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The Vulnerability Concept and its Application to Food Security

P.L. Lucas
H.B.M. Hilderink

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RIVM, P.O. Box 1, 3720 BA Bilthoven, telephone: 31 - 30 - 274 91 11; telefax: 31 - 30 - 274 29 71

National Institute for Public Health and the Environment (RIVM)
Global Sustainability and Climate (KMD)
Netherlands Environmental Assessment Agency
P.O. Box 1, 3720 BA Bilthoven
The Netherlands

Telephone	:	+31 30 2744549
Fax	:	+31 30 2744464
E-mail	:	Paul.Lucas@rivm.nl
Website	:	http://www.rivm.nl/ieweb

Abstract

This report describes an operationalisation of the term ‘sustainable development’, by introducing the vulnerability concept. Vulnerability describes the degree to which a system is likely to experience harm due to exposure to a hazard, and thereby identifies unsustainable states and processes. The operationalisation is presented in a framework, which incorporates the three elements of vulnerability, i.e. exposure, sensitivity and coping capacity. The framework links model outcomes, represented as indicators, towards an overall measure of sustainability of a certain sector or system. The overall vulnerability is determined by the potential impact (exposure plus sensitivity) and the coping capacity, which is the impact that may occur given projected global change and the degree to which adjustments in practices, processes or structures can moderate or offset the potential for damage. The advantages of the approach are the transparency of the indicator framework and the linkage of the framework with simulation models (existing knowledge). To test the methodology, it is applied on the issue of food security, resulting in a measure for the overall vulnerability of countries towards food shortages. The results of this analysis are in line with the degree of food deprivation on a regional scale, as determined by the FAO. These similarities in results indicate that the chosen indicator framework is a reasonable proxy for food security and that the conceptual framework gives good prospects for the analysis of other unsustainable states and processes.

Keywords: Sustainable Development, Global Change, Vulnerability, Food Security

Rapport in het kort

Dit rapport beschrijft de operationalisatie van de term `duurzame ontwikkeling' door gebruik te maken van het kwetsbaarheidconcept. Kwetsbaarheid beschrijft de mate van schade dat een systeem kan ondervinden door blootstelling aan een bepaalde druk en beschrijft daarmee niet duurzame processen. Voor de operationalisatie wordt een raamwerk geïntroduceerd dat bestaat uit de drie elementen van kwetsbaarheid, namelijk blootstelling, gevoeligheid en aanpassingscapaciteit. Het raamwerk maakt gebruik van modelresultaten, indicatoren, die worden geaggregeerd tot een algemene maat van duurzaamheid voor een bepaalde sector of systeem. De kwetsbaarheid wordt beschreven door de potentiële impact (blootstelling plus gevoeligheid) en de aanpassingscapaciteit, dat wil zeggen de gevolgen die kunnen ontstaan door mondiale veranderingen in het menselijke en milieusysteem en de graad waarin mogelijke aanpassingen de schade kunnen matigen of compenseren. De voordelen van de benadering zijn de transparantie van het indicatorenraamwerk en de koppeling met simulatiemodellen (bestaande kennis). Om vervolgens deze methodiek te toetsen is het toegepast op het probleem van voedselveiligheid, wat resulteert in een maat voor de kwetsbaarheid van landen voor voedseltekorten. De resultaten van deze analyse zijn op regionale schaal in lijn met de mate van voedseltekorten zoals gerapporteerd door de FAO. Deze gelijkenis geeft aan dat het gekozen indicatoren raamwerk een redelijke proxy geeft voor voedselveiligheid en dat het conceptuele raamwerk goede vooruitzichten biedt voor het toepassen op andere niet duurzame processen.

Trefwoorden: Duurzame Ontwikkeling, Global Change, Kwetsbaarheid, Voedselzekerheid

Contents

1. Introduction

The interconnection between human and environmental systems at the global level has become one of the focal points of research in the last decades. The concept of global change describes these human-induced changes in the environment. The recognition of the effect of human activity on climate change is only one of the global interrelations. Access to resources and their quality have an unequivocal effect on humans too, with health outcomes as one of the testifying factors. The report of the World Commission on Environment and Development (WCED) titled, ‘Our Common Future’ (WCED, 1987), established the link between environment and development issues, and laid the basis for the use of the term, ‘sustainable development’. Since then, many refinements, additions and alternatives have been introduced (IUCN/UNEP/WWF, 1991). Applying the concept of sustainable development resulted in Agenda 21, which can be seen as a first attempt to formulate an international action programme. More recently, the Millennium Development Goals (MDGs) have been defined, which have been commonly accepted as the framework for monitoring development progress (see Box 1).

Where Sustainable Development aims at improving the quality of life, without interfering with other systems and future generations, sustainability implies an ongoing development driven by human expectations about future opportunities, based on current issues (Cornelissen, 2003). A useful concept for analysing sustainability is the vulnerability concept, which can be used to describe possible threats to the human-environment system and thereby threats to its sustainability. Many studies can be found in the literature using the vulnerability concept with respect to climate change (e.g. IPCC, 2001; Smit and Pilifosova, 2003), and sustainable development (e.g. Polsky et al., 2003; Turner et al., 2003). Although most studies concerning sustainable development so far have a qualitative nature, several quantitative studies have been published, elaborating on indicators and indicator aggregation (e.g. Metzger and Schröter, 2004).

In this study we propose an operationalisation of the vulnerability concept from a modeller’s perspective, linking closely to our in-house models. Chapter 2 describes the vulnerability concept and presents the overall framework. This framework can be used to construct indices describing (un)sustainable processes for different themes and spatial scales. As the framework links model outcomes (indicators) to the different elements of vulnerability (exposure, sensitivity and coping capacity), Chapter 2 also gives a broad description of indices and indicators and some first insights in their aggregation towards the elements. To illustrate our approach and to assess its applicability, we elaborate the framework on the problem of food security (embedded in the first MDG). Chapter 3 presents a literature survey, describing the state and dynamics of food security, while Chapter 4 presents our indicator framework and its application. Chapter 5 discusses the applicability of the overall framework as well as the presented application on food security, while the last Chapter, 6, presents our conclusions.

Box 1: The Millennium Development Goals

The Millennium Development Goals (MDGs) commit the international community to an expanded vision of development and recognise the importance of creating a global partnership. They address many of the most enduring failures of human development, while placing human well-being and poverty reduction at the centre of the global development objectives to:

1. Eradicate extreme poverty and hunger
2. Achieve universal primary education
3. Promote gender equality and empower women
4. Reduce child mortality
5. Improve maternal health
6. Combat HIV/AIDS, malaria and other diseases
7. Ensure environmental sustainability
8. Develop a global partnership for development.

With the MDG framework, the policy aims are set out for the coming 15 years by assigning associated targets for the 8 goals set, while a list of 48 indicators has been defined to measure progress (UNDP, 2003).

2. The vulnerability framework

As mentioned in the introduction, a useful concept in analysing unsustainable processes is the vulnerability concept (Turner et al., 2003). The concept will be outlined in the first part of the chapter, along with the overall framework that can be used to analyse threats to the sustainability of human-environmental systems. The second part will discuss the operationalisation of the framework, i.e. indicators and indices and their aggregation towards an overall measure of vulnerability.

2.1 The overall framework

In its Third Assessment Report, the Intergovernmental Panel on Climate Change (IPCC, 2001) defines vulnerability to climate change as ‘the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change’. The Advanced Terrestrial Ecosystem Analysis and Modelling (ATEAM) project (Metzger and Schröter, 2004) draws on the vulnerability work of the IPCC to deal with the risks that global change poses to the well-functioning of ecosystems by assessing the vulnerability to global change of sectors relying on ecosystem services. Here, the IPCC definition of vulnerability was extended to ‘the degree to which an ecosystem service is sensitive to global change plus the degree to which the sector that relies on this service is unable to adapt to the change’. Polsky et al. (2003) broaden the scope of assessment even more, defining global change vulnerability as ‘the likelihood that a specific coupled human-environment system may experience harm from exposure to stress associated with alterations of societies and the biosphere, accounting for the process of adaptation’. Finally, in the third Global Environment Outlook (UNEP, 2002) as ‘the interface between exposure to the physical threats to human well-being and the capacity of people and communities to cope with those threats’. As our focus is on Sustainable Development in a general sense, the last definition is used as a starting point for our analysis.

One of the more advanced applications closely related to the vulnerability concept is the Syndrome approach. The Syndrome approach describes Global Change as ‘a co-evolution of dynamic partial patterns of unmistakable character’ (Schellnhuber et al., 1997). This approach was originally proposed by the German Advisory Council on Global Change (WBGU, 1995) and further conceptualised and developed by the Potsdam Institute of Climate Impact Research (PIK). The Syndrome approach represents a global view on local and regional dynamics of environmental degradation, identifying *functional patterns of human-nature interaction* (Syndromes) representing sub-dynamics of Global Change (Lüdeke et al., 2004) (see Box 2 for details). Although the Syndrome approach has proven to be a useful concept for the analysis of global change, the emphasis in this report is on the operationalisation of the vulnerability concept. For this purpose, we present a framework based on the literature on this subject, in which certain insights from the Syndrome approach are used.

Vulnerability can be described by three elements: exposure, sensitivity and coping capacity (IPCC, 2001; Turner et al., 2003). Exposure can be interpreted as the direct danger, i.e. the stressor, while the sensitivity describes the human–environmental conditions that can either worsen the hazard or trigger an impact. As a system can be exposed to many different stresses simultaneously, it can also feel sensitivity to different exposures. Yohe and Tol (2002) have therefore defined vulnerability as a function of different exposures and the accompanying sensitivities towards them. In line with the work of Yohe and Tol (2002), Metzger and Schröter (2004) introduce the term potential impact, defined as a function of the exposure and the sensitivity. In this way, the coping capacity represents the potential to implement adaptation measures so as to avert the potential impacts. Determinants of the coping capacity are awareness, ability and action (Schröter et al., 2003), determined by economic wealth, technology, information and skills, infrastructure, institutions, social capital and equity (IPCC, 2001). The proposed framework is schematically represented in Figure 1.

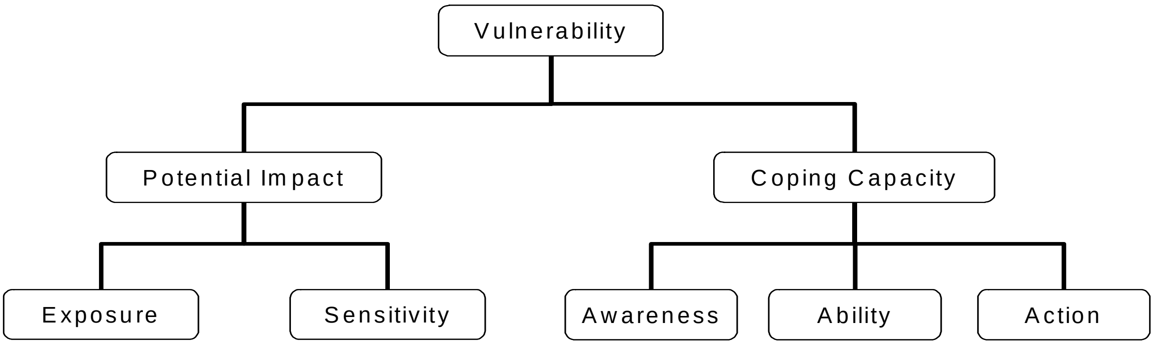

Figure 1: The overall vulnerability framework.

The vulnerability concept and the syndrome approach are useful concepts in the communication of model results to policy-makers. The syndrome approach describes non-sustainable processes, while the vulnerability concept describes potential hazards for a system. However, both approaches describe the same dynamics, as the proneness of a region to a syndrome can be compared with the potential impact of the vulnerability concept.

Box 2: The Syndrome approach

The basic elements for a systematic description of the syndrome dynamics are called symptoms. The term ‘syndrome’ refers to a typical co-occurrence of different symptoms that describe complex natural or anthropogenic dynamic phenomena. Global Change refers mainly to the anthropogenic system, whereas the symptoms are either direct expressions of human-nature interaction or are indirectly induced by it; syndromes are the interaction patterns of these complex phenomena. Syndromes are qualified at three levels: disposition, exposition and intensity. The disposition describes the proneness of the region to certain syndromes, determined by the structural properties that persist over a medium- or long-term period. Exposition factors are rather short-term events that can activate a syndrome if the disposition is high. Finally, the intensity describes how far the system has gone in the negative spiral.

2.2 Indicators and index construction

The vulnerability framework is a hierarchical aggregation of elements describing the different aspects of vulnerability. In the vocabulary of the Syndrome approach, these elements are the symptoms, which can quantitatively be described by indicators. As the symptoms are interrelated causally, the indicators representing the symptoms should address these interrelations. Models can be used to systematically structure relations between indicators, with Integrated Assessment models being most applicable. Using models does not only allow for simultaneous assessment of different vulnerabilities, but also for the assessment of the co-benefits and trade-offs between the elements within a single vulnerability.

In general, indicators are used to monitor developments and gain insight into the dynamics of reality. Such reality can be characterised by a huge collection of variables and their interactions and relationships. Using the right indicators and indices for further communication reduces the large quantity of data, while retaining the most essential information. Where indicators are pieces of information designed to communicate complex messages in a simplified, (quasi)-quantitative manner (Rotmans, 1997), indices are multi-dimensional composites made from a set of indicators and/or indices (Hilderink, 2004). To prevent confusion, we will define indicators and indices below.

A set of indicators and indices is referred to as an ‘indicator framework’ and an aggregate of indicators and indices as a ‘composite indicator’. So the vulnerability framework presented in the previous chapter is an ‘indicator framework’ and the potential impact and the coping capacity are ‘composite indicators’. Furthermore, the individual vulnerability elements can be described by indicators and indices.

Several composite indicators are known from the field of sustainable development, for example, the Human Development Index (UNDP, 1990), the Genuine Progress Indicator (Venetoulis and Cobb, 2004) and the State Of the Future Index (Glenn and Gordon, 2004). Examples of composite indicators having to do with vulnerability mapping are the ‘Index of Vulnerability’ of Lonergan et al. (1998) and the climate globalisation vulnerability maps of TERI (2003). The most important task in calculating these and other composite indicators is transforming the different indicators, measured in different units, into the same unit and choosing the right method to aggregate them in an overall index.

As composite indicators are based on indicators that have no common meaningful unit of measurement, there is no obvious way of weighting these indicators (Saisana and Tarantola, 2002). The least complex method is equal weighting, which assigns each indicator the same weight, and thereby determines the mean of all determinants. More sophisticated methods are generally based on expert judgement, and so incorporate extra knowledge in the indicator aggregation step. Methods based on expert judgement are participatory methods; for this it is necessary to bring together experts with a broad spectrum of knowledge. A possibly useful method for the problem at hand, which requires a large degree of expert involvement, is fuzzy-logic (MAthWorks, 2000; Zadeh, 1965). Although fuzzy-logic is useful for a broad spectrum of issues, it can be used to map qualitative models using quantitative indicators. Among many other studies, the method has been used in sustainability science to assess the contribution of sustainability indicators to sustainable development (Cornelissen, 2003) and to determine the disposition and intensity factors for different syndromes (Cassel-Gintz et al., 1997). In our analysis, fuzzy techniques can be used to map the quantitative indicators to their qualitative equivalents, after which they can be aggregated into an overall indicator using logical statements.

3. The state and future of food security

In its background paper, the Millennium Project task force on hunger defines food security as ‘the ability to have steady access to sufficient amounts of safe and nutritious food for normal growth and development, and an active healthy life’ (Scherr, 2003). The FAO defines food security as ‘a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life’ (FAO, 2001). This chapter draws on the second definition and describes the most important determinants of food security as well as its current state. Furthermore, several model approaches to food security are discussed, along with their strengths and weaknesses.

3.1 Determinants of food security

Important determinants of food security are socio-economic developments such as population growth and increase in income, and developments with respect to sanitation, health and education (Scherr, 2003). Population growth obviously increases the overall demand for food products, while a higher income can increase the demand for more and better food, i.e. an increase in purchasing power can increase the demand for livestock products, and thereby animal feed, as human diets tend to include more meat and milk products. According to the FAO (2001), the death rate from disease among undernourished children is much higher than among those better nourished, which increases the importance of sanitation and health. Furthermore, undernutrition is widespread where parents are poorly informed about requirements of good nutrition.

While food security used to depend primarily on natural conditions, pests and resource qualities, nowadays it is more dependent on income for purchasing food, and thus healthy economies, and the well-functioning markets. This is reflected in the evolution of the concept of food security (Maxwell and Frankenberger, 1992). In the 1970s, food security was mainly seen as a national supply problem. As a result of the green revolution, the production in developing countries tripled, mainly because of irrigation, fertiliser use, pest management and research. In the developing world, the countries that profited most are located in more fertile lands and have a good infrastructure, irrigation or adequate rainfall, access to improved seed, fertiliser, credit and markets and locations where the government supported such a transformation. On the other hand, countries suffering from climatic stress, low and declining soil fertility and sparse adoption of fertilisers, ecosystem degradation associated with intensified crop production, poor access to markets and weak enabling-government policies did not benefit at all. In addition, increased production in developing countries has not always resulted in an increase in food consumption by the poor. This is mainly due to their (very) low-income levels, which makes it difficult to extend their diet by imports, and the fact that a large share of the produced crops is used to either feed the animals or for export to sell to wealthier consumers (the so-called cash-crops).

With this development, the food security concept shifted from a supply and production problem to a poverty and market problem, in which purchasing power and access to food entitlements play an important role (Sen, 1981). Therefore food security can be seen, not only as a problem of worldwide production itself but also as an allocation problem with respect to the people inhabiting this planet. Different aspects influence this distribution, with income and political stability being the most important ones.

According to the IPCC (2001), food production is mostly influenced by the availability of water, nutrients and temperature. Temperature change could open new areas to cultivation, but might also increase the risk of heat or drought stress. The world food price, as an indicator of food vulnerability, is predicted to increase due to climate change, thereby increasing the number of people at risk of hunger (Parry, 2004). Water availability, used for irrigation, is mainly dependent on rainfall and evaporation, while climate change can decrease runoff, which increases stress on water resources (Arnell, 2004).

Box 3: The Millennium Development Goal on hunger

At the first World Food Summit in 1974, political leaders from around the world set a goal to eradicate hunger in the world within 10 years. As this goal was not reached government leaders gathered again in 1996 for the second World Food Summit and committed themselves to reducing by half the number of chronically undernourished by the year 2015. This target was then adopted in one of the Millennium Development Goals (MDGs). In the MDGs, the problem of food security is addressed by the first goal, i.e. the eradication of extreme poverty and hunger. The targets set for this goal are to halve, between 1990 and 2015, the proportion of people living on less than $1 a day and those who suffer from hunger. The percentage of the ‘children under five years of age who are underweight’ and the ‘population below minimum level of dietary energy consumption’ are used as indicators to measure progress of the second target. In addition to achieving half of the first goal, better nutrition can contribute to the attainment of the other MDGs (SCN, 2004)

3.2 The current state of food security

In their annual reports ‘The State of Food Insecurity in the World’ (SOFI) the FAO presents chronic food insecurity by stating the number of undernourished people and the severity of the under-nourishment, using population data and the amount of food available to them. Furthermore, the share of the population suffering from undernutrition is reported using data on people's weight, height and age. Where under-nourishment is defined as food intake that is insufficient to meet the daily dietary energy requirements, undernutrition is the result of under-nourishment, poor absorption and/or poor biological use of nutrients consumed.

A short overview of the applied method to determine the percentage of the population suffering from under-nourishment, i.e. the prevalence of under-nourishment, is given below, while an in-depth description is reported by Naiken (2002). The prevalence of under-nourishment is determined by combining the food distribution and the average minimum requirement. The average minimum caloric requirement on a country scale is determined by the number of calories needed by different age and gender groups, and the proportion of the population each group represents. Combining the available calories from local food production, trade and stocks, together with a distribution function describing the inequality in access to food, results in the distribution of the food supply within the country. Results from the FAO study are presented in Table 1.

Table 1: People undernourished (source: FAO, 2000; FAO, 2002)

	People undernourished			Prevalence of under-nourishment			Depth of under-nourishment*	Diet diversity***
	1979-1981	1990-1992	1998-2000	1979-1981	1990-1992	1998-2000	1996-1998	1996-1998
	(Millions)			(%)			(kcal/person/day)	(%)
Asia and the Pacific	**727.3**	**567.3**	**508.1**	**32**	**20**	**16**	**262**	**64**
East Asia	307.7	198.2	128.4	29	16	10	247	61
Oceania	1	1	1	24	25	27	260	56
Southeast Asia	88	77	64	25	17	12	230	66
South Asia	331	292	315	37	26	24	292	65
Latin America and the Caribbean	**45.9**	**58.8**	**54.8**	**13**	**13**	**11**	**206**	**38**
North America	3	4	5	4	5	5	210	47
Central America	5	5	7	20	17	20	284	43
The Caribbean	5	7	8	20	26	25	240	51
South America	34	42	35	14	14	10	221	38
Near East and North Africa	**21.5**	**26**	**40**	**9**	**8**	**10**	**202**	**59**
Near East	146	201	244	14	21	34	213	57
North Africa	91	121	140	7	6	6	183	62
Sub-Sahara Africa	**125.4**	**166.4**	**195.9**	**36**	**35**	**33**	**294**	**66**
Central Africa	15.1	22	45.1	34	35	57	344	69
East Africa	42.5	73.7	83	35	44	41	314	63
Southern Africa	17	34	37.1	33	48	43	337	72
West Africa	50.7	36.7	30.7	40	21	14	239	67
Total	**920**	**818.5**	**798.8**	**28**	**20**	**17**	**255**	**61**

* Numbers are taken from the FAO (2000) on a country scale and aggregated to regions.
** The share of cereals and roots and tubers in total Dietary Energy Supply (DES)

The FAO (2000) estimates the total number of undernourished people at about 800 million, which is far from the MDG target (UNDP, 2003). Table 1 shows Asia to be on track, while Sub-Saharan Africa and the Near East remain far from the target; Latin America would be somewhere in between. Most of the global decrease is due to China, along with Indonesia, Vietnam, Thailand, Nigeria, Ghana and Peru, while in the remainder of the developing world, the number of undernourished people has increased. Sub-Saharan Africa has the highest prevalence of under-nourishment and also the largest increase in the number of undernourished people, mainly in Central Africa. This large decrease is driven by the collapse into chronic warfare of the Democratic Republic of Congo.

The depth of under-nourishment is calculated to determine the severity of under-nourishment (FAO, 2002). The depth of under-nourishment is the difference between the minimum caloric requirement and the per capita calories available to the undernourished. Table 1 shows that although there are more chronically undernourished people in Asia and the Pacific, the depth of under-nourishment is clearly the greatest in sub-Saharan Africa. The table also shows a clear relation between the prevalence and depth of under-nourishment.

The combination of the prevalence and depth of under-nourishment is called the degree of food deprivation. Table 2 presents a distinction of five food deprivation groups, while Figure 2 presents these groups on a country scale. The countries that face the most pressing and difficult problems are in the last group, suffering from chronic instability and conflict, poor governance, erratic weather, endemic poverty, agricultural failure, population pressure and fragile ecosystems. This group includes eighteen countries in sub-Saharan Africa, and Afghanistan, Bangladesh, Haiti, Mongolia and the Democratic People's Republic of Korea.

Table 2: The 5 groups of food deprivation (source: FAO, 2000).

Prevalence of hunger: percent of population undernourished	Depth of hunger: number of kilocalories missing from the diets of the undernourished			
	< 200 (Low)	200-300 (Moderate)	> 300 (High)	TOTAL
	Number of countries, colour-coded by group			
< 5% (Low prevalence)	52	0	0	52
5-19% (Moderate prevalence)	17	29	0	46
≥ 20% (High prevalence)	0	31	23	54
TOTAL	69	60	23	152

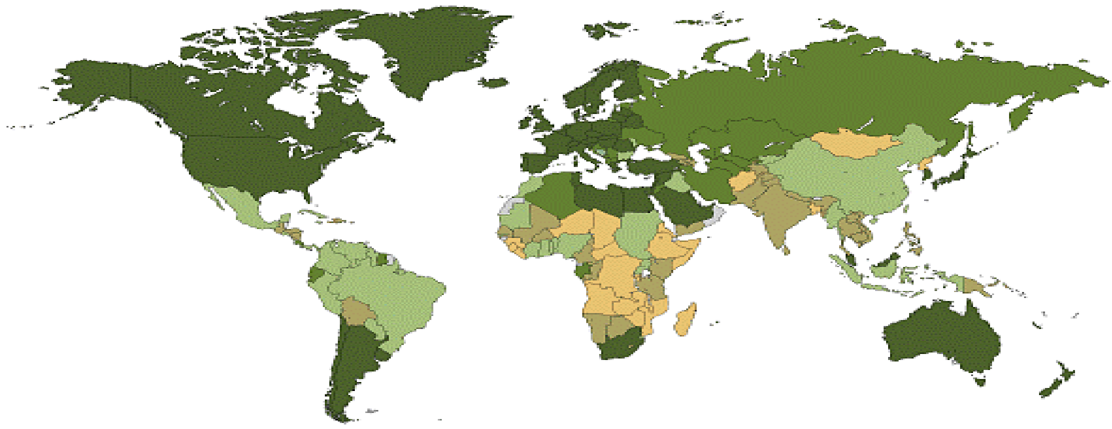

Figure 2: The degree of food deprivation, 1996-98 (source: FAO, 2000).

Where the degree of food deprivation is an indicator for a steady access to sufficient amounts of safe food, the diet diversity is an indicator for steady access to sufficient amounts of nutritious food (FAO, 2002). A lack of dietary diversity and essential minerals and vitamins contributes to an increased mortality rate. For example, iron deficiency greatly increases the risk of death from malaria, and vitamin A deficiency impairs the immune system, increasing the annual death toll from measles and other diseases (FAO, 2002). The FAO defines the dietary composition, or as we call it the diet diversity, as the share of cereals and roots and tubers in total Dietary Energy Supply (DES); this is presented in the last column of Table 1.

Next to the annual SOFI reports the World Food Programme (WFP) have developed an information tool, Vulnerability Analysis and Mapping (VAM), to support food aid activities, using the Standard Analytical Framework (SAF) (WFP, 2002). The framework is based on the vulnerability concept, described by the exposure to risk and the ability to cope. The exposure to risk is determined by the frequency and the severity of natural and man-made hazards, as well as the socioeconomic and geographic scope of those hazards. The coping capacity is determined on a household level, including production, income and consumption levels as well as the ability to diversify their sources of income and consumption to effectively mitigate the food insecurity risks.

3.3 Modelling approaches to food security

Several models have been developed to better understand the underlying dynamics of food security, and to assess their possible future development. These models aim to integrate some of the relevant dynamics of the different sub-systems, especially their interactions. To gain better insight into the work already done, we will briefly discuss three of these studies below, including their strengths and weaknesses.

Fischer et al. (2002) report an integrated ecological-economic assessment of the impacts of climate change on agro-ecosystems with respect to the world food and agriculture system. They developed the Basic Linked System (BLS), which links national agricultural-economic models with respect to financial flows and trade at an international level. The BLS is combined with an Agro-Ecological Zones (AEZ) model, a GIS-based framework to simulate crop production and crop-specific environmental limitations. The total number of people suffering from under-nourishment is determined by correlating the share of undernourished to the ratio of average national food supply relative to aggregate national food requirements (FAO, 2001). The ratio is affected by the direct impact of climate change on domestic food production, as well as by the indirect effects related to income changes and prices of food imports.

Kemp-Benedict et al. (2002) focus on the effect of income distribution on hunger, stating a relation between hunger and income inequality. Their methodology was used in the Global Environment Outlook (UNEP, 2002), where hunger is a key poverty variable. In their analysis they use the income distribution and the hunger line, a threshold income below which individuals are unable to obtain the required calories to sustain a normal level of activity. The hunger line tends to increase with income. Because rising average income is accompanied by a reduction in traditional support mechanisms, those most in need would have to spend more to maintain a given level of comfort.

The land and food sub-model TERRA, part of the TARGETS model (Tool to Assess Regional and Global Environmental and health Targets for Sustainability) (Rotmans and de Vries, 1997), simulates the key features in land-use and land-cover changes that result from demand for food and forest requirements. Along with the interactions with the other sub-models, TERRA is used to explore whether food insecurity can be eliminated while safeguarding the productive potential and broader environmental functions of agricultural resources for future generation (Strengers et al., 1997). The major drivers in their study were the animal-versus-vegetable food demand, fertiliser use, the level of irrigation, available arable land and the impact of climate change on food production. The most important interactions with the other sub-models are population growth, agricultural investments, biofuel demand, climate change, soil fertility, irrigation and erosion. For their analysis, they carried out 27 experiments by interpreting the so-called 'background', 'worldview' and 'management style' in terms of three active perspectives from the Cultural Theory (Thomson et al., 1990), i.e. the hierarchist, the egalitarian and the individualist. Population dynamics and income levels determine the background. The worldview, which entails a coherent view of how the world functions, results in a relation between income levels, and vegetable and animal food demand. The management style determines the level of fertiliser use and irrigation, and the availability of arable land, while climate change is an impact of human behaviour and has its response in food production. The modelling exercise does not result in the total population suffering from under-nourishment, but rather presents the rising risk of a global mismatch between food supply and demand due to the different backgrounds, worldviews and management styles.

Both Fisher et al. (2002) and Kemp-Benedict et al. (2002) base their calculations on the assumed income levels, income distribution and population numbers. In addition to these factors, Fisher et al. (2002) include the impacts of climate change in their model approach, by incorporating the direct impact on domestic food production and the indirect effects related to income changes and the prices of food imports related to the global availability of food. Strengers et al. (1997) applied a more integrated approach, including different sub-models for other domains or themes (water and economy, for example). Both Fisher et al. (2002) and Strengers et al. (1997) included climate change in their calculations, while Strengers et al. (1997) only reported possible global mismatches in supply and demand, and so lacking in distribution effects. One major aspect lacking in the three studies is the quality of the diet, i.e. food diversity, indicating a steady access to sufficient amounts of nutritious food. Sufficiency of food does not only imply the required DES, but also enough variety to meet an individual's requirement of all specific nutrients. Another major aspect ignored in the models is the so-called institutional domain. Factors such as political stability, trade barriers, or government regulations can have large effects on the functioning of markets (only included in Fischer et al., 2002) and even on the production of food itself.

4. Applying the vulnerability framework to food security

This chapter presents the application of the vulnerability framework on the problem of food security. It presents an assessment of the overall food vulnerability, i.e. possible threats to food security in the world. The indicators used in the analysis were selected on the basis of the literature survey of Chapter 3 and the availability of indicators in our models and databases. Therefore, the proposed indicator framework does not claim to be complete, but should be regarded as an initial implementation.

The indicators used and their inter-linkages, geared towards the overall vulnerability, are graphically presented in Figure 3, while their position in the vulnerability framework and their origin and scale are described in Table 3. A more technical description is given in the following sections. In our analysis, we use results from the IMAGE 2.2 model (Alcamo et al., 1998; IMAGE-team, 2001) (see Appendix B for details) supplemented with several data sets. The available data is incorporated on different geographical scales. Most environmental indicators determined in the model are available at a grid-cell level, including the population densities, while most other socio-economic indicators are available at a regional level. The external dataset are used to desegregate regional data towards a country level, which is also the scale on which the vulnerability elements are determined.

Due to the preliminary character of the analysis and to overcome the problem of the time-consuming step of involving experts in the index construction, literature is used to map the indicators towards values between 0 and 1. Equal weighting is used for the aggregation of these indicators towards the three vulnerability elements and to aggregate exposure and sensitivity into the potential impact. As it is difficult to incorporate the coping capacity in the potential impact, the coping capacity will be presented separately and will not be aggregated with the potential impact into an overall vulnerability index.

Table 3: Position, origin and scale of the different indicators used.

Element	Determinant	Indicator	Source	Scale
Exposure	Quantitative exposure	Caloric balance index	TES	Country
	Qualitative exposure	Food diversity index	TES	Region
Sensitivity	Economic dependence on agricultural sector	Fraction agricultural value added in total GDP	World Bank (2003)	Country
	Income distribution	GINI-coefficient	World Bank (2003)	Country
	Income level	GDP per capita (PPP) index	World Bank (2003)	Country
	Water availability	Water stress index	WaterGAP	Country
	Land degradation risk	Water erosion hazard index	LDM	Grid/Country
	Land degradation risk	Desertification risk index	TES/AOS	Country
	Land availability	Land availability index	TES	Country
Coping capacity	Problem awareness	Literacy rate index	World Bank (2003)	Country
	Problem awareness	GINI-coefficient	World Bank (2003)	Country
	Adaptation ability	Life expectancy index	World Bank (2003)	Country
	Adaptation ability	Infrastructure density index	DCW (1992)	Grid/Country
	Adaptation action	GDP per capita (PPP) index	World Bank (2003)	Country

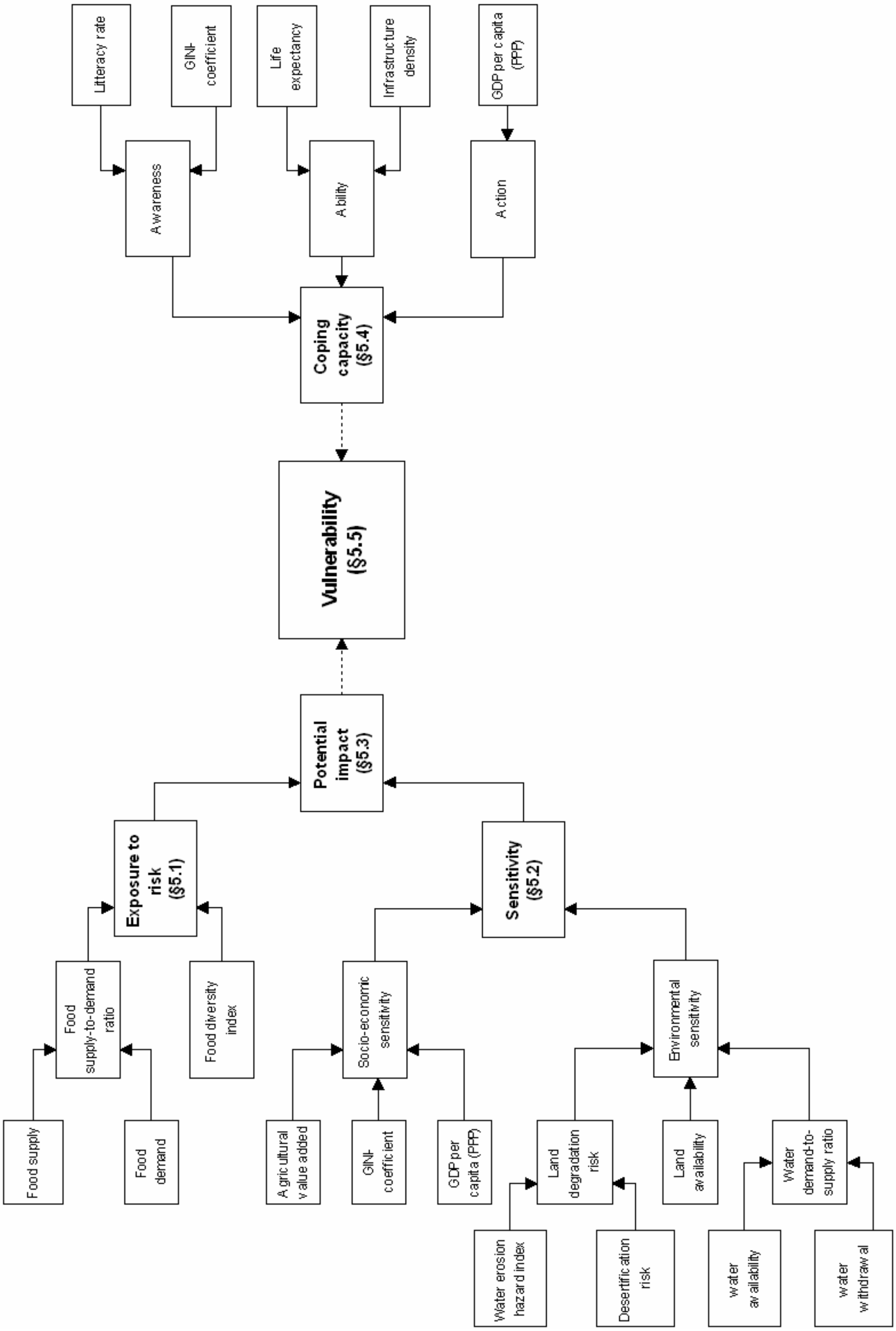

Figure 3: The aggregation of the different indicators towards the overall vulnerability.

4.1 The exposure to risk

Exposure to the risk of food insecurity is described by quantitative and qualitative exposure, i.e. the food supply to food demand ratio, and the food diversity index, respectively. The food supply to food demand ratio describes the nearby access to sufficient food, i.e. the national availability of calories without having to trade with other nations. The food diversity index describes the access to nutritious food, i.e. the national diversity of food products in the total diet (including trade). The food supply to food demand ratio is determined using output from the Terrestrial Environment System (TES), graphically represented in Figure 4, while the food diversity index is determined by AEM only.

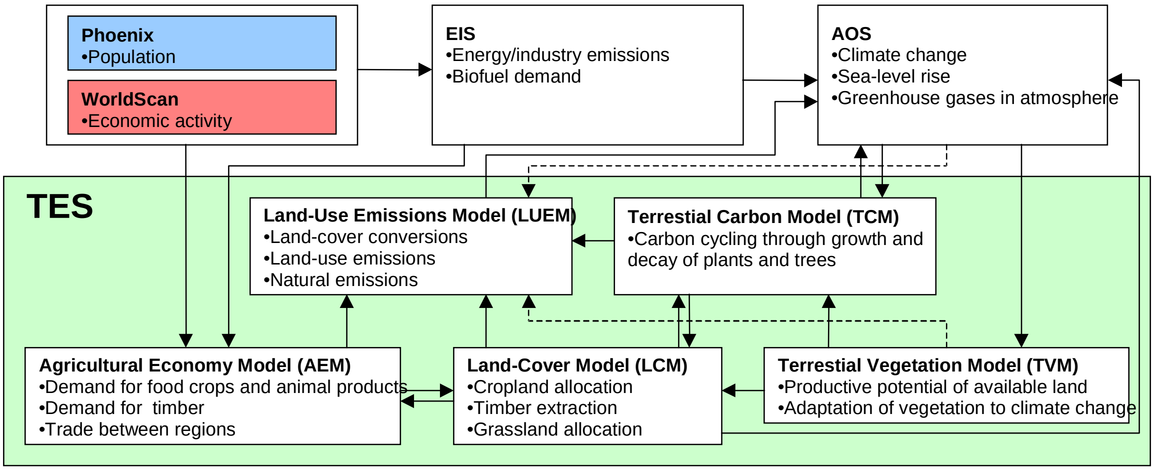

Figure 4: The Terrestrial Environment System (TES) of the IMAGE 2.2 framework.

The food supply to food demand ratio (FR_C) is the total food production ($\sum P_G$) divided by the total food consumption ($\sum C_G$) in total calories, both on a country scale:

$$FR_C = \sum P_G / \sum C_G \, . \qquad (2)$$

The subscript G indicates a grid level, while the subscript C indicates a country scale. Seven food-crop types (temperate cereals, tropical cereals, rice, maize, pulses, roots and tubers and oil-crops) and five animal-product types (beef, buffalo meat, milk products, pork, poultry and eggs, mutton and goat meat) are distinguished (Strengers, 2001), while the food types are summed using their caloric values. According to Fischer et al. (2002), hunger and thereby food insecurity can be completely eliminated for supply-to-food demand ratios greater than 1.7. We index the ratio between 0 and 1 using this relation, with 1.7 representing no exposure and 0 representing maximum exposure, respectively.

The caloric consumption is represented by the product of the total population on a grid level (POP_G) and the minimum dietary energy requirement ($MDER$):

$$C_G = POP_G * MDER \, . \qquad (3)$$

The population density is determined by the Phoenix model, while the minimum dietary energy requirement is set to 2200 Kcal/cap/day (FAO, 1996).

The caloric production (P_G) is determined by the Land-Cover Model (LCM), which simulates the changes in land use and land cover in time (Alcamo et al., 1998). The model attributes the regional demand for food to the grid cells in the different regions, taking into account agricultural trade between regions and the potential productivity of the different crops per grid cell. Furthermore, the attributing here incorporates nearby water supply, agricultural activity and population density. To determine the amount of food available for human consumption, the crops used for animal feed ($P_{feed,G}$) and the crops used for other purposes than food consumption ($P_{other,G}$) are subtracted from the total food production, i.e. food crops ($P_{food,g}$) and animal products ($P_{animal,G}$):

$$P_G = P_{crops,G} + P_{animals,G} - P_{feed,G} - P_{other,G}\,. \tag{4}$$

The total number of animals per type (A_R) is determined on a regional scale by AEM. To determine the food production of animal products on a grid scale, the regional amounts are scaled down. For this purpose, a distinction is made between grazing animals (dairy and non-dairy cattle, and sheep and goats) and pigs and poultry. The grazing animals are distributed over the most productive grasslands, using a combined indicator of grassland area (GA_G) and the grass quality (GQ_G):

$$A_G = (GA_G * GQ_G \Big/ \sum (GA_G * GQ_G)) * A_R\,. \tag{5}$$

Pigs and poultry are assumed to be present where people are living. Animal productivity for the five animal categories, combined with the ratio of slaughtered animals, results in the total production per animal product per cell. To determine the food consumption of the animals ($P_{feed,G}$), feed for the grazing animals is equally spread over the region they live in and subtracted from the relevant cell, while feed for pigs and poultry is subtracted from the cells they live in. Finally, food used for other purposes, ($P_{other,G}$), available on a regional scale, is equally spread over the grid cells in the appropriate region according their production levels.

The FAO diet diversity indicator (2000), as presented in Table 1 for the 1996-1998 period, is used to determine the food diversity index (FD_C), which is defined as the amount of cereals, and roots and tubers ($DIET_R$) as a fraction of the total consumption (C_R), both on a regional level:

$$FD_R = DIET_R \big/ C_R\;. \tag{6}$$

Aggregating the quantitative and the qualitative exposure results in the overall exposure as presented in Figure 5. The figure indicates that the highest Exposure occurs in North Africa, the Middle East and Central Asia. These regions have limited potential crop areas. Other high exposures are indicated in the rest of Africa, Central America, the rest of Asia and parts of Europe. The first three regions have a limited production along with relatively one-sided food diversity. For the European countries the caloric production is limited as these countries show large imports of feed crops due to their large livestock. The Formal Soviet Union and South America show a medium to low exposure as their food production is sufficient but their diet diversity limited. The rest of Europe, North America and Oceania finally show a low exposure as both their production as their diet diversity are high.

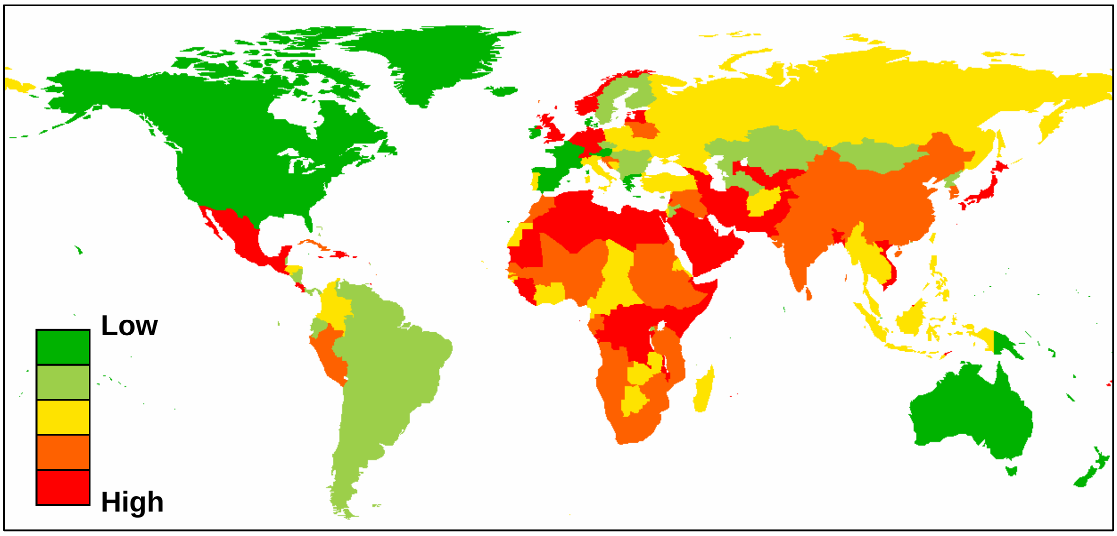

Figure 5: Exposure to risk for the year 2000.

4.2 The sensitivity

The sensitivity towards food insecurity is divided in two groups, i.e. the socio-economic and the environmental sensitivity. The socio-economic sensitivity is described by the ability to buy food on the world market and by the importance of the agricultural sector in the national economy. The environmental sensitivity is described by the environmental conditions for growing crops, i.e. the availability of water (for irrigation), the risk of land degradation, and the availability of productive arable land for agricultural extension.

The ability to buy food abroad is described according to the average income level and the distribution over the population, i.e. GDP per capita corrected for purchasing power and the GINI-coefficient, both taken from the World Bank (2003). To determine the GDP per capita index, the HDI methodology is used (UNDP, 2003). The GINI-coefficient can take values from zero to one; with ‘zero’ representing complete equality and ‘one’ complete inequality. A full description of GINI-coefficients and their calculations is given in Kemp-Benedict et al. (2002). The World Bank (2003) reports GINI-coefficients for different years between 1990 and 2000 for different countries. In this analysis we assumed that all these coefficients are taken for the year 2000.

The importance of the agricultural sector in the national economy is represented by the proportion of the agriculture value added in national GDP. According to the FAO (2003) the agricultural value added is highly correlated with the prevalence of undernourishment. A similar, but weaker, relationship can be found between agricultural employment and undernourishment. In this analysis, the agriculture value added is taken directly from the World Bank (2003) and used as a percentage of total GDP.

The availability of water is expressed by the water-stress index determined by the WaterGAP model (Alcamo et al., 2000). As presented in Figure 6, the water stress is defined by the long-term average of annual withdrawal-to-availability ratio. The ratio describes how much of the average annual renewable water resources of a river basin are withdrawn for human purposes (in household, industrial, agricultural and livestock sectors). In principle, the higher this ratio, the more intensively the waters in a river basin are used. This reduces either water quantity or water quality (or even both) for downstream users. Water stress increases when either water withdrawals increase and/or water availability decreases.

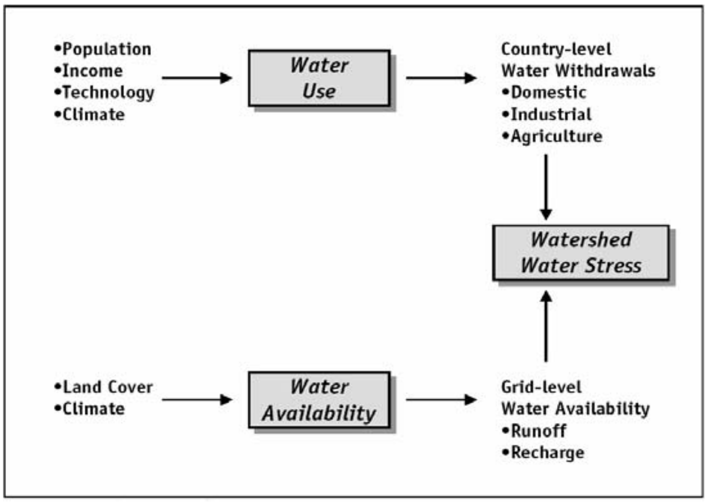

Figure 6: Block diagram of the WaterGAP model (Alcamo et al., 2000).

The risk of land degradation is described by the water erosion hazard index of Hootsmans et al. (2001) and the desertification risk, as outlined by Leemans and Kleidon (2002). The water erosion hazard index is a qualitative description of the land degradation process of water erosion based on the work of Batjes (1996) who used a simplified version of the Universal Soil Loss Equation (USLE) of Wischmeier and Smith (1978). The index is calculated by the Land Degradation Model (LDM) from IMAGE 2.2 (implemented as an impact module), using output from AOS and TES. The approach is based on the concepts of susceptibility and sensitivity to water erosion (Figure 7), taking into account future climate and land-cover changes. Susceptibility to water erosion is based on the terrain erodibility index and the rainfall erosivity index. Sensitivity to water erosion outlines the risk that water erosion will occur in the short term, as described by the land-use/change index. Hence, the susceptibility to water erosion represents, in actual fact, the sensitivity of the bare soil surface.

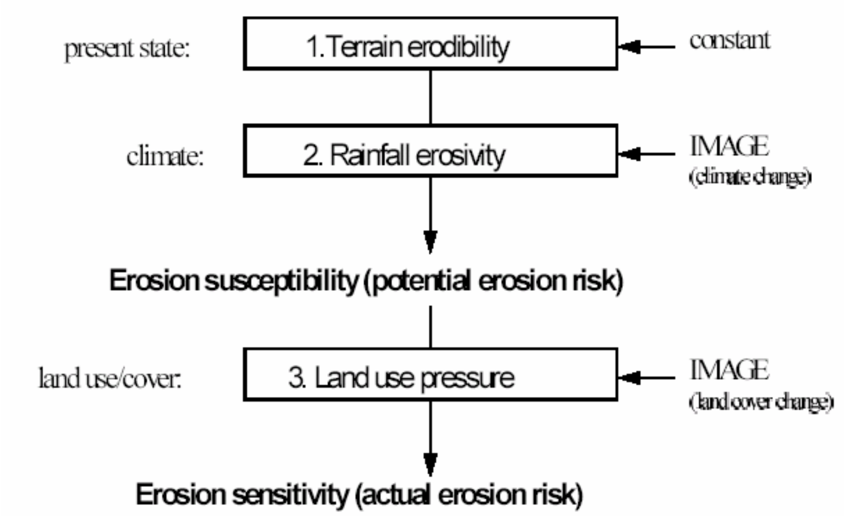

Figure 7: The general approach for determining the water-erosion sensitivity (Source: Hootsmans et al., 2001).

Desertification is defined in the Convention on Desertification as the degradation of land in dry lands (arid, semi-arid and dry sub-humid areas) resulting from various factors, including climatic variations and human activities (UN, 1994). Leemans and Kleidon (2002) distinguish five classes of aridity corresponding to major geographical zones. The ratio of annual mean precipitation (P) over the annual mean potential evapotranspiration (PET) can be used to determine the degree of aridity (AR_G):

$$AR_G = P_G / PET_G \,, \tag{7}$$

where dry lands are the regions with a P to PET ratio between 0.03 and 0.75 (Leemans and Kleidon, 2002). The desertification risk (DR_C) is determined as the agricultural area in dry land areas ($\sum AD_G$) as a fraction of the total agricultural area ($\sum AA_G$), both of them on a country scale:

$$DR_C = \sum AD_G \Big/ \sum AA_G \tag{8}$$

The availability of productive arable land for agricultural extension is represented by the land-use pressure index, which is the ratio of productive cropland already in use. Total productive cropland per country (PCL_C) is determined as the total area (OPP_G), where the potential productivity (PP_G) of the most productive crop in the country is greater than 20% of its theoretical maximum:

$$PCL_C = \sum \begin{matrix} PP_G \geq 0.2 \rightarrow OPP_G \\ PP_G < 0.2 \rightarrow 0 \end{matrix} \tag{9}$$

The land-use pressure index is then determined as the total area of cropland used (UCL_C) as percentage of total productive cropland:

$$LPI_C = UCL_C / PCL_C \tag{10}$$

Aggregating the indicators and indices for the socio-economic and environmental sensitivity according to Figure 3, results in the overall sensitivity as presented in Figure 8. The most sensitive regions are North and South Africa, the Middle East, and Central Asia, mainly due to very large desertification risks, high land-use pressure and high water stress. For Central Africa the sensitivity is also rather high, although the problem here is merely socio-economic than environmental, as their economy is largely dependent on agriculture and the income levels are the lowest in the world. For Europe, the land-use pressure is a limiting factor and to a lesser extent water stress and the water erosion hazard. North America and Oceania have a medium desertification risk, water erosion hazard and land-use pressure. For South America the determinants largely differ per country, from a more dominant socio-economic sensitivity in the North to a more environmental sensitivity in the South. For Asia the determinants are also more mixed. Most Asian countries have a medium to high socio-economic sensitivity, while especially India has a large water erosion hazard and desertification risk, and both China and India have a medium land-use pressure.

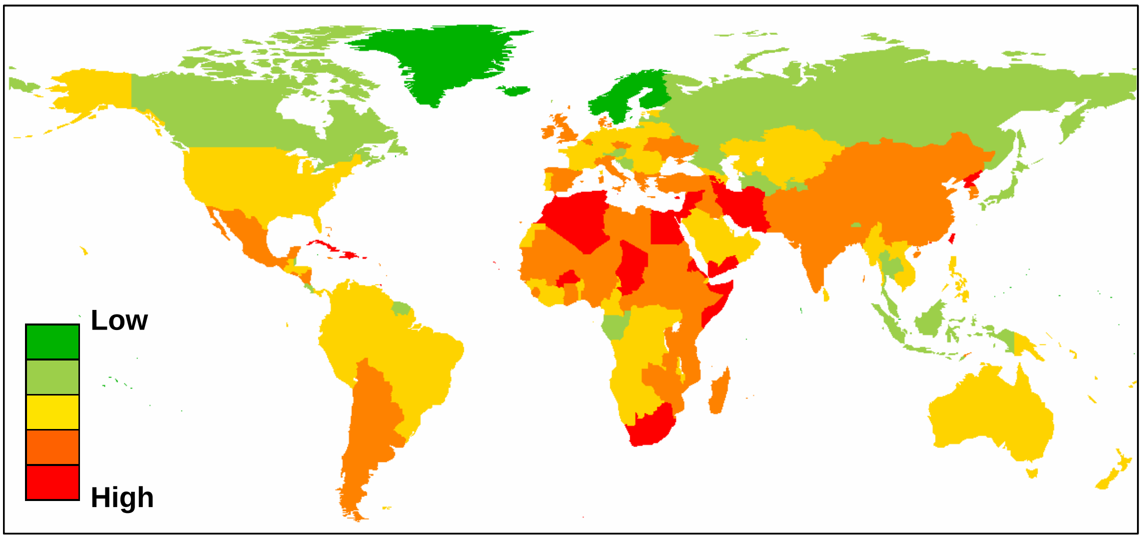

Figure 8: Sensitivity for the year 2000.

4.3 The potential impact

The potential impact of food insecurity is determined as the average of the exposure and the sensitivity as presented in Figure 5 and Figure 8. According to Figure 9, the regions with the largest potential impacts are Africa, Central America, the Middle East and Central Asia. These regions do not only show the largest exposure, but also the largest sensitivity. A medium potential impact is found in South, East and South-east Asia, South America and certain countries in Northern and Eastern Europe. North America and Australia show the lowest potential impact, as they are completely self-supportive and do not suffer too much from erosion hazards and water shortages.

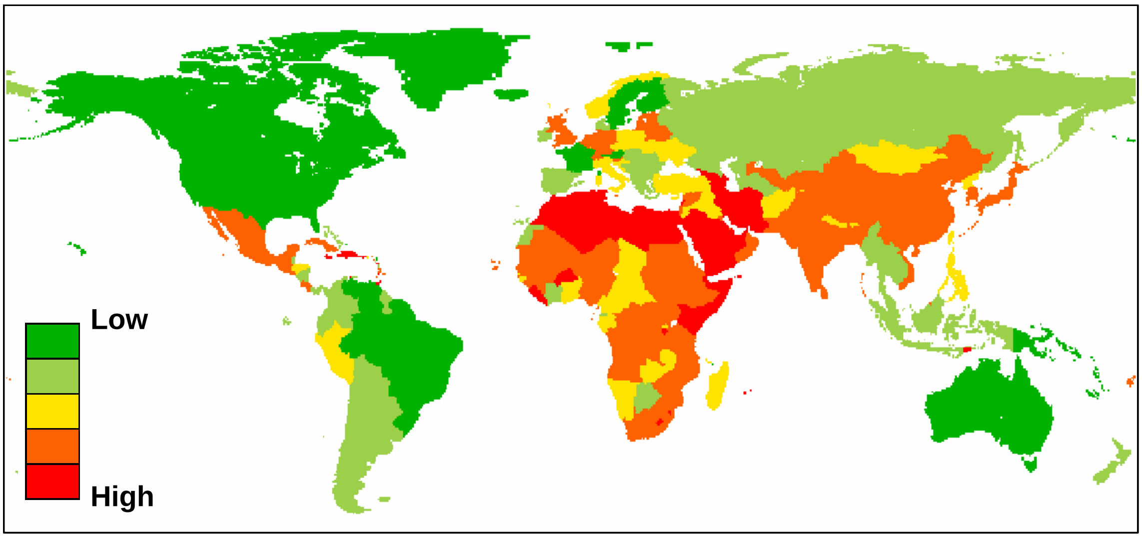

Figure 9: Potential Impact for the year 2000.

4.4 The coping capacity

The coping capacity is broken down into three components, i.e. awareness, ability and action (Schröter et al., 2003). Awareness is described by income inequality and the literacy rate, ability by the available infrastructure and the life expectancy, and action by the income levels corrected for purchasing power.

According to Schröter et al. (2003), income inequality describes the encouragement of awareness-building in society, where the literacy rate describes the available knowledge and thereby the level of comprehension of the problem. In this analysis, GINI-coefficients are used to describe the degree of income inequality (see section 4.2); taken from the World Bank (2003). The literacy rates are obtained from UNESCO (2003) and UNDP (2002), and indexed using the HDI methodology (UNDP, 2003).

The ability component describes in what way society is equipped to address the problem (Schröter et al., 2003), which is expressed by the infrastructure density and the life expectancy. For this purpose, infrastructure maps from the GLOBIO project (UNEP, 2002) are used, which are based on the Digital Chart of the World (DCW, 1992). For each grid cell, the total length of each infrastructure type (roads and railways) is determined in degrees, which gives an indication of the infrastructure density per cell. The infrastructure on a grid basis is weighted towards population density to determine the infrastructure density per country. Finally, the density on a country scale is divided by the maximum density to obtain an index between 0 and 1. Data on life expectancy is obtained from the UN Population Division (UN, 2002), where the HDI methodology is used to obtain the life expectancy index (UNDP, 2003).

Finally, income levels are used to describing the flexibility of a society to take action. The same as for socio-economic sensitivity, the income levels are described by GDP per capita corrected for purchasing power, and taken from the World Bank (2003). Again, the GDP index is determined using the HDI methodology (UNDP, 2003).

The coping capacity (see Figure 10) shows large differences for the various world regions. Coping capacity is greatest for Northern America, Western Europe, Australia and Japan. For North and South Africa, Central and South America, Asia, the Middle East and the Former Soviet Union, the coping capacity shows a medium position. Exceptions apply to Yemen, Afghanistan, Pakistan, Nepal and Papua New Guinea, and to a lesser extent, Bhutan, Bangladesh, Cambodia and Mongolia, where the coping capacity is much lower than their neighbouring countries. For Central Africa the coping capacity is the lowest. These countries are able to cope with part of the problem, but if the potential impact is high, a considerable part of the population can suffer from food shortages. The most important determinants for Central Africa are the low-income levels and the low life expectancies, while the literary rates are also among the lowest in the world. For the regions with a medium coping capacity, the above mentioned drivers also show a medium position, while the western regions show the highest income levels, literary rates and life expectancies. The income distribution is worst for Latin America and Southern Africa. Finally, the infrastructure density is the highest in Western Europe and Japan and slightly lower in North America, Australia and China.

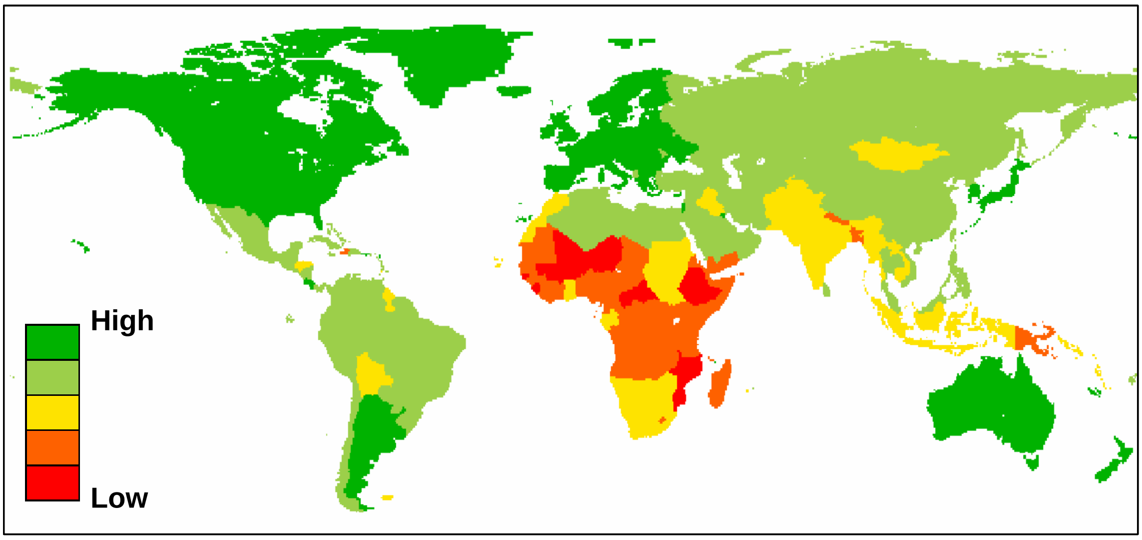

Figure 10: Coping capacity for the year 2000.

4.5 The overall food vulnerability

Although we do not combine the potential impact with the coping capacity in a quantitative way, comparing both determinants in qualitatively reveals the most vulnerable regions. Sub-Sahara Africa shows the lowest coping capacity, which, combined with its relatively large potential impact, results in very high food vulnerability. Western Europe and Japan have enough coping capacity to offset their potential impact, while North America and Oceania have both a low potential impact and a high coping capacity. The Asian countries show more intermediate food vulnerability, as they have a medium potential impact as well as a medium coping capacity. The same holds for Central America. Finally, Central Europe and the Formal Soviet Union show a medium to low vulnerability as their potential impact is medium to low and their coping capacity shows a medium position.

5. Discussion

The proposed operationalisation of the vulnerability concept seems to be a good start to assess global change and sustainable development in a quantitative manner. The framework presented provides a transparent and flexible way to link various model outcomes and indicators, resulting in an overall measure of sustainability of a certain sector or system. The method allows for vulnerability assessments that identify the so-called hot-spots, i.e. areas and people most vulnerable to a series of stresses. The transparency allows us to trace vulnerable sectors or systems back to their underlying determinants, while linkage allows us to assess different views and to explore possible future developments in a consistent way. The latter is useful in assessing the development against certain targets, for example, the MDGs.

A strong element of this approach is that the overall vulnerability can be traced back to the vulnerability elements and the indicators from which they are built. It is therefore possible to determine the most important drivers of the observed vulnerability. This allows us to assess specific policy to either alter the influence of the driver or to diminish the drivers' adverse effects on the overall vulnerability. Another advantage of the approach is that current indicators can be easily extended or substituted by alternative indicators. This allows for the incorporation of different views on the problem at hand and the use of different choices for the variables describing it. A third advantage is the possibility of applying scenario analyses, making it possible to assess future vulnerabilities in a quick and transparent way. The combination of scenario analyses and policy interactions, and the implementation of different views, results in a flexible and interactive tool, which can be easily used in communicating sustainability issues to policy-makers.

Besides these strong points, the approach also contains some weaknesses. As the real vulnerabilities mostly take place at a community or even household or individual level, the smallest unit ideally reveals the most detail. The combination of data from different geographical scales, e.g. grid-level data, national averages and even regional statistics, can therefore overlook hot-spots where they should be indicated. Another weakness of the approach is formed by indicator normalisation and index construction techniques. The most important tasks in computing these and other composite indicators is transforming the indicators into the same unit and choosing the right method to aggregate them in an overall index. As the different indicators have their origins in different domains, and are measured in different units on different spatial scales, their transformation into the same unit and the aggregation towards an overall index is not straightforward and univocal. Although the equal weighting applied in the study presented here is simple and transparent, it might not be the most effective method, especially because it does not include any extra knowledge of the system. It is therefore very important to include experts in the indicator selection and aggregation steps. Furthermore, different aggregation techniques should be applied to come up with more robust results.

The results of mapping food vulnerability are in line with the degree of food deprivation on a regional level, as presented in Figure 2. Although some countries do not stand out in our analysis, they do in Figure 2. This holds mainly for the most emerging countries in Asia, and especially for North Korea. The differences can partly be explained by differences in the two concepts, while for some countries, especially North Korea, relevant data is missing. The degree of food deprivation represents the degree of access to sufficient amounts of safe food, while food vulnerability indicates if this steady access is in danger. The former is the undernourishment itself, while the latter is the risk of an increase in the severity of the undernourishment. Furthermore, food vulnerability does not include by external stresses as institutional incapabilities, conflicts and natural disasters such as floods and droughts. In terms of the syndrome approach, the overall vulnerability describes the proneness towards food insecurity, while the degree of food deprivation is the intensity. Therefore, the difference can be explained by the external stresses. To better address the problem of food security using the vulnerability concept, these factors should be included in the framework, whereas the institutional capabilities and conflicts can be incorporated in the coping capacity and the natural disasters in the exposure.

6. Conclusions

This document has reported on the quantitative operationalisation of the vulnerability concept for assessing global change and sustainable development. Vulnerability describes the degree to which a system is likely to experience harm due to exposure to a hazard, thereby identifying potential unsustainable states and processes. The operationalisation has been presented in a framework that links model outcomes from the three domains of sustainability with the different elements of vulnerability, i.e. exposure, sensitivity and coping capacity. The framework combines exposure with sensitivity, resulting in the potential impacts, i.e. the impact that may occur given projected global change. The potential impact is compared with the coping capacity, i.e. the degree to which adjustments in practices, processes or structures can moderate or offset the potential for damage, to come to an overall measure of vulnerability. As the framework links model outcomes (represented by indicators) to an overall measure of sustainability for a certain sector or system, the method can be used to identify so-called hot-spots for the problem at hand. The advantages of this approach are the transparency of the indicator framework and the linkage of the framework with simulation models. The transparency allows us to trace vulnerable sectors or systems back to their underlying determinants, while the linkage allows assessment of different views and exploration of possible future developments.

The framework applied to food security has proven to be a valuable approach for gaining insight into its underlying regional determinants. The overall food vulnerability presented, although preliminary, gives a reasonable indication of the hot-spots. The results are in line with the degree of food deprivation, as determined by the FAO, while differences can be explained mainly by the differences in the approaches. In a subsequent step, the indicator framework can be applied to a scenario analysis using future projections of the different indicators. As overall food vulnerability seems to be a good proxy for the degree of food deprivation, a scenario analysis using the proposed indicator framework can be applied to assessing future impacts of socio-economic and environmental developments on the food security.

A more in-depth study should examine the indicators chosen for calculating the overall food vulnerability, along with their relevance and descriptive capacity. Furthermore, the index construction will need more research, with fuzzy techniques seeming to be the most suitable method at the moment. Both actions will be important steps in the further development of the approach presented and will require a large degree of expert involvement. Other actions to be taken are extrapolating the indicators and indices to the future using different scenarios, and incorporating of external stresses as institutional incapabilities, conflicts and natural disasters such as droughts and floods. Finally, although there are similarities to the FAO measure of food deprivation, extra attention should be given to the validation of the outcomes to expand our confidence in the method.

Although this report presents only a first step in the quantification of global change and sustainable development, the application of the proposed framework to food security does give a good overview of the usefulness of the approach and signals important steps for future research. After confidence with the current application has been built up, the framework can be applied to other issues related to needs. Combining these frameworks will give us the ability to assess several vulnerabilities at once, and thereby gain insights into their inter-linkages. Scenario analysis and policy applications can be used to help policy-makers find robust solutions for the complex issues and dilemmas of global change and sustainable development.

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Appendix A: Glossary

Coping capacity: the degree to which adjustments in practices, processes or structures can moderate or offset the potential for damage or take advantage of opportunities created by global change.

Composite indicator: an aggregate of indicators and indices.

Degree of food deprivation: a measure of the overall food insecurity situation in a country, based on a classification system that combines prevalence of undernourishment and depth of undernourishment.

Dietary energy deficit: the difference between the average daily dietary energy intake of an undernourished population and its average minimum energy requirement.

Dietary energy intake: the energy content of food consumed.

Dietary energy requirement: the amount of dietary energy required by an individual to maintain body functions, health and normal activity.

Dietary energy supply (DES): food available for human consumption. At country level, it is calculated as the food remaining for human use after deduction of all non-food consumption (exports, animal feed, industrial use, seed and wastage).

Diet diversity: an indicator for steady access to sufficient amounts of nutritious food, defined as the share of cereals and roots and tubers in total DES.

Depth of under-nourishment: magnitude of the dietary energy deficit of the undernourished population.

Exposure: the nature and degree to which the human and environmental systems are exposed to global change.

Indicators: pieces of information designed to communicate complex messages in a simplified, (quasi)-quantitative manner.

Indicator framework: a set of indicators and indices.

Indices: multi-dimensional composites made from a set of indicators and/or indices.

Food insecurity: a situation that exists when people lack secure access to sufficient amounts of safe and nutritious food for normal growth and development and an active and healthy life.

Food security: a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life.

Malnutrition: an abnormal physiological condition caused by deficiencies, excesses or imbalances in energy, protein and/or other nutrients.

Minimum dietary energy requirement: in a specified age/sex category, the amount of dietary energy per person that is considered adequate to meet the energy needs for light activity and good health. For an entire population, the minimum energy requirement is the weighted average of the minimum energy requirements of the different age/sex groups in the population.

Potential impact: all impacts that may occur given projected global change without considering planned adaptation.

Prevalence of under-nourishment: proportion of the total population suffering from dietary energy deficit.

Sensitivity: the degree to which a human–environment system is affected, either adversely or beneficially, by global change.

Under-nourishment: food intake that is insufficient to meet dietary energy requirements continuously.

Undernutrition: the result of undernourishment, poor absorption and/or poor biological use of nutrients consumed.

Vulnerability: the likelihood that a specific coupled human–environment system could experience harm from exposure to stresses associated with alterations of societies and the biosphere (sensitivity), accounting for the process of adaptation.

Appendix B: The IMAGE 2.2 model

The IMAGE 2.2 model (Integrated Model to Assess the Global Environment) was originally developed to assess the impacts of anthropogenic climate change but has been expanded to a more comprehensive coverage of global change issues from an environmental perspective (Alcamo et al., 1998; IMAGE-team, 2001). The model framework consists of a set of linked and integrated models, which collectively describe important elements of the long-term dynamics of global environmental change (see Figure 11).

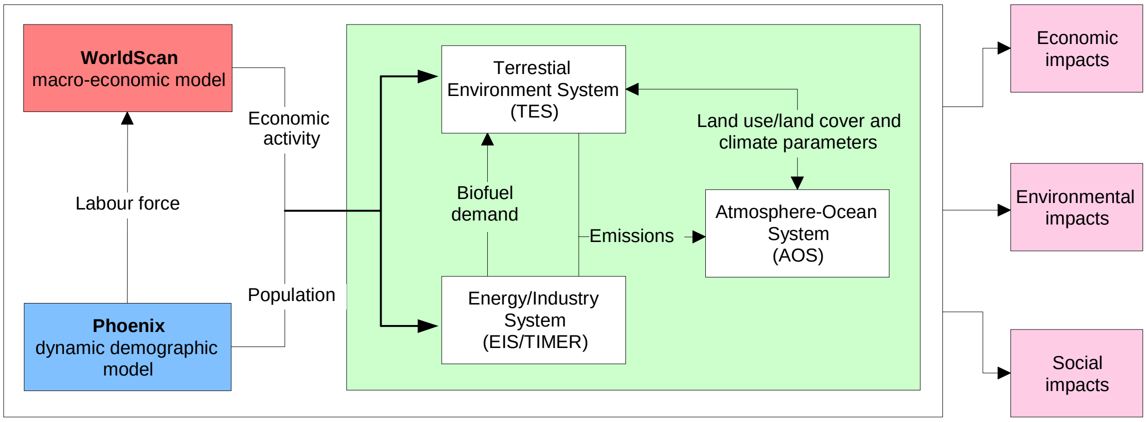

Figure 11: IMAGE 2.2 model linkages and integration of the sub-models.

The chain starts with the dynamic population model, Phoenix, and the general equilibrium economy model, WorldScan, forming the input for three fully integrated systems of models: the Terrestrial Environment System (TES), the Energy-Industry System (EIS) and the Atmospheric Ocean System (AOS). Results from the models are used to determine several impacts. The indicators are computed on different geographical scales, i.e. a grid scale of 0.5^{o} by 0.5^{o} or a 17-region scale (Kreileman et al., 1998). The different sub-models are described below.

Phoenix describes, positions and analyses various long-term population issues. A systems dynamic modelling approach is applied to describe demographic changes as a composite of its underlying components: the epidemiological and fertility transitions. The effects of future fertility behaviour and mortality patterns on population size and age structure can be explored under varying socio-economic and environmental conditions (Hilderink, 2000).

WorldScan is an Applied General Equilibrium model based on neo-classical economic theory. Although the model is designed to analyse international economics, it can also be used to analyse energy, transport, trade and environmental policies. The model distinguishes 11 sectors, where the inputs for each sector are products taken from the other sectors, low- and high-skilled labour, capital, and land & resources. Growth of GDP is modelled as a function of the growth of capital, labour and technology, while trade is endogenously calculated and the allocation of macro consumption over time and categories is region-specific (CPB, 1999).

TES computes changes in biomes due to climate change and land-use changes on the basis of regional consumption, production and trading of food, animal feed, fodder, grass and timber, with consideration of local climatic (change) and terrain properties. The model also computes emissions from land-use changes, natural ecosystems and agricultural production systems, and the exchange of CO_2 between terrestrial ecosystems and the atmosphere (Alcamo et al., 1998).

EIS/TIMER calculates regional energy consumption, energy-efficiency improvements, fuel substitution, and the supply and trade of fossil fuels and renewable energy technologies. The model computes emissions of greenhouse gases (GHG), ozone precursors and acidifying compounds on the basis of energy use and industrial production (de Vries et al., 2001).

AOS uses the emission estimates of TES and EIS to calculate changes in the atmospheric composition, taking oceanic CO_2 uptake and atmospheric chemistry into consideration. Subsequently, AOS computes changes in climatic properties by resolving the changes in radiative forcing caused by greenhouse gases, aerosols and oceanic heat transport (Eickhout et al., 2004).