USING A COST-BENEFIT ANALYSIS TO SELECT THE OPTIMAL FLOOD PROTECTION MEASURES

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ABSTRACT

The river Scheldt originates in France, flows trough Belgium and discharges in the North Sea in the Netherlands. The Scheldt estuary is a unique tidal estuary with salt, brackish and freshwater marshes and shallow waters. This unique estuarine nature however is at risk because of urban-industrial developments. In addition, the tides also create the risk of flooding by storms. The riparian states Belgium and the Netherlands have agreed to develop a long-term strategy for a more safe, natural and accessible river, considering sea level rise. For this purpose, Flemish and Dutch governments commissioned a cost-benefit analysis of flood protection measures. Measures evaluated include storm surge barriers, dike heightening and floodplains with or without the development of wetlands. The study builds on a multidisciplinary approach and team including hydrologist, engineers, ecologists and economists. The technical parameters are based on meteorological and hydrological models for assessing risks of flooding and the effect of protection measures. It takes into account the impact of global warming. Ecosystem models were used to evaluate the goods and services of nature development. An optimal flood protection strategy was developed, and the optimal solution was tested using different kinds of uncertainty analyses for a wide variety of technical and economic parameters.

The results illustrate the importance of sea level rise, which require long time horizons for assessment of effects of measures. It also shows that an integrated analysis based on the concept of" risk of flooding" and "goods and services of nature development" is a very useful approach to assist decision-making processes on designing flood protection measures and this approach is certainly applicable to other estuaries.

INTRODUCTION

The river Scheldt originates in France, flows trough Belgium and discharges in the North Sea in the Netherlands (figure 1). The Scheldt estuary is a unique area as tides create unique ecosystems with salt, brackish and freshwater marshes and shallow waters. This unique estuarine nature disappeared partly by urban-industrial developments including water quality issues dredging and land reclamation for agriculture and living.

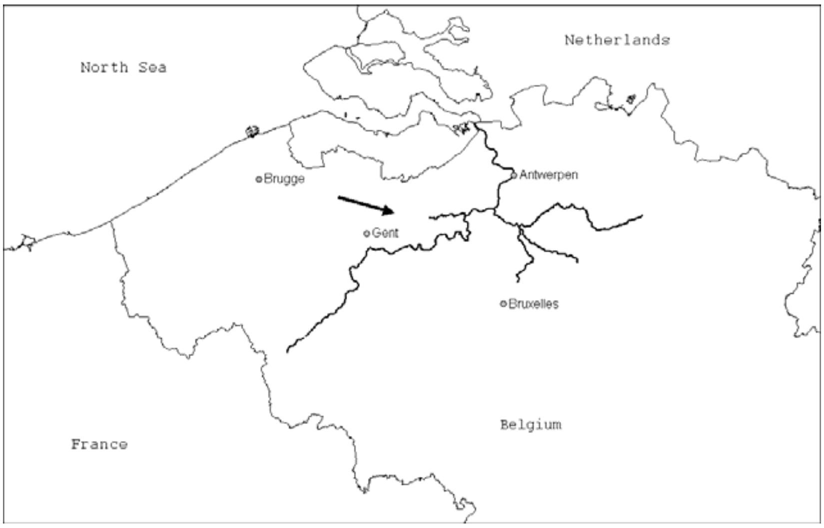

Figure 1. Location of the Scheldt Estuary

Because of these reasons, the risk of flooding increased. In 1953 and 1976, the Netherlands and Belgium respectively knew very strong storm floods with devastating consequences. The Belgian government created a framework for safeguarding the Sea Scheldt basin against storm tides: The Sigma plan [1]. It consisted mostly of building dykes along the river side, next to a few controlled flood areas. The option to build a flood barrier downstream Antwerp was rejected in a cost benefit analysis in the early eighties.

Today recent floods and sea level rise indicate that a new analysis is required. The Flemish government wanted to update its flood protection policy, taking into account the future sea level rise. The Flemish government commissioned a cost-benefit analysis of flood protection measures. Alternative solutions to increase the safety level are: a flood barrier downstream Antwerp, the use of the Eastern Scheldt as a controlled flood area, heightening of dykes and the creation of more controlled floodplains. The latter fits best in integrated water basin management because the areas may be complemented with nature development, education and recreation.

The objective of the study was to develop a multi-disciplinary approach integrating hydrologic models, economics, environmental economics and ecological sciences in a cost benefit framework. Imperative for this methodology was that is was able to estimate the impacts of sea level rise on the risk of flooding. The methodology was used to evaluate the costs and benefits of the different policy measures. The benefits of nature development along the Scheldt river had to be integrated.

METHODOLOGY

A multidisciplinary approach

To determine the optimal flood protection measurements several models were combined in a multidisciplinary approach as illustrated in figure 2.

A cost calculation model was used to determine comparable costs for the different flood protection measures and nature development measures. A meteo-hydrologic model predicted the impact of storms and floods with different chances of occurence, for scenarios with and without global warming and with and without flood protection measures. A GIS based damage model determined the damages following flooding or safety benefits of flood protection. Impacts of wetland creation on water quality were estimated with an external ecological model. These results were combined with an economic module to assess the environmental benefits on water quality and amenity in economic terms. This module builds on literature and specific CVM studies for impacts on amenity and non-use values. All results of previous models were integrated into a cost-benefit model to consistently compare costs and benefits of different policy options, including uncertainty analysis. (e.g. assessing relative impact of different assumptions related to sea level rise, economic growth and discounting) The time horizon for the model is 2100. This model calculates the cost-effectiveness of the selected measurements and based on these outcomes the measurement package was being optimised.

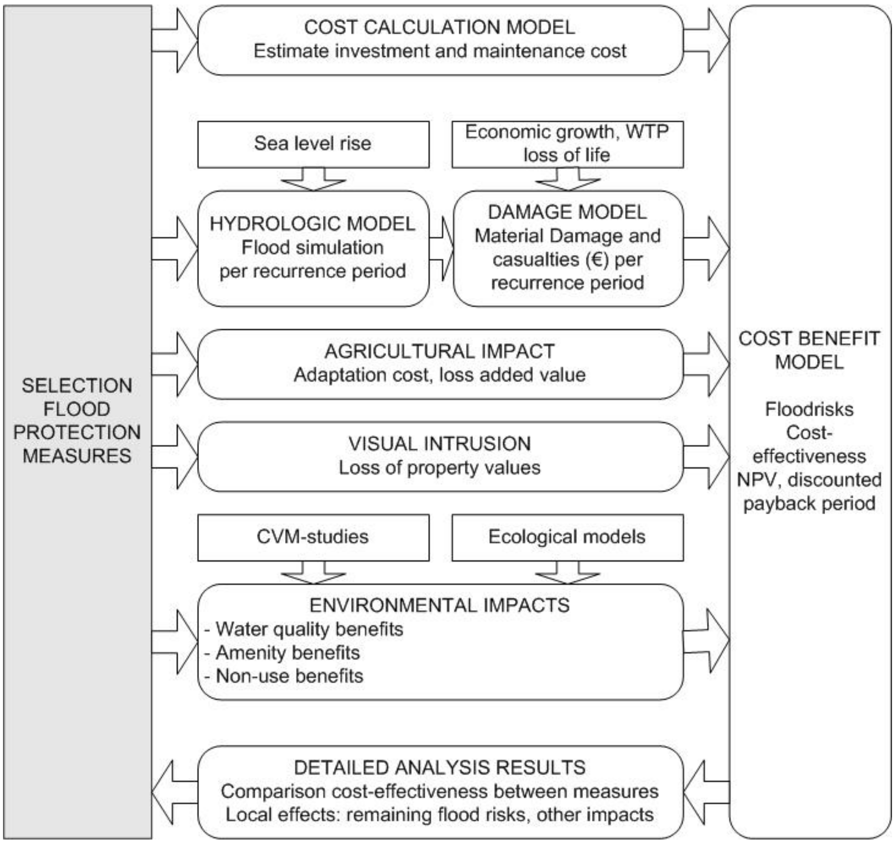

Figure 2. A set of multidisciplinary models in a cost-benefit framework

Benefits of reduction of flood risk

The hydraulic model MIKE11 was used. This model simulated floods for several recurrence periods between 1 and 10000 years. The model results in water depths and rate of climb for different areas along the river Scheldt.

To determine the safety benefits the model is combined with geographical data and damage functions into a GIS based model. (based on work of [2], [3],[4])

This model also takes into account the sea level rise, as a consequence of the climate change, because it plays an important role in determining the safety benefits (see figure 3). Together with the sea level rise, extreme weather conditions will increase.

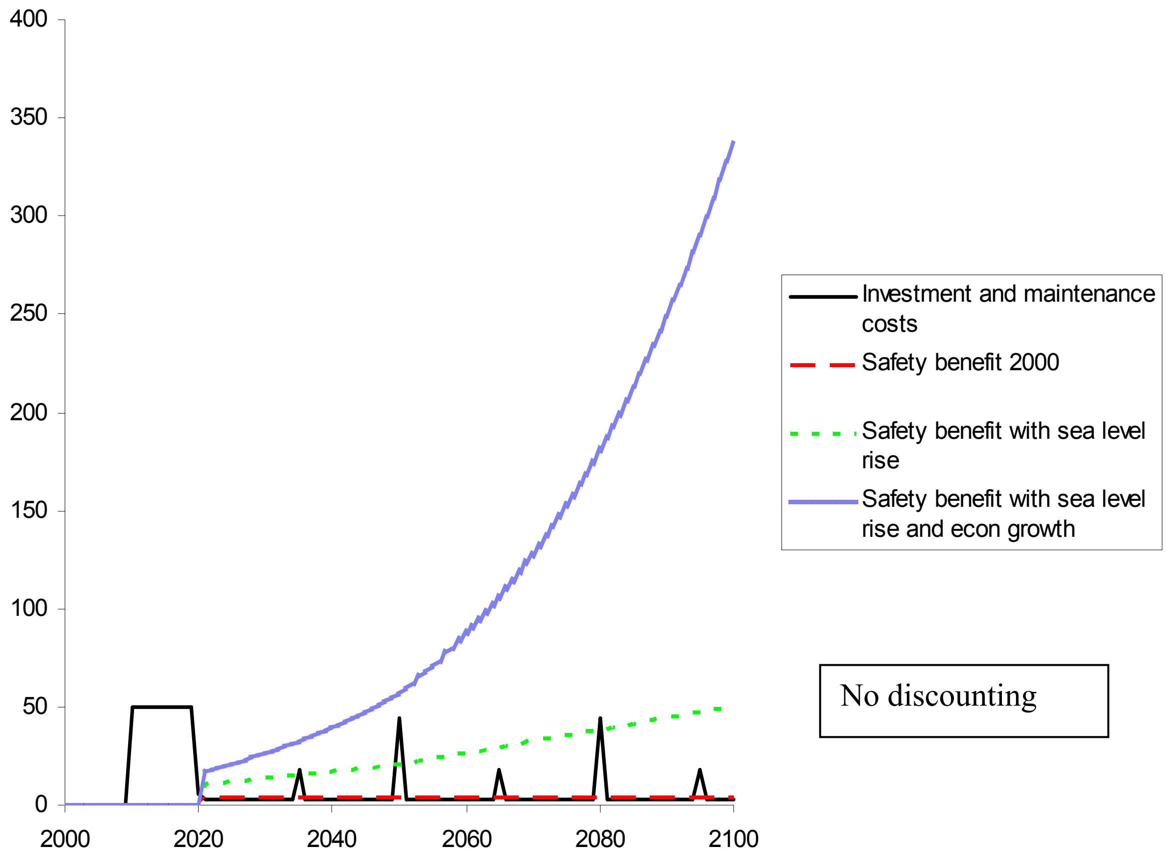

Figure 3. the evolution up to 2100 of costs and flood protection benefits of a storm barrier near Antwerp, with and without sea level rise and with and without economical growth. Safety benefits are calculated into detail for different periods of recurrence for the year 2000 and for the year 2100 with a sea level rise of 60 cm compared with the year 2000. These data will be used to determine safety benefits for intervening periods.

Safety benefits for these intervening periods are calculated based on linear interpolation between these calculated values. A linear increase from 0 cm in 2000 to 22 cm in 2050 and from 22 cm in 2050 and 60 cm in 2100 is assumed as central value. When other sea level rises are checked in a sensitivity analysis, the year in which safety benefits are equal to safety benefits corresponding with a sea level rise of 60 cm changes. For a sea level rise of for example 90 cm it is assumed that sea level rises with 33 cm (or 22/60 x 90 cm) in 2050 and values for all intervening periods are still derived with linear interpolation. Calculated benefits at a sea level rise of 60 cm apply in the year 2074.

The method described above allows to estimate the expected damages for one year, for a typical storm. These need to be aggregated to calculate the total risk using a risk function approach.

$$\text{risk} = \sum_{j}^{i} (\text{the probability of occurrence of flooding x damage caused by that flood})$$

with i, j all possible flooding (e.g. with a the probability of occurrence once a year until once in 10.000 years)

As it was not possible to calculate damage for every single type of storm, a representative set of storms was simulated. To include all the probable storms, the following formula was developed:

$$\text{Risk} = 0.500\ S_1+0.2389\ S_2+0.1320\ S_5+0.0780\ S_{10}+0.0408\ S_{25}+0.0143\ S_{100}+0.0026S_{500}+0.0009S_{1000}+0.00031S_{4000}+0.00015S_{10000}$$

Other Impacts

When new floodplains are build, the current land use, which is mostly agriculture or a mixture of agriculture, woodlands and nature, will change. In the cost-benefit analysis the loss of agricultural outputs and the goods and services delivered by the new riverine wetlands are weighted.

The loss of agriculture outputs consists of adaptation costs for moving certain high value crops into other areas and loss of the added value. The value of the goods and services of the wetlands was calculated by various methods in environmental economics. [5] [6]. A lot of the services of a controlled floodplain were modelled by the OMES-model, especially built to model the effects of the floodplains on the river. [7]

Cost-benefit analysis

All the effects of the different measures were then integrated into a cost-benefit analysis. The net present value and the discounted payback period were used as indicators for the cost effectiveness of the measures.

In a first phase a number of typical alternative protection schemes was assessed. Based on the results of the first phase, a local optimization procedure was carried out in a second phase.

RESULTS

The dominant impact categories for the cost-benefit model are (investment) costs and flood protection benefits. Impact of sea level rise on the flood risks is large, which increases the flood protection benefits significantly. Other impacts are at least an order of magnitude smaller.

Due to the sea level rise the total costs of the storm surge barrier, a large infrastructure project, had a pay back period of approximately 40 years. However, as the result is subject of many parameters and uncertainties, sensitivity analysis shows that the project could not be paid back within its technical lifetime in every situation (e.g. slower sea level rise, higher discount rate, slower economic growth). Higher dykes and floodplains could offer substantial flood protection benefits at relative low costs compared to a storm surge barrier, although they did not guarantee a full protection against flooding for very strong but very exceptional storms.

Therefore, a second phase was set up to find the optimal combination between dyke heightening and floodplains. This optimization procedure lead to a measurement package including the construction of 1325 ha floodplains and a heightening of 24 km dykes. This signifies a cost saving of 8 million € compared with the cheapest option of phase 1. The safety benefits are higher then any of the options in phase 1, even higher then benefits of the storm surge barrier.

The impact of sea level rise on total results was very significant. Flood risks increased 10 fold when considering a sea level rise of 60 cm. Payback times varied between 10 years in case of a sea level rise of 120 cm and 92 years in case of no sea level rise.

CONCLUSION

Results show that risks of flooding will increase significantly due to sea level rise. Due to this increasing risk extra measures are needed along the river Scheldt. Although more statistic measures as a storm surge barrier near Antwerp offer more protection for very extreme storms, a balanced combination of dykes and floodplains can offer higher benefits at lower costs.

This means that classical ways of protection schemes with unique protection levels along a river are less beneficiary than a risk-based approach. The results have been used for the development of a bi-national long term strategy for the Scheldt estuary. The approach can be used in other areas, provided a minimum set of data is available.

Acknowledgements
This paper builds on work and data of a study commissioned by the Waterways and Marine Affairs Administration of the Environment and Infrastructure Department of the Ministry of the Flemish Community (Belgium) (see www.sigmaplan.be) and the Dutch-Flanders project organisation ProSes established by the Dutch and Flemish governments to develop the long term vision for the Scheldt estuary (see www.proses.be). We acknowledge the input of many scientists and policy makers into these projects, especially CPB on the cost-benefit framework, Flanders Hydraulics Research for assessment of flood protection benefits, Prof. P. Meire and his team at the University of Antwerp for assessment of ecological effects and Dr. E. Ruijgrok for the CVM studies. Our research profited from the remarks of the members of the scientific advisory board of ProSes and steering committees of both studies. We remain solely responsible for the errors.

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ADVANCED USE OF ELECTRICAL METHODS IN THE STUDY OF THE AQUIFERS: THE CAMI PROJECT EXPERIENCE

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INTRODUCTION

The CAMI (Water-bearing Characterization with Integrated Methods) project gives a contribution to the realization of the 2000/60/CE, using a integrated method to characterize the hydrographical district and to analyse the environmental impact of the human activities and their sustainability.

The aim of CAMI is to apply an innovative methodology in order to obtain a wide data set of integrated geophysical, geochemistral and reclaimation methodologies to allow: (1) the planning of the amounts of water resources to be assigned to different uses (civil, agricultural, industrial), (2) the impact evaluation on water resources of new industrial and civil settlements, (3) the quantification of underground waters and (4) the research in water ecosystems. The methodology proposed within CAMI will be initially developed in a pilot test area located in Veneto - Friuli Venezia-Giulia regions (NE of Italy), where an alluvial aquifer is present.

In this paper the results of the electromagnetic geophysical methods applied to CAMI project are presented. ERT (Earth Resistivity Tomography) and TDEM (Time Domain Electromagnetic) surveys are used to describe the aquifer features and to evaluate its quality.

A 4D electrical data set will illustrate the seasonal evolution of the aquifer. One of the limitation of the ERT survey is the depth of investigation, limited at about 100 m of depth, but, by the integration of the ERT and TDEM methods it is possible to obtain geophysical information about the structure and the quality of the whole aquifer, starting from the surface up to a depth of 700 m where the basement saturated with brackish water is present.

The detailed resistivity and chargeability models obtained from the geoelectrical survey are guidelines for the exploitation and the management of the water. At the end of the project all the geophysical data will be integrated and compared with the other data acquired in the project in order to produce a model of the aquifer.

Geophysical Investigation

These data were gained by combining Electrical Resistivity Tomography (ERT) to get the best detail of the shallower part (from surface to about 100 m b.g.l.) and Time-Domain ElectroMagnetic soundings (TDEM) to get the whole 3D resistivity model of the subsurface down to the maximum investigation depth of about 1000 m b.g.l.

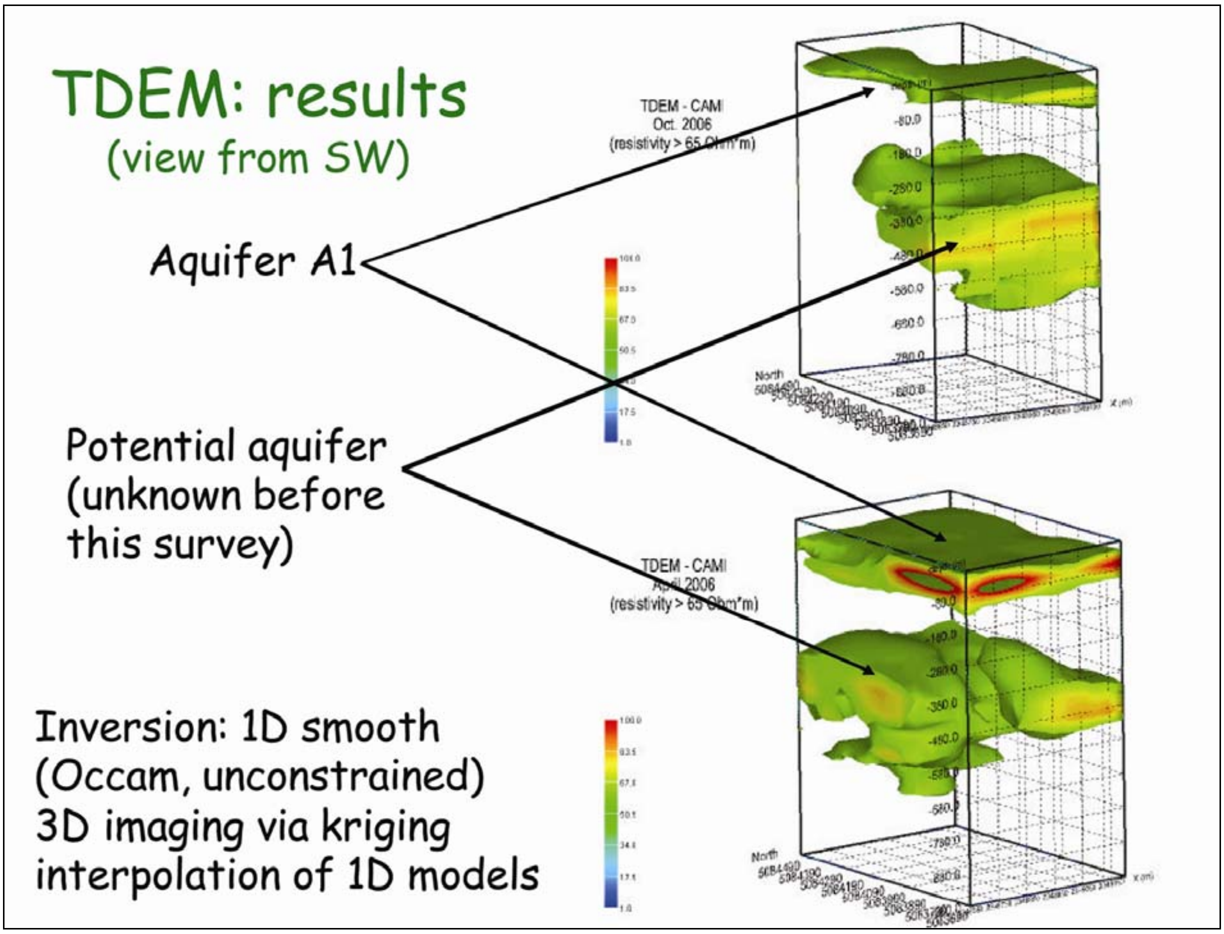

Figure 1. The results of the TDEM survey.

The acquisition parameter of the TDEM data were as follows: a) transmitter loop 200X200 square loop, b) receiver loop: 100 circular turns of 1 m diameter, c) Geonics TEM57/PROTEM time gates spanning high to medium frequencies (.087 to 28.1 ms). Some cultural noise perturbed the latest time gates. A number of 14 TDEM soundings was executed in the area using 3 transmitter loops and measurement points both inside and outside the loops, at an average distance of 200 m. An area of about 0.5 km2 was thus investigated.

Geoelectric data were acquired using a Syscal R2 resistivimeter having 128 electrodes for the depth acquisition and a Syscal Pro having 48 electrode for the 3D survey. A Wenner geometry was used for the 2 D lines while a Dipole-dipole geometry was used for the 3D survey.

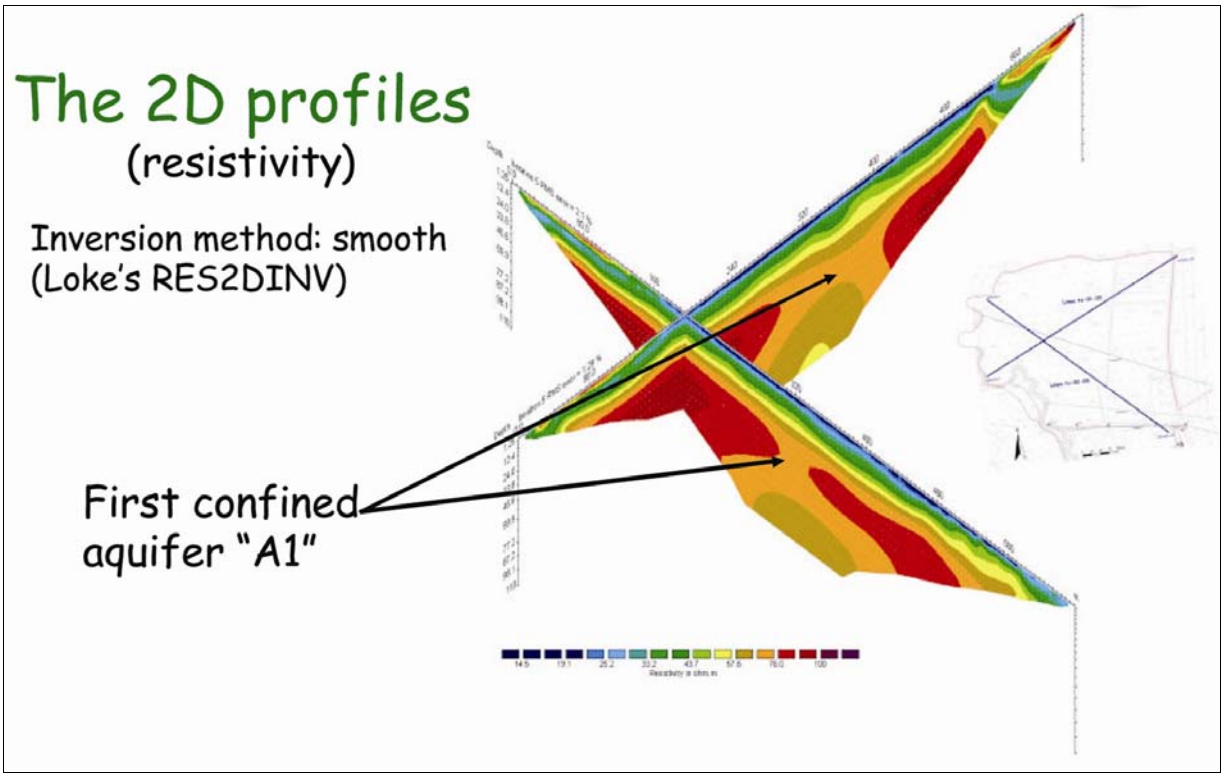

Figure 2. Resistivity model of the 2D ERT lines: The first acquifer is evidenced.

Occam's style inversion of ERT and TDEM data was performed using commercial software (RES3DINV: Loke and Barker 1996a, 1996b; EMIGMA: e.g. Parker et al. 1997). The estimated model furnished a detailed map of the resistivity distribution from the surface to the maximum depth of investigation (Figure 1).

Based on the hydrogeologic conceptual model and on in-situ measured resistivity values of the bearing water, the model defines with great detail the first confined aquifer, buried between 30 and 60 m b.g.l. As far as the aquifer buried at about 180 m b.g.l is concerned, its depth to thickness ratio is unfavourable, and therefore it was not well resolved by indirect measurements. Based on regional geologic knowledge of the subsurface at depth, the resistive body, laying at about 350 m b.g.l., and whose thickness was estimated to be at least 200 m, should be composed of coarse, porous sediments and thus it is potentially a huge fresh-water reservoir, not already detected by direct investigation in the test area.

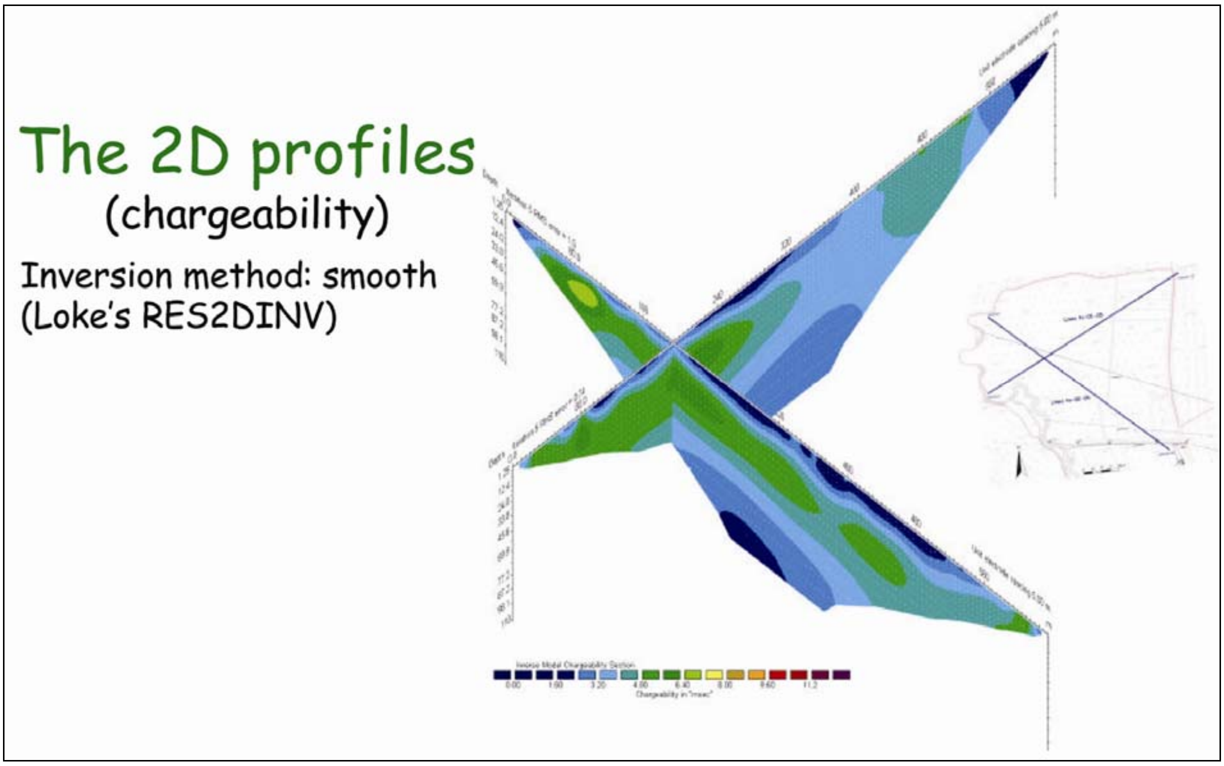

Figure 3. Chargeability model of the 2D ERT lines. Note that the aquifer has higher chargeability values than the clay levels.

Repeated TDEM measurements after 6 months showed a resistivity variation of about 12-14%, within the first confined aquifer, which resulted in excellent agreement with direct fresh water conductivity measurements. This variation is to be connected with a different exploitation rate due to seasonal variations of the pumping activity for civil uses.

CONCLUSIONS

A repeated ERT-TDEM survey was performed in a test area to estimate both the resistivity model of the subsurface, its hydrogeological significance and its variation with time. The test area is characterised by hydrogeological conditions of relevant quality and of vulnerability of fresh groundwater resources. High-density resistivity measurements performed with both ERT and TDEM allowed to get the whole sequence of confined fresh-water aquifers in the area and was successful to monitor the conductivity evolution of the exploited reservoir.

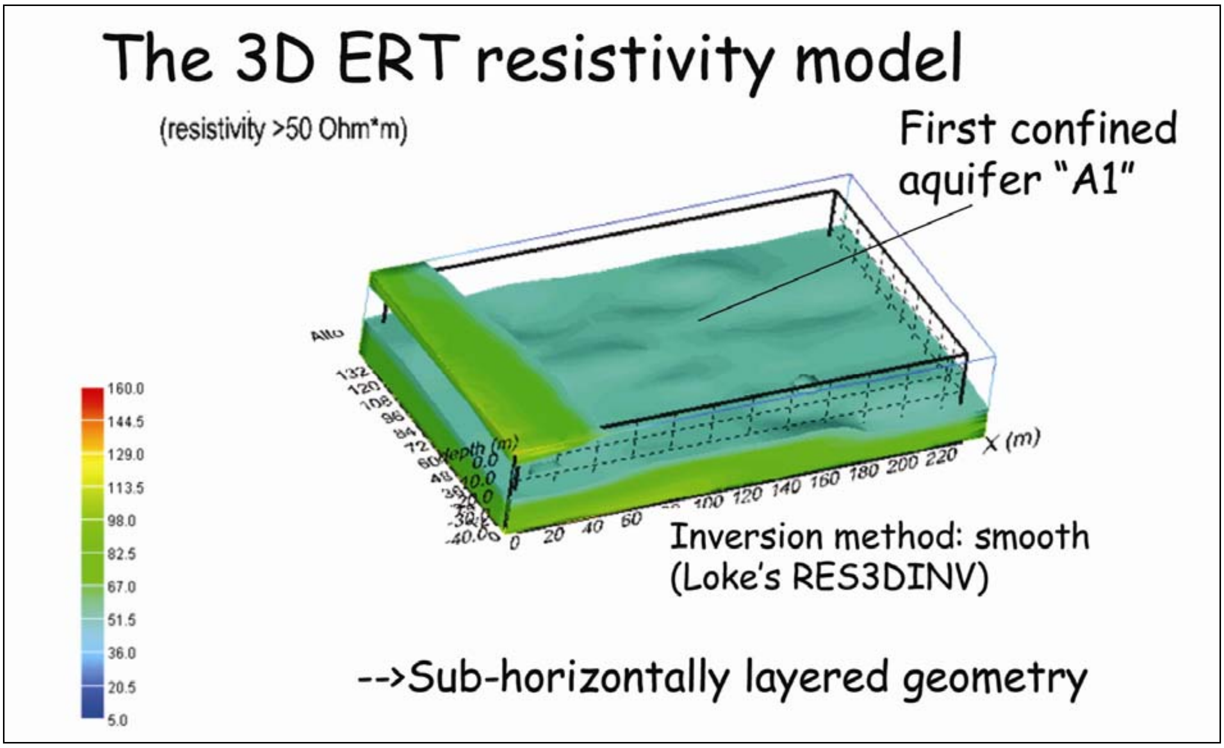

Figure 4. Resistivity model of the top of the first aquifer. Only the resistivity of the aquifer is evidenced

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INTERACTIVE SIMULATION GAME FOR INTERNATIONAL CARBON EMISSIONS TRADING

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ABSTRACT

A dynamic simulation based network game for carbon emissions trading in international markets is developed. The purpose of this simulator is twofold: First, it can be used and further developed as a platform for learning in and about the complexities of international carbon markets as an institution of climate regulation. Second, it can serve as a platform for experimental analysis of emerging economic behavior.

The dynamic model consists of two differential equations (two state variables) representing the *carbon emissions* and the *emissions quotas* of individual countries /regions respectively. Carbon emissions increase according to a business as usual scenario and decrease by the country's abatement decision. Emissions quotas increase as emission rights are issued by the regulator and as they are purchased from the international market; and decrease as emissions are realized by the country and as they are sold in the market. Each country is committed to an international treaty that annually issues the carbon emission rights. For each country, associated national abatement costs are represented by *marginal abatement cost* functions (MACs).

The dynamic model is designed as a seven player interactive network game. The players' task is to reduce their emissions and /or sell /buy emission quotas for over several simulated years so that they comply the treaty. The international market can be designed in several ways representing central auctioning or bilateral trading alternatives. For each alternative, the *unit emissions quota price* can be set with respect to the bids and asks of individual players. The players' purpose is to manage their task with minimum cost on to their national economies.

We run economic experiments on the current version which represents emissions trading under the proposed *Contraction & Convergence* global treaty with a single bid central auctioning mechanism. C&C is a long term global climate regulation plan that considers contraction of carbon emissions with converging per capita emission rights. Single bid central auctioning allows the players to submit their bids and asks once each simulated year. Results show that at the start of the game quota prices fall due to oversupply, but as the countries are faced with stringent reduction targets and increasing abatement cost, they increase. Those who manage timely reductions have a better chance to comply the treaty with lesser costs.

INTRODUCTION

According to economic theory, under specific conditions, an appropriate tradable-permit system can minimize the cost of reaching a predefined environmental target. In a perfectly competitive market, permits flow towards their highest-valued use. Those that would receive lower value from using the permits have an incentive to trade them to someone who would value more (Tietenberg, 2003). A tradable permit system consists of a socially agreed quota (a cap on total carbon emissions), distribution of this quota among polluters (countries /regions) and a trade mechanism under which the quota holders are free to trade their share. Under the ideal model, a polluter /appropriator will reduce down to the level where marginal cost of abatement equals the price of permit in the market. This leads to equi-marginal abatement costs, a cost effective outcome (Daly and Farley, 2004, pp. 380-81). For example, the 1992 United Nations Framework Convention on Climate Change (UNFCCC) recognizes this principle and opens the way for international emissions trading, which is now being implemented under the terms and conditions of 1997 Kyoto Protocol.

The players in tradable permit system are interconnected through a market institution and they make periodic decisions on how much to tax (abate) and /or how much to trade their emissions so that they minimize their costs or maximize their earnings while they comply an international treaty. Although economic theory predicts the cost effective outcome (competitive emission permit price, expected costs and earnings) under equilibrium conditions, the interaction of multiple players and the dynamics involved in emission trading makes it difficult to predict the long term behavior of permit prices and costs and earnings of individual countries. Dynamic simulators and simulation games can be an invaluable tool for learning in and about this complex environment and they can serve as the basis of an experimental evaluation of alternative rules and institutions.

Tradable emission permit systems are analyzed by games and laboratory experiments. For example, Fouquet 2003 reports the results of a carbon trading game designed to help people understand the concepts of carbon trading and develop insights on how permit prices may develop. Bohm and Carlén 1999 analyses the cost efficiency of several emissions trade mechanisms among four Nordic countries (Denmark, Sweden, Norway and Finland). Klaassen et al. 2005 describes three emissions trading experiments testing three alternative institutions: single bid and Walrasian central auctions and bilateral sequential trading. However, many of these experimental evaluations are static in the sense that, they consider either single or a few rounds of trade and the time dimension and long term interaction of the players are not explicitly answered. However, many viable policy alternatives for climate protection regimes are long term in nature and requires a dynamic and transient analysis rather than equilibrium solutions.

With this perspective we developed an interactive simulation game for carbon emissions trading and performed several tests on London based Global Commons Institute's Contraction and Convergence (C&C) proposal for climate protection. In this paper, we present the model structure, C&C framework, the gaming functionality and results from experiments.

MODEL

The *Carbon Emissions* and *Emission Quotas* accumulation structure for each country /region is represented by a two stock (second order) dynamic model (Figure 1). Model works on annual basis on discrete time steps, i.e. the emissions reduction and /or quota selling/ buying decisions are taken each year and the *Carbon Emissions* and *Emission Quotas* are updated annually. *Carbon emissions* grow according to a fixed business as usual *BAU growth fraction* and *reduce* according to the country's annual carbon abatement strategy. The business as usual (BAU) growth in emissions stands for the inertia of the system due to economic growth and existing conventional energy infrastructure under the absence of any specific abatement strategy. Growth fraction is set to 1.5% per year for US, Japan, EU and FSU and 3% per year for China, Brazil and India.[4] Note that, *reduction* is the player's decision interacting with the simulation game. Therefore:

(1) Carbon Emissions(t+1)=Carbon Emissions(t)+Carbon Emissions(t)*BAU growth fraction–reduction

Carbon emissions are initialized for each country /region to its value in year 2000 based on the data sourced from Carbon Dioxide Information Analysis Center (CDIAC) in 2003 by Global Commons Institute's (GCI) contraction and convergence simulator available from GCI's web site.[5] In the next section, however, we shall see that the gaming functionality is set to start in year 2005 rather than 2000 since the experiments are performed in year 2005 and 2006.

Emission Quotas increase as quotas are issued for each year according to the exogenous contraction and convergence scenario; increase or decrease as they are sold or purchased in the market; and decrease as they are consumed, i.e. as carbon emissions are realized for that year. Note that quota traded is the player's decision. Therefore:

(2) Emission Quotas(t+1)=Emission Quotas(t)+quota issued+quota traded–quota consumed

[4] Different models attribute different business as usual growth fractions for national carbon emissions. EPPA estimates that world carbon emissions will grow by an annual average of 2.1% if no political measures are taken, while POLES's estimate for the same variable is 1.8% (Criqui, P., M. Silvana, L. Viguer. 1999. Marginal abatement costs of CO2 emission reductions, geographical flexibility and concrete ceilings: an assessment using the POLES model, *Energy Policy* 27: 585: 601). The dissaggregation of these global growth fractions among North and South countries (in Kyoto's terminology, among Annex B and non-Annex B countries) by both models show lower BAU growth fractions in the North and higher BAU growth fractions in the South.

[5] Global Commons Institute – Contraction and Convergence, copyright 1997-2003, www.gci.org.uk.

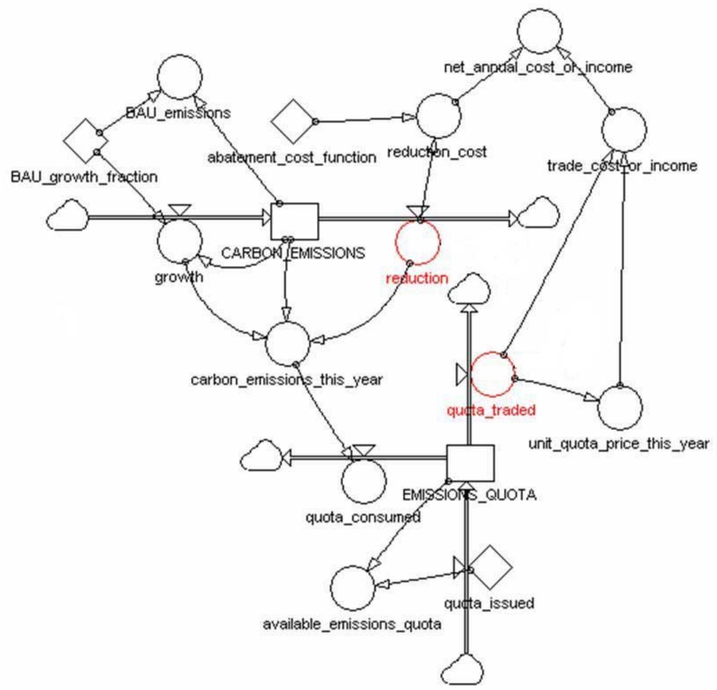

Figure 1. The simulation model.

Contraction and Convergence Framework

Quota is issued according to an exogenous contraction and convergence scenario. Contraction and convergence (C&C) is a cap-and-trade policy with a unique transient approach to the highly debated baselines problem, i.e. at the starting year, each country is entitled to emit at its historical levels but over the years, national emission rights (carbon emission allowances) change as per capita emission rights converge towards a universally agreed, fixed equal value (Meyer, 2000).

National /regional carbon emission quotas based on alternative contraction and convergence scenarios can be studied on CGI's C&C simulator. Each C&C scenario needs to be based on several assumptions about a target atmospheric CO_2 concentration; a contraction year at which the global carbon emissions is reduced to the target emissions level; a convergence year at which the per capita carbon emission rights become equal; and a population cut-off year, after which further population growth does not account to a further increase in national /regional emission rights. The contraction and convergence scenario adopted in our analysis assumes a target atmospheric CO_2 concentration at 550 ppm, contraction at year 2100 and convergence and population cut-off year at 2060. To be consistent with EPPA, the national emission quotas calculated in CGI's C&C simulator is aggregated for the EU and FSU.[6] The calculated annual emission quotas for the seven countries /regions are illustrated in Figure 2.

[6] EU aggregates the 15 member states until year 2004 (France, Italy, Germany, Belgium, Holland, Luxemburg, England, Denmark, Ireland, Greece, Spain, Portugal, Austria, Sweden and Finland). FSU aggregates Russia, Ukraine, Latvia, Lithuania, Estonia, Azerbaijan, Armenia, Belarus, Georgia, Kyrgyzstan, Kazakhstan, Moldavia, Tajikistan, Turkmenistan, and Uzbekistan. "The Ideas and Algorithms behind Contraction and Convergence and Alternative C&C Options" is available on www.gci.org.uk.

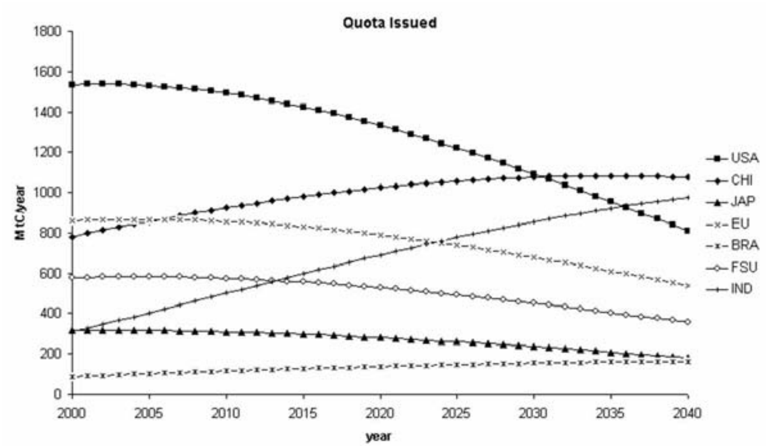

Figure 2. Annual national /regional carbon emission quotas issued with respect to C&C 550 ppm target concentration; contraction year 2100; convergence and population cut-off year 2060.

The Market

Unit quota price is set at each round according to the quota demand and supply in the market. The simulator collects asks and bids from the seven participating countries /regions and calculates the price at which total demand equals total supply. Each country /region offers five alternative prices for five alternative supply and /or demand quantities. For each price offered by seven players, individual supply /demand quantities are calculated by piecewise linear interpolation. Then the aggregate supply and demand curves are constructed. Since the asks and bids are submitted as decreasing supply /increasing demand with decreasing prices, multiple equilibrium on the aggregate supply-demand curve is avoided. The price where demand equals supply (the equilibrium) is decided by piecewise linear interpolation between the two prices corresponding to the lowest over-demand and lowest over-supply. In case such equilibrium is not found, there is either over-supply or over-demand. For over-supply case, price is set at the minimum price offered; the over-supply at this price is distributed over all suppliers at that price in proportion to their individual supply quantities. For over-demand case, price is set at the maximum price offered; the over-demand at this price is distributed over all demanders at that price in proportion to their individual demand quantities.

Abatement Costs (Taxing Emissions)

Abatement cost calculations are based on marginal abatement cost curves generated by EPPA general equilibrium model and sourced from Ellerman et al., 1998. These curves represent the marginal abatement costs (or shadow prices) corresponding to alternative fractional emission reductions by year 2010. The prices are given in 1985 US$. Ellerman et al., 1998 creates quadratic fits for these MAC curves and their integrals stand for the total abatement costs corresponding to alternative fractional emission reductions by year 2010. Figure 3 illustrates these marginal abatement cost curves for the seven EPPA regions chosen for our experiments. Indeed, adopting these EPPA curves in the current dynamic model arises two questions: First, these curves are generated for year 2010 commitments but our time horizon is longer than this time frame under which the parameter estimates are assumed valid. Second, ours is a dynamic approach where the countries /regions reduce their emissions every year according to their annual commitments, i.e. with respect to the quota available to them for that year. By doing that, regions benefit from early reductions as it slows down their future BAU emissions growth and reduces their total reductions (hence, total costs) as they achieve a fixed emissions target compared to their static abatement costs for the same target. On the hand, our purpose is not to precisely calculate the abatement costs, but what is important is the relative magnitude of abatement costs of different regions and their characteristic functional forms. Since these two attributes do not change under dynamic and static calculations, we accept our choice of abatement cost functions valid.[7]

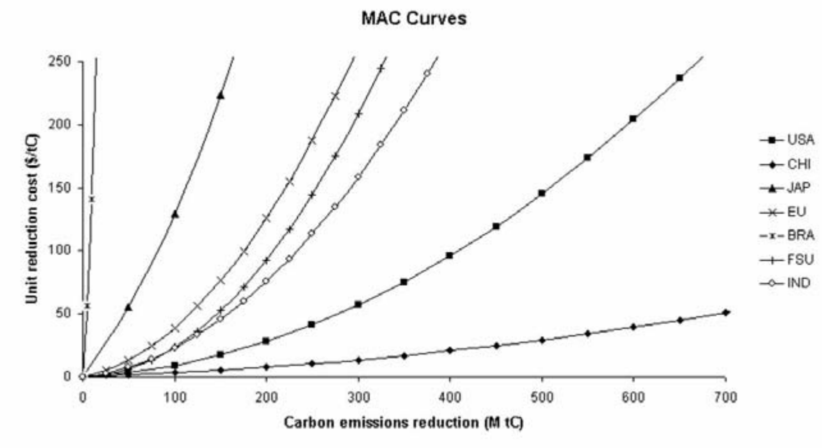

Figure 3. EPPA Generated Marginal Abatement Cost Curves - 2010.

The model calculates the abatement costs and costs /benefits from trade every year. Abatement cost depends on the *abatement cost function* and *reduction* that year. *Trade cost /income* depend on *quota traded* and *unit quota price* that year. Their sum is the *net annual cost /income*.

THE GAME

The simulator is implemented on *Powersim Constructor* (Powersim, 2000). Figure 4 is the simulator interface. The upper left frame presents information for the current year. *Issued emissions quota* (MtC) stands for the annual amount allocated according to the C&C plan. *Available emissions quota* (MtC) is the net amount with the surplus /deficit transferred from the previous year. *BAU emissions* represent the business as usual emissions that will occur by the end of current year. For the regions, US, Japan, EU and FSU, *BAU Emissions* (MtC) is 1.5% over last year's emissions, while for the regions China, Brazil and India, it is 3% over. For each year, the difference between the *available emissions quota* and *BAU emissions* has to be managed within the acceptable quota surplus /deficit limits which is set as 20 /10% of last year's emissions respectively for the current game. Any year, no country can reduce more than 5% of their emissions (illustrated by *maximum possible reduction*), because a reduction beyond this amount is highly unrealistic from technological and policy making perspectives. The *trade range* (MtC) depicts the possible range of sales /purchases that can be realized for

[7] The simulator takes annual BAU growth fractions 1.5% and 3% for the developed and developing countries respectively. When no-trade dynamic costs for 25 years are compared to static costs calculated for the same target emissions level, these percentages correspond to approximately 1.3% and 2.8% BAU growth assumptions respectively for their MAC curves. That is, if the MAC had assumed 2.8% for a developing country /region such as China, then the resulting abatement cost calculated by the simulator based on 3% annual growth for the next 25 years would be equal.

that year without violating the country's annual commitment to the C&C treaty. Positive values stand for purchases and negative values for sales.

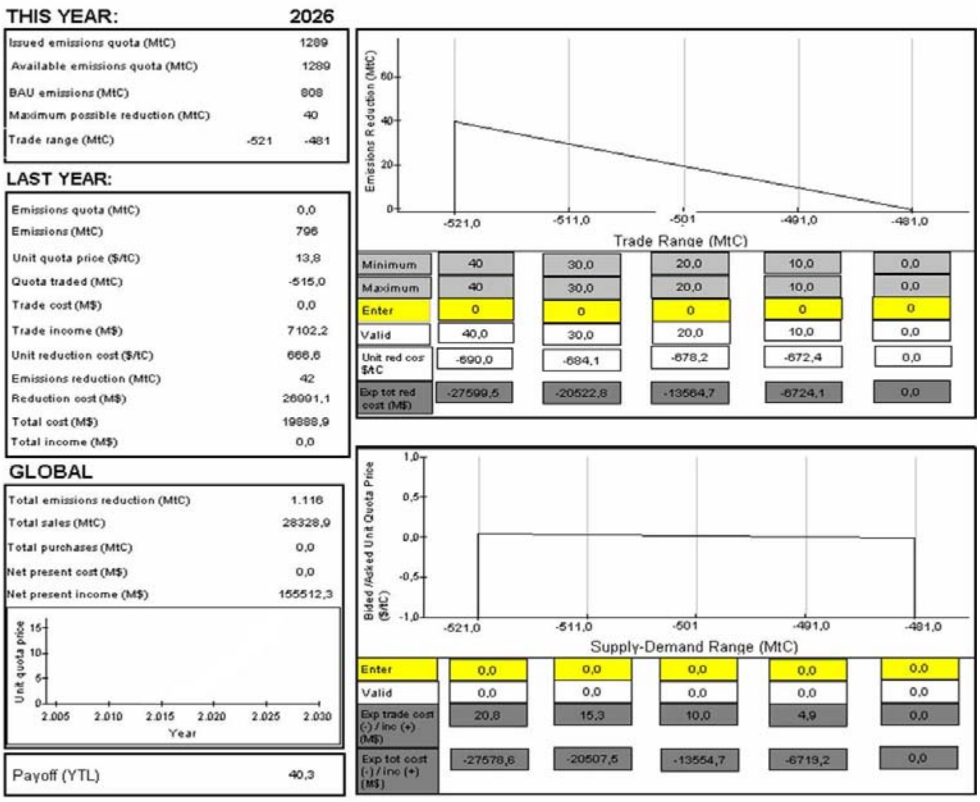

Figure 4. Simulator interface.

For every possible trade amount within this range, there corresponds a minimum and a maximum reduction amount (a reduction range) that needs to be satisfied so that the country complies the treaty. With this design that brings annual limits to the trade range and to the corresponding reductions, penalty due to non compliance is ruled out.

The middle left frame presents information realized last year. *Emissions Quota* represents the quota surplus or deficit transferred to the current year. *Emissions* (MtC) , *unit quota price* ($/tC), *quota traded* (MtC, negative for sales and positive for purchases), *trade cost* or *trade income* (M$), *unit reduction cost* ($/tC), *emission reduction* (MtC), *reduction cost* (M$), *total cost* or *total income* (M$) appear in order in this frame.

The lower frame keeps track of global indicators realized up to the current year in simulation. These are *total emissions reduction* (MtC), *total sales* (MtC), *total purchases* (MtC) and *net present cost* (M$) or *net present income* (M$). Net present cost /income is the 3% discounted accumulation of costs /incomes generated each year and is the basis of subjects' payoff calculation.

Subjects enter their reduction decisions on the upper right graph. The horizontal axis is the trade range calculated by Equation 4. The vertical axis is the corresponding emissions reduction choices. The design of this graphical instrument avoids the subjects enter decisions violating their commitments to the treaty. The *minimum* and *maximum* possible reductions corresponding to the trade amounts on the horizontal axis (calculated by Equation 6 are presented on the first two rows below the graph. Underneath, subjects *enter* their decisions within this range. In case an invalid decision is entered, the simulator corrects the subject's choice and presents a valid choice on the row labeled *valid*. Hence, the subjects are urged to check the consistency of their choices by observing the equality of the values that appear on the two rows labeled *enter* and *valid*. Below these rows, subjects are able to observe corresponding *unit reduction cost* ($/tC) and *expected total reduction cost* (M$) of their choices. The graphical representation of subjects' choices helps them to see that the simulator linearly interpolates the values in between their entered valid choices.

The lower right graph helps the subjects submit their asks and bids to the market. The horizontal axis is the supply-demand range exactly equal to the trade range of the previous graph (supply negative values, demand positive values). Vertical axis is the asked /bided unit quota price ($/tC). Subjects are allowed to enter any price provided that they submit decreasing prices with decreasing supply and increasing demand. If they fail to obey this rule, the simulator arbitrarily modifies their choice on the *valid* row. Hence, here again, subjects are urged to check the consistency of their choices by observing the equality of values on *enter* and *valid* rows. *Expected trade cost /income* for these choices appear below. Under that, *expected total cost /income* is the sum of emission reduction cost calculated on the previous graph and the trade cost /income. The graphical representation of the asks and bids mean that the simulator linearly interpolates the values between subjects' entered valid choices. The ask at the left most corner of this graph means, the subject is eager to sell that amount at any price over his entered price choice. The bid at the right most corner of this graph means, the subject is eager to buy that amount at any price below his entered price choice.

These two graphs help the subjects finalize their alternative reduction and trade choices before submitting their asks /bids to the central auctioneer. Once they decide (on all alternative trade-reduction combinations and asks and bids), they submit by hitting a button on the screen, then the simulator collects the information, calculates the equilibrium price and realizes the corresponding trade and reduction amounts for the seven players (as described in Section II). Simulator advances one time unit (one year).

RESULTS

Figures 5 and 6 illustrate results from an experiment that does not allow banking /borrowing of emission quotas, i.e. the permits expire each year. The five buyers, USA, Japan, EU, Brazil and FSU, all make reductions larger than that would be expected and the sellers China and India increase more than that would be expected if they sought for equi-marginal outcomes at each round of trade. Permit prices monotonically increase as further reductions become more costly.

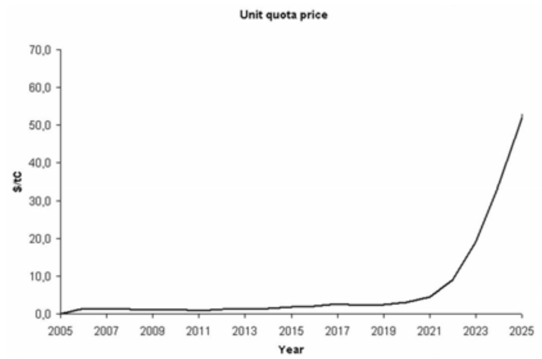

Figure 5. Permit price development.

DISCUSSION

Interactive simulation gaming can be used for learning in and about the complexities of pollution permits trading in several environmental resource management contexts, such as fisheries, water pollution control, irrigation water allocation, air pollution control and global climate protection. Current version of carbon emissions trading simulator represents five potential buyers (USA, Japan, EU, Brazil, FSU) and two potential sellers (China, India) in an international market under C&C framework for the simulated time period of 2005-2025. Results not presented in this paper illustrate, both the buyers and sellers benefit from trade. If the buyers follow a moderate abatement strategy from the very start but do not try to assume seller positions in future rounds, they increase their benefits. For the sellers, this creates reduced earnings.

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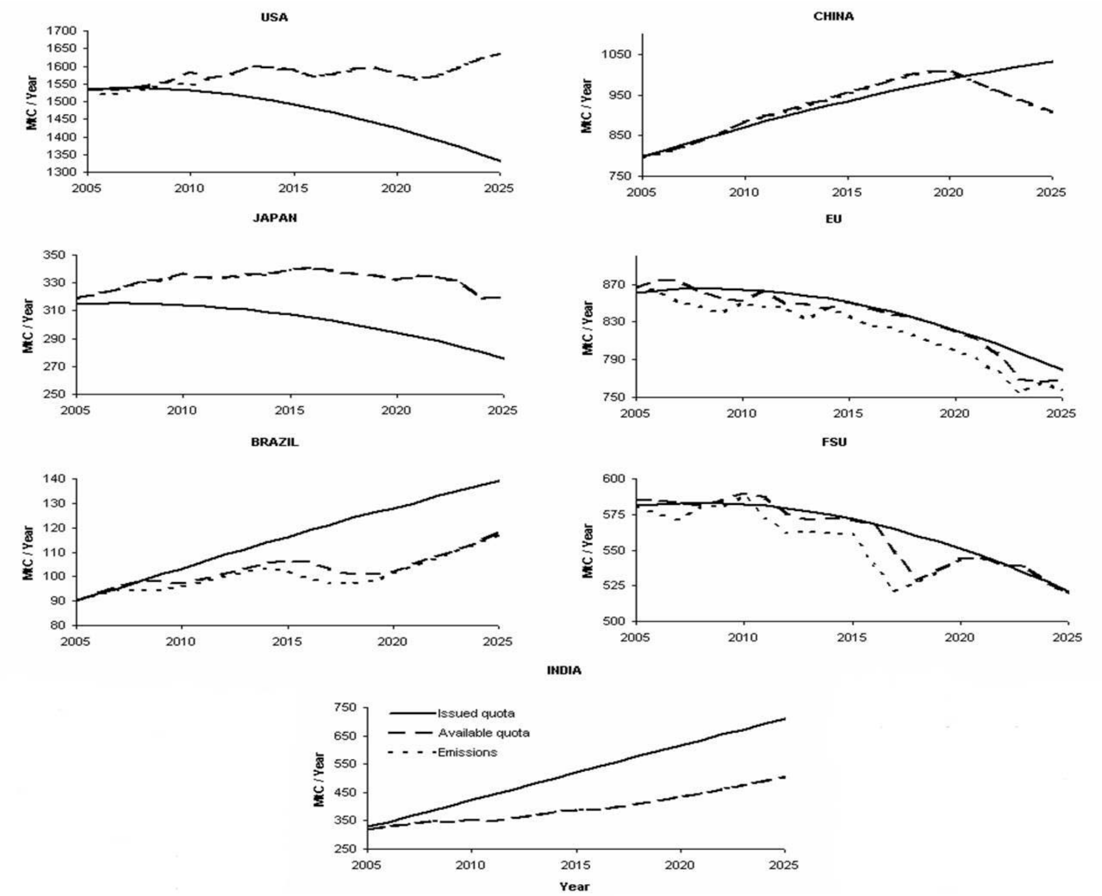

Figure 6. Observed emissions behaviors at an experimental trial.

ENERGY CONSUMPTION EFFECTS ON AIR POLLUTION IN I.R.IRAN

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ABSTRACT

The economy of I.R.Iran is so related to oil that has had many environmental problems especially air pollution in urban areas in recent years. Statistics show that most of the time, the condition of air quality is in crisis level especially during fall and winter seasons. Rapid and high population growth has had large amount of fossil fuels consumption in all sectors including transportation, industry, agriculture, residential and commercial and public services and air pollution and healthy problems.

Iran's abundance of fossil fuel resources has tended to discourage the country's incentive to shift to cleaner alternative energy sources for its energy needs that must be considered in future programming. These are discussed in this paper.

Key words: Energy, Renewable, Non-renewable, Air, Pollution, Iran

INTRODUCTION

Iran is the second largest crude oil producer of OPEC that holds 9% of the world's oil reserves. It also has the world's second largest natural gas reserves that is estimated 812 trillion cubic feet in proven natural gas and has also huge potential for gas development [2)]. This statistics indicates that the energy consumption is increased during the last century. The clean sources of energy are also shown to be used in recent years [8)]. In the last two decades, consumption of all available kind of energy has been increased in Iran [3)]. According to statistics, the total energy consumption was 5.18 quadrillion Btu, which is about 1.3% of the world energy consumed in 2001. It is equivalent to the consumption of 80.3 million Btu per capita energy including 51% oil, 47% natural gas, 1% each coal and hydroelectric. [5)]

An abundant of fossil fuel resources is available in Iran. This tends to discourage the pursuit of alternative renewable energy sources. Renewable energy consumption is very limited as compared to high world's oil and natural gas reserves in Iran.

Iran's 1997 renewable energy consumption[8] including hydropower, solar, wind, tide, geothermal, solid biomass and animal products, biomass gas and liquids, and industrial and municipal wastes totaled 106 trillion Btu, 6% increase over the previous year [1,3].

In this paper, the situation of both energy in Iran and their effect on air pollution especially carbon emission are discussed.

ENERGY CONSUMPTION

Major factor behind the suffocating air pollution in Tehran and other Iranian cities is the dramatic rise in the country's energy consumption. From 1980-1998, Iran's total energy consumption ramped up from 1.6 quadrillion Btu (quads) in 1980 to 4.7 quads in 2000. Tehran's 2 million cars alone use 7 million liters (1.85 million gallons) of gasoline daily. With an abundance of oil in Iran, petroleum products are subsidized, and their cheap cost deprives producers of incentives to make them more fuel-efficient. [3)] Table 1 indicates energy production and consumption by source in 1999. [4)] As shown in the table, the consumption amount of renewable energy in Iran is not considerable as compared to other three main energy sources of fossil, oil and gas. Table 2 shows energy consumption by different sectors in 1999.

Table 1. Energy Consumption by Source (in thousand metric tons oil equivalent)

Kind of Energy	Iran	% of Middle East & North Africa	% of the world
Total Fossil Fuels	102422	20.47	1.13
Coal & its products	1271	4.11	1.29
Crude oil & natural gas liquids	70184	17.01	2.5
Natural Gas	49671	24.21	1.2
Hydroelectric	427	7.5	1.14
Renewable, excluding hydroelectric	786	6.58	1.11
Primary solid biomass (includes fuel wood)	786	7.16	1.2
Biogas & liquid biomass	0	3	14931
Geothermal	0	202	43802
Solar	0	756	2217
Wind	0	2	1748
Tide, wave & ocean	0	0	53
Nuclear	0	0	661901

Table 2. Energy Consumption by Different Sectors (%)

Sector	%	% in the World
Industry	29	31.69
Transportation	28	25.99
Agriculture	5	2.46
Commercial and public services	7	7.58
Residential	26	27.33
Other	5	4.95
Total	100	100

ENERGY POLLUTION

Iran has had many environmental problems especially air pollution in urban areas in recent years. Statistics show that most of the time, the condition of air quality is in unhealthy and crisis level especially in fall and winter. Major air pollution sources especially in urban areas are vehicle emissions, refinery operations, and industrial and power plants. [6)]

Iran's energy-related carbon emissions have been on a steady climb for two decades. Since 1980, carbon emissions in Iran have risen by 240%, from 33.1 million metric tons emitted in 1980 to 80.8 million metric tons emitted in 2000 (Figure 1). With the growth in Iran's population has come an increasing number of cars, and automobile exhaust has contributed greatly to the fact that Iran now accounts for 1.3% of the world's total carbon emissions. [3)] The amount of carbon, different hydrocarbons, ozone, etc is on unhealthy level in industrialized and populated cities like Tehran, Tabriz, and Ahvaz, too.

Regarding to 5.18 quadrillion Btu total energy consumed, per capita carbon emissions is 0.4 metric tons. This means that fuel share of carbon emissions is oil, natural gas and coal is 53, 45 and 1 percent, respectively.

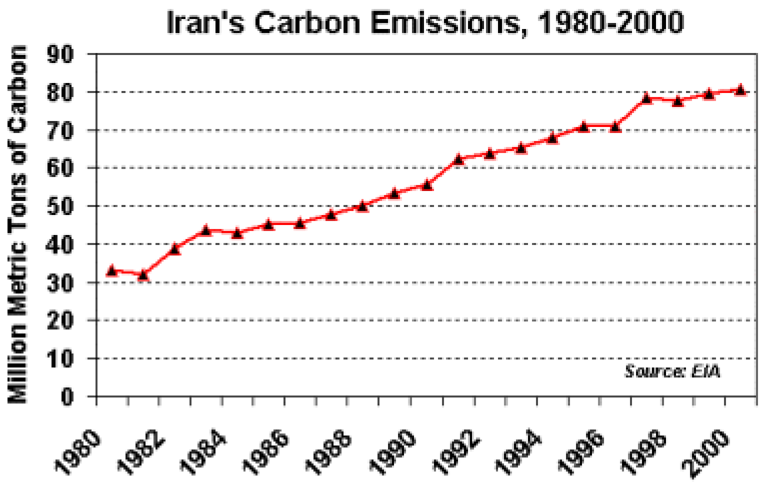

Figure 1. Carbon Emission in Iran [3)]

According to statistics, energy related carbon emissions are 90.1 million metric tons that is about 1.4% of world total carbon emissions. It has been shown that among four main pollutant sources including transportation, industry, power plants and buildings, the share of transportation in PM-10 and hydrocarbons (HC) emission is 87.3 and 70.2 percent, respectively. In addition industries emit the most amounts of SO_x and NO_x, which is about 64 and 42 percent, respectively. This means that transportation is the main sources of pollution in Tehran and all cities of Iran.

Statistics shows that 70% of air pollution in Tehran is resulted from automobiles. The ages of automobiles in Tehran are from 10 to 22 years (average age is 15.9 years) that have an important role on air pollution. Unfortunately, the amount of fuel consumption in private cars is very high as 26 percent of them are old and consume 50 percent of total fuel. [6)]

It is estimated that 3,000 tons of carbon monoxide, 450 tons of hydrocarbons, 30 tons of sulfur and two tons of lead emission are emitted into the atmosphere of Tehran every day.

This is one of the highest levels in the world. As a result, the number of urban residents who die from air pollution related diseases is increasing every year.[1)]

CONCLUSIONS

Iran imports a considerable amount of fuels especially gasoline every year. A huge amount of pollutants are also emitted to the urban air. In conclusion some suggestions are given as follows:

- By decreasing energy consumption especially in transport section, emitted pollutants will be decreased. So, the amount of energy consumption especially gasoline must be optimized by the authorities as soon as possible.
- The government has considered this problem, but more emphasize and high activities and researches must be done to achieve the objectives.
- Plan for substituting old cars with new cars by the government must be seriously implemented.
- By encouraging and training people, it is possible to save energy and money and expand it in solving air pollution problem. Programs for encouraging people to use equipment with low energy-consumption must be done by NGOs by full support of government.
- Rapid implementation of "Green Government Plan" for determination and optimization of the amount of energy consumption in the governmental organizations and offices and encouraging other offices to implement it. In this plan, the amount of energy and waste must be determined to minimize the use of paper, water, energy, and etc. [7)]
- More attention must be considered in use of clean energies by the authorities.
- A comprehensive environmental assessment of fuels should be done not only the end-uses but also the production, conversion and transport of energy into consideration. For example, energy production from biomass including lignocelluloses crops, grains, sugar crops, oil seeds, terpenold crops and algae are good research topics.
- More investigation on bio-fuels is necessary. As they can use for internal combustion engines, they may replace fossil fuels in some cases.
- Production of biogas from animal dung and other organic residues has a number of theoretical advantages. It produces a proper fuel for uses such as cooking and lighting that can be used in the small communities which are far from cities in which transportation of energy is difficult and expensive especially during winters. This will be a good source of energy with the least cost and difficulties. [8)]

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