.4 tons in 2007. The United States alone generate 20 % of the global CO_2 emissions, despite a population of less than 5 % of the world total. In the mean time, China, contributing to a comparable share of global emissions (21 %), accounts for 20 % of the world population. India, with 17 % of the world population, contributes less than 5 % of the CO_2 emissions. Therefore, the levels of per capita CO_2 emissions are very diverse. Yet, one American citizen is annually responsible of 19.1 tons of CO_2 emissions, that is the equivalent of four Chineses, sixteen Indians, or 80 sub-Saharan Africans issued from least developed countries.

Table 3
OECD and non-OECD populations (millions);
part of the world CO_2 emissions from fuel combustion (%);
CO_2 emissions per capita (tons) in 1990 and 2007 and recent trends (%)
(adapted from IEA 2009)

Region	Population 2007	% world population (2007)	% world CO_2 emissions (2007)	CO_2 emissions per capita (1990)	CO_2 emissions per capita (2007)	CO_2 emissions per capita Evolution 1990-2007
World	6,609	100	100	4	4.4	+ 10 %
OECD	1,185	17.9	46.8	10.6	11.0	+ 3 %
North America	441	6.7	24.0	15.6	15.4	– 1 %
Pacific	201	3.0	7.8	8.4	10.7	+ 27 %
Europe	543	8.2	15.1	7.9	7.5	– 5 %
Non-OECD	5,424	82.1	53.2	2.2	2.7	+ 25 %
Europe	53	0.8	1.0	6.5	5.1	– 21 %
North Africa	157	2.4	1.3	1.6	2.3	+ 41 %
Sub-Saharan Africa	802	12.1	1.9	0.7	0.6	– 6 %
Middle East	193	2.9	5.1	4.5	7.2	+ 61 %
Ex-USSR	284	4.3	8.4	12.6	8.5	– 33 %
Latin America	461	7.0	3.7	1.7	2.2	+ 30 %
Asia - China	2,148	32.5	10.6	0.8	1.4	+ 70 %
China	1,327	20.1	21.2	2.0	4.6	+ 133 %

In addition, such data sets on the carbon footprint of nations (tabs. 2, 3) only take into account production-based inventories. Very few studies include the emissions associated with consumption of goods and services in each country. Consumption-based accounting of CO_2 emissions differ from traditional estimates. GUAN *et al.* (2009) showed that half of the CO_2 emissions increase recorded in China during the early 2000's was due to production of goods for exportation. In 2004, 23 % of global CO_2 emissions were traded internationally, primarily as exports from China and other emerging markets to consumers in developed countries. These studies generally find that rich countries have a larger carbon footprint than their territorial emissions, while the opposite holds for poor countries. In some wealthy countries, including Belgium, Switzerland, Sweden, Austria, the United Kingdom, and France, > 30 % of consumption-based emissions were imported, with net imports to many Europeans of > 4 tons CO_2 per capita in 2004. Net import of emissions to the United States in the same year was somewhat less: 10.8 % of total consumption-based emissions and 2.4 tons CO_2 per person. In contrast, 22.5 % of the emissions produced in China in 2004 were exported to consumers elsewhere (DAVIS & CALDEIRA 2010).

Thus, if Rais Akhtar clearly claims that CO_2 emissions per capita are far from being equivalent, especially for what regards India when compared to any OECD country, Karimou Ambouta adds that Sub-Saharan Africa CO_2 emissions per capita have decreased by 6 % in recent years (1990-2007), while such data have increased by 10 % at the global level (tab. 3), which proves that the development of the poorest populations is still insufficient and scaring.

Both Rais Akhtar and Karimou Ambouta believe that the "common but differentiated responsibility", one of the key principles in the United Nations Framework Convention on Climate Change (UNFCCC) [1]*, is not respected. Since it is recognized that developed countries are principally responsible for the current high levels of greenhouse gases (GHG) emissions in the atmosphere as a result of more than 150 years of industrial activity, these industrialized developed countries have to take the lead in addressing the climate problem by drastically reducing GHG emissions while excluding developing countries from binding GHG emissions reductions (BROECKER 2007). As it is presented in table 4, this is not the case.

Except for Europe (probably), none of the developed countries will respect their Kyoto Protocol's commitments. As an example, with a GHG emissions increase of 33 % between 1990 and 2006, New Zealand will not respect its obligation under the Kyoto Protocol to reduce its emissions to 1990 levels on average over the 2008-2012 commitment period. In addition to that, the country proposed a GHG reduction objective of – 20 % by 2020 before the

* Numbers in brackets [ ] refer to the notes, p. 333.

Table 4

Official GHG emissions [2] evolution from 1990 to 2006 in some selected developed countries, their GHG emissions reduction commitment within the Kyoto Protocol and their quantified emission limitation and reduction objectives (QELROs) before the Copenhagen Conference

Countries	GHG evolution (1990-2006)	Kyoto Protocol's commitment (by 2008-2012)	Proposed QELROs for 2020 before Copenhagen Conference
Europe*	-2,7%	– 8,0 %	– 20 % to – 30 % compared to 1990 levels
USA	+ 14,0 %	None	– 15 % compared to 2005, that is – 3 % compared to 1990
Japan	+ 5,8 %	– 6,0 %	– 15 % compared to 2005, that is – 25 % compared to 1990
Canada	+ 54,8 %	– 6,0 %	– 20 % compared to 2006, that is + 24 % compared to 1990
Australia*	+ 6,6 %	+ 8,0 %	– 5 % to – 25 % compared to 2000, that is – 3 % to – 24 % compared to 1990
New Zealand*	+ 33,0 %	0 %	– 10 % to – 20 % compared to 1990

* For Europe, Australia and New Zealand, the lowest QELRO is unconditional while the highest one corresponds to a special objective in the case of a global agreement (OZER 2009a, UNFCCC 2009).

Copenhagen Conference, cutting by half its emissions in fourteen years: an impossible target when considering previous and future energy scenarios, even without including consumption-based emissions. The position of Canada is even worse. While its obligation under the Kyoto Protocol is to cut its GHG emissions by 6 % to 1990 levels on average over the 2008-2012 commitment period, these have increased by over 50 %. Their proposed reduction objective is – 20 % compared to ... 2006, that is allowing a 24 % increase between 1990 and 2020: a very unpleasant objective for an industrialized developed country with respect to developing countries expectancies!

In addition to that, Karimou Ambouta stressed that his country, Niger, lost over one third of its forest cover between 1990 and 2005, mainly because of fuel wood consumption (FAO 2006). Although forest clearing has an impact on GHG emissions trough LULUCF, he asked what the responsibility of the Nigeriens in the climate change context is since less than 10 % of the population has access to electricity. According to him, this statement demonstrates the lack of development strategies, especially for what regards energy. Yet, CO_2 emissions per capita from fossil fuel combustion in Niger are estimated to be 0.1 ton per year (OZER 2009b), over one hundred times less than OECD average (tab. 3). In the meantime, Niger records losses of biodiversity, suffers from advancing desertification, and has to deal with recurrent rainfall deficits causing food shortages and starvation.

This last conclusion, which is common to many poor countries, introduced the topic of "climate justice" and adaption strategies including its cost and feasibility, raising the question of sustainable development in developing countries, especially arid ones.

For those topics, all speakers agreed with these concerns. The important question of "climate justice", leitmotiv of many NGOs, has been studied elsewhere but is not a top priority of negotiators (*e.g.* Bode 2004, Halme 2007, Ragueneau 2009). Costs and feasibility of adaption strategies have a central place in current post-Kyoto negotiations and are sensible ethical questions (Johansen 2007, Adger *et al.* 2009, Parry *et al.* 2009, Glemarec 2010). Sustainable development in developing countries is clearly the central cross-Conventions issue with little global answers (Mwebaza & Kotze 2009).

Although some viewpoints may differ among scientists, the main conclusion of the round table is that climate negotiations will be very difficult since, at the political level, most of the above discussion is of little interest compared to the socio-economic interests of different nations or group of nations (*e.g.*, rich, emerging and poor economies).

NOTES

[1] Article 3 of the UNFCCC states: "The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities. Accordingly, the developed country Parties should take the lead in combating climate change and the adverse effects thereof".

[2] Considering all GHG (CO_2, CH_4, NO_2, HFCs, PFCs and SF_6) as well as land use, land-use change and forestry (LULUCF). All data expressed in CO_2 equivalent (CO_2 eq). http://unfccc.int/

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