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Integrated Scenarios for Assessing Biodiversity Risks†

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ABSTRACT
The rapid loss of biodiversity (however measured) constitutes an urgent need to develop policy strategies that reduce the anthropogenic pressures on biodiversity. To go beyond short-term curative measures, such strategies must address the driving forces causing the pressures in an integrated fashion, covering a wide range of policy domains. The development of scenarios and their illustration by modelling are essential tools to study the aggregate human impacts on biodiversity, and to derive well founded policy options to preserve it. However, so far socio-economic, climate and biodiversity models exhibit a wide range of assumptions concerning population development, economic growth and the resulting pressures on biodiversity. This paper summarizes the efforts undertaken in the framework of the ALARM project by an interdisciplinary team of economists, climatologists, land use experts and modellers to identify pressures and drivers, and to derive effective policy strategies. It describes the challenges of such a kind of work, bringing together different world views necessarily inherent to the different fields of investigation, presents preliminary results, indicates necessary policy priorities and suggests urgent issues for future research. Copyright © 2007 John Wiley & Sons, Ltd and ERP Environment.

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Introduction

THERE IS A BROAD CONSENSUS AMONGST EXPERT SCHOLARS THAT THE RAPID LOSS OF BIODIVERSITY continues, although the number of species lost (let alone the loss of ecosystem and genetic diversity) cannot be quantified. Biodiversity is influenced by a combination of natural processes (e.g. evolution, succession) and anthropogenic pressures (e.g. land use, nitrogen deposition, climate change, alien species invasions). Changes in biodiversity have impacts on ecosystem stability (although it is not fully understood how) and on the socio-economic system. Biodiversity is an element of the linked human–environment system but research so far has mainly concentrated on isolated elements of this system and not on the interlinked system as a whole. Developing effective strategies for biodiversity preservation has been declared a key political task; the World Summit for Sustainable Development (WSSD) in Johannesburg 2002 and the Biodiversity Convention (CBD) call for a 50% reduction in the

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loss of biodiversity by the year 2010, and the European Union has set itself the target to end biodiversity loss in its territory by the same date (WSSD, 2002; Council, 2004). However, this will not be achievable without significant policy changes. Such strategies will require the transdisciplinary combination of capabilities, concepts, insights and tools of several disciplines (e.g. ecology, chemistry, economics and political science) and stakeholders (CBD, 2001, 2006).

For new policies to be effective, socio-economic research has to improve the understanding of damage mechanisms, of how social and economic driving forces create pressures affecting biodiversity. A major challenge is to ensure that the assumptions used by the various disciplines in their respective research programmes are consistent. The current situation of non-integrated research tools and often contradictory perceptions, recommendations and predictions is not sustainable. ALARM is one of the EU funded research efforts designated to overcome this kind of problem. It is an integrated project (IP) in the EU's Sixth Framework Programme comprising 67 scientific institutes with about 250 scientists participating in the five project modules, testing methods to assess the loss of biodiversity and to develop strategies to reverse this trend (Settele *et al.*, 2005). One of the tools developed for the latter purpose is a set of integrated scenarios developed by the interdisciplinary, cross-module modelling group, and their assessment by project participants and external stakeholders. This is though to contribute to

- integrated knowledge production, including risk assessment tools,
- the development of adaptive strategies, robust in diverse futures, to actively deal with uncertainty,
- anticipation of long-term and indirect effects (foresight regarding possible futures),
- the iterative formulation of objectives, reflecting diverse values (e.g. by discussions with the advisory boards),
- interactive strategy development by actors with various sources of influence and
- enhancing the congruence of governance space and problem space in problem definitions.

If bioscience analysis could produce one clear-cut, unambiguous, comprehensive and sensitive measure of biodiversity, it has been argued, this could by means of its simplicity be policy relevant. However, the state of the art in bioscience does not support this ambition, and the trend of biodiversity measurement goes another way, with important implications for the choice of models to be used in analysing the current and possible future trends of biodiversity loss. The CBD, for instance, has chosen the level of ecosystems as the basis for describing biodiversity, not the more familiar level of species diversity or the rather unexplored one of genetic diversity. The indicators chosen by the CBD in October 2003 to measure biodiversity trends do not include an aggregate indicator for ecosystem diversity, but rather species-based state, plus pressure and response indicators in a somewhat erratic mix brought about by political compromising and data availability considerations (CBD, 2003a, 2003b).

In a nutshell: comprehensive measures of total biodiversity are unavailable, and proxies are unreliable, time consuming, expensive or insufficient. Consequently, while still important for biodiversity monitoring, bioscience based measures (often focusing on some selected elements of biodiversity) offer only limited potential for deriving political biodiversity protection priorities. In this situation, and given the urgency of providing policy relevant information for the prevention of further losses, another basis must be found for deriving priorities for action.

The Policy Challenge

It seems improbable or at least a matter of a distant future that biodiversity will become institutionalized as a policy field in its own right, on at least formally equal footing with fiscal, foreign or agricultural policy. While social policy, after a century on the agenda, is fairly well established but in no way of equal

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political weight compared with economic policy, development cooperation, gender equity and environmental policy are 'young policies' still struggling not to be overlooked, after more than three decades of having been put on the political agenda (Bundesregierung, 1971). Given this experience, in order to be effective *right now*, biodiversity protection (politics and policies) should not be separated from other policy domains with the intention to avoid compromises, but, to the contrary, they need to get out of the preservation policy niche to be effective; i.e., they need to be 'mainstreamed'. In other words, institutionalization of biodiversity protection is an essential condition of success (IUCN CEM, 2006), and it must cover all three levels of institutions, i.e. organizations, mechanisms and orientations (Czada, 1995; Spangenberg *et al.*, 2002). While organizations (public agencies, expert groups, NGOs, international conventions, . . .) do exist and orientations are documented by opinion polls, volunteering and on the policy level by legislation and the ratification of conventions, mechanisms represent the main problem. Although there is still room for improvement regarding capacity building and education, the key challenge is to integrate biodiversity concerns into the day-to-day working mechanisms of state, business and society.

Changing the *modus operandi* of our societies is a huge challenge, but a necessary one: for the safeguarding of biodiversity, end-of-the-pipe solutions and compensation such as establishing protected areas are simply not enough, as long as the pressures on biodiversity continue unabated.

Consequently, any effective biodiversity protection strategy must be broadly based, addressing production, consumption and administration patterns and attitudes alike, and so must scenarios developed to derive efficient strategies for biodiversity pressure reduction. This requires a paradigm shift – which is the common ground for biodiversity and sustainability policies (Martens, 2006). Consequently, despite the explicit international targets and programmes, the best chance for biodiversity preservation is not 'to go it alone', but to integrate biodiversity into sustainability politics (accepted for instance as the overarching policy principle by the European Union).

However, before promising strategies can be developed and integrated into the sustainability context, first the relevant pressures have to be identified in order to properly represent them in the scenario narratives and either in the model runs or in their interpretation (Spangenberg, 2007). Otherwise, the scenarios might be consistent and interesting from an economic, social or agricultural point of view, but irrelevant (since they do not permit relevant conclusions) for biodiversity reservation.[1]

Focus on Pressures

For effective biodiversity protection policies, pressure reduction must be achieved for all three levels of biodiversity, and thus the relevant pressures have to be identified. Fortunately, in Europe, the main anthropogenic disturbance factors (i.e. pressures) are fairly well established (EuroStat *et al.*, 1998; Spangenberg, 1999; UNEP, 2002; EEA, 2004, 2005; see Spangenberg, 2007, for a more detailed analysis) and could be summarized in a list of relevant pressures for each level biodiversity, i.e. ecosystems, species and genetic. Combining the three lists resulted in a *biodiversity pressure inventory*, permitting us to identify those pressures that are mentioned more than once as very important pressures (VIPs) and to address them in constructing the scenarios and deriving policy recommendations (reducing them is an obvious priority for biodiversity protection policies). In total, the very important pressures (mentioned in at least two of the three lists of key pressures) in a combined inventory are the following.

[1] Besides initial desktop research, the detailed identification of relevant pressures was conducted by the ALARM socio-economic team, in close cooperation with the bioscience modules. The results were refined after discussions with a wide range of colleagues at the ALARM General Meetings. They are documented in the project deliverables and will be published separately in more detail.

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- *Fragmentation*. The reduction of biotope size and thus of population numbers is threatening genetic diversity through reduction of habitats below the level necessary for successful reproduction, and by the stochastic processes of genetic drift (Trepl, 1999).
- *Overuse and land transformation*. Exploiting biological resources beyond their regeneration capacity (be it on the species level, e.g. in the case of fish stocks, or by changing the ecosystem character, e.g. by draining of wetlands, or overburdening ecosystem resilience, e.g. by waste disposal or tourist use) is one of the key anthropogenic pressures on human-managed ecosystems.
- *Chemicals*. Regarding pesticides, even the 'dirty dozen' including DDT, Aldrin and Dieldrin has not yet been phased out completely, although their toxic effects have been known for decades (Carson, 1963). Other persistent organic chemicals accumulate in the environment, and petroleum products are a frequent pollutant of aquatic systems. Knowledge about the detrimental effects of certain pharmaceuticals, their degradation products and other endogenous disruptors, substances that selectively interfere with the regulatory system, is more recent, but no less worrying.
- *Climate impacts (including hydrological changes)*. For instance, Thomas *et al*. (2004) predict that 24% (15–37%) of species will be committed to extinction by 2050 in the case of a mid-range climate warming. They furthermore show that by reducing warming to the minimum feasible today fewer losses result (18%), whereas high climate change results in an average loss of 35%.
- *Biological pollution*. The competition with deliberately or unconsciously anthropogenically introduced foreign or modified species may alter the species and product composition of ecological systems and tends to reduce their productivity (Vilà and Weiner, 2004; Vilà *et al*., 2004). Although most invasions cause little change of the overall ecosystem character in the long run, some do, and for instance invasive weeds can have significant economic impacts on agricultural yields (Pimentel *et al*., 2005).

This analysis is also confirmed by the Synthesis Report of the Millennium Ecosystem Assessment (MEA), a global endeavour started in 2002 with the task of examining how changes in ecosystem services influence human well-being (MEA, 2005). It lists as the main pressures

- habitat transformation, particularly from conversion to agriculture,
- overexploitation, especially overfishing,
- invasive alien species,
- pollution, particularly nutrient loading, and
- anthropogenic climate change.

The results of the pressure analysis determine the kinds of response needed: they must be focussed on the socio-economic system generating the biodiversity pressures.

Demarcation

The generation of such pressures is neither intentional nor incidental, but the result of ongoing socio-economic processes and policies. In the majority of cases, the negative impact on biodiversity has been detected too late (or not at all), and has been dealt with by suggesting additive measures for biodiversity protection (instead of questioning the basic drivers causing these pressures). Such suggestions often corresponded to the state of the art in biodiversity research, as the bulk of it has focussed on organisms or species and on ecosystem types, not on anthropogenic processes which can be reflected in scenarios and models.

As opposed to this species-centred perspective, the justification of policy measures rests implicitly or explicitly on the functional attributes of the ecosystem level ('ecosystem services'). Their utility can be aesthetic as much as economic, but the general approach is anthropocentric and focussed on the short to medium term availability of such services (see Figure 1). According to the Millennium Ecosystem Assessment, they should 'include provisioning services such as food, water, timber, and fiber; regulat-

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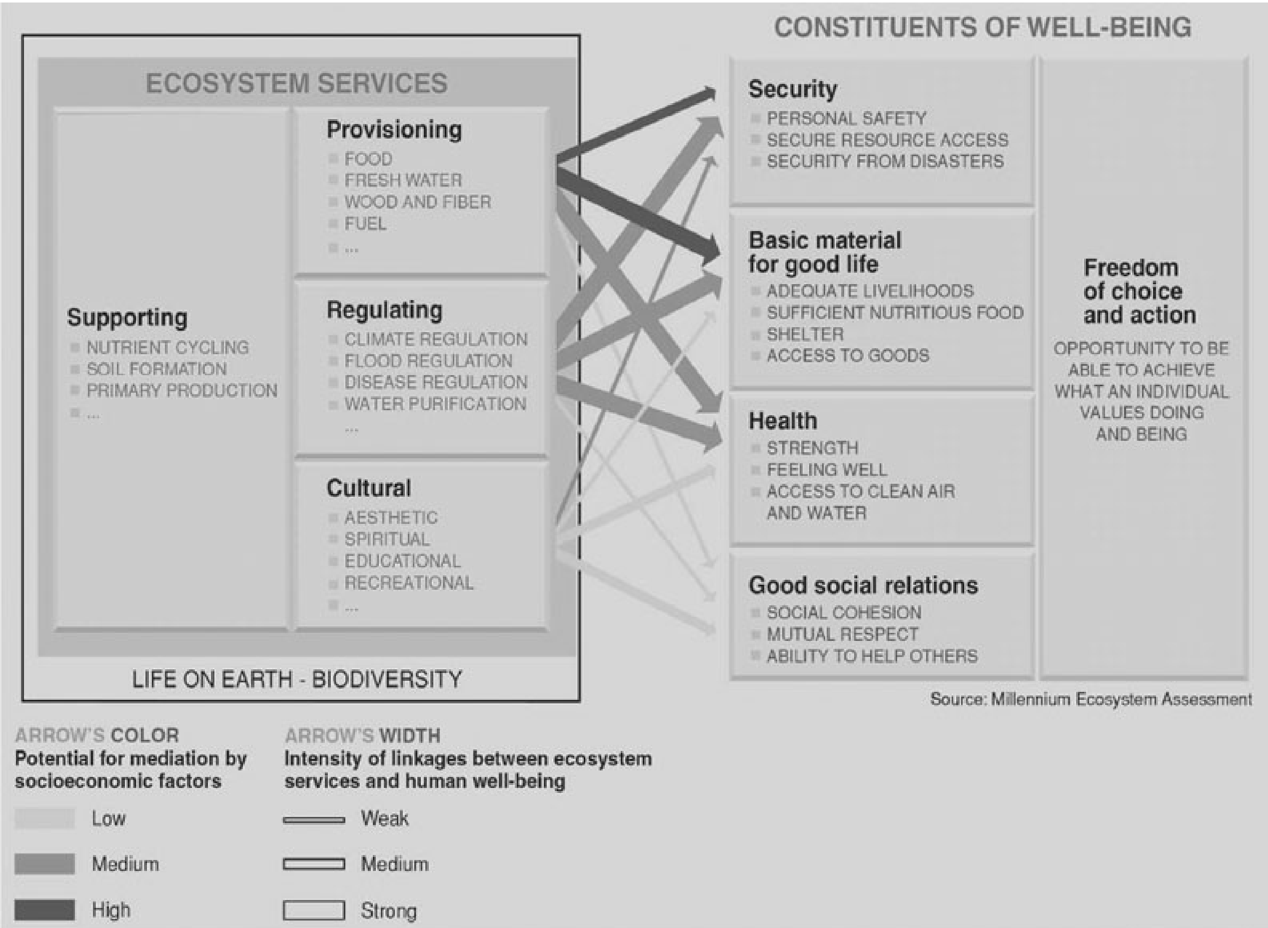

Figure 1. The impact of ecosystem services on human well-being
Source: MEA, 2005, p. 13.

ing services that affect climate, floods, disease, wastes, and water quality; cultural services that provide recreational, aesthetic, and spiritual benefits; and supporting services such as soil formation, photosynthesis, and nutrient cycling' (Reid, 2002).

Assessing human impacts on the services and deriving mitigation strategies is a complex, multi-step undertaking. Martens describes the steps to be taken: 'sustainability at the systemic level must be assessed, bringing to bear the following procedural elements: *analysis* of deeper lying structures of the system, *projection into the future*, and *assessment* of sustainable and unsustainable trends. *Evaluation* of the effects of sustainability policy and the *design* of possible solutions through sustainable strategies also belong here'. An important analytic instrument for this purpose is 'scenarios that describe sustainable and unsustainable developments, including unexpected events, changes, and lines of fracture' (Martens, 2006, p. 40, emphasis by the author).

Driving Forces: the Rationale for Socio-Economic Scenarios

The pressure analysis is but a first step towards policy definition, not yet the solution: for the scenarios, the drivers causing the pressures must be identified (although directly addressing certain pressures

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might be necessary as a kind of emergency relief in particularly critical situations). Only if the driving forces are adequately reflected in the scenario dynamics, allowing projections into the future and the analysis of unsustainable trends, is it possible to compare different scenarios regarding their expected impacts on biodiversity, and to derive suitable priorities for strategic policy action. For this behalf, scenarios must be relevant not only from a biodiversity perspective, but also from a policy point of view, i.e. addressing relevant problems with effective means. Otherwise they would miss their explicit objective, improving the effectiveness and efficiency of strategy proposals for making the everyday mechanisms of business and politics better compatible with biodiversity concerns. In other words: if the intention is to mainstream biodiversity protection within the political processes by transforming biological insights regarding pressure sources into criteria applicable in decision making, the scenarios must be formulated in the language of decision makers at the appropriate level.

Political and administrative decisions, including those on biodiversity pressure management, are taken at the local, regional, national or supranational level, and they apply within political borders, not within ecological boundaries. Driving force analysis identifies the anthropogenic causes of biodiversity loss, i.e. the agents of pressure generation and their institutional frames and hierarchies. In order to be effective, demands for pressure regulation must fit into the administrative and political decision making framework, and to have long-term effects they should not be all curative but address the causes, i.e. the driving forces (as far as under uncertainty such causal relationships can be established). The challenge is then to find strategies on the institutionally adequate scale (in the ALARM project for the 27-member European Union), *informed* by bioscience analysis, helping to steer decision making with a sufficient degree of reliability towards effective biodiversity preservation. Other information is helpful to contextualize the message, but the essence must refer to what the decision makers can influence.

A systematic analysis of driving forces would ideally be conducted as a participative process involving administration and civil society. In the course of such a process, a 'pressure–policy matrix' would be established, a tool that has been suggested to cross the governmental policy domains (ministries, agencies, for the EU Directorates General) with identified pressures. The cells of the matrix would contain the relevant policies as driving forces; as far as civil society participates, behavioural routines and preferences could be listed on their part (Spangenberg, 2005).

However, as such an exercise is beyond the capabilities of a research project, we have chosen to identify the EU policies driving the pressures identified, based on desktop research, plus subsequent stakeholder discussions within the ALARM Consultative Forum, comprising civil society, science and policy representatives with expertise at the European, national and regional levels. As a result, the following drivers were identified as causing the main pressures at the European Union level.

- Common agricultural policy (including fisheries policies and forest policy): in this domain of EU policies, reducing overuse would be beneficial for biodiversity, but also cost saving and a contribution to global sustainable development.
- Chemicals policy: it has an important influence on chemicals risk and is heavily influenced by vested interests. The recent process of watering down the new chemicals regulation initiative REACH illustrates this point.
- Energy policy: the emphasis on deregulated markets and reduced prices is not necessarily helpful to combat climate change, to the contrary. Economic versus environment conflicts abound in the short term.
- Transport policy, internal market regulations and Trans European Networks (TENs): transport is the most important growing source of greenhouse gas emissions in the EU, with air transport showing the fastest growth. It also contributes to fragmentation.
- Trade policy: as conducted by the EU, it emphasizes the unhindered flow of goods and services within the Union, and (with some exceptions) between the Union and the rest of the world. Controls that

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would be helpful to reduce biological invasions are usually considered as an impediment to free trade and not pursued.

- Biotechnology policy forces even countries and regions not willing to do so to accept the deliberate release of genetically modified organisms (GMOs) in the name of the Common Market. While most industrial uses of GMOs seem to be without unacceptable risk, the deliberate release, including the use in agriculture, is highly disputed.
- Structural Funds are the main tool for the EU level to influence regional planning (funding criteria explicitly mention sustainability as a key objective), and could address fragmentation and transformation, if properly enforced and monitored.

Combining driving force analysis with bottom-up and top-down, forecasting and backcasting scenario techniques, decision support can then be provided to all relevant levels of decision making, and for all relevant sectors.[2]

Status Quo and Challenges

So far no comprehensive model has been developed integrating the diverse relevant ecological, economic, individual and societal processes linking driving forces, pressures and impacts. This is due not only to the overwhelming complexity such a model would have to accommodate, but also to different system characteristics such as system boundaries and timescales, and the lack of knowledge regarding their interactions. Probably, no such integrated model is possible, and what could be achieved at best is a group of separate but coupled models. Amongst these, externally set assumptions would be harmonized and the results of one used as input to the others (e.g. as table functions). For instance, while population development could be based on joint assumptions, growth data from an economic model might be used by land use and climate models, which in a next step would interact (emissions from land use and climate impacts, respectively). Their results in turn would influence the economic modelling exercise by inducing the need for adaptation expenditure or by modifying productivities. Obviously, such a process of model harmonization must be an iterative one, implying the need for time and other resources.

Unfortunately, the state of the art is rather far away from this optimal situation. Instead, socio-economic, climate and biodiversity models exhibit a wide range of assumptions concerning population development, economic growth and the resulting pressures on biodiversity. The scenarios used by the Intergovernmental Panel on Climate Change (IPCC) (the SRES scenarios) do not include either climate protection policies so far, or the impacts these might have on economic growth. Consequently, the Millennium Ecosystem Assessment scenarios, which include climate protection policies, expect less and slower climate change than the IPCC's SRES scenarios (which at the same time are considered rather conservative by other sources). Computable global equilibrium (CGE) models are frequently used for predictions, but they are unable to reflect the structural change that is characteristic of any market economy, in particular in the long run (which may be a rather short-term view from a climate research perspective).

Therefore, as a first step, it is necessary to derive consistent assumptions and scenario interpretations from a comparative analysis of existing models and scenarios from several disciplines. Assessing their overlaps and the possible contradictions between the results of one and the assumptions of other scenarios can help get a better assessment of the relevance of specific scenario results by contextualizing them with the outcome of other modelling exercises. Similarities in results can confirm the robustness

[2] Each level or sector requires a specific contextualization and an adequate methodology mix. The ALARM scenarios are dedicated to support public policies at the EU level; in a number of case studies they are supplemented by qualitative regional (sub-national) scenario narratives. In a comparable manner, scenarios could have been developed for the national level or for business sectors.

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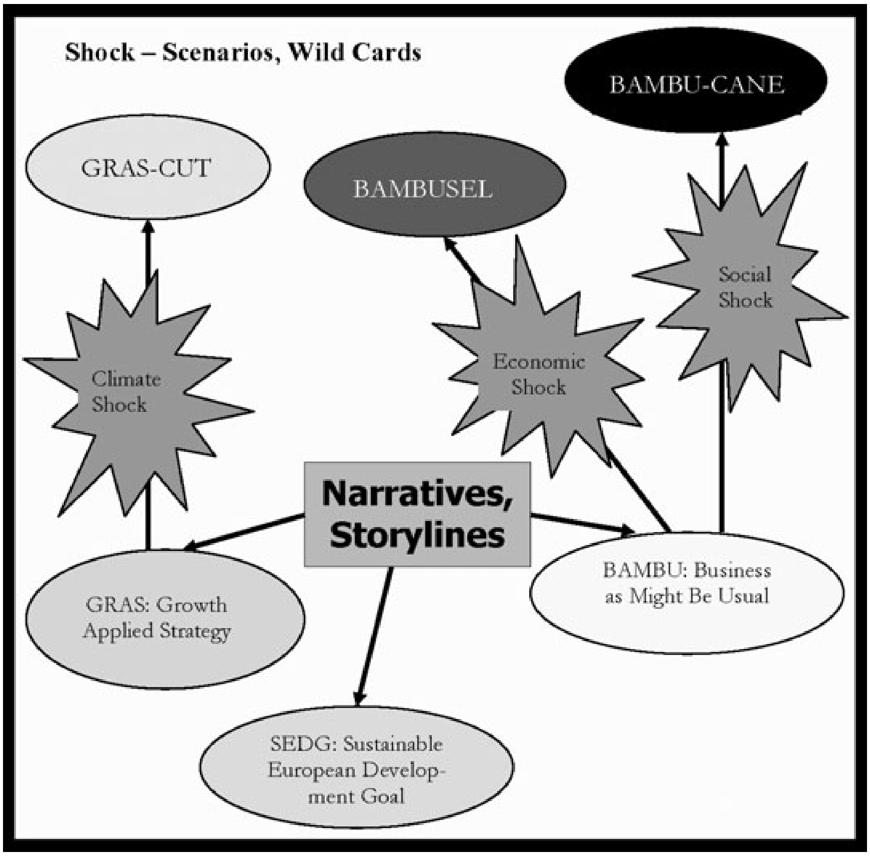

Figure 2. Scenarios in ALARM: core scenarios and derived shock scenarios
Source: author.

of the scenarios chosen and that the results are not mere model or data artefacts, but like any sensitivity analysis they can also raise doubt regarding specific outcomes (see e.g. Bockermann *et al.*, 2005). This way, a complementary, cross-disciplinary knowledge base can be developed in order to support effective policy decisions and provide a basis for future modelling exercises on all levels.

The ALARM Core Scenarios

Each ALARM scenario consists of a storyline or narrative, of which several elements are quantitatively illustrated by different, partly integrated models (Figure 2). The narratives have been drafted by the project team and were discussed for their consistency and plausibility with the external stakeholders constituting the ALARM Consultative Forum (representatives of science, politics, NGOs and trade unions engaged in sustainability policies).[3] Thus people's and organizations' different world views are taken into account. To enhance the bioscience relevance of the scenarios, additional discussions were held with the scientists of the ALARM consortium.

[3] For the central role of the future of labour for sustainable development see the work of Hans-Boeckler-Foundation (2001) and Spangenberg (2004); for the role of trade unions see the work of Springett and Foster (2005).

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The three scenarios analysed cover a broad range of social, economic, political and geo-biosphere parameters, emphasizing the internal coherence of each scenario, but also the conflicts of interest between the different aspects of sustainable development (Kaivo-oja, 1999). One scenario (BAMBU – business as might be usual) is what the IPCC calls a policy driven one, i.e. a scenario extrapolating the expected trends in EU decision making and assessing their sustainability and biodiversity impacts. It includes climate mitigation and adaptation measures and explicit but not radical biodiversity protection policies.

The two others describe different policy orientations discussed by relevant stakeholders in Europe. The first (GRAS – growth applied strategy) is a liberal, free-trade, globalization and deregulation scenario. Regarding climate change, its focus is on adaptation rather than mitigation, with some measures taken to limit climate change. Provisions for biodiversity protection (and other environmental problems) are limited and will only be taken when the problem emerges. The scenario policies show no interest in social and institutional sustainability; economic sustainability is interpreted mainly as economic growth.

The alternative (SEDG – sustainable European development goal) is a backcasting scenario (an inverse projection) dedicated to integrated environmental, social, institutional and economic sustainability. Inverse projection implies that the scenario is normative, designed to meet specific goals and deriving the necessary policy measures to achieve them. This represents a precautionary approach, designing measures under uncertainty to avoid not yet fully known future damage.

To illustrate the scenarios in a coherent manner with different simulation models, it is necessary to compare and where necessary reconcile the model assumptions – a task not made easier by the different time horizons, levels of uncertainty and spatial resolutions (grid based versus national data), but an essential one to address the different spatial levels relevant to sustainability and biodiversity preservation strategies (Giddings *et al.*, 2002).

Although there is in the meantime a diversity of climate models and scenarios, we have opted for the IPCC's 'official' scenarios, as the IPCC is the most authoritative source and its scenarios are the basis of most policy discussions (IPCC *et al.*, 2000). Amongst these SRES scenarios we haven chosen three particularly fitting to the expected climate development under the three ALARM scenarios, one called A1FI for the liberal scenario, as both the GRAS scenario and A1FI are growth scenarios based on a neoliberal policy approach. For the policy scenario BAMBU and the inverse projection SEDG the choice of a suitable SRES scenario was less obvious, as both – unlike the SRES scenarios – include mitigation measures. For BAMBU we have chosen the so-called A2 scenario, as this seems to match the past developments that – although the emissions in the modelling period will be different – determine the climate trend, due to the time lag between emissions and atmospheric warming. The choice was even more difficult for the SEDG scenario, as the initially discussed stabilization of atmospheric of GHG concentrations at 450 ppm CO_2 equivalents is not included in any SRES scenario. However, as desirable as this target value may be, due to the limited action taken in the last decade it is most probably not realistic to achieve anyway. We have chosen therefore the SRES scenario leading to a stabilization at 550 ppm, the B1 scenario. As this is achieved not due to mitigation, but as a result of economic problems, the SEDG and the SRES B1 worlds are significantly different; we decided to use B1 as a kind of 'climate envelope' but ignore the socioeconomic considerations of SRES B1.

In illustrating the storylines, each of these three climate scenarios was discursively combined with a narrative-specific run of a spatially explicit land use model disaggregated to the NUTS 3 level (based on the ATEAM project models, recalculated), and with the econometric input–output model GINFORS, developed in the EU-funded MOSUS project. The latter combines economic data with energy and material flows, and calculates domestic economic development, resource consumption, emissions and employment plus the global trade in some 40 categories of goods (aggregating some minor trading nations, in particular from Africa, as 'rest of the world'). Although the models used are global ones, the focus of the analysis is on Europe, and how changes there affect the world (and vice versa).

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Economic development trends cannot be spatially disaggregated to a sub-national level based on the available data, but for their impacts we have developed rules to spatially differentiate population density, migration, income disparities and income development.

Preliminary Results and Discussion

The emission trajectories resulting from the econometric model are lower than those assumed in the SRES scenarios. Nonetheless, no specific corrective factors for the SRES scenarios need to be suggested, as the deviation of the emission paths will lead to changes in climate effects only beyond the scenario perspective: evolving input–output models (unlike Computable Global Equilibrium Models (CGEs), which however underestimate the structural change occurring in the medium to long run) cannot be usefully run for more than 20 years, so the time horizon is a simulation to 2020 with a projection of some parameters to 2050. However, looking at the SRES narratives, it is obvious that the BAMBU and the SEDG scenarios and the economic and land use model runs used to illustrate them (they are combined to use each other's data) do not describe an A2 or a B1 world, respectively. Developing climate scenarios including adaptation and mitigation, and the socio-economic effects thereof (including the multiple feedback loops) should thus be a priority issue for the future climate research at the IPCC level.

The econometric model does not directly take into account the effects of climate change, but is the basis for assessing the relevance of the potentially affected regions and sectors. The discussion (part of the narrative) confirms the limited economic impacts of climate change in the observation period under the BAMBU scenario. The results are in the range of those from other sources expecting between 0 and 3% loss of GDP growth over a 50 year period, i.e. the equivalent of 0–8 months of economic development.[4] Affected sectors include forestry (in Europe less agriculture), tourism (more structural change than growth impediment) and to some degree the construction sector. The impact on biodiversity is mixed: some drivers continue to increase (e.g. transport), while others become less severe (e.g. agriculture). In the growth scenario, as expected, most drivers become more serious, emissions rise and climate change is accelerated. The income distribution becomes more uneven, and salaries stagnate, but unemployment goes down more rapidly than in the other scenarios (a general decline is the result of demographic trends). The sustainable development scenario SEDG demonstrates that even a radical mitigation policy in Europe will result in nothing more than a delay in global warming of a few years, unless other parts of the world follow suit (most importantly the USA and the BRICS countries, Brazil, Russia, India, China, South Africa).

The conclusion for climate policy is that as the impacts, e.g. on biodiversity, but also on the living conditions in the South, are serious, action must be taken and Europe is well advised to be a frontrunner. However, international cooperation must make sure that other parts of the world follow in the post-Kyoto phase, maybe like minded countries first, such as those in the Renewable Energy Coalition launched in Johannesburg in 2002.

A second conclusion is that it is in vain to hope that for cost reasons the market or the business sector would be forced to act on their own behalf; instead, dedicated political decisions are needed to set the framework right for climate mitigation. Adaptation will happen fairly easily in the business sector, as the speed of change in the economic system is so much higher than in the bio-geosphere that it can easily accommodate these changes of the environment. However, in the infrastructure, changes are much slower and political intervention (regulations, incentives) will be needed.

[4] For an overview see the review section of the *Stern Review*, which – unlike its cost projections – is fairly undisputed (Stern Review, 2006).

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Beyond Extrapolation: the ALARM Shock Scenarios

Besides improving scenarios and solidifying their results by comparative analysis, the limits inherent to all these modelling exercises must be assessed. The most important ones result from gradualism, i.e. the internal dynamics of the models based on marginal, linear changes, which is typical for simulation exercises. To be policy relevant, however, scenarios have to take the effects of non-linear developments into account, in particular if they are singular events with widespread consequences, severe enough to change the development trajectory.

One way to deal with them is to develop a variety of shock scenarios against the backdrop of linear simulation runs, to illustrate how future developments can be different from any extrapolation of past trends. The real future will most probably include such shocks, although by their very character we cannot predict them, either which ones will occur or when this will be the case (nonetheless, vulnerabilities can be assessed, and precautionary measures can be taken, reducing a probability that is not quantifiable). Such shocks could include economic crises, reducing the future rate of economic growth as well as the level of economic activity upon which the growth is supposed to build, social crises such as wars, environmental catastrophes (the 2005 tsunami and hurricanes are just a case in point), technological breakthroughs with positive or negative effects, and other non-predictable events such as natural disasters.

Thus three additional hazard driven scenarios (shocks or 'wild cards') were developed as artificial experiments, combining a narrative characterized by deviation from one of the core scenarios by one disturbance event with long-term and large-scale impacts. They could only be partly simulated; partly they were developed as model-supported semi-quantitative narratives. The three shocks include an environmental shock (gulf stream collapse 2050), an economic one (peak oil 2010) and a societal one (a pandemic). The environmental shock is most probable with the highest temperature increase, and thus modelled as a deviation from the GRAS scenario (GRAS plus cooling under thermohaline circulation collapse: GRAS-CUT). The occurrences of the economic and social shock were considered both not to be influenced by current policy choices and thus constructed as deviations from the *status quo* policy scenario (BAMBU plus shock in energy price level, BAMBU-SEL, and BAMBU plus contagious natural epidemic, BAMBU-CANE) (Figure 2). All these events are possible, plausible, but improbable at any given point of time (although over a longer time period the World Health Organisation (WHO) considers a pandemic unavoidable, and peak oil is quite probable to occur sooner rather than later).

Preliminary Results and Conclusions

For the gulf stream (or, more precisely, the THC) collapse, since the warming was of limited economic effect, so is the interim cooling if it materializes after 2050 as assumed in the scenario – nowadays the shock would be significant, but this is not a plausible scenario.

The quadrupling of the oil price first sounds like a safe receipt for an economic disaster, and so it is (minus a fifth of the GDP) – for less than five years. Then the economic growth (not the GDP) bounces back to the old level, or possibly even more, since due to international trade the money that has flown out of the oil and gas importing countries comes back in the form of product orders. As a result, the economic damage is limited, but since a high bill has to be paid for imports, the social sustainability impact of the changing distribution patterns is serious. It resembles the wave of poverty resulting from the East Asian economic crisis a few years ago. What would be the most plausible policy response? For Europe, most probably a massive investment in biofuels (they can be on the market within a year, faster than most alternatives, they provide fluid fuel and they are based on already existing technologies, infrastructures and policy strategies). The expected result is a massive pressure on agricultural land and

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forests, leading to significant losses of biodiversity (as a deviation from BAMBU, with policies mainly focussed on domestic biofuel production, the pressure is on the European landscape; as a deviation from GRAS, demand would be covered by massive expansion of ethanol and palm oil from Brazil and South East Asia, with dangerous impacts on their biodiversity). So what looked like an economic crisis turns out to be a social one, and the policies to mitigate it will most probably create an environmental disaster (even if they may reduce GHG emissions).

The pandemic is either an economic transformation with some sectors losing and others winning (such as health care, pharmaceuticals etc.), with an overall reduction of GDP below 10% and an early rebound, or leads to the total collapse of the economy. The latter would be the case if 20% or more of the population dropped off the formal production and consumption processes – some dead or on sick leave, but most trying to escape infection by avoiding all occasions where many people meet, i.e. work places, shopping centres, cultural events – or even the cities as such (as observed in the bird flu epidemic in China).

For us, these examples illustrate the need to further develop integrated social, environmental, economic and climate models (far beyond what we now have at hand), as the impacts can shift from one domain to another, and any model not representing the different domains might lead to policy recommendations with dramatic but not recognized side-effects. In particular, the different timescales of models and the fact that they are based on rather linear extrapolations of past trends hinder a realistic assessment of possible future development trends. In ALARM this problem is moderated (not solved) by discussing all simulation results against the background of the narratives and using the simulation results selectively, based on their fit with the story line (the primacy of the narrative). This procedure makes it possible to accommodate even diverging simulation data (such as the SRES scenarios in a non-SRES world) without generating inconsistencies; it provides a high degree of flexibility and enforces a consequently integrated assessment.

Outlook

According to our experience, with the help of the comparative analysis of different scenarios and the illustration of some of their aspects by different models, and by using shock scenarios extending the range of potentially possible futures taken into account regardless of their probability, the validity of future projections and the range of future options assessed can be significantly enhanced. At the same time, the analysis provides input for future modelling exercises, by creating a shared interdisciplinary knowledge base that can be used in future scenario development.

In the political domain, this allows us to develop strategies and test them regarding their robustness in a wide number of possible futures (strategies that prove effective under a variety of different futures can be considered robust and, if successful, a good choice for sustainability and biodiversity strategies). Such 'safe bet' or 'no regret' policies are the first choice in situations of enduring uncertainty (which in policy making is more often the case than not, in particular with respect to long-term objectives).

In the scientific domain, such an analysis provides input for future modelling exercises, by creating a shared interdisciplinary knowledge base, which can be used in future scenario development. It helps to assess the relevance of feedback loops and the robustness of scenario-based expectations and recommendations.

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