GLOBAL CHANGE AND ECOSYSTEMS

6th Framework Programme No 515234

IASON:International Action for the Sustainability of the Mediterranean and Black Sea Environment

Coordinator: Hellenic Centre for Marine Research, Greece

Management Policies in the Mediterranean and Black Seas (WP5)

Assessment of the Ability to develop dependable socio-economic projections for the coastal zone using coupled environmental and socio-economic models *(D5.3)*

Workpackage responsible leader
Dr. Laurence Mee
University of Plymouth, UK

Project no.: 515234
Project acronym: IASON

Project title: **I**nternational **A**ction for **S**ustainability of the Mediterranean and Black Sea Envir**O**nme**N**t

Instrument: Specific Support Action

Thematic Priority: 6.3 GLOBAL CHANGE AND ECOSYSTEMS

Deliverable 5.3
Assessment of the ability to develop dependable socio-economic projections for the coastal zone using coupled environmental and socio-economic models

Due date of deliverable: April 2006
Actual submission date: August 2006

Start date of project: 1st January 2005 Duration 18 months

Organisation name of lead contractor for this deliverable: Hellenic Centre for Marine Research (HCMR)

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	**X**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Introduction

This deliverable combines the two deliverables described as D5.3 “Assessment of the ability to develop dependable socio-economic projections for the coastal zone” and D6.3 “Report on the requirements for coupling ecosystem models with socio-economic projections”. The report covers both quantitative (General Equilibrium) and semi-quantitative (Bayesian) models.

1. The Potential of CGE Economic Modelling to Assess Environmental Impacts

General Equilibrium (GE) models are particular investigation tools which are being increasingly used within the economic discipline to assess the economic implications of a wide set of “perturbations”, be they dependent upon policy decision (like e.g. the implementation of tax or trade policies) or induced by non-economic “shocks” like for instance a sudden factor of production scarcity induced by a natural disaster. The wide range of their applications highlights their flexibility, nevertheless they also suffer from some limitations.

In what follows, after having introduced opportunities and limitations of CGE models (section 2), and presented some of their applications in the field of climate-change impact assessment (section 3), we intend to explore the possibility to use this investigation tool to asses economic consequences of ecosystem changes (section 4).

1.2 CGE Models: flexible tools for economic evaluation exercises

CGE models describe the economy through the behaviour of optimising producers and households which demand and supply goods and factors. Adjustment processes to excess demand and supply determine equilibrium prices in all markets. Profit maximisation under perfect competition and free market entrance guarantee zero profits and the optimal distribution of resources. Generally CGE models obey to the “Walrasian” or “Neoclassical” paradigm, that is perfect competition and market clearing, nonetheless they are flexible enough to accommodate for imperfectly competitive industries with market power and existence of profits.

The appealing features of CGE models are: their flexibility in evaluating a wide range of economic and non economic shocks, the suitability to highlighting adjustment processes and accordingly "second" order effects, and last, but not least, a certain degree of familiarity by policy decision makers.

The "multi-purpose" nature of CGE models. At the beginning, CGE models were developed mainly to analyse international trade policies and relationships. To a lesser extent they were used also by public sector economists to assess the welfare effect of given taxation policies. But, soon, they started to be used by economists to investigate the changes in economic conditions induced by the most diverse driving forces. A good example is the economic assessment of environmental "issues" like environmental policies or even environmental phenomena like climate change. Indeed, notwithstanding their complexity, the economic implications of these facts can be finally represented as changes in productivity, supply or demand for different inputs and/or outputs. This kind of information can be "typically" processed by a CGE model and the final welfare implications can be determined.

Highlighting interdependences and "higher order" effects. The peculiar feature of CGE models is market interdependence. All markets are linked, as factors of production are mobile between sectors and internationally, thus each price signal of excess demand or supply in one market induces a cost-minimizing input reallocation concerning the entire economic system. But this is also true for the demand side: responding to scarcity signal in one market, utility-maximising consumers readjust their entire consumption mix. As a consequence, CGE models can capture and describe the propagation mechanism induced by a localised shock onto the global context via price and quantity changes and vice versa. Moreover they are able to assess the "systemic" effect of these shocks, that is the final welfare or general equilibrium outcome which is determined after all the adjustment mechanisms at play in the economic system operated. These "higher order" effects are usually very different from the initial impacts.

Acquaintance of policy environments. Finally, it is worth to stress that CGE models have been used for policy advices by many years now to major institutional bodies like the EC and public agencies. Accordingly they are rather familiar to policy decision makers which is an important aspect contributing to easing the communication between the scientific and the policy fields.

Notwithstanding notable recent-years improvements, particularly in the field of computational capacity, allowing the construction of increasingly complex models and facilitating data management, CGE models still suffer from some “typical” drawbacks. First of all they are hugely data demanding: the “behavioural” parameters characterising demand and supply functions and technological factors are generally “calibrated” in order to reproduce a given economic “equilibrium” observed in a given point in time. This equilibrium is based on social accounting matrices (SAM) which need to specify all the inputs to and outputs from each of the sector and country represented, including tariffs, subsidies, savings, etc..

Secondly, they focus on macro-economic relationships, thus a detailed description of the technological side remains outside the scope of the investigation. Indeed technical substitution possibilities and technological improvements are usually considered only to a limited extent.

Thirdly also the geographical specificity is “rough”: pursuing macro-economic relevance, usually the finest detail provided is the country level.

Finally these models are mostly static or consider highly simplified dynamics: this is a shortcoming imposed by the computational burden of their huge structure that interfaces many countries and sectors.

1.3. Economic evaluation of climate change impacts: some example of the use of CGE models

In what follows we report two examples of economic assessment of climate change impacts using CGE models, appropriately integrated with information stemming from climatologic and environmental disciplines and modelling approaches. The welfare evaluation regards climate change impacts on agriculture and of sea level rise.

1.3.1 Climate change impacts on agriculture

The methodology

Bosello and Zhang, (2005) propose an “integrated assessment” exercise conducted for eight world macroregions, that couples with the so-called “soft-link” approach a Global Circulation Model (GCM), an agricultural sub-model and an economic model. The GCM used is a reduced-form of the Schneider-Thompson GCM: starting from CO_2 emissions, it provides information on the expected increase in average world temperature and CO_2 concentration in the atmosphere. This average data is then disaggregated into 22 geo-climatic zones following Giorgi and Mearns (2002) and fed into a crop productivity change module. This module (Tol, 2004) extrapolates changes in yields respect to a given scenario of temperature increase. It is based on data from Rosenzweig and Hillel (1998) which report detailed results from an internally consistent set of crop modeling studies for 12 world regions and 6 crops' varieties. The role of CO2 fertilization effect is explicitly taken into account. Finally, changes in yields are used as input in the global economic model in order to assess the systemic general equilibrium effects.

To do this, it is made an unconventional use of a standard multi-country world CGE model: the GTAP model (Hertel, 1996), appropriately modified.

In a first step, benchmark data-sets for the world economy "without climate change" at some selected future years (2010, 2030, 2050) are derived inserting, in the model calibration data, forecasted values for some key economic variables: endowments of labour, capital, land, natural resources, as well as variations in factor-specific and multi-factor productivity.

In the second step climate change shock on agriculture, modelled as a change in the productivity of land devoted to the production of the different crops in the different regions, are imposed over these benchmark equilibria.

This exercise suffers from some major limitations. We mention the following:

- firstly an analysis at the world level requires heroic simplifications and generalizations of both climatic conditions and crop responses. A very narrow number of observations is used to provide information on vast areas inducing an unrealistic uniformity,
- secondly - apart from temperature and CO2 fertilization effects - other important impacts of climate change on agriculture are missing, primarily interrelations with water availability and with livestock,
- thirdly adaptation at the farm level is partly disregarded especially decisions on cultivation timing as the exercise is purely static. Moreover there is not a land use model defining the optimal allocation of land among competing alternatives; land is a production factor used only by the agricultural sector and not for instance by the residential or the industrial sectors, as a consequence also the mechanism governing the decision on cultivation location results highly simplified,
- finally the exercise concentrates only on few kinds of cereal crops.

Nonetheless, it is particularly useful in highlighting substitution mechanisms and transmission channels within and between economic systems. It allows to represent and disentangle those adaptation mechanisms at work in the modern economies that can amplify or smooth an initial shock and produce a final effect largely different from the original stimulus.

Results

In what follows we are commenting results for 2050 when, according to our calculations, temperature is expected to increase 0.93°C respect to year 2000. Results for the other benchmark years are qualitatively similar.

As can be seen (tab. 1) the productivity of land used for the cultivation of rice and wheat, generally increases benefiting of the improved fertilization effect due to higher CO_2 concentration. The opposite happens to cereal cultivation. RoA1, CHIND and RoW are partly different: the first two show an increased while the last a decreased land productivity in all crops.

As expected the price of different crops moves in opposition to productivity (tab. 3).

Firstly it is worth noticing that direct productivity shocks are bigger than final general equilibrium effects on GDP. This because the economy can substitute land for other inputs (e.g. capital), or vice versa.

Then, in line with all the more recent literature, effects on GDP are generally small, (negative for USA, EEx and RoW, positive for the other regions) and relatively more negative for developing countries. What is interesting to note here, is how the change in land productivity propagates to GDP and to international capital flows. It is firstly worth recalling the rather peculiar mechanism GTAP uses to allocate capital internationally: a central bank collects savings from the regional households that save a given amount of their income and then proceeds to redistribution. The engine of the entire process is the equalization of the expected rate of return to (price of) capital in all regions. As shown by table 1, GDP is positively (negatively) affected when the net effect on land productivity is an increase (decrease). In the GDP gaining (loosing) regions the positive (negative) aggregate result fosters(depresses) the demand of all inputs including capital, capital increases(decreases) its real price (tab. 3) and subsequently capital inflows(outflows) are stimulated (tab.1).

Also a substitution effect is at play here: when land productivity increases, land prices tend to decrease as a given agricultural output can be produced with a lower amount of land. This causes a substitution away from relatively costly factors, capital and labor, to the cheaper land. Capital price decreases and capital tends to exit the region. (The same reasoning applies, reversed, in case of a land productivity decrease).

If we consider capital prices and flows, due to the (low) degree of substitution between capital and land, the aggregate effect always prevails.

Nevertheless this is not generally true considering the land price where the productivity effects dominate the aggregate effect. An example particularly clear is CHIND: here land productivity unambiguously increases with a positive effect on GDP, but land price decreases.

Note also that generally terms of trade effects act as smoothers: a relative decrease in GDP induces a shift toward domestic goods by domestic and foreign consumers attracted by decreasing prices. This decreases the price of imports and increases the price of exports. Again this is not always the case. In three regions terms of trade effects amplify rather than smooth the GDP result: USA, where changes in terms of trade strengthen the negative performance of production and JPN and CHIND where they reinforce the positive one.

The interplay between terms of trade and capital flows explains also the different sign that sometimes is observable in the household utility index respect to GDP.

Finally tab. 2 reports industrial production. In general positive GDP and productivity changes translate in similar changes in production level, particularly of agricultural industries.

Tab. 1

	Exogenous Shocks on Land Productivity in Different Agricultural Industries (% change w.r.t. baseline)			Endogenous Responses (% change w.r.t. baseline)				
	Rice	Wheat	Cereal Crops	GDP	Private Utility Index	Co2 Emissions	Terms of Trade	Internat. Capital Flows
USA	1.214	1.497	-1.702	-0.023	-0.047	-0.056	-0.183	-0.152
EU	1.811	1.046	-1.134	0.006	-0.005	-0.004	-0.048	0.019
EEFSU	1.856	3.641	-0.822	0.011	0.008	0.001	-0.016	0.037
JPN	0.973	0.399	-1.999	0.004	0.012	0.035	0.023	0.082
RoA1	6.624	8.993	3.619	0.067	0.046	0.032	-0.080	0.1
EEx	1.349	2.063	-1.659	-0.013	0.047	0.010	0.214	-0.002
CHIND	3.962	5.068	0.870	0.212	0.215	0.012	0.095	0.98
RoW	-1.791	-1.599	-4.891	-0.126	-0.099	-0.175	0.076	-0.35

Tab. 2

Endogenous Responses: Industry Output by Region (% change w.r.t. baseline)								
	USA	EU	EEFSU	JPN	RoA1	EEx	CHIND	RoW
Rice	-0.581	-0.498	0.045	-0.086	1.867	-0.015	0.461	-0.505
Wheat	-1.025	-0.507	0.513	-3.835	5.851	-0.94	0.715	-2.604
CerCrops	-0.523	0.867	0.794	0.511	5.304	0.228	1.7	-3.335
VegFruits	-0.386	0.379	0.129	0.206	0.08	-0.111	0.352	-0.355
Animals	-0.348	0.112	0.096	0.024	0.182	-0.077	0.4	-0.435
Forestry	-0.011	0.023	0.023	-0.022	-0.057	0.022	-0.082	0.01
Fishing	0.126	-0.033	0.017	0.004	-0.11	-0.01	0.082	0.032
Coal	0.05	-0.021	-0.012	-0.127	-0.079	-0.008	-0.153	0.194
Oil	0.08	0.005	-0.003	-0.079	-0.071	-0.004	-0.223	0.205
Gas	0.089	0.018	-0.016	-0.053	-0.191	-0.012	-0.666	0.438
Oil_Pcts	-0.077	-0.006	0.015	0.01	0.078	-0.014	0.162	-0.04
Electricity	0.02	-0.006	-0.013	-0.012	-0.135	0.002	-0.051	0.094
Water	0.004	0.003	0.006	-0.008	0.016	0.035	-0.037	0.008
En_Int_ind	0.145	-0.027	-0.042	-0.094	-0.276	-0.076	-0.332	0.257
Oth_ind	-0.165	0.027	0.032	0.058	-0.072	-0.054	0.284	-0.345
MServ	0.015	-0.012	-0.012	-0.002	-0.018	0.007	0.082	0.085
NMserv	0.004	-0.004	0.005	-0.008	0.022	0.034	-0.076	0.017

Tab. 3

Endogenous Responses: Primary Input (Real) Prices by Regions (% change w.r.t. baseline)								
	USA	EU	EEFSU	JPN	RoA1	EEx	CHIND	RoW
Land	1.948	-0.003	0.422	-0.399	0.873	1.091	-0.745	2.156
Lab	-0.121	-0.037	-0.02	0.015	0.003	-0.088	0.977	-0.414
Capital	-0.121	-0.038	-0.023	0.016	0.034	-0.096	1.04	-0.451
NatlRes	0.304	-0.046	-0.043	-0.048	-0.414	-0.108	-0.103	0.061
Endogenous Responses: Industry Prices by Regions (% change w.r.t. baseline)								
Rice	-0.932	-2.311	-1.726	-0.826	-4.646	-0.916	-4.924	3.515
Wheat	-1.586	-1.569	-3.067	-1.776	-4.37	-1.488	-5.439	0.911
CerCrops	3.374	1.976	1.568	1.761	-0.409	2.635	-0.315	4.395
VegFruits	0.9	0.247	0.335	0.157	0.521	0.618	-0.017	0.73
Animals	1.653	0.181	0.297	0.6	0.495	0.648	-0.113	0.782
Forestry	-0.048	0.058	0.072	0.104	0.034	0.048	0.744	-0.357
Fishing	-0.079	0.053	0.062	0.115	0.031	0.023	0.354	-0.275
Coal	-0.157	-0.011	0.031	0.068	0.083	0.018	0.486	-0.091
Oil	-0.088	0.013	0.034	0.069	0.028	0.015	0.323	-0.085
Gas	-0.21	0.012	0.032	0.109	0.04	0.016	0.55	-0.343
Oil_Pcts	-0.072	0.015	0.033	0.085	0.033	0.017	0.336	-0.089
Electricity	-0.214	0.005	0.029	0.124	0.12	0.017	0.655	-0.339
Water	-0.18	0.007	0.038	0.132	0.125	0.023	0.754	-0.381
En_Int_ind	-0.163	0.018	0.044	0.123	0.095	0.05	0.43	-0.2
Oth_ind	0.131	0.092	0.087	0.093	0.129	0.131	0.069	0.187
MServ	-0.188	0.015	0.045	0.131	0.118	0.037	0.52	-0.339
NMserv	-0.178	0.017	0.046	0.131	0.115	0.055	0.625	-0.293

1.3.2 Impacts of climate-change induced sea level rise

Methodology

Bosello et al. (2004), propose an integrated assessment exercise valuating the economy-wide estimates of sea-level rise for eight world macroregions in an hypothetical "no protection scenario" based on a uniform sea-level average increase of 25 cm. The methodology followed is similar of the one followed in the previous exercise. As far as land loss is concerned, the amount of land loss - implemented in the CGE model as loss of the production factor "land" - is calculated by an "external" module based on the Global Vulnerability Assessment (Hoozemans *et al.*, 1993), Bijlsma *et al.* (1996), Nicholls and Leatherman (1995), Nicholls *et al.* (1995) and Beniston *et al.* (1998).

Results

Looking at table 4: the fraction of land lost is quite small in all regions. The highest losses affect Oil Exporter Countries (EEx), loosing 0.18% of their dry land, followed by Japan (JPN) and the Rest of the World (RoW), both with a 0.15% loss. The value of the land lost is large in absolute terms, but quite small if compared to GDP (EEx has the biggest value: 0.1% of GDP). Generally, developing regions – CHIND and RoW – experience direct losses higher than those of developed countries, because their economies are more agricultural. The high loss in EEx is partly due to their losses of energy exports (see below).

GDP falls in all regions, especially in CHIND (-0.030%), EEx (-0.021%) and RoW (-0.017%).[1] Two aspects are worth noticing: first, general equilibrium effects influence the cost distribution. GDP losses for the Former Soviet Union (EEFSU), the Rest of Annex 1 (RoA1), EEx and RoW are lower than the direct cost of the lost land, whereas the opposite occurs to USA, EU, JPN and CHIND; in the case JPN, the GDP losses are even 10 times as large as the direct costs. Second, there is no direct relationship between the environmental impact and the economic impact. For instance, JPN exhibits the second highest amount of land lost, but the second smallest loss of GDP. CHIND, on the contrary, has the third smallest relative amount of land lost, but the highest cost in terms of GDP. This highlights the importance of conducting a general equilibrium analysis in this context, as substitution effects and international trade work as impact buffers or multipliers.

Since land is an essential factor in agriculture, agricultural industries bear the biggest impact of the loss of land, as can be seen in terms of higher prices and lower production levels (Table 5).

The regional impacts are illustrated in Table 6. In general, lower GDP losses are associated with investment inflows, so it is important to clarify the role played here by the investments.

Land loss is a direct resource shortfall, that is, a negative economic shock, which reduces income and consumption levels. The value of primary resources tends to fall, with the exception of the resource “land”, which is getting scarcer.

The international allocation of investments is driven by the relative price of the capital in each country. The higher the capital return, the higher the share of international investments

[1] Note that the change in the *net* domestic product is the sum of the change the *gross* domestic product and the direct costs of land loss. This implies that, overall, the direct cost method underestimates the true costs of land loss, a point also noted by Darwin and Tol (2001).

flowing into a country, with implications in terms of regional GDP variations, since investment is one component of GDP.

In turn, changes in the price of capital services are determined by two overlapping, and opposite, effects. On one hand, the negative shock lowers the value of national resources, including capital. On the other hand, economies try to substitute land with capital. Capital supply is fixed in the short run, though, and the higher demand for capital translates into higher capital returns.

The fall in the relative price of capital services is particularly strong in EEx, CHIND and RoW. This explains why regional GDP decreases relatively more than private consumption in these regions (as can be seen through the changes in the households utility index).

International trade also matters, through its effects on the terms of trade. In particular, two main effects are at work here: higher world prices for agriculture benefit net-exporters of agricultural goods (USA, RoA1, EEx), whereas lower prices for oil, gas, coal, oil products, electricity, energy intensive industries harm the net-exporters of energy products (EEx, EEFSU).

Labour, capital and *energy* substitute the land loss. At the same time, overall economic activity falls. In the OECD regions, the former effect dominates. The growth in market services raises the consumption of oil products, mainly by the transportation industries. Consequently, CO_2 emissions increase, despite the fall in GDP. In developing regions, the latter effect dominates; the decrease of GDP is associated with a decrease in CO_2 emissions. carbon dioxide emissions rise.

Tab. 4: No protection scenario: main economic indicators

	Land lost (% change w.r.t. baseline)	Land lost in km^2	Value of land lost		GDP (% change w.r.t. baseline)	Household utility index (% change w.r.t. baseline)	CO_2 Emissions (% change w.r.t. baseline)
			1997 million US$	% of GDP			
USA	-0.055	5000	102	0.0002	-0.002	-0.005	0.010
EU	-0.032	1015	187	0.0010	-0.001	-0.005	0.012
EEFSU	-0.018	4257	611	0.0100	-0.002	-0.006	0.005
JPN	-0.153	575	20	0.0001	-0.001	0.003	0.035
RoA1	-0.006	1065	221	0.0030	0.000	0.008	0.015
EEx	-0.184	31847	15556	0.1010	-0.021	-0.015	-0.008
CHIND	-0.083	10200	324	0.0030	-0.030	-0.062	-0.024
RoW	-0.151	71314	13897	0.0600	-0.017	-0.014	-0.012

Tab. 5: No protection scenario: price and production levels by industry

	Price index for world supply (% change w.r.t. baseline)	Quantity index for world supply (% change w.r.t. baseline)
Rice	0.484	-0.054
Wheat	0.314	-0.040
CerCrops	0.389	-0.042
VegFruits	0.360	-0.058
Animals	0.329	-0.045
Forestry	-0.102	-0.017
Fishing	-0.057	-0.020
Coal	-0.068	-0.012
Oil	-0.081	0.004
Gas	-0.066	0.001
Oil_Pcts	-0.075	0.004
Electricity	-0.058	-0.007
En.Int_in	-0.042	-0.013
Oth_ind	0.044	-0.033
MServ	-0.040	0.003
NMServ	-0.040	0.007

Tab. 6: No protection scenario: industrial output and price of primary factors by region

Industry Output (% change w.r.t. baseline)								
	USA	**EU**	**EEFSU**	**JPN**	**RoA1**	**EEx**	**CHIND**	**RoW**
Rice	-0.020	0.040	-0.013	-0.019	0.056	-0.086	-0.028	-0.073
Wheat	-0.051	-0.022	0.008	-0.259	0.043	-0.080	-0.033	-0.076
CerCrops	-0.020	0.037	0.060	-0.069	0.103	-0.116	-0.025	-0.083
VegFruits	-0.029	0.031	0.036	-0.078	0.087	-0.128	-0.050	-0.078
Animals	-0.026	-0.016	0.020	-0.035	0.022	-0.094	-0.077	-0.079
Forestry	-0.041	-0.024	-0.026	-0.031	-0.024	-0.015	-0.001	-0.011
Fishing	-0.007	-0.012	-0.017	-0.019	-0.033	-0.015	-0.036	-0.016
Coal	-0.009	-0.013	-0.008	-0.091	-0.058	0.016	-0.007	-0.012
Oil	-0.011	-0.024	-0.008	-0.064	-0.033	0.013	0.019	0.000
Gas	0.003	-0.036	-0.005	-0.042	-0.048	0.036	0.022	-0.014
Oil_Pcts	0.014	0.013	0.009	0.017	0.024	0.002	-0.034	-0.006
Electricity	0.001	-0.010	0.003	-0.010	-0.023	-0.007	-0.025	-0.006
En_Int_ind	-0.013	-0.015	-0.007	-0.040	-0.051	0.006	-0.003	-0.005
Oth_ind	-0.021	-0.017	-0.019	-0.010	-0.009	-0.083	-0.035	-0.071
Mserv	0.003	0.001	0.000	0.005	0.002	0.010	-0.036	0.011
NMServ	0.003	0.003	0.005	0.003	0.010	0.009	0.060	0.014
Investment	0.008	0.008	-0.013	0.031	0.022	-0.066	-0.172	-0.043
Price of primary factors (% change w.r.t. baseline)								
Land	0.534	0.514	0.532	1.019	0.607	0.804	0.467	0.802
Labor	-0.051	-0.051	-0.059	-0.002	-0.026	-0.123	-0.196	-0.108
Capital	-0.051	-0.048	-0.061	-0.001	-0.025	-0.127	-0.212	-0.112

1.4. Potential for future developments: social-economic evaluation of changes in ecosystem services in the Mediterranean-Black Sea region.

The use of CGE models to provide economic assessment of climate change impacts, offers a useful example on how other kinds of environmental changes, like those linked to ecosystem services, can be evaluated economically.

A key issue is the translation of the environmental information into an economic format suitable to be “processed” by a CGE model; that is changes in productivity, supply, or demand for factors of production, goods or services.

Take as an illustrative example the case of biodiversity loss in a specific region like the Mediterranean and Black Sea.

In principle, this complex phenomenon can be evaluated economically by means of a CGE model, once biodiversity services have been linked to relevant economic indicators for the economic systems under scrutiny. Many possibilities are at hand.

One would be for instance to decrease appropriately the productivity parameters of those economic sectors whose production depends on biodiversity, like say the pharmaceutical and/or the tourism sectors. This can be done either decreasing the productivity of the factors of production employed by these sectors, or decreasing the productivity of health care and tourism services themselves when they are used as intermediates.

Alternatively, always working on the “supply side”, biodiversity could be explicitly introduced as a production factor contributing to production together with other “traditional” inputs, labour and capital, and then it can be appropriately reduced.

Finally, changes in demand can be also modelled: for example a decrease in visitors’ arrivals due to the loss of attractiveness of an area with impoverished biodiversity will be modelled as a decrease in demand for the tourism industry in that region.

Once these changes have been calculated, they are imposed as input information to the CGE model. This information take the form of “shocks” to an initial economic equilibrium determining a new final equilibrium. By comparing the two different states of the world, insights on costs and benefits for the overall economic system can be gained.

It is worth to note that the determination of changes in productivity, production or demand is only the first step for the economic evaluation provided by the CGE model. Indeed it will offer a “general equilibrium”, or in different words, a “welfare” assessment of those initial “shocks”, taking into account all the adjustment mechanisms triggered by the initial perturbations.

At the same time, as well exemplified by the case of biodiversity, “linking” ecosystem services to clearly identifiable economic variables (productivity, demand or supply) is fundamental to allow the evaluation itself. This phase requires a high effort of “integration” or multidisciplinarity spanning over natural and social sciences and involving different expertises.

2. Bayesian Belief Networks

In recent years the use of Bayesian modelling in environmental applications has started to become popular. Bayesian models can be viewed as DPSIR (Driver Pressure State Impact Response) models that have a numerical basis with semi quantitative predictive functions.

Currently ELME, an EU funded project under framework 6, is using this technique to explore how changes in human lifestyles may impact the marine environment. Approximately 30 models have been produced examining four major issues, habitat loss, eutrophication, chemical pollution and unsustainable extraction of marine living resources in the four regional seas surrounding the EU, the Black, Mediterranean and Baltic seas and the North East Atlantic. These models in conjunction with predictive scenarios of driver variables up to 2025 will be used to highlight probable issues facing policy managers in the next 20 years.

A simple example of a Bayesian Belief Network (BBN) is shown in figure 1; arrows represent links between variables; the variable that the arrow points from directly or indirectly impacts the variable it is pointing to. Using the terminology of DIPSAR models, the highest level of variable which impact throughout the model are the drivers, these directly impact the pressures and from there the state variables.

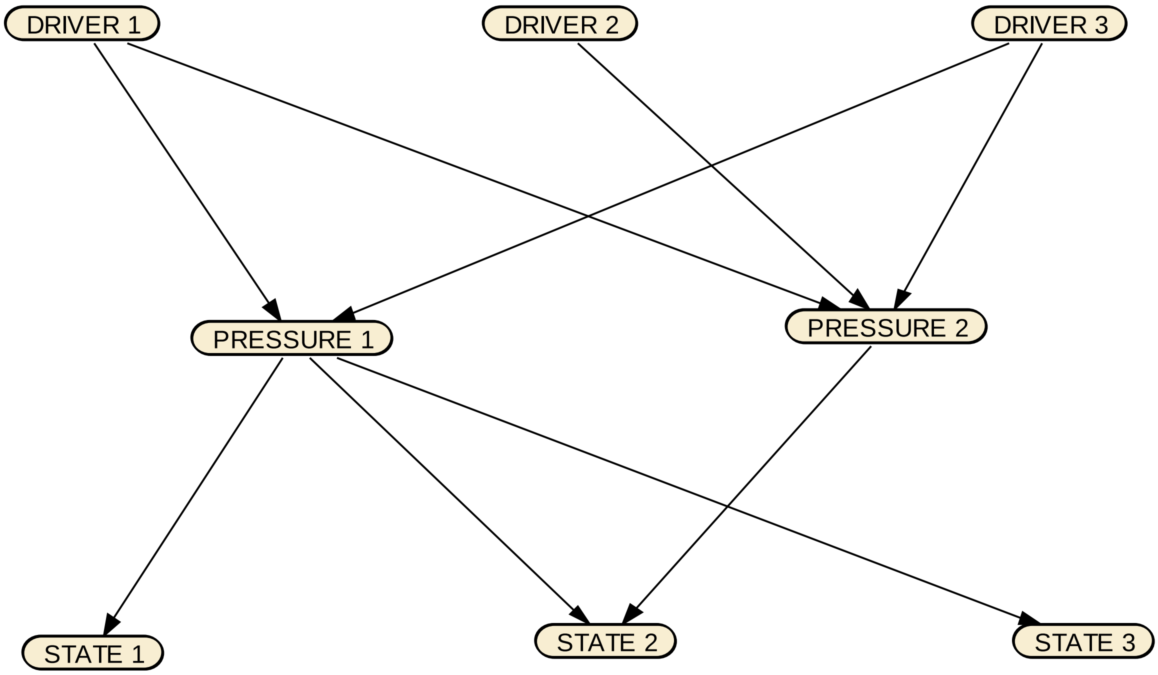

Fig. 1. A simple Bayesian Belief Network.

The model works by determining the probability that in a given situation a variable will fall within a certain range of data. The boundaries of these ranges are artificially imposed by the modeller based on the distribution of the data (generally splitting the data into two around the mean of those data) or pre existing important threshold values. In environmental modelling these pre existing thresholds are generally biological (a threshold concentration of a substance that is known to have a biological impact) or legislative (a concentration of a pollutant above which an environmental standard is breached).

Historical data are used to populate the model so as to determine the relationships between variables linked to each other in the model. From these data the probability of the value of the variable falling within specified ranges is calculated. The relationship of these states with variables impacting them are also calculated such that manipulation of those impacting variables allows updating of the rest of the model. A populated BBN is shown in figure 2, in this case the states of each variable are labelled as either ‘true’ or ‘false’.

The populated model can then be used to forecast the impact of changing the state of variables and examining how they influence the rest of the model. In figure 3 the driver variables have been set to ‘false’. In the context of an environmental model we could suggest that these three driver are ‘Government subsidies’, ‘high fines’, and ‘level of investment’. We can then manipulate these variables on the basis of predictions as to their likely state in the future, *or* to investigate the impact *if* these courses of action were taken. The rest of the model updates to align with the probabilities changed from this forcing. The probability values can be compared with the original model’s probability values so as to determine the impact of changes of the drivers on the rest of the model.

This methodology has two major advantages over more typical mechanistic modelling techniques in that the functional relationship between two variables need not be know. The model simply bases the relationship between the variables based on probabilities. Instead of *y* being a function of *x* such that when *x* is of a known value the model calculates a single value of *y*, this system simply calculates the probability that *y* will be a certain state given a known value of *x*. The second advantage of Bayesian modelling results from this, the capacity of a model to function even with large amounts of missing data. Some variables may be included functionally on the basis of *expert opinion* whereby the probability of variable *y* being in a particular state for a given value of *x* can be specified rather than relying on data to calculate those probabilities.

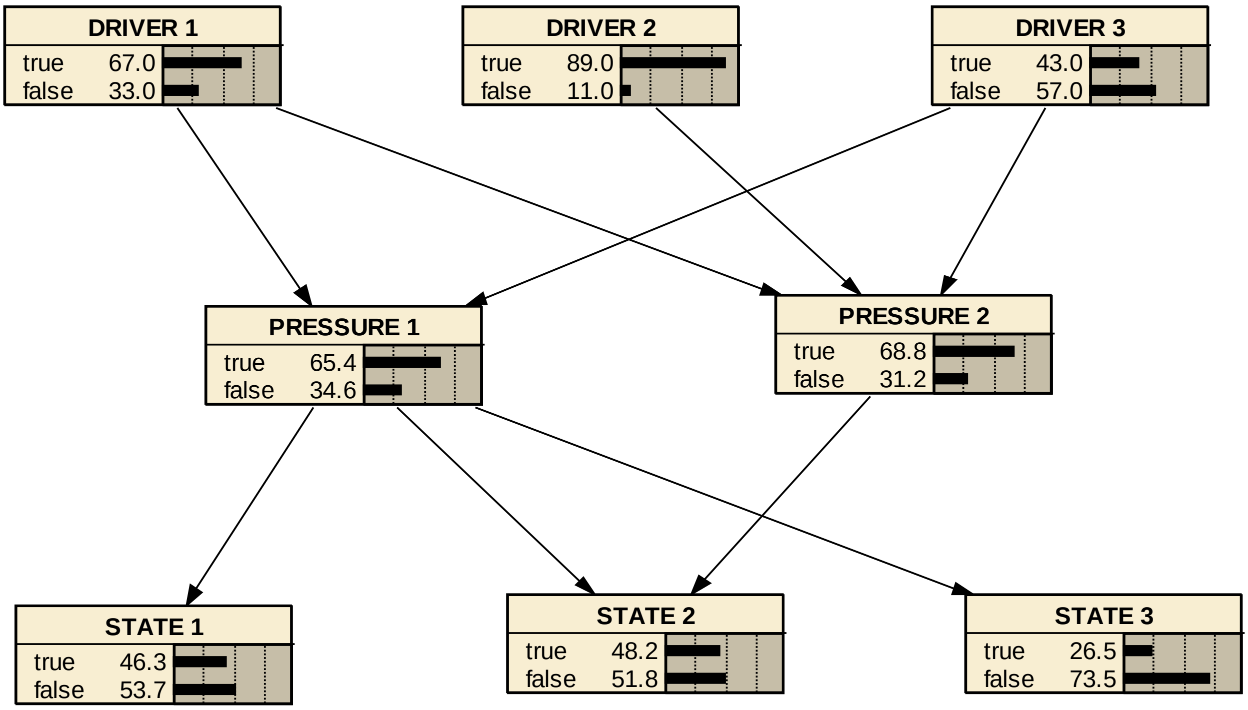

Fig. 2. A BBN populated with data showing the probabilities that each variable will be in one other state (true or false).

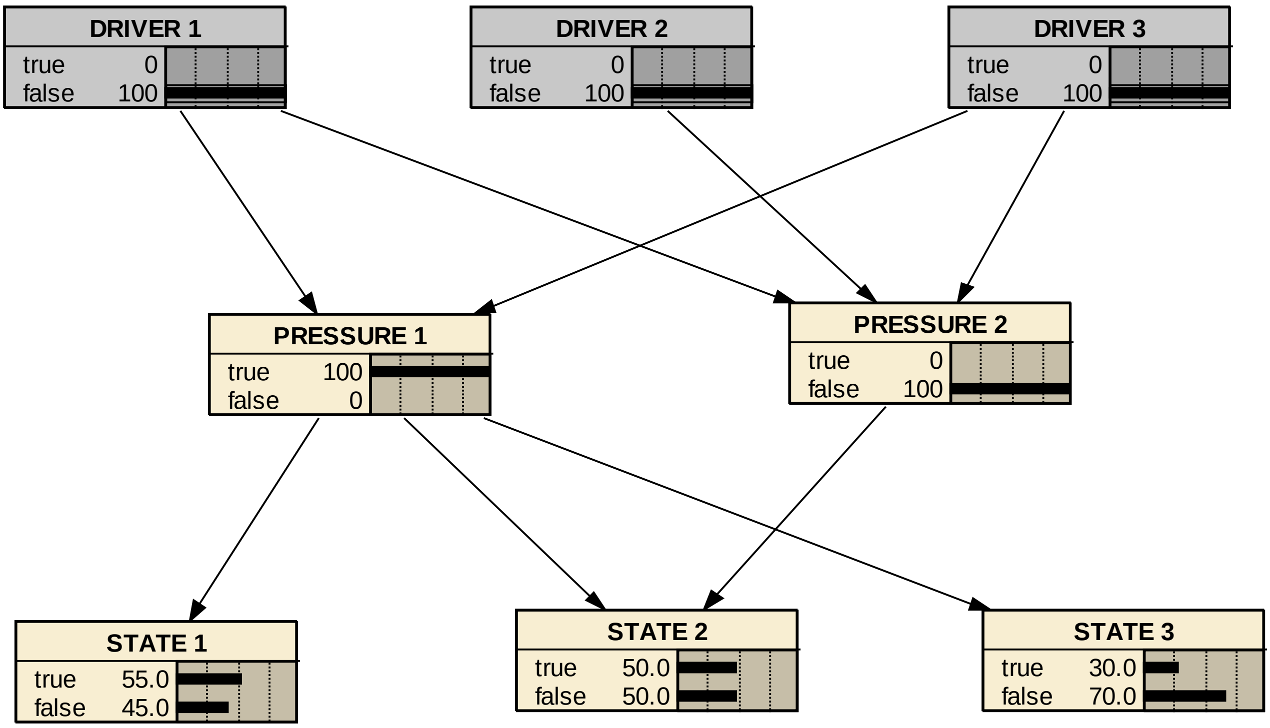

Fig. 3. Predictive scenarios based on the suggested state of drivers in a BBN, note the differences in the State variable probabilities between figures 2 and 3.

References

Beniston, M., Tol, R. S. J., Delecolle, R., Hoermann, G., Iglesias, A., Innes, J., McMicheal, A. J., Martens, W. J. M., Nemesova, I., Nicholls, R. J., & Toth, F. L., 1998, "Europe," in *The Regional Impacts of Climate Change -- An Assessment of Vulnerability, A Special Report of IPCC Working Group II*, R. T. Watson, M. C. Zinyowera, & R. H. Moss, eds. (eds.), Cambridge University Press, Cambridge, pp. 149-185.

Bijlsma, L., Ehler, C. N., Klein, R. J. T., Kulshrestha, S. M., McLean, R. F., Mimura, N., Nicholls, R. J., Nurse, L. A., Perez Nieto, H., Stakhiv, E. Z., Turner, R. K., & Warrick, R. A., 1996, "Coastal Zones and Small Islands," in *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses -- Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, 1 edn, R. T. Watson, M. C. Zinyowera, & R. H. Moss, eds. (eds.), Cambridge University Press, Cambridge, pp. 289-324.

Boerlage, Brent, 1994, Link Strength in Bayesian Networks, Tech. Report 94-17, Dept. Computer Science, Univ. of British Columbia, BC.

Bosello, F., Lazzarin, M., Roson, R. and R.S.J. Tol, 2004, “Economy-wide estimates of climate change implications: sea-level rise”, FEEM Note di Lavoro 96.04.

Bosello, F. and J. Zhang, 2005, “ Assessing climate change impacts: Agriculture ”, FEEM Note di Lavoro 94.2005.

Charniak, Eugene, 1991, “Bayesian networks without tears” in AI Magazine (Winter 1991), 12(4), 50-63.

Darwin, R. F. and Tol, R. S. J., 2001, "Estimates of the Economic Effects of Sea Level Rise", *Environmental and Resource Economics*, 19, 113-129.

Dean, Thomas L. and Michael P. Wellman, 1991, Planning and Control, Morgan Kaufmann, San Mateo, CA.

Giorgi, F. and L.O. Mearns, 2001, 'Calculation of Average, Uncertainty Range, and Reliability of Regional Climate Changes from AOGCM Simulations via the Reliability Ensemble Averaging (REA) Method,’ *Journal of Climate*, **15**, 1141-1158.

Heckerman, David, 1993, “Causal independence for knowledge acquisition and inference” in Uncertainty in Artificial Intelligence: Proc. of the Ninth Conf. (July, Washington, DC), David Heckerman and Abe Mamdani (eds.), Morgan Kaufmann, San Mateo.

Heckerman, David and Jack Breese, 1994, "A new look at causal independence" in Uncertainty in Artificial Intelligence: Proc. of the Tenth Conf. (July, Seattle, WA), Ramon Lopez de Mantaras and David Poole (eds.), Morgan Kaufmann, San Mateo, CA.

Heckerman, David, Abe Mamdani and Michael P. Wellman, 1995, “Real-world applications of Bayesian networks” in Communications of the ACM, 38(3), 24-26. Introduction to this special issue of CACM on belief networks.

Henrion, Max, John S. Breese and Eric J. Horvitz (1991) “Decision Analysis and Expert Systems” in AI Magazine (Winter 1991), 12(4), 64-91.

Hertel, T.W., (1996) *Global Trade Analysis: Modeling and applications*, Cambridge University Press.

Hoozemans, F. M. J., Marchand, M., & Pennekamp, H. A. 1993, *A Global Vulnerability Analysis: Vulnerability Assessment for Population, Coastal Wetlands and Rice Production and a Global Scale (second, revised edition)*, Delft Hydraulics, Delft.

Lauritzen, Steffen L. and David J. Spiegelhalter, 1988, “Local computations with probabilities on graphical structures and their application to expert systems” in J. Royal Statistics Society B, 50(2), 157-194.

Matheson, James E., 1990, “Using Influence diagrams to value information and control” in Influence Diagrams, Belief Nets and Decision Analysis, Robert M. Oliver and J. Q. Smith (eds.), John Wiley & Sons, Chichester.

Neapolitan, Richard E., 1990, Probabilistic Reasoning in Expert Systems: Theory and Algorithms , John Wiley & Sons, New York.

Nicholls, R. J. & Leatherman, S. P., 1995, "Global Sea-level Rise," in *When Climate Changes: Potential Impact and Implications*, K. M. Strzepek & J. B. Smith, eds. (eds.), Cambridge University Press, Cambridge.

Nicholls, R. J., Leatherman, S. P., Dennis, K. C., and Volonte, C. R., 1995, "Impacts and Responses to Sea-Level Rise: Qualitative and Quantitative Assessments", *Journal of Coastal Research*, 14, 26-43.

Qi, Runping, 1994, Decision graphs: Algorithms and applications to influence diagram evaluation and high-level path planning under uncertainty, PhD Thesis, Dept. of Computer Science, Univ. of British Columbia, Canada.

Also Tech. Report 94-27, Dept. of Computer Science, Univ. of British Columbia.

Qi, Runping and David Poole, 1995, “New method for influence diagram evaluation” in Computational Intelligence, 11(3).

Rosenzweig, C., and Hillel, D., 1998, ' Climate Change and the Global Harvest: Potential Impacts of the Greenhouse Effect on Agriculture. ' Oxford University Press. New York, N.Y..

Russell, Stuart and Peter Norvig, 1995, Artificial Intelligence: A Modern Approach, Prentice Hall, Englewood Cliffs, NJ.

Shachter, Ross D., 1986, “Evaluating influence diagrams” in Operations Research, 34(6), 871-882.

Shachter, Ross D., 1988, “Probabilistic inference and influence diagrams” in Operations Research, 36(4), 589-604.

Shachter, Ross D., 1989, "Evidence absorption and propagation through evidence reversals" in Proc. of the Fifth Workshop on Uncertainty in Artificial Intelligence (Windsor, Ont.), 303-308. Later republished in: Henrion, Max (ed.) (1991) Uncertainty in Artificial Intelligence 5, North-Holland, Amsterdam.

Smith, James E., Samuel Holtzman and James E. Matheson, 1993, "Structuring conditional relationships in influence diagrams" in Operations Research, 41(2), 280-297.

Spiegelhalter, David J., A. Philip Dawid, Steffen L. Lauritzen and Robert G. Cowell, 1993, "Bayesian analysis in expert systems" in Statistical Science, 8(3), 219-283.

Zhang, Lianwen (Nevin), 1993, A computational theory of decision networks, PhD thesis, Dept. of Computer Science, Univ. of British Columbia, BC, Canada. Also released as Tech. Report 94-8, Dept. of Computer Science, Univ. of British Columbia, BC, Canada.

Zhang, Lianwen (Nevin), Runping Qi and David Poole, 1994, "A computational theory of decision networks" in International Journal of Approximate Reasoning, 11(2), 83-158.

Zhang, Lianwen (Nevin) and David Poole, 1996, "Exploiting causal independence in Bayesian network inference" in Journal of Artificial Intelligence Research, 5, 301-328.