Towards a Global Integrated Sustainability Model

GISMO1.0 status report

Background Studies

Netherlands Environmental Assessment Agency

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Abstract

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Sustainable Development, comprising the link between the environment and development issues, is very complex, and includes many interrelations between social, economic and environmental developments. To address these complexities and interrelations, a new modelling project was initiated. The primary aim of this project is to operationalise and quantify the concept of sustainable development through a modelling framework: the *Global Integrated Sustainability MOdel* (GISMO). Taking the distribution, continuation and improvement of *Quality of Life* as the main outcome of sustainable development - with health, poverty and education as its main pillars - the model addresses changes in quality of life as a consequence of changes in the three sustainability domains (the social, economic and environmental domain). By describing and integrating the three domains in one modelling framework, the underlying dynamics of (un) sustainable development can be assessed, including the feedbacks, trade-offs and co-benefits within and between the three domains, as well as within and between time (inter-generational equity) and space (intra-generational equity). In addition, by including the institutional domain - sometimes referred to as a fourth sustainability domain – the model enables to evaluate the contributions by different policy options and interventions to the improvement in the quality of life and its synergies and trade-offs with the environment. This report presents the rationale behind the project and discusses the methodological aspects. Furthermore, it presents the GISMO1.0 model and provides the agenda for future model developments.

Keywords: Sustainability modelling, Health, Education, Poverty, Quality of Life

Rapport in het kort

Het ontwikkelen van een mondiaal geïntegreerd duurzaamheidsmodel
GISMO1.0 statusrapport

Duurzame Ontwikkeling is een complex begrip en omvat een breed scala aan relaties tussen sociale, economische en milieuontwikkelingen. Om deze complexiteit te kunnen begrijpen en analyseren heeft het Planbureau van de Leefomgeving (PBL) een nieuw modelleringsproject gestart: het Global Integrated Sustainability MOdel (GISMO). Met het GISMO project wordt het concept duurzame ontwikkeling verder uitgewerkt, met gezondheid, armoede en onderwijs als belangrijke pijlers van kwaliteit van leven. Het doel van het project is om (veranderingen in) kwaliteit van leven in relatie tot de drie duurzaamheidsdomeinen te analyseren. Daarnaast worden binnen het project beleidsopties en interventies geëvalueerd die moeten resulteren in verbetering van de kwaliteit van leven, inclusief mogelijke synergie met, of afwenteling op het milieu. Dit vereist dat de drie duurzaamheidsdomeinen in één modelleringskader worden geïntegreerd om inzicht in onderliggende mechanismen van (on)duurzame ontwikkeling te adresseren en mogelijke terugkoppelingen, afwentelingen en meekoppelingen te analyseren binnen en tussen deze domeinen, evenals in de tijd (gelijkheid tussen generaties) en ruimte (intra-generationale gelijkheid). Ook wordt het institutionele domein, dat soms als vierde duurzaamheidsdomein gedefinieerd wordt, in relatie tot de andere drie domeinen meegenomen, bijvoorbeeld om de voorwaarden te kunnen aangeven waaronder de beleidsopties effectief kwaliteit van leven kunnen verbeteren. Het doel van dit rapport is een beschrijving van het GISMO Project waaronder de achterliggende filosofie, de methodologische aspecten van het geïntegreerd modelleren, het model GISMO1.0 en de agenda voor toekomstige modelontwikkelingen.

Trefwoorden: Duurzame Ontwikkeling, modellering, Gezondheid, Educatie, Ontwikkeling, Kwaliteit van leven

Preface

This project was undertaken as part of the Strategic Research programme of the Netherlands Environmental Assessment Agency. The GISMO-project team would like to express their appreciation for the various contributions from other colleagues at the Netherlands Environmental Assessment Agency. In particular Arthur Beusen, Ton Manders, Bas Eickhout, Tom Kram, Joop Oude Lohuis and Fred Langeweg have been very helpful with their comments and advice. We would like to thank Louis Niessen (Johns Hopkins School of Public Health, iMTA EUR) for his valuable insides on modelling health dynamics. Finally, we want to bring into memory the two workshops we have had together with our counterparts in Global Sustainably modeling both at the University of Denver and at the TARU institute in India. Both Barry Hughes and Aromar Revi, as representatives of their respective institutes, have become very valuable and warm oversees connections. The use of the economy module of the “International Futures model (IFs) with Pardee” has been invaluable for our modelling efforts. Also the contributions from Aro and friends always bring in the experience of real world problems of developing countries, from a developing expert’s perspective. We hope to continue having these kinds of inspiring and necessary meetings!

Contents

1 Introduction

The relation 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 environmental change describes the human-induced changes in the environment, on the global level. The recognition of the effect of human activity on climate change is only one of the global interrelations (IPCC, 2007). Changing ecosystems, and the goods and services they provide, have an undeniable effect on humans too, with consequences for their health status as one of the attesting factors (Millennium Ecosystem Assessment, 2005).

The report of the World Commission on Environment and Development (WCED), titled Our Common Future (1987), was among the first to establish the link between the environment and development issues and putting the term, 'sustainable development' on the political agenda. Operationalising the concept of sustainable development in global policies resulted in Agenda 21. This can be seen as a first attempt to formulate an international action programme for sustainable development (UN, 1993). Seven years later, the Millennium Development Goals (MDGs) were defined, which have been commonly accepted as the framework for development (UN, 2000a).

The link between the environment and development issues is very complex and includes several interrelations between social, economic and environmental development (also known as the three sustainability domains; People-Planet-Profit). Adequate tools and concepts are required to assess these complexities and interrelations, with respect to future developments and policy interventions. Understanding these interrelations gives insight into how development is interconnected with environmental aspects, and supports policymakers to assess the direct and indirect effects of policies on the various domains. To address these issues, a new modelling project is under development: the Global Integrated Sustainability MOdel (GISMO).

The GISMO project intends to operationalise the concept of sustainable development by analysing the two-way relationship between global environmental change and human development. Its primary aim is to assess the quality of life and changes therein, following changes in the three sustainability domains. Furthermore, the project aims to evaluate the contributions by policy options and the effects of interventions on the improvement of the quality of life and its synergies and trade-offs with the environment. Within the GISMO project, the concept of sustainable development will be operationalised through the modelling of the socio-economic domain, while building on a long history of modelling experiences at the Netherlands Environmental Assessment Agency (PBL): the TARGETS model (Rotmans and De Vries, 1997) and the IMAGE model (MNP, 2006). The three sustainability domains will be integrated in one modelling framework, to gain insight in the underlying dynamics of (un)sustainable development and to analyse feedbacks, trade-offs and co-benefits within and between these various domains, as well as within and between time (inter-generational equity) and space (intra-generational equity). Furthermore, the institutional domain, sometimes included as the fourth sustainability domain, will be considered and related to the three domains, to address the conditions under which policy options and interventions can effectively contribute to an improving quality of life. Where the IMAGE model describes the impacts of socio-economic development (population, economy and technology) on the global environment, the GISMO model should also address the feedbacks of global environmental change on the socio-economic developments. In this way, the GISMO project can be regarded as complementary to the IMAGE model.

This report describes the GISMO project, justifying its approach. It reports on the rationale behind the project, discusses the methodological aspects, presents the GISMO1.0 model and provides the agenda for future model developments. Chapter 2 elaborates on the concepts of *Sustainable Development* and *Quality of Life*. Chapter 3 presents the GISMO project, focusing on its goals and purposes, including the theoretical foundations and methodological steps to operationalise these goals. In Chapter 4, the GISMO1.0 model is presented, while Chapters 5 to 8 present the various (sub)models included, which capture the three main dimensions of Quality of Life (health, education and economy). In Chapter 9, global Quality of Life is quantified in line with Chapter 3. Finally, Chapter 10 presents a conclusive discussion on the current status of the model and a modelling agenda for the future.

2 Sustainable Development and Quality of Life

The GISMO project intends to operationalise the concept of sustainable development. In the *Second Sustainability Outlook* (MNP, 2007) the distribution, continuation and improvement of quality of life are considered to be the main outcome of sustainable development. Adopting this definition, the GISMO project's primary aim is to assess quality of life and changes therein, following changes in the three sustainability domains. Furthermore, the project aims to evaluate policy options and interventions for improving quality of life and its synergies and trade-offs with the environment. There have already been many predecessors of sustainability modelling. In this chapter, an overview of the various aspects of sustainable development is given, including a description of modelling approaches attempting to capture them. Furthermore, a brief overview is given of the facets of *Quality of Life* and ways to quantify it.

2.1 Sustainable Development

There are numerous definitions of sustainable development. One of the most commonly used definitions remains that of the *World Commission on Environment and Development* (WCED), sometimes referred to as the *Brundtland Commission*. The WCED report *Our Common Future* (WCED, 1987) established the link between environment and development issues and firmly put the term 'sustainable development' on the political agenda. WCED defined sustainable development as 'Development that meets the needs of the present, without compromising the ability of future generations to meet their own needs'. Since then, many refinements, additions and alternatives have been introduced. There have been many attempts to come up with a policy agenda to address sustainable development. One of the earlier attempts was *Agenda 21* (UN, 1993), which was agreed upon at the *1992 United Nations Conference on Environment and Development* in Rio de Janeiro. Agenda 21 was meant to be a comprehensive agenda for taking action, globally, nationally and locally, and comprised four chapters: Social and Economic Dimensions (e.g., poverty, consumption, population and health); Conservation and Management of Resources for Development (e.g., biodiversity, climate, pollution); Strengthening the Role of Major Groups (e.g., children, women, NGOs) and Means of Implementation (including science, technology transfer, international institutions and financial mechanisms).

One of the more recent initiatives is the *Millennium Development Goals* (MDGs), an ambitious agenda for reducing poverty and improving living conditions of the global poor. The MDGs are drawn from the actions and targets contained in the *Millennium Declaration* that was adopted by 189 nations and signed by 147 heads of state and governments during the UN *Millennium Summit* in Johannesburg, in September 2000. The MDGs show a large overlap with Agenda 21, though the emphasis has shifted somewhat towards human development. Another step forward is the inclusion of specific, quantified targets in the MDGs. For the eight goals and twenty accompanying targets, 48 indicators have been identified for monitoring development. By the assigning of the eight goals the policy targets for 2015 were also set:

- MDG1: Eradicate extreme poverty and hunger;
- MDG2: Achieve universal primary education;
- MDG3: Promote gender equality and empower women;
- MDG4: Reduce child mortality;
- MDG5: Improve maternal health;
- MDG6: Combat HIV/AIDS, malaria and other diseases;

- MDG7: Ensure environmental sustainability;
- MDG8: Develop a global partnership for development.

The strength of the MDGs lies in the broad support it enjoys, with 191 nations adopting the Millennium Declaration. A challenge is how to achieve the goals, especially in combination with the mutual relationships between the underlying processes. ‘Can poverty and hunger be halved by 2015 (MDG1), while ensuring environmental sustainability (MDG7)?’ - a question very relevant in the context of sustainable development. Furthermore, the interdependency of the various MDGs is illustrated by the goal for primary education, which will also, indirectly, reduce child mortality.

2.1.1 Capturing sustainable development

Since the 1950s, the systems approach has been used to describe complex dynamic systems in several multi- and interdisciplinary research areas, such as computer science, operations research and management (Kramer and Smit, 1991). The breakthrough for the systems approach occurred in the 1970s, with the publication of the first report to the *Club of Rome* called *Limits to growth* (Meadows *et al.*, 1972). The computer simulation model *World3*, an example of a systems dynamic approach, was used in this report. World3 and its precursor World2 (Forrester, 1971) are considered representatives of first-generation modelling approaches of the interactions between the human or societal system and the environmental system (Opschoor, 1999). By interlinking human and environmental systems, conditions for sustainable growth could be determined, given limited natural resources. This modelling approach – and especially some of the resulting doomsday scenarios – received lots of criticism, but also strong support. Among the supporters were the publications *Interfutures* (OECD, 1979), *Global 2000* (Barney, 1980) and *Our Common Future* (WCED, 1987). These studies formed the second generation of modelling approaches, which went in the same direction as *Limits to Growth,* but they were more qualitative in nature (Opschoor, 1999).

In the nineties, more quantity-oriented, integrated assessment (IA) models were developed, marking the third generation. One of the objectives of IA modelling is to support public decision-making by developing a coherent framework for assessing impacts and trade-offs between social, economic, institutional and ecological determinants (Rotmans *et al.*, 1997). In the first instance, most IA models concentrated either only on the environmental system, for example IMAGE (Rotmans, 1990; Alcamo, 1994) and RAINS (Hordijk, 1991), or the economic system, for example GREEN (Lee *et al.*, 1994) and *WorldScan* (Geurts *et al.*, 1995), only exogenously including the societal system. More recently, such population and health aspects are included as an interacting subsystem in global models, such as TARGETS (Rotmans and De Vries, 1997; De Vries, 2001) and GUMBO (Boumans *et al.*, 2002), describing the human-environment system, on a global scale. Other models, which could be regarded as sustainable-development models, include *PoleStar* (Raskin *et al.*, 1999), which is a world-regional model, and global models covering the national scale, such as *International Futures* (Hughes and Hildebrand, 2006), *Threshold21* (Millennium Institute, 2004) and RAPID IV (Futures Group, 1999). Model development will not stop here, but continues to produce and yield more refined and improved approaches. Especially, the capturing of the human/social dimension with a simulation model might have outgrown its infancy stage and deserves specific attention in order to mature. Also, the use of models for supporting policy decisions and policy-making can be improved, not only by emphasising images of the future as model outcomes, but also by addressing the uncertainties associated with projected futures.

2.1.2 Modelling Sustainable Development

Five of the above-mentioned models have been evaluated in more detail, with respect to their potential contribution to the GISMO project. This evaluation encompasses the descriptiveness of the models, with respect to the three sustainability domains (economy, ecology and human-social), the inclusion of the institutional domain and its integration, and the presentation of the model results to the user (see also 2003).

The GUMBO model clearly focuses on ecosystems, presenting a good degree of integration with the social, economic and institutional domains, while lacking a good description of these domains. Threshold 21 lacks a good presentation of the institutional and environmental domains. Nevertheless, the model has a high level of integration, is rather transparent and has an easy-to-use interface. Furthermore, the human-social domain is well covered. *PoleStar* is more of an accounting model. It covers a small degree of integration, and lacks an institutional domain. It uses scenario inputs for GDP and population, without modelling any feedbacks on them. Nonetheless, the model is transparent and provides a good presentation of results. International Futures covers all domains and their integration. The main advantage of this model is its in-depth world coverage (on a country basis) and the economic and institutional modules. Although it takes some time to get acquainted with the interface, the model covers a lot of policy handles for interventions and scenario construction. Finally, the TARGETS model shows a good integration of the three main domains of sustainability and best describes the human-social domain. However, the model scores negative with its economic module and the poor presentation of an institutional domain, as well as its spatial application, as it only presents the global scale.

From the above can be concluded that the evaluation of the International Futures model is the most positive, since the domains are depicted and interrelated in a transparent way (with the economy module as the centre of the integration). Moreover, the model covers a spatial breakdown towards country level, with the most relevant interactions modelled between them (e.g., trade, aid and international institutions). Nevertheless, all five models have their own distinct strong elements, for example, the coverage of the human-social domain of Threshold 21 and the TARGETS model. The latter model has already triggered the desegregation towards a regional version of the population and the energy module within the IMAGE model. Therefore, we conclude that, although International Futures is the overall best, distilling the strong elements out of all five models contributes to our own global sustainability modelling project. The development of new concepts – from scratch – neglecting past efforts and experience, should thereby be avoided.

2.2 Quality of Life

One of the most important ultimate ends of sustainable development is, without any doubt, human well-being or quality of life. Well-being and quality of life are considered here as interchangeble. Quality of life can be regarded as the crucial outcome of underlying processes in the economic, ecologic and social/human domains. It does not only contain one's own quality of life, but also that of others, which shows a similarity with WCED's definition of sustainable development (WCED, 1987). In this section, a brief overview is given of (a selection of) theoretical approaches of quality of life and how these could be operationalised in the context of sustainable development. The focus will not be on the theoretical embedding, but rather on how various approaches could be linked to or included in our simulation models.

2.2.1 Theories of quality of life - a brief overview

Quality of life comprises more than income (Canoy and Lerais, 2007). However, alternative indicators are not so easy to find, since one has to specify which aspects make up this quality, and how they could be measured. There have been different attempts to classify various approaches of quality of life. Three fundamental aspects are recommended to be taken into account (Gasper, 2004a):

- measure of subjective well-being (SWB) versus objective well-being (OWB), i.e. feeling versus non-feeling aspects;
- self-reported versus non self-reported measures;
- universal measures, which can be applied at all times and in all places, versus relative or time- and place-specific measures.

Parfit (1984) distinguished the following three categories of theories: 1) Hedonism, in which well-being is seen as a pleasure, 2) Desire, which focuses on how a person can best fulfil his desires, and 3) Objective List Theories, also known as substantive good conceptions. This list is not exhaustive and can be (and is) easily extended with other categories (Gasper, 2004b), for example, well-being seen as free choice, or well-being seen as a favourable capability.

A useful categorisation is given by Robeyns (2004). Broadly speaking, three fundamental approaches for well-being are distinguished: resource-based theories, utilitarianism, and the capability approach. A similar classification is described by Gasper, taking the following levels of focus as a starting point: 1) Information on inputs, money-metric focus; 2) Non-fulfilment non-money metric information; and 3) Fulfilment satisfaction information.

The first approach takes material and resources as the main aspect relevant to well-being. This does not only comprise financial resources, but also a broad spectrum of means, which can be used to promote well-being. The main point is how people, themselves, can fill in how they want to achieve there own interpretation of well-being. The role of governments is to enable people to use the resources. Such an emphasis can be found in economic theories, where (a means of) well-being is freely taken as welfare and/or income. The use of GDP as a proxy for welfare has been broadly criticised (but still seems a powerful indicator, given its frequent use). This approach can also be criticised, because it does not give a fitting description of what quality of life is all about (as an intrinsic goal of life), but only reveals which means are important to achieve a certain level of well-being.

The second approach, utilitarianism, does not put the means at the core of well-being but focuses on how people experience or value the quality of their own lives, using subjective measures such as satisfaction or happiness. One of the problems of this approach is that it highly depends on how people define the criterion – this can be different for every person. Such an individual-based definition of well-being makes operationalisation at a higher abstraction level rather difficult.

The third approach, the capability approach, looks at the real possibilities a person has, to do or to be something and to develop him- of herself or flourish. In this approach, people have the choice of whether they use these possibilities to come to such a development, or not. This

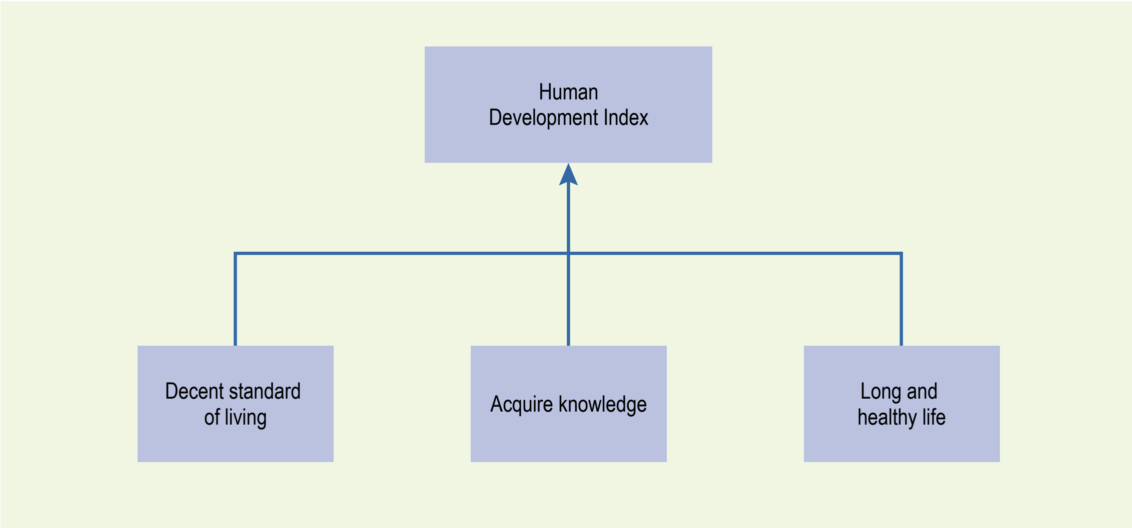

Figure 1 The three dimensions of the Human Development Index (HDI).

could be extended by defining realised capabilities as 'functionings'. A point of criticism can be that this approach leaves room for interpretation, since it only indicates capabilities relevant to quality of life, without identifying what this quality is, exactly. An advantage of this approach is the universality of this theory, which allows for application to various situations and countries.

The capability approach might best suit the way sustainability aspects are dealt with at PBL (Robeyns and Van der Veen, 2007), although the resource-oriented and the utilitarianism appraoches should not be completely left out, since they also represent relevant aspects of quality of life. Putting the relation between means and ends (or goals) at the central point of study, is closely connected with the ongoing sustainable-development discussion on trade-offs between the various sustainability domains. The capability approach combines a more objective-oriented perspective (means, and the freedom of choice to achieve well-being), with a more subjective-oriented dimension (realisation of well-being, strongly related to outlook on life and perception of what sustainable development is).

2.2.2 Existing approaches and measurements

There are many approaches to and measurements of Quality of Life. Some of them are more strictly embedded in one of the three theoretical approaches, while others seem to follow a more pragmatic approach. A brief overview is given of some of the approaches which are the most commonly used and the most authoritative.

UNDP's Human Development Index
An example of an application of the capability approach, which has been elaborated in quantitative indicators, is the *Human Development Index* (HDI). The HDI was introduced in the human development report 1990 and has been refined several times, since (UNDP, 1994; UNDP, 1995; UNDP, 1996; UNDP, 1997). The purpose of the HDI is 'to map the concept of human development' in order to 'capture as many aspects as possible in one simple composite index and to produce a ranking of development achievement' (UNDP, 1996, p. 28). The UNDP defines human development as a process of enlarging people's choices. In principle, these choices can be infinite and can change, over time. But at all levels of development, the three essential choices are: leading a long and healthy life, acquiring knowledge and having access to the resources

needed for a decent standard of living (see Figure 1). In the human development reports, the UNDP quantifies the HDI by using GDP per capita (in Purchasing Power Parity terms), combined enrolment ratios of primary, secondary and tertiary education and the life expectancy at birth, respectively.

The commonly used HDI is an example of a simple but solid measure of human development. The criticism concerns the interchangeability of the dimensions, although this is considered to be a positive aspect by others (Millennium Ecosystem Assessment, 2005). For example, for a country where people's income is around the world average, a life-expectancy increase of 1 year, is assumed to be equal to the increase in annual income of approximately $100. This interchangeability seems to be inevitable when constructing a composite index. Other critique on the HDI is that, although the three dimensions are also relevant to developed countries, the indicator choice limits its use to developing countries. Furthermore, the indicators seem to focus more on quantity rather than on quality. For developed countries, the use of literacy is a rather meaningless indicator since it is already almost 100% for most countries, while the contribution of income to quality of life suffers from diminishing returns at income levels. Also life expectancy is not the only concern in developed countries in improving mortality; it is also the quality of the extended life that has to be taken into account. Finally, the HDI only takes averages into account, thereby neglecting the underlying distribution. Applying the HDI for different groups of people might cover this shortcoming. The UNDP did this by making the HDI gender-specific resulting in the Gender-related Development Index (GDI). These two gender components were then aggregated again, including a penalty factor for inequality. This could be done along other dimensions and groups of people (urban-rural, rich-poor).

In line with the HDI, the Millennium Development Goals can be considered. They have a much broader scope than the HDI does, although the overlap with the domains of the HDI is big (see also UNDP, 2006). Furthermore, the MDGs also cover environmental and institutional aspects, as well as gender issues, which are not directly included in the HDI. The MDGs are also discussed in the previous chapter.

Health-related quality of life: Disability-adjusted life years (DALYs)
In most of the Quality of Life approaches, health has a prominent role (Daly, 1990; Nussbaum and Sen, 1993; Prescott-Allen, 2001). Although the HDI includes 'a long and healthy life', the choice for the associated indicator – life expectancy – only expresses the length and leaves health aside. Since the 1970s, people are trying to capture both mortality and morbidity in one indicator (Fanshel and Bush, 1970). In the 1990s, the World Bank and the WHO formalised a combined indicator in their *Global Burden of Disease* study, by introducing 'disability-adjusted life years' (DALYs). The DALY is – together with 'quality-adjusted life years' (QALYs) – probably one of the most commonly used, so-called Summary Measure of Population Health (SMPH) (Murray *et al.*, 2002). These days, the WHO yearly reports the DALY in their World Health Reports (e.g. see WHO, 2006). The DALY quantifies health loss, based on two components: years lost due to premature mortality, and years lived with a certain disease or disability. The loss of quality of life due to a disease or disability, depends on the incidence and duration of this disease and its severity, expressed in a disability weight ranging from 0 (perfect health) to 1 (dead). The loss of quality of life due to premature mortality is based on the age at the time of death and the number of years a person could have continued to live. One DALY can be thought of as one lost year of 'healthy' life and the burden of disease as a measurement of the gap between current health status and an ideal situation, in which everyone lives into old age, free of disease and disability (WHO, 2006). In some variants of the DALY, discount rates for future

health are included to reflect the time preference. In addition to discounting, age-weights are applied, which allow for different valuing of years lived at different ages.

Nevertheless, the DALY has received much criticism, especially concerning its use in economic evaluations (Cohen, 2000). The approach explicitly presupposes that the lives of disabled people have less value than those of people without disabilities and that life at certain ages is more valuable than at others (Arnesen, 1999). The disability weights, essential for aggregating different diseases to an overall measure for disease burden, are also subjected to criticism. However, given these considerations, the DALY approach provides a comprehensive index, not only for comparing different diseases and even death, but also for analysing the effects of underlying health risks, if used cautiously.

Millennium Ecosystem Assessment and UNEP's GEO-IV

The *Millennium Ecosystem Assessment* (MA, Millennium Ecosystem Assessment, 2005) tried to specifically address the linkages between ecosystems' goods and services, to the well-being of groups of people and individuals. Ecosystems' services are categorised by provisioning (e.g., food, fresh water), regulating (e.g., climate, flood and disease regulation), and cultural (e.g., aesthetic, spiritual, recreational). Their conceptualisation is done through the assumed multi-dimensional continuum of the two extremes: well-being and poverty. The selection of items is mainly based on '*voices of the poor*' (Narayan and Petesch, 2002). The following well-being elements are used in the Millennium Ecosystem Assessment (2005, p74):

- The necessary material for a good life (including secure and adequate livelihoods, income and assets, enough food at all times, shelter, furniture, clothing, and access to goods);
- health (including being strong, feeling well, and having a healthy physical environment);
- good social relations (including social cohesion, mutual respect, good gender and family relations, and the ability to help others and provide for children);
- security (including secure access to natural and other resources, safety of person and possessions, and living in a predictable and controllable environment with security from natural and human-made disasters); and
- Freedom and choice (including having control over what happens and being able to achieve what a person values doing or being).

These aspects are considered as the ends or constituents of well-being, while the ecosystems services represent the means. Various elements of the aforementioned theories and approaches seem to be present, although a more sound theoretical foundation of selection criteria is not given. Unfortunately, a more practical operationalisation also seems to be lacking. This framework served as a starting point for the UNEP's GEOIV (UNEP, 2007), especially given the more central position of environmental issues (Wonink *et al.*, 2005). The MA approach was meant to interrelate the environment to human well-being. However, the lack of a more quantified elaboration, both in those interrelations and in the choice for indicators, forms a big obstacle.

3 The GISMO model

This chapter describes the objectives and purposes of the GISMO model. Three main objectives have been identified: capturing quality of life, integration of the three sustainability domains, and addressing policy options and interventions. These objectives have their own associated methodological choices of how to bring them into operationalisation, which will be discussed here. The chapter concludes with practical steps towards the GISMO1.0 model, which focuses on health, education and the basic economy.

3.1 Model objectives and purposes

The objective of the GISMO model is threefold.
- The *first objective* is to address *Quality of Life*, taking the distribution, improvement and continuation of Quality of Life as the main outcome of sustainable development.
- The *second objective* is to develop an integrated framework, to gain insights in underlying dynamics of (un)sustainable development and to analyse feedbacks, trade-offs and co-benefits within and between the economic, social and environmental domains, as well as within and between time and space.
- The *third objective* is to analyse the impacts of policy options and interventions in terms of quality of life, and its synergies and trade-offs with the environment.

The framework, as shown in Figure 2, is used to present these three objectives. It includes the overarching first objective of addressing quality of life, as well as the integration of the three sustainability domains. With respect to the third objective, the institutional domain as a fourth domain is added (Spangenberg and Bonniot, 1998).

3.2 Quality of Life and simulation models

Taking the distribution, continuation and improvement of *Quality of Life* as the main outcome of sustainable development (objective 1 of the GISMO project), brings along the issue of how to address Quality of Life in the context of a modelling framework. A quality-of-life indicator or index should preferably (Hilderink, 2004):
- have a sound theoretical foundation and be multidimensional;
- have a clear interlinkage with the three sustainability domains;
- be generic and applicable worldwide;
- allow operationalising in a modelling framework.

The operationalisation of Quality of Life will always be subjected to criticism. The various perspectives, depicted in chapter 2, seem to be irreconcilable, at least when it comes to the selection of indicators and even creating an index. However, taking Quality of Life as the main outcome of sustainable development and having the aim of quantitatively describing future sustainable developments, requires further concretisation to be able to link Quality of Life to our simulation models. Most of the quality-of-life approaches, presented in section 2.2, have similar domains. Income, education and health seem to be the most important aspects, completed with people's social structures. The latter reflects aspects of social cohesion, social justice, societal structures, family life and participation (other than labour). This brings along difficulties when

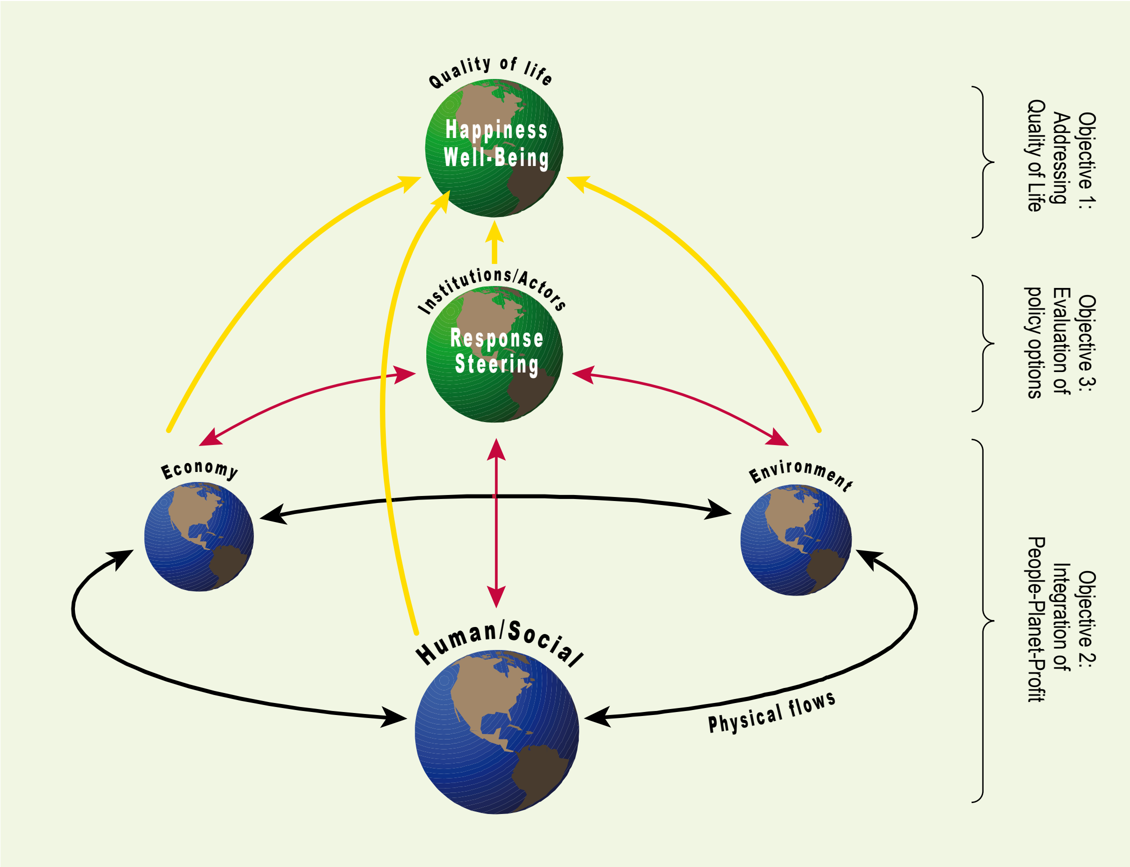

Figure 2 The three objectives of the GISMO project.

linking them with quantitative indicators and operationalising them in a modelling framework. Only for the first three aspects various indicators are available which are also included in the HDI.

Keeping the limitations of the HDI in mind, as well as the options for alternative approaches, the HDI can offer a good point of departure for the exploration of future developments of Quality of Life. Because life expectancy only reflects 'number of years', while the quality of those years might be as important, the Disability-Adjusted Life Years (DALY) can be used as a supplement to life expectancy. The use of the DALY approach can also increase the distinctive power of the index for developed countries. Another advantage of the DALY is that it also allows for tracing of the underlying health risk factors, including socio-economic and environmental ones. Furthermore, the indicator set of the MDGs can be included in the modelling framework, as an additional approach. The MDGs cover the three dimensions of the HDI, with a broader set of indicators tailored for development, expanding education and health coverage, but also including environmental issues (MDG7). As the environment is only included to a small degree, the link between the environmental issues could be strengthened by the approach of the Millennium Ecosystems Assessment, which explicitly addresses the link between Quality of Life and ecosystems' goods and services.

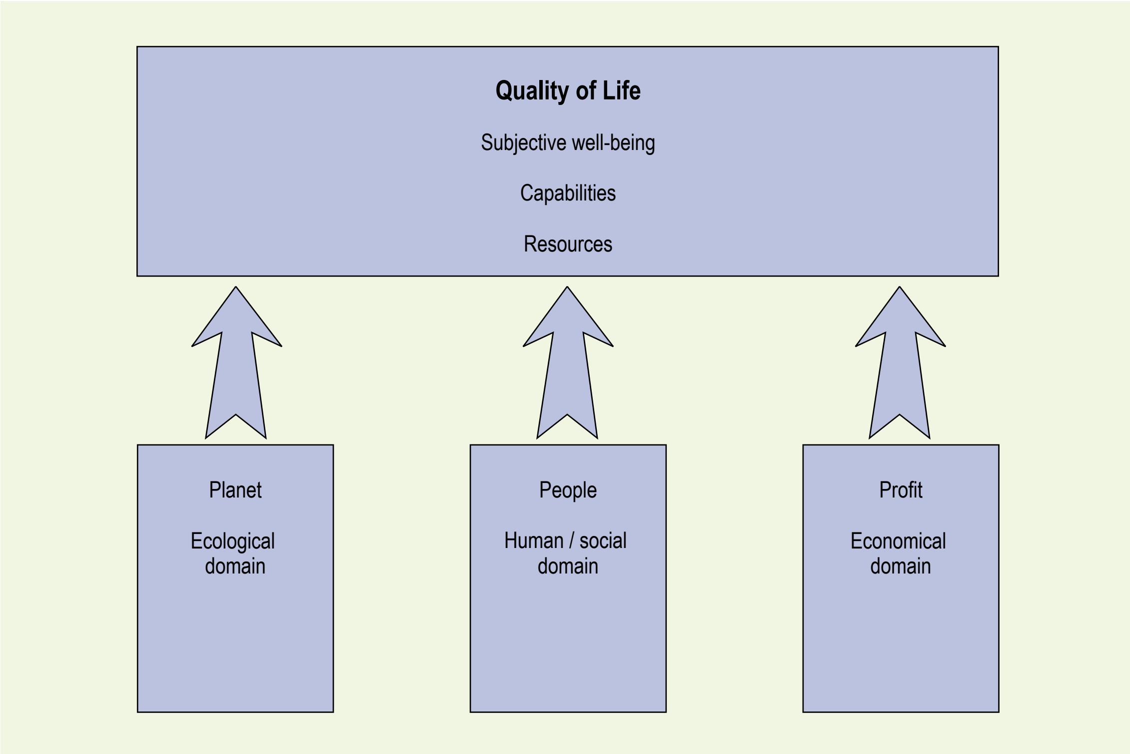

Figure 3 Multidimensional Quality of Life linked to the three sustainability domains.

3.3 Integration of the three sustainability domains

The second objective of the GISMO project is to integrate the three sustainability domains. The three domains were introduced in the 1990s and focused on different types of capital: economic, social and natural capital, and the degree to which people have access to them (Munasinghe, 1992; World Bank, 1995). This concept knows many successors and is considered to be the main outcome of sustainable development in the second sustainability outlook (MNP, 2007). This integration of the three sustainability domains is crucial in taking the interactions, feedbacks and possible trade-offs and co-benefits into account; not only within, but also between the three domains.

In this case, the three domains are mainly used as a mechanism to analyse the broad spectrum of Sustainable Development issues. In practice, most models and/or sub-models do not strictly follow this overall division. Not only can the interconnection of the issues be ambiguous – which seems to be the nature of Sustainable Development – but also the way in which issues play a role in the underlying processes. Is education considered as a main characteristic of the labour force and therefore an economic-oriented facet, or is it considered as a factor determining fertility behaviour and health outcomes, and therefore a more human-oriented facet. A similar interwovenness can be found with poverty, which can be considered as an outcome of income distribution, or as the inability of individuals to escape from their situation because of their limited capabilities. The three domains should, therefore, be seen as a guiding principle, not to be used too strictly, but, rather, as an organising framework to position various indicators.

To deal with integration, the three domains can be covered by several models, which are cooperating within a modelling framework. The approach of using several models within a modelling framework, is called modular design. The basic principle is that all models in the framework

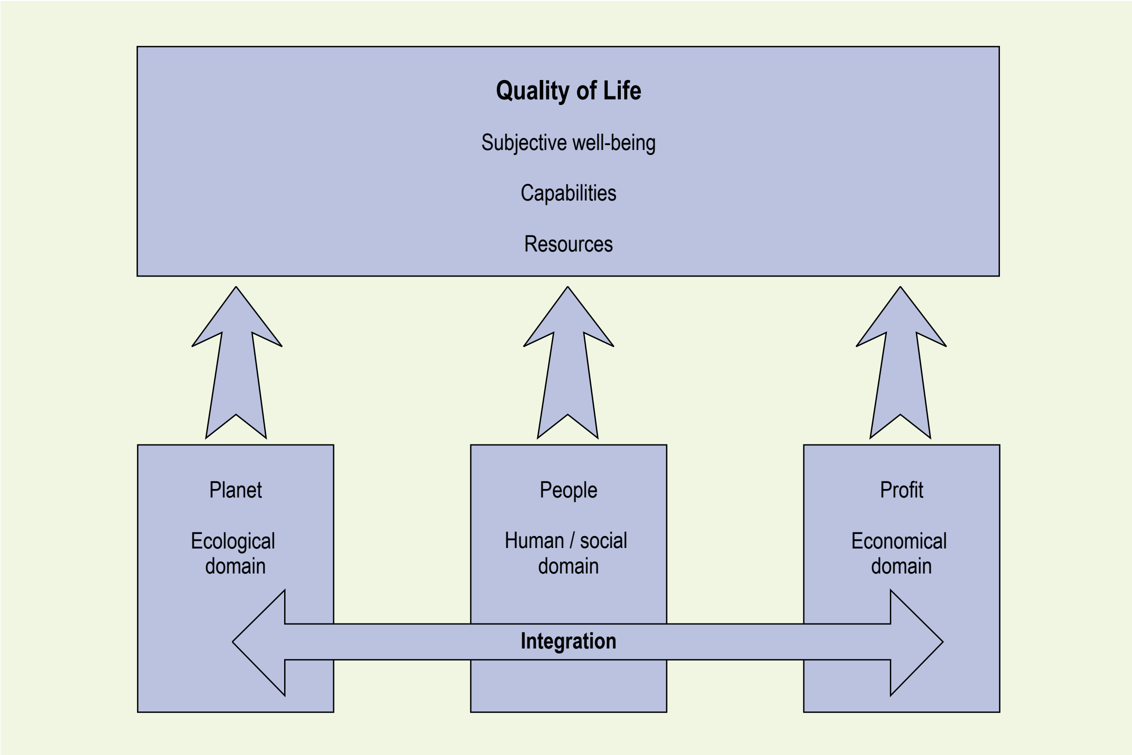

Figure 4 Integration of the three sustainability domains.

are independently created and are able to run both individually, and in combination with other models within the framework. Applying a modular design has several advantages. Models can be developed separately from the framework, and thus also be used for partial analyses. Modular design enables users to include only those models of particular interest. Furthermore, it allows substituting particular models with alternative approaches, to explore different perspectives on real-world dynamics. Finally, the possibility of running models in an integrated way – taking into account the interactions and feedbacks – may also provide a better insight into the dynamics between the domains.

To run models within a modelling framework, they need to be linked to each other. A more standard way of linking models is connecting them in series, which means that one model runs a complete simulation and the resulting output is fed into the next model. Series-coupled models, therefore, run individually and one after the other, which makes series-coupling quite a limited type of integration. A more advanced way of linking models is coupling them in a dynamic way, which means that the models run simultaneously and exchange data at each time step during the simulation. As a result, dynamically coupled models run in close cooperation. The models are linked in time and space and, therefore, their equations are solved simultaneously, so the outcomes of the models are dependent on each other. Dynamic coupling provides continuous feedback and integration of the models.

3.4 Including policy options and interventions

The third objective of the GISMO project is to identify policy options and interventions, to analyse their impacts in terms of Quality of Life and the environment, that is, to make ex-ante evaluations of possible policy interventions, using the policy handles which the model provides.

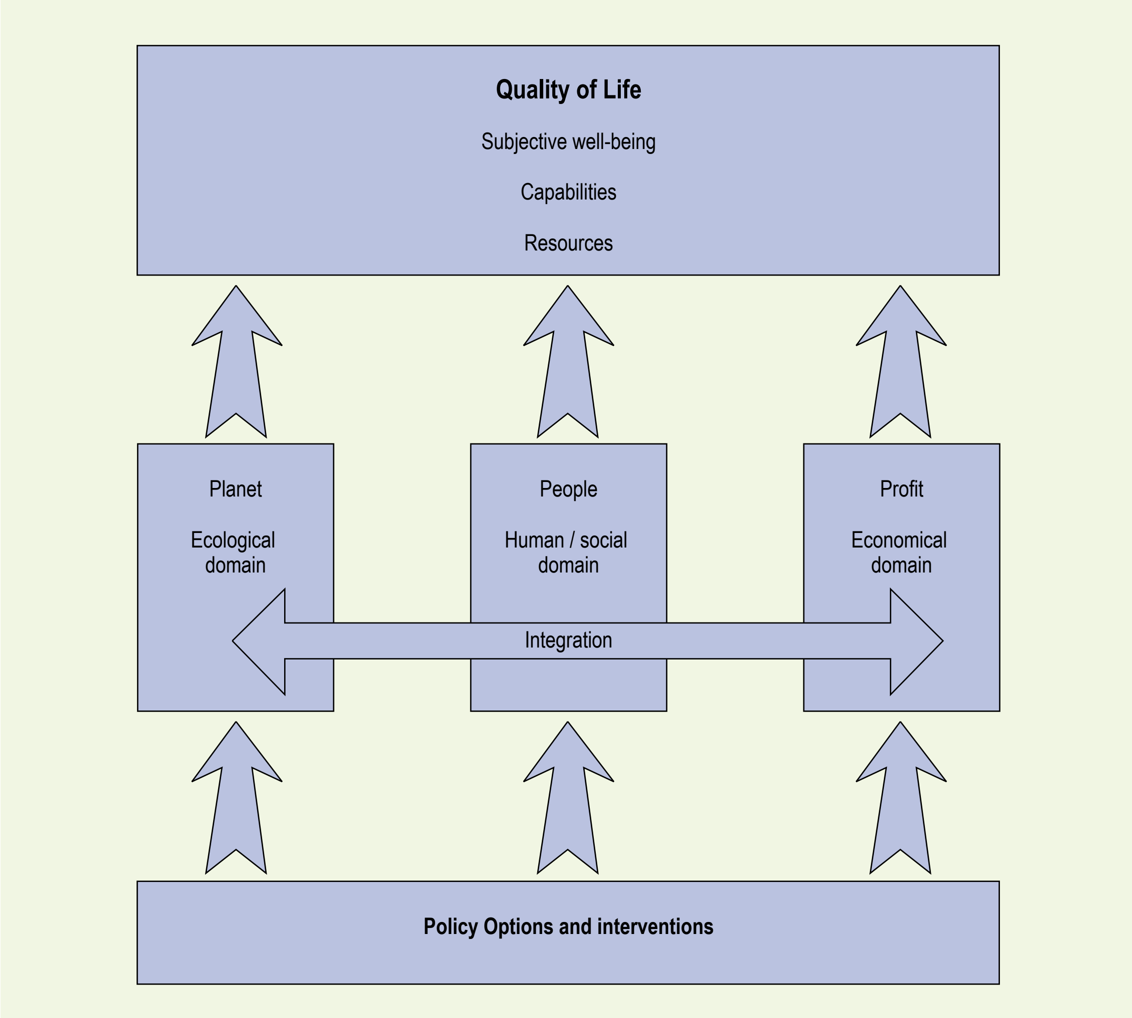

Figure 5 Including policy options and interventions.

The integrated framework, already described in the previous two sections, allows for analysing trade-offs and co-benefits between gains and losses in quality of life and the environment.

There are a number of interventions which can be analysed in the different domains, largely linked with the policy options identified in the MDGs (especially MDG8). MDG8 is about 'global partnership for development' and focuses on a number of facets of development aid, which, collectively, should lead to a practical approach of the development agenda. These are:

- Official development assistance (ODA);
- Debt cancellation for the least developed countries;
- Access to (world) markets;
- Availability of affordable medicines and new technologies;
- Reducing youth unemployment levels.

In addition, more specific options can be distinguished, such as investments in social capital (health, education) and physical capital (agriculture, energy), policies concerning global environmental changes (climate change, air pollution, biodiversity loss) and technological changes (in the agricultural and energy sector).

Such a global partnership requires that various stakeholders work together at various levels. Firstly, the governments of developing countries play an important role. The donor countries are also active, via bilateral aid programmes or multilateral institutions; in this case, including the United Nations, the World Bank, the World Trade Organisation and the European Union. The business community also has an important role to play, via public-private cooperation projects and FDI (*Foreign Direct Investments*). A fourth group includes the non-governmental organisations (NGOs), who often play a supporting role for Western governments and as advisors to the UN. Finally, there is the money that foreign migrants send to their families back home. This private money amounts to a considerable quantity and is important for development.

The intended model should enable an analysis of the impacts of specific options or policy packages that are on the political agenda, or to develop scenarios that either meet a specific target (backcasting) or explore the consequences of contrasting future scenarios. These options can be evaluated in terms of their contribution to improving quality of life, as well as to environmental impacts and their costs. However, it is important to make the distinction between what can be analysed with a model and what is the actual instrumentation in policy-making. Sometimes these two almost overlap, as is the case in climate policies, where a price on carbon that is used to restrict the model resembles a carbon tax or an emissions trading system. In many other cases this is less straightforward. Analysing the consequences of increasing agricultural productivity in the model, does reveal how this could be realized. It is, however, increasingly recognised that we need to learn more about the implementation of public policies, as part of the assessments. This requires insight in global governance, including power relations, vested interests and institutional conditions for interventions. To some extend, this can be made part of the model analysis, when identifying the risk factors that negatively impact the quality of life. An example of this is the occurrence of state failures or conflicts (Cincotta *et al.*, 2003; State Failure Task Force, 2003) which are highly correlated to economic factors (material well-being, openness of the economy), environmental factors (deforestation, low availability of cropland and/or freshwater) and demographic factors (a large youth bulge, rapid urban growth) These indicators provide an opportunity for identifying areas that are vulnerable to conflict and where a low effectiveness of interventions can be expected framework.

4 Towards GISMO1.0: a practical plan

Now that the more-theoretical aspects have been elaborated on, the next step can be taken towards the actual development of an integrated model, namely GISMO1.0. This section presents the models which are included and the methodology of linking these models, as well as a procedure for evaluating the resulting integrated model framework.

4.1 The models included

Starting point of the modelling is to use existing models, when possible. Ideally, the project would have the disposal of a large set of models, which can be flexibly used within the framework. To cover the three sustainability domains, several models can be used. Traditionally, MNP –and now PBL – has a strong background in environmental modelling, with the IMAGE model as one with the longest record and one of the most advanced ways of dealing with broad environmental issues (Rotmans, 1990; Alcamo, 1994; MNP, 2006). The model was originally developed to assess the impacts of anthropogenic climate change, but has recently been expanded to a more comprehensive coverage of global change issues from an environmental perspective, such as climate impacts, land degradation, water stress, biodiversity and water and air pollution. As part of the IMAGE framework, TIMER is an energy-system simulation model that has been developed to analyse the long-term trends in energy demand and efficiency and the possible transition to renewable energy sources. For population and health issues, the PHOENIX model is used (Chapter 4). This model has recently been refined with a better epidemiological foundation, the inclusion of diseases next to death (Chapter 5), and an education module, capturing the dynamics of the education process (Chapter 6). This health model covers several socio-economic and environment-related risks, the latter of which are linked to outcomes from the IMAGE framework. Until recently, PBL was lacking an in-house economic model which could be used in the GISMO framework. Therefore, collaboration with the University of Denver has been established to use the economic module of the *International Futures* (further referred to as IFs Economy). The model IFs Economy has a system dynamics approach and describes different actors, including a government that allocates expenditures for education and health services (Chapter 7).

For GISMO1.0, the PHOENIX model and IFs Economy are fully integrated, covering the human/social and economic domain, respectively. For the environmental domain pre-run scenarios from the IMAGE and TIMER models are used. Thus, IMAGE and TIMER are not yet integrated into the modelling framework. Simple dynamics and the interlinkages of GISMO1.0 are graphically represented in Figure 6. The dark blue lines represent established links between models, accompanied by the variables which are shared. The light blue lines represent links for future model developments, such as integrating the environmental domain into the framework.

4.2 Coupling models

As stated in Section 3.3, dynamically linking the models is the best way to express feedbacks, trade-offs and co-benefits between the three sustainability domains. Initially, the population & health module PHOENIX and the economy module IFs Economy comprised one model, written in the M programming language (De Bruin et al., 1996; Tizio, 2008). The main module of this integrated model handled the exchanging of variables between these two major modules.

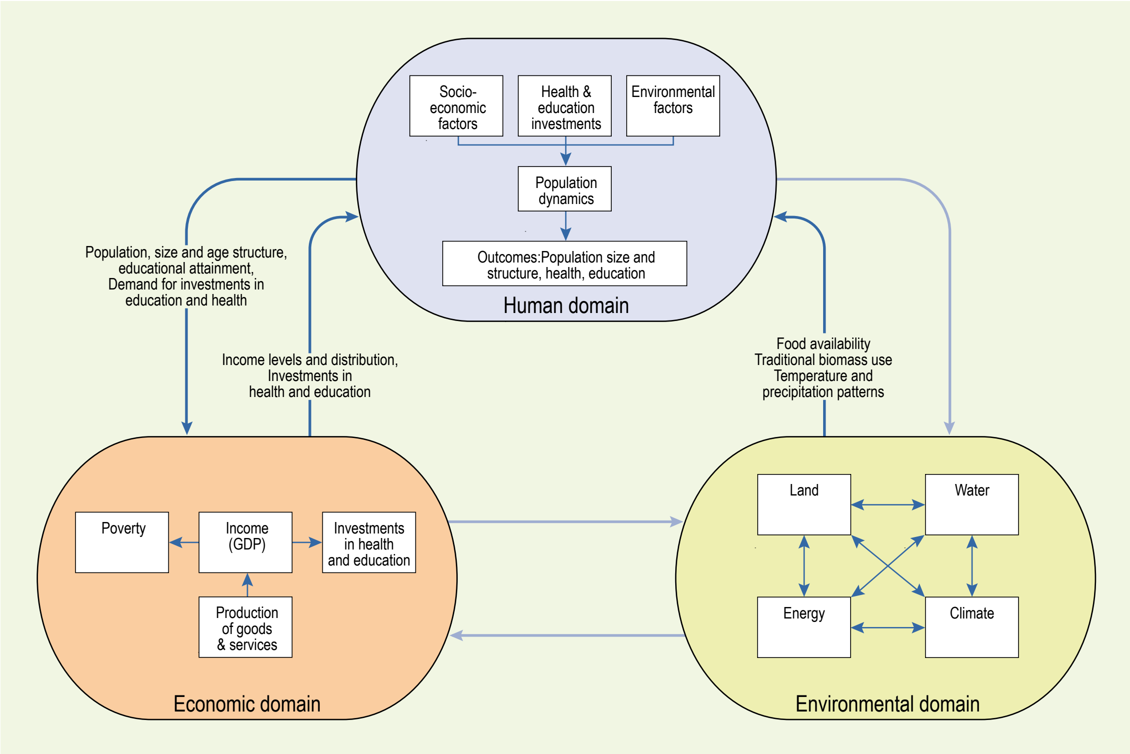

Figure 6 Interlinkages between the three sustainability domains.

Furthermore, the environmental inputs (food, climate and energy use) were read from input files resulting from pre-run scenarios of IMAGE and TIMER.

To make the GISMO1.0 model fit the principle of modular design, the model was split into two parts: the PHOENIX model and IFs Economy, with both models able to run individually. The design of these separated modules is similar to their design in the integrated model: they contain the same supporting modules and their main modules handle the exchange of variables between the modules. However, in IFs Economy, the PHOENIX module is replaced by a dummy module that only reads data from input-files, and in the demography model, IFs Economy is replaced by a dummy module doing the same.

The PHOENIX model and IFs Economy are now coupled, using the dynamic coupling tool Typed Data Transfer (TDT) (Linstead, 2004), developed at the Potsdam Institute for Climate Impact Research (PIK). TDT facilitates the exchange of data in a language-independent way, which allows the coupling of models that are written in different programming languages. When coupled through TDT, the models exchange their data through communication channels, being sockets or 'tubes'. TDT functions handle the opening and closing of sockets and data is written or read by means of a call to the appropriate TDT function. Configuration files provide a description of the data to be transferred (name, type, size), a description of the communication channel (name, type) and the coupling time interval(s). Besides, as TDT creates interdependency between models, synchronisation of the models should be considered carefully, to avoid deadlocks.

For GISMO this means that the PHOENIX model and IFs Economy could be run independently or simultaneously and exchange variables during simulation. The variables are now sent by the major modules from one model and received by the dummy modules from the other model (Figure 7). Instead of reading data from input files, the dummy modules now pass on the vari-

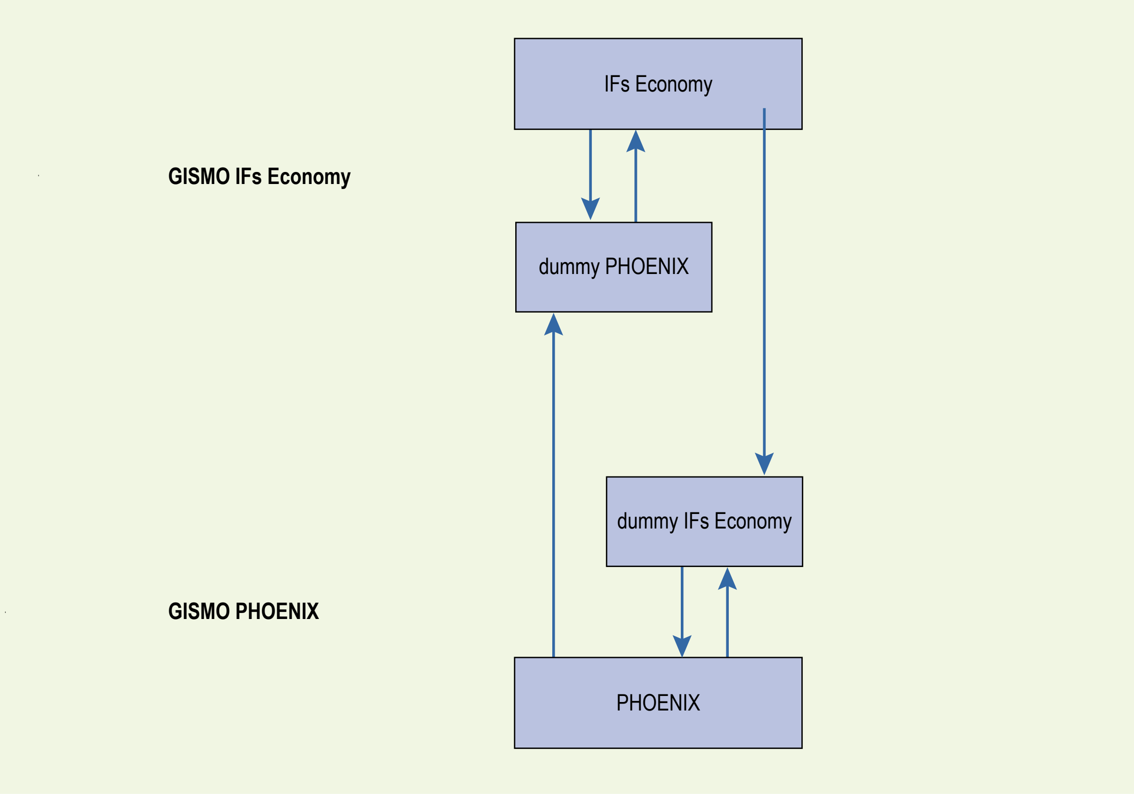

Figure 7 The PHOENIX model and IFs Economy coupled trough TDT, running simultaneously and exchanging variables during simulation.

ables received from the other model. The environmental inputs remain untouched and are still integrated to output files from IMAGE and TIMER.

In the original integrated model, the two major modules are depending on each other's data. Because the models were fully integrated, they could be run as such and no circular reference exists within the model. For the split model, the modules within the PHOENIX model and IFs Economy are not depending on each other's output, as it can be read from file. Each model has one module that performs calculations, while the other module is just a dummy which reads from file. Therefore, there is no risk of a circular reference within the models. However, when coupled through TDT, the PHOENIX model and IFs Economy itself are depending on each other's data. There is, thus, a chance of a circular reference between the models, a so-called deadlock – where the models are both waiting for each other's data and cannot proceed. To avoid this circular reference, the PHOENIX model is set one step ahead of IFs Economy (Figure 8). The coupling of two M models through TDT automatically causes a time delay, that is, values which are sent by one model on the current time 't' can only be used by the other model on 't + coupling step'. This is because an M model must know the current situation before the calculation of the next time step, but can only set its variables once for every time step. Coupling an M model with a model written in another programming language does not necessarily introduce such a delay.

The PHOENIX model and IFs Economy now both have the same design as in the initial integrated model. When they are coupled through TDT they exchange the same variables as the corresponding modules in the integrated model. Furthermore, the synchronisation between the two models is handled in the same way as is the synchronisation between the modules in the integrated model. Therefore, the integrated model and the TDT-coupled models function in a similar way.

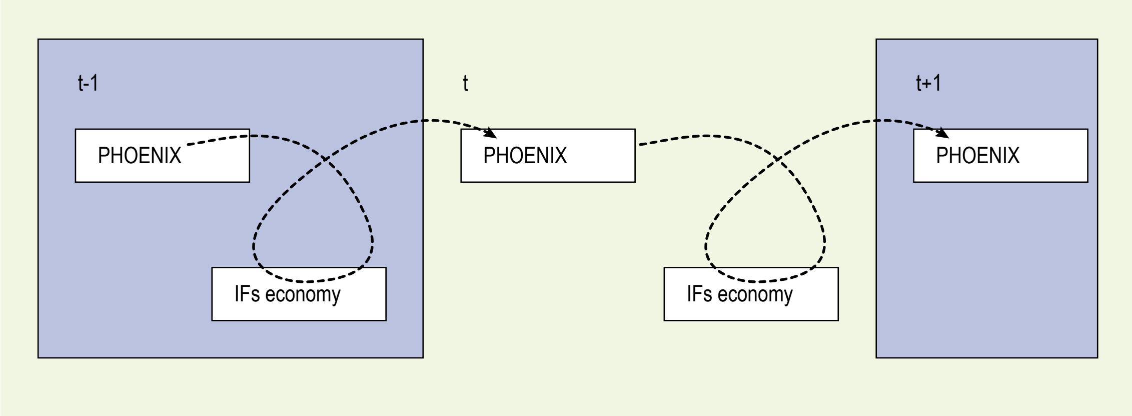

Figure 8 The sequence of models with TDT: PHOENIX is always one step ahead of IFs Economy.

TDT is generally used to couple models that are fully independent. Such models may have been coupled before through a so-called soft coupling, that is, one model runs for a complete simulation period and the resulting output data are fed into the next model which, subsequently, runs a complete simulation. Coupling through TDT puts such models in a new situation where they are forced to exchange information and subsequently influence each other during a simulation. The simulation of the 'soft' coupled models may, therefore, be different from the TDT-coupled models. The model evaluation section (Section 4.3) provides an overview of how to deal with these differences from a model-evaluation perspective.

4.3 Model evaluation

In addressing the question of whether and when, and to what extent, a model is suitable for its intended purpose(s), model evaluation is a crucial process during the lifecycle of a model.

In line with the views advocated by Oreskes (1998), Beck (2002), Pascual (2003), and Prisley and Mortimer (2004), we have chosen the more neutral term 'model evaluation' for this process, instead of the more value-laden and often ambiguously defined terms 'validation' and 'verification'. This process is meant to build confidence in model application(s) and increase transparency and insight in a model's strengths and limitations, thus enabling an informed judgement on the credibility of the model results for the application at hand (NRC, 2007). In this section, the model evaluation describes the general procedure and implications for a coupled model like GISMO.

4.3.1 A generic approach

The various stages of model evaluation (see Figure 9) can be linked to the lifecycle of the model which typically starts with the identification of a need for modelling and continues with the initial development of a conceptual view of the problem and its essential features. Elaborating further on this conceptual model, a more formalised model form is developed, which is subsequently implemented in a computational model. This computational model is further parameterised and linked to data, to make it suitable for subsequent application and use. In Appendix B, a further elaboration is given of these evaluation stages.

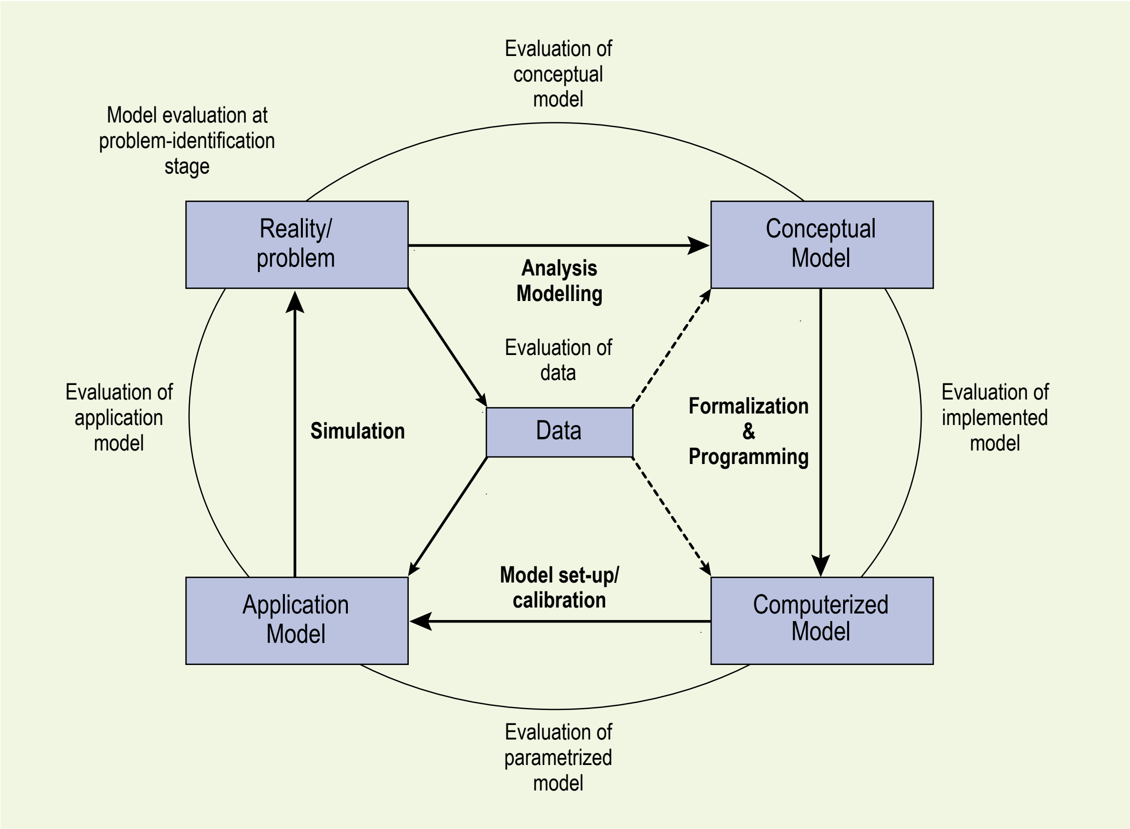

Figure 9 A simplified representation of the modelling cycle, illustrating the position of the various forms of evaluation (modified from Sargent, 2003; and Refsgaard and Henriksen, 2004).

Model evaluation is, therefore, an ongoing process which continues for as long as the model remains in use, and new insights and data, or new and changing applications occur. It helps to answer important questions, such as (Beck, 2002; Nguyen and De Kok, 2007): (a) Is the model based on generally accepted science and computational methods? (b) How is the choice of model supported by the quantity and quality of available data? (c) Is the behaviour of the model system in agreement with the observed and/or expert's anticipated behaviour of the real system of interest? (d) How well does the model perform its designated task or serve its intended purpose, while meeting the objectives set by Quality Assurance project planning?

Model evaluation comprises qualitative, as well as quantitative examinations of the model, involving activities as peer review, corroboration (to make more certain) of results with data and other information, quality assurance and quality control checks, uncertainty and sensitivity analyses (see Appendix C). In its very essence, evaluation is always an activity linked to the specific question/application at hand and, therefore, should be considered as a relative activity rather than an absolute. Using an existing model for a novel application, thus, requires a re-establishment of evaluation activities.

To which extent the evaluation activities will be performed depends, in practice, on the specific performance requirements of the model, as well as on the present state of knowledge, the availability of time, expertise and data. Model evaluation has to be a transparent, traceable, reproducible and well-considered activity, and it is important to explicitly document the results of the model evaluation. This should, ideally, also include an indication of what further testing or improvement of the model should be done in the future, identifying responsibilities, accountabilities and resources needed to ensure this (see Appendix B).

4.3.2 Model evaluation for coupled models

The model evaluation procedure, sketched in the foregoing and in Appendix C, is a generic one which can likewise be applied to stand-alone models, as well as to integrated system models which consist of a coupling and integration of various (sub-)models. This latter situation, which is the case for GISMO, requires some extra attention for the effects of model coupling/integration.

For an adequate evaluation of the integrated model it no longer suffices that the various constituent models have already been evaluated or calibrated, in a stand-alone modus. Their functioning in a coupled, integrated mode should be specifically evaluated, and this might also require some re-calibration of the constituent models, if their original (stand-alone) parameter settings are no longer representative for this integrated mode.

It will be especially necessary to evaluate if the coupling of the (sub-)models is constructed in the intended, proper fashion and functions. This requires, first of all, that the conceptual outline of the coupling is evaluated: does the qualitative description of how variables from one model influence the variables of the other model and vice versa render a correct representation of the scientific assumptions it is based on? Are the interrelationships and feedbacks between the (sub-)models represented adequately?

The second step is to check the implementation of the conceptual coupling in computer code. The relationships between variables, as stated in the conceptual coupling, should first be correctly translated in mathematical relationships in both models, and their numerical implementation should adequately reflect this. The subsequent software implementation of the coupling process consists of appropriate data transfer and job control and scheduling of the various modules. For GISMO, this process is supported by the TDT data transfer library software, which enables coupling of modules written in different languages and running on heterogeneous platforms. The core task for the evaluation of this implementation process consists of checking whether this process renders a coupling which conforms to the conceptual coupling, without introducing unacceptable artificial effects or deviations due to numerical approximations and coupling-scheduling effects (for instance the dynamic coupling of two models implemented in M introduces a time delay, causing one model to be always one time step ahead of the other).

Finally, the performance of the dynamically coupled models should be examined for the application at hand. To gain insight in the effects and added value of the coupling, it is recommended to compare the results of dynamically coupled simulations with results from situations where the corresponding models were run individually.

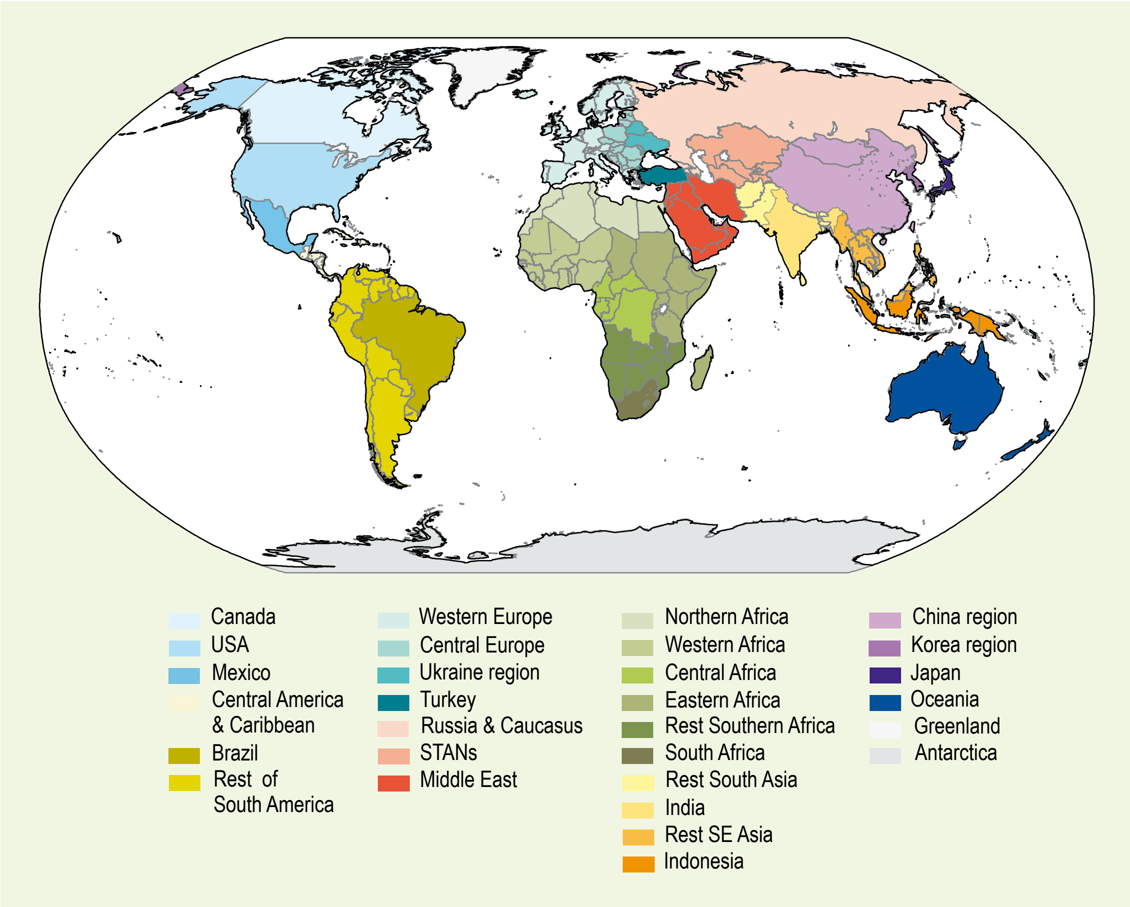

Figure 10 The 27 GISMO regions.

4.4 Regional breakdown

The global models at PBL have a regional breakdown in the world's regions and major countries (MNP, 2006). These breakdowns are based on considerations of homogeneity of environmental, economic, and human/social aspects. The GISMO breakdown in 27 world regions is presented in Figure 10. GISMO follows a similar breakdown as TIMER and IMAGE. The only difference with TIMER is that Western Africa is split into Western Africa and Central Africa. In Appendix A, the regional breakdown of IMAGE and TIMER are given.

5 PHOENIX Population model

Putting Quality of Life at the central stage of Sustainable Development raises the issue whose quality of life we are referring to. This asks for the distinction of people in our models. To be able to address the need of future generations, we first need to know how many people will make up those next generations, and which characteristics determine their needs? To reveal part of this, understanding population dynamics and its underlying driving forces is a crucial step.

5.1 Components of population change

The (natural) growth of the population is a result of the difference between the total number of births and deaths. Birth and death rates can be related to the total population size, which results in the crude birth rate (CBR) and the crude death rate (CDR), reflecting the numbers of births and deaths, respectively, per 1000 persons in a given year. Although CBR and CDR are often used to describe population dynamics, there is a serious problem when it comes to interpreting them. The CBR generally declines, as a result of two forces: (i) the decline of fertility, referred to as de-greening of a population, measured in terms of the expected number of children born per woman; and, ii) the ageing of the population, which is a consequence of the reduction in mortality levels in combination with past fertility decline, reducing the proportion of women of fertile age. Both CBR and CDR depend on the age structure of the population, which is the cumulative product of past mortality and fertility. Therefore, a correct analysis of mortality and fertility is only possible if the effects of a specific age structure are taken into account. Instead of crude birth and death rates, age-specific data are preferred for demographic analysis. Such data are commonly known in their aggregated forms, that is, the total fertility rate (the number of children that a woman would have given birth to at the end of her reproductive life span, if current age-specific fertility rates prevailed) and life expectancy (number of years a birth cohort may be expected to live, given the present mortality experience of a population). The third basic component of population change is migration, which can by external (international migration) and internal flows (e.g., rural to urban).

5.2 Demographic transition

The profound transformation of changing fertility and mortality patterns is generally referred to as demographic transition. It was classically defined by Notestein (1945) and Davis (1945), although its intellectual history goes back much further (Szreter, 1993). The demographic transition is not an isolated process; it is part of a much broader transformation, observed in a growing number of countries since the 18th century and is commonly referred to as 'modernisation'. In the economic domain, modernisation involves a rise in real output and wide-ranging innovations and improvements in the production, transportation and distribution of goods. On the demographic and social side, modernisation involves significant alterations in fertility, mortality and migration, as well as in family size and structure, education and the provision of public health.

At the level of the individual, modernisation is characterised by an increased openness to new experiences, increased independence from authority, belief in the efficacy of science, and ambitions for oneself and one's children (Easterlin, 1983). These interrelations of manifold processes inevitably lead to a considerable variety in fertility decline between and within populations, although the pattern of the demographic transition is remarkably consistent in all parts of the world. Important differences exist in the position of individuals and groups on the trajectory of transition. The concept of demographic transition expresses plausible descriptions of the fertility decline in the idiom of post-war concerns with population and development (Cotts Watkins, 1987; Szreter, 1993).

Historical data indicate that fertility and mortality show rather gradual changes. The process of migration is less well understood, because: (i) migration consists of two components, emigration and immigration, both with different dynamics while still related with the migrant population; (ii) the relationship between the determinants, such as economic opportunities, conflict situations, extreme environmental events, and these migration components are often not fully understood; analyses of these relationships result in associative rather than causal connections; and (iii) some of these determinants have a high incidental nature, which causes difficulties in forecasting migration patterns.

5.3 Modelling population change

Throughout history, people have tried to forecast the size of the population. Frejka (1996) provided an overview of existing long-range population projections, dating from the time of Gregory King (1648-1719) at the end of the 17th century, who even made estimates for the year 20,000. The early long-range projections were based on mathematical extrapolation of total numbers or growth rates. In the general component framework provided by (Notestein, 1945), different stages of demographic changes were distinguished by sex and age structure of a population. The population growth rates of the different stages are associated with assumptions on the components of fertility, mortality and migration. Since 1945, this cohort-component methodology has been refined and widely applied (Lutz, 1996; Hilderink, 2000b; UN, 2000b).

5.4 PHOENIX population and health model

In GISMO, population projections are modelled using the PHOENIX model (Hilderink, 2000b; Hilderink, 2000a). PHOENIX is used to explore, develop and analyse different demographic scenarios at various geographical aggregation levels (i.e., regional, national and grid cell). The demographic core of PHOENIX is formed by a cohort-component model, consisting of 27 major world regions, 100 one-year age groups and the two sexes.

The inflow of the demographic model, the number of births, is provided by a fertility model. The outflow in PHOENIX is provided by the mortality model, which calculates the age and sex-specific number of deaths based on a selection of health risks. Migration, as the third demographic component, is taken exogenously. Figure 11 shows the PHOENIX model with the context, position and the interrelationships.

5.4.1 Fertility model

A fertility model is used in PHOENIX to describe age-specific fertility rates, resulting from a process of diffusion of innovation (Retherford and Palmore, 1983; Rodriguez and Aravena, 1991; Montgomery and Casterline, 1993; Rosero-Bixby and Casterline, 1993). Innovation is a concept, comparable to Easterlin's modernisation, which is considered to be the main driving

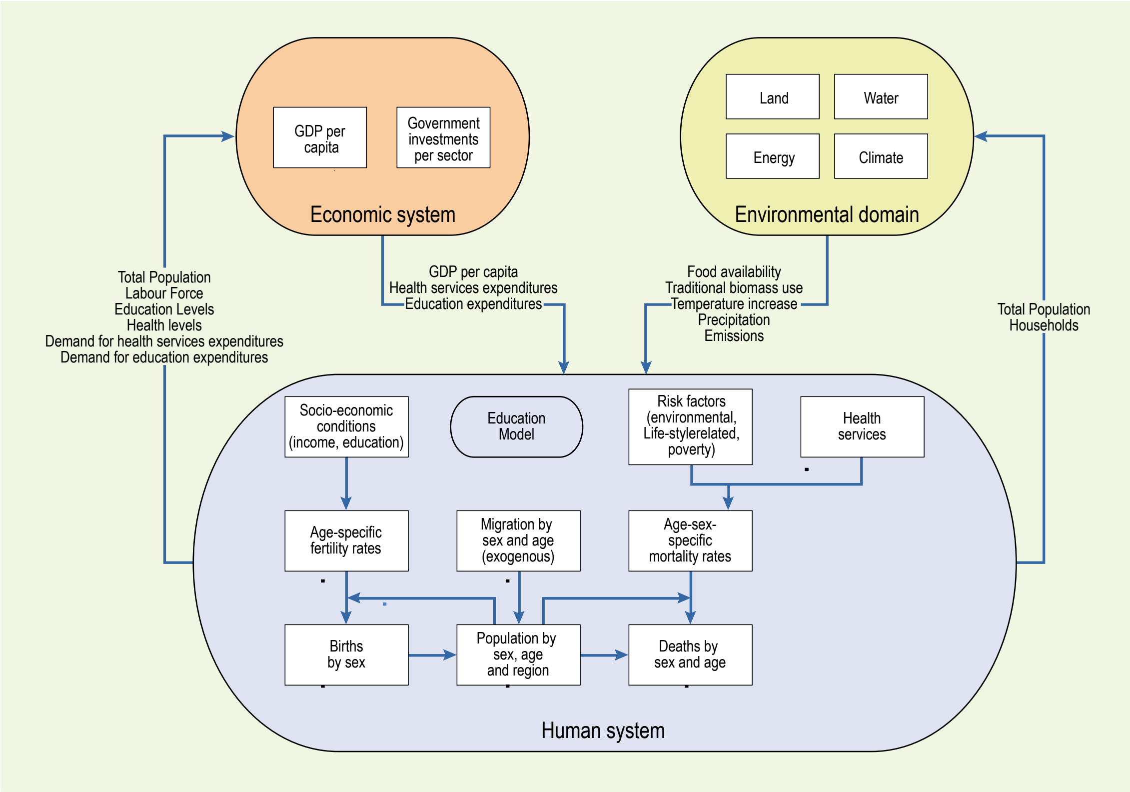

Figure 11 Conceptual model of PHOENIX.

force behind changes in fertility patterns (Easterlin, 1983). In PHOENIX, these fertility changes are modelled through the total fertility rate (TFR), that is, the average number of children that a woman would have, given current age-specific fertility rates. These age-specific fertility rates (i.e., the number of children per woman in a particular age group) are obtained by using look-up functions linked to the TFR. These look-up functions are based on the region-specific data (IDB, 1997; UN, 2004). The level of TFR is modelled, based on the relationship with a woman's educational attainment and economic characteristics. Women's educational attainment has an even stronger effect on fertility than does men's education or other characteristics of households, such as wealth (INFO Project, 2003). The set-off and the rate of the fertility transition are strongly influenced by (female) education levels, the higher educated tend to have less children, at least in the first demographic transition. There are theories which state that at very high development levels higher educated women have more children. The phenomena is referred to as the 2nd Demographic transition (Lesthaeghe and Van de Kaa, 1986; Van de Kaa, 1987). However, both in the Netherlands an in Japan there is no indication of such a changing pattern and is a higher level of education of women associated with lower fertility levels (Retherford *et al.*, 2004; CBS, 2006). The various levels of educational attainment (no education, primary, secondary and tertiary) together determine the convergence level of the TFR. The level of the human development index determines the speed of convergence.

Son preference

The disregarding of the *son preference effect* was already revealed by Hutter *et al.* (1996) for India. On a highly aggregated global level, this effect is rather small, but it can have an effect that is not negligible in countries, such as India, Pakistan, Bangladesh, China and South Korea. This preference for male children puts upward pressure on fertility levels, because many couples continue to have children until a son is born, resulting in a higher TFR than without gender preference. Data from six countries with a strong son preference – Bangladesh, Egypt, India, Nepal, Pakistan, and Turkey – show that the number of women pregnant at the time of the survey was 9% to 21% higher than it would have been in the absence of son preference. In India, if there were no son preference, the national fertility rate would fall by 8%. This effect becomes more evident with a rise in contraceptive prevalence (Nag, 1991). However, with increasing education and continuing modernisation son preference gradually fades away. In Sub-Saharan Africa, Southeast Asia, Latin America and the Caribbean, fertility levels are relatively unaffected by couples' desire to have a child of a specific sex (INFO Project, 2003). We have included a son preference factor, which increases the converging level of fertility for the aforementioned regions. This factor depends on the level of the Human Development Index and is assumed to be at the maximum of 20% when the HDI values 0, linearly reducing to 0% when the HDI values 1.

5.4.2 Mortality model

The mortality component of PHOENIX determines the outflow of the population. Where the inflow of the population, the number of births, obviously concerns the first age group only, mortality is specified for age groups separately. Mortality patterns resemble a U-shape. Mortality is high in children up to five years, relatively low between 5 and 25 years and then steadily increases to high levels. Also, a distinction between the two sexes is essential. Especially in the higher age groups, women show lower mortality. The causes behind mortality are much more fragmented then is the case for fertility. Chapter 3 – health modelling – describes in detail how health has been taken into account. The way it is modelled transcends its functionality within the demographic model. In the demographic model, mortality is the most important. We interpret health in a broader way, by also covering morbidity.

5.4.3 Migration

Given the previously mentioned difficulties in capturing migration dynamics, net migration is taken into account exogenously, based on the data provided by the UN (2004). The UN assumes that "the future path of international migration is set on the basis of past international migration estimates and an assessment of the policy stance of countries with regard to future international migration flows". It is not further specified what these policy stances are. The only variant included is the zero migration variant. Lutz (Lutz, 1996) provides a better starting point, to vary with future migration patterns. The age structure of migrants is assumed to be constant in time and the same for all regions, and is based on the European migration flows (Eurostat, 2005).

5.4.4 Urbanisation

In an increasingly urbanising world, the differences between urban and rural populations play a relevant role in the modelling of demographic processes. In 2008, the urban population will be larger than the rural population, for the first time in history, while in 1950 only 29% of the population was considered urban. Next to the incorporation of rural populations through the expanding of urban areas, the demographic processes which cause the increase in urban population are natural population growth and people migrating to the city. These migration flows mainly originate from rural areas, although international migration can also contribute.

According to the UN projections (UN, 2006), the urbanising trend will continue and in 2030 almost 60% of the world population will live in urban areas. As Figure 12 shows, most of the

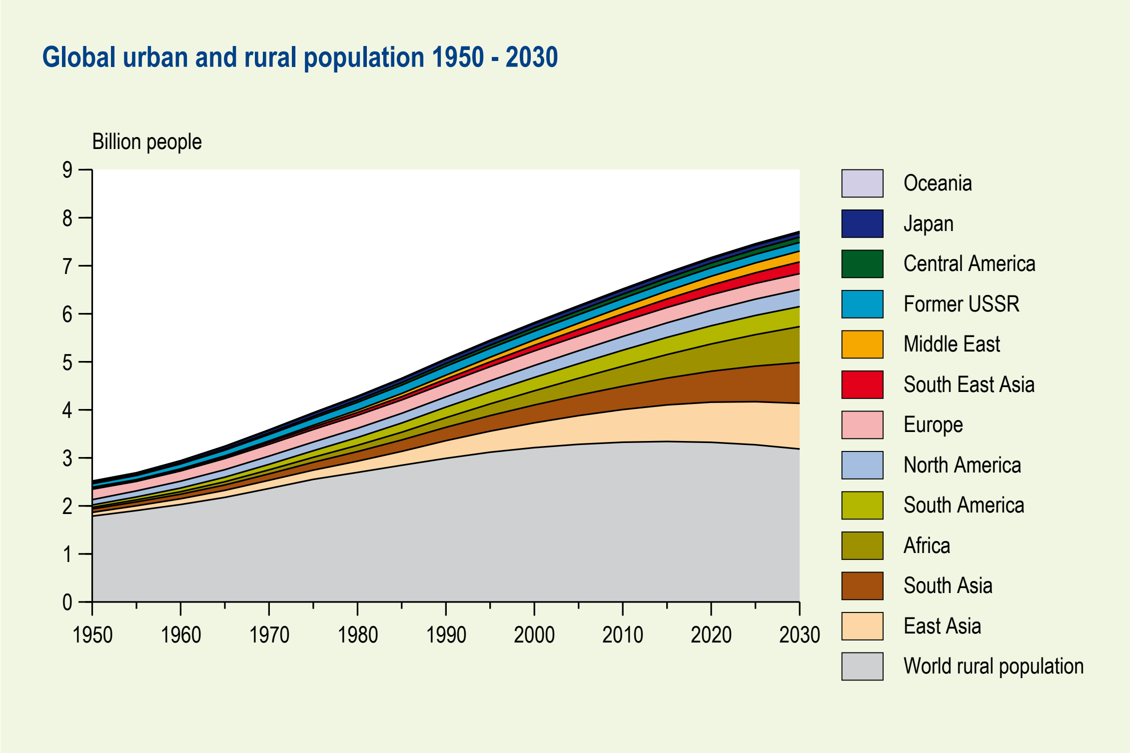

Figure 12 Urban population by region and the global rural population, 1950-2030 (UN, 2006).

urban population growth will take place in the developing regions of Asia and Africa. The rural population will even start to decline, towards the year 2030.

The most recent *State of the World Cities* publication (UN-Habitat, 2006) reports that today, globally, one in every three city dwellers lives in a slum, totalling about one billion people. If current trends continue, the global slum population will reach 1.4 billion, in 2020. Most slum dwellers (94%), however, live in developing regions, meaning that the growth in global urban population over the coming decades will mostly be absorbed by slums in those regions. These trends have different demographic characteristics and will have specific global, regional and local effects on human health, environmental sustainability and economic development, which need to be incorporated into GISMO. In the GISMO1.0 version, these aspects are only partially dealt with. Many of the health-risk factors have a rural–urban distinction, while the fertility and socio-economic facets lack these characteristics. Section 10.2.1 describes some of the activities undertaken to improve this.

5.5 Discussion

Using a cohort-component model to describe population changes is a widely-used methodology. PHOENIX differs from the other approaches in the explicit modelling of the underlying factors which drive fertility and mortality, where others mostly use exogenous input data for the Total Fertility Rate and the mortality levels. Another, rather valuable step in the validation of PHOENIX, is the start of the simulation in 1950, which implies having to reproduce historical pathways for fertility and mortality. The model evaluation of previous versions of PHOENIX has been done in an elaborate way, including extensive sensitivity and uncertainty analyses (Hilderink, 2000b). This model evaluation procedure proved that the model was more than capable of reproducing historical population dynamics. However, since these versions, new model developments have taken place, which require a repetition of this procedure. Part of this procedure, for example, is doing a conceptual validation of the methods applied. The extended procedure will be part of the further model evaluation steps (see section 4.3).

The aspect which is getting the least attention in all approaches, is the inability of modelling migration in a better way than by mere input scenarios, often even without much variation in the future. For long-term simulations – as is the aim in GISMO – this is rather unsatisfactory, especially given the facts that positive net migration is, currently, the only reason that the European population is not decreasing, and that the topic draws a lot of attention in the public debate.

6 Health model

The health dimension has been identified as one of the major outcomes concerning quality of life. This chapter presents a methodology to describe health dynamics in the broader context of sustainable development. The methodology provides a quantitative exploration of the future, concerning the health aspects of populations, given the changes in socio-economic conditions (e.g., income level and distribution, and education) and environmental conditions (e.g., food availability, safe drinking water and sanitation, and malaria risks). It does not describe health conditions and status, in every detail, but focuses on the context in which the health transition takes place, and explores the underlying dynamics and interactions between the human system and the economic and environment systems.

6.1 The health transition

The health transition can be viewed as the interplay between three underlying transitions, namely the epidemiological, the risk and the demographic transition. The epidemiological transition (Frenk *et al.*, 1993), addresses changes in disease patterns, mortality patterns, and the conditions associated with these changes (Bobadilla *et al.*, 1993). Improved conditions, such as education, health services and female autonomy, have brought countries on the way to low mortality levels (Caldwell, 1993). The transition in the disease patterns is normally accompanied by a transition in the underlying health-risk factors causing these diseases (Smith, 1997). This shift is illustrated in Figure 13. The relevance of distinguishing this risk transition from the epidemiologic transition, can be justified by the following three aspects (Smith, 2001): i) possible long latencies between risks and ill-health outcomes; ii) some risks have a low probability of occurring but can have high health impacts; and iii) some risks might be described only statistically (e.g., low-level exposure to carcinogens).

The third and last component of the health transition is formed by the demographic transition. The positioning and interlinkage of the three components of the health transition are presented in Figure 14.

One of the arising issues is the effect of mortality reduction on morbidity levels. The effect of mortality reduction provides an opportunity to express morbidity as being associated with the process of ageing (Olshansky *et al.*, 1991; Evans *et al.*, 2001). In the situation of a complete epidemiological transition, life expectancy will be over 80 years, but includes a long period of morbidity due to the prevalence of one or more diseases. Therefore, the objective is not only a reduction in mortality rate, but also a compression of morbidity. Nonetheless, despite its importance, the understanding of disease occurrence is still limited, not to mention understanding future patterns of diseases. However, the epidemiological transition theory provides a potentially powerful framework for the study of disease and mortality in populations, especially for the study of historical and international variations (Mackenbach, 1994). In the next section, several measurements of population health are presented, which also address morbidity.

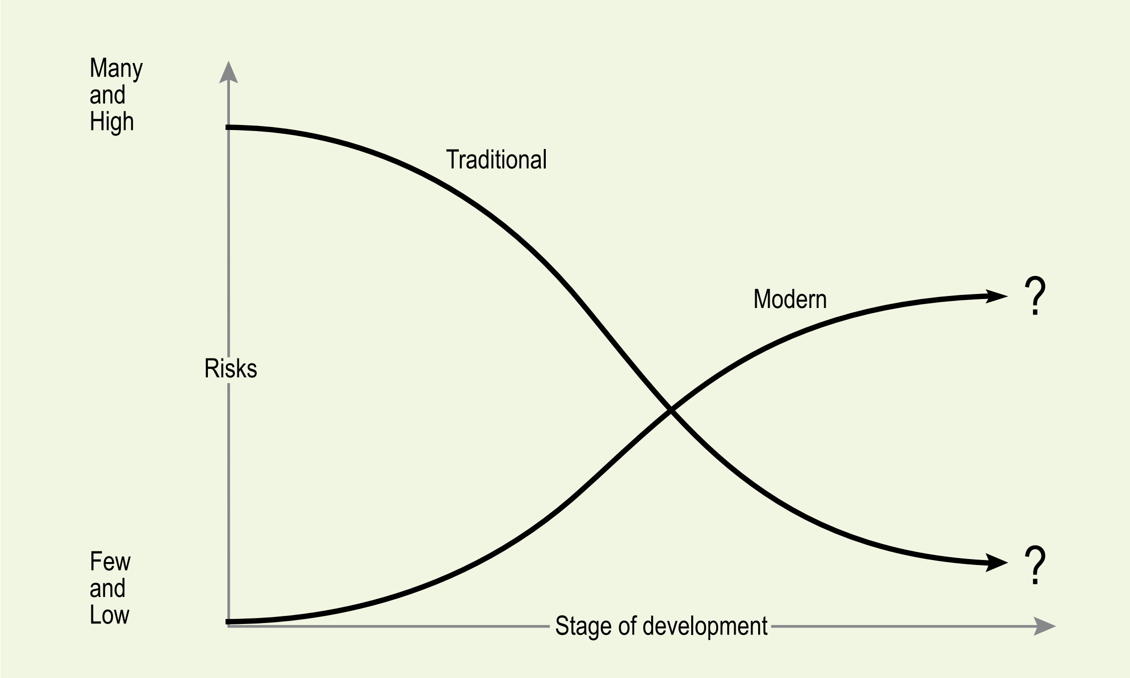

Figure 13 The risk transition: a shift from traditional to modern health risks, by level of development (derived from Smith, 1997).

6.2 Population Health

There are various ways of measuring population health, depending on their intended use (Murray *et al.*, 2002). Health measures range roughly from more static measures for monitoring the health status of a population, or comparing different (sub-)populations to provide more insights into underlying dynamics and causes of death. The most commonly used measure of the mortality levels is life expectancy. The life expectancy reflects the mean number of years that age cohorts (persons born in the same year) may expect to live, when current levels of mortality prevail. The life expectancy can be calculated for all ages. The combination of the age at which death occurs, and the life expectancy a person would have had at their time of death, result in the number of years of life lost (YLL). The summation of YLL over all annual deaths in a population, results in the total number of life-years lost, due to premature mortality.

Murray and Lopez (1994), developed a methodology, in which morbidity is also taken into account. Their methodology is similar to the YLL. They quantified the number of years of life lived with a disease (YLD), by taking into account incidence, prevalence and duration of the disease, combined with the severity. The sum of the YLL and YLD results in disability-adjusted life years (DALY) and expresses a measure of the burden of disease. The WHO (WHO, 2002) linked the burden of disease with the most important health-risk factors. Figure 15 presents the main risks factors, attributable to loss of DALYs, on a regional and global scale. It shows that in Africa childhood and maternal undernutrition account for more than 40% of all attributable DALYs, while in Europe addictive substances (e.g., tobacco and alcohol) and diet-related and physical inactivity factors (e.g., blood pressure and overweight) are responsible for the vast majority of health losses. The effect of sexual and reproductive risks, mainly HIV/AIDS, is clearly visible in Africa, but also forms a growing threat in other regions, such as in Asia (UNAIDS, 2004). Environmental risks are present in all regions and cause about 15% of the DALY loss,

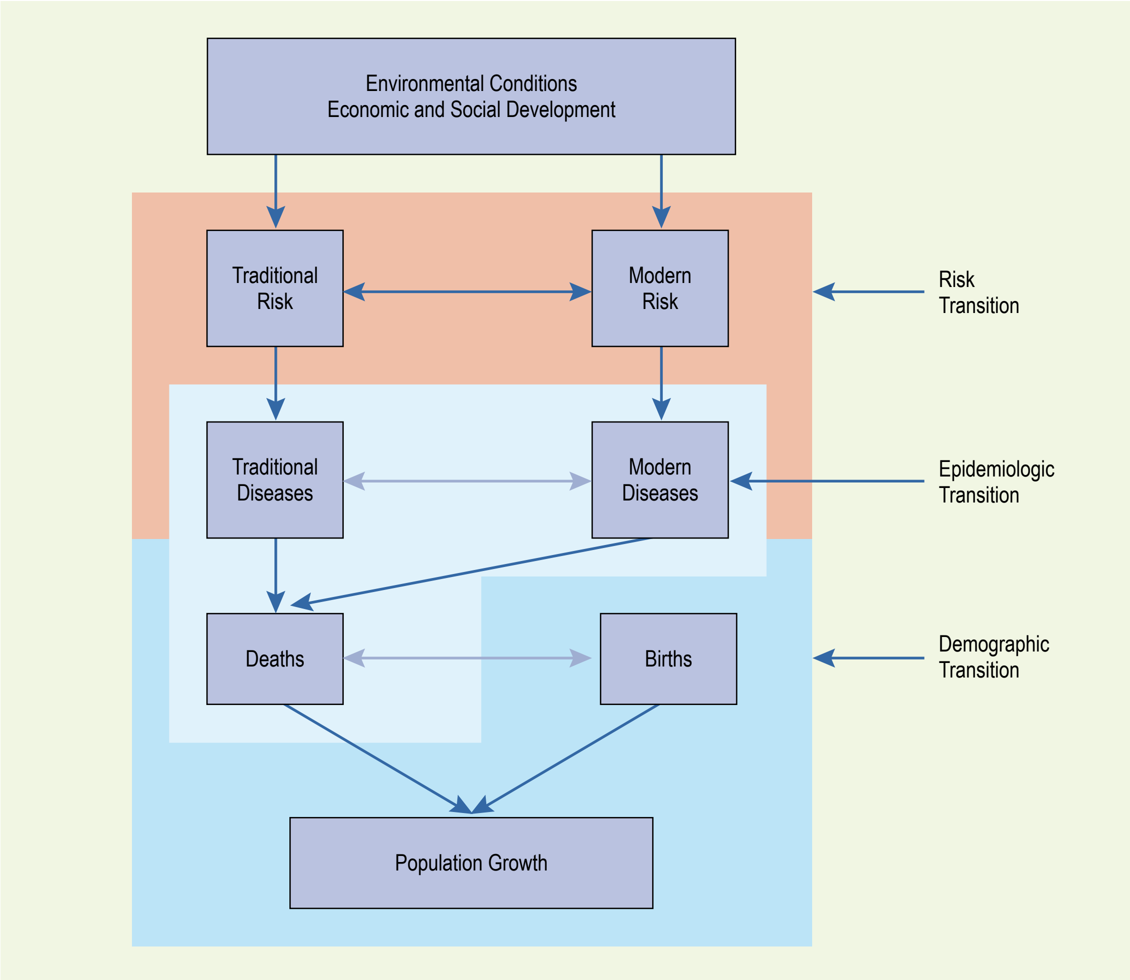

Figure 14 The health transition, consisting of a risk, epidemiologic and demographic transition (Source: Smith, 1997).

worldwide, with unsafe water and sanitation being the most important component (6.8%), followed by indoor air pollution (4.8%), climate change (1.6%) and urban air pollution (1.0%).

6.3 Existing Approaches

The modelling of health outcomes can be done at various levels of comprehensiveness (see for complete overview Niessen, 2003). There are various approaches to model health aspects in such a way that the underlying dynamics are taken into account. These vary from the more simple life-table models, which focus mainly on health outcomes (e.g. Dowd and Manton, 1990; Mosley and Becker, 1991), to an integrated dynamic approach, such as applied in the TARGETS model (Rotmans and De Vries, 1997). In the latter, the emphasis is on the dynamic behaviour and multi-state modelling, following the causal-effect chain of exposure-incidence-prevalence-death (see Figure 16). Incidence can lead to death (case fatality), to a cure within a year, or to the disease staying prevalent. The situation of the disease being prevalent, results in a higher mortality rate each year (late fatality). The transition rates between these states are age and sex-specific, but depend also on the level of health services expenditure. Beside the transition rates, in relation to cure, health expenditures are allocated to primary prevention, influencing the distribution of exposure categories, and secondary prevention, influencing incidence rates.

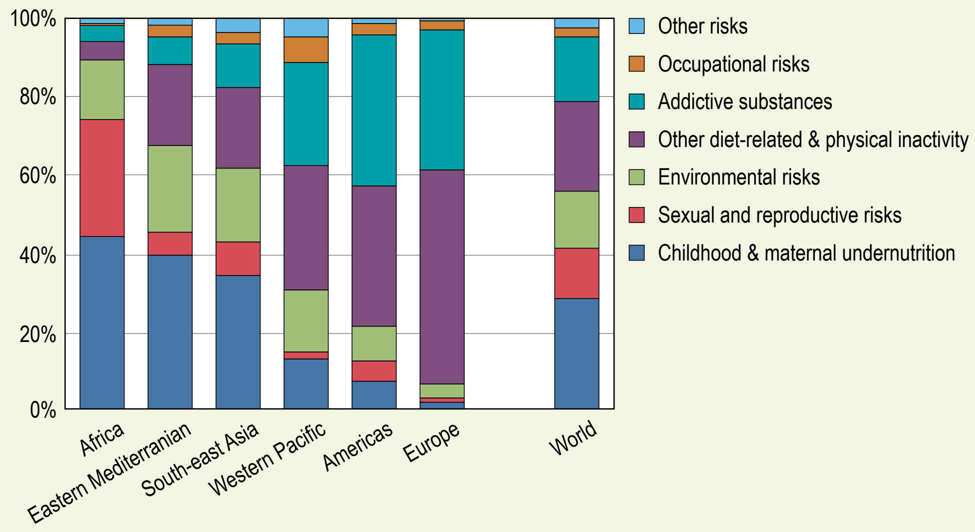

Figure 15 Risk factors for attributable Disability-Adjusted Life Years (DALY) for selected regions (based on: WHO, 2002).

Other, less comprehensive approaches cover only part of the cause–effect chain, focusing on a single disease, or ignoring disease states. For example, the PHOENIX model (Hilderink, 2000b) does not explicitly distinguish disease states, but describes mortality levels, applying relative risks associated with the same exposure categories as in TARGETS. Another way of modelling are regression techniques, for example, making use of correlations between health expenditures and education levels at the one hand, and Healthy Life Expectancy (HLE) at the other (Evans et al., 2001).

International Futures (Hughes and Hildebrand, 2006) is another simulation model that aims at describing mortality outcomes, in relation to broad health determinants. Instead of mortality rates, the direct effect of health determinants on life expectancy is modelled, using look-up tables to obtain age- and sex-specific mortality rates. Starting with a base level of life expectancy, which is a function of GDP per capita (PPP), three other factors are taken into account: starvation deaths, AIDS deaths and war deaths. These additional factors are brought into operationalisation by a multiplier on life expectancy, which is also related to the level of medical expenditures. This approach will be updated, following the Global Burden of Disease methodology (Mathers et al., 2003). A similar approach is used in the model Threshold21 (Millennium Institute, 2004) with the exception, that some additional risks factors are included (clean water, pollution, crowding).

The TARGETS approach provided a comprehensive modelling framework, describing various aspects of population health. One disadvantage of this model is the data-intensity of the approach. Given the rather large number of transition rates, which are mostly age and sex specific, together with the lack of a comprehensive empirical data set, make an application for more than one region rather difficult. The exposure–death approach of PHOENIX reduces the number of transition rates, drastically, but is limited in describing morbidity. This approach also has a relatively high data-requirement level, given the age–sex specific transition rates. Although T21 and IFs might provide simpler approaches for describing mortality, a major disadvantage is the limited empirical validation of the used death multipliers. The lack of empirical validation

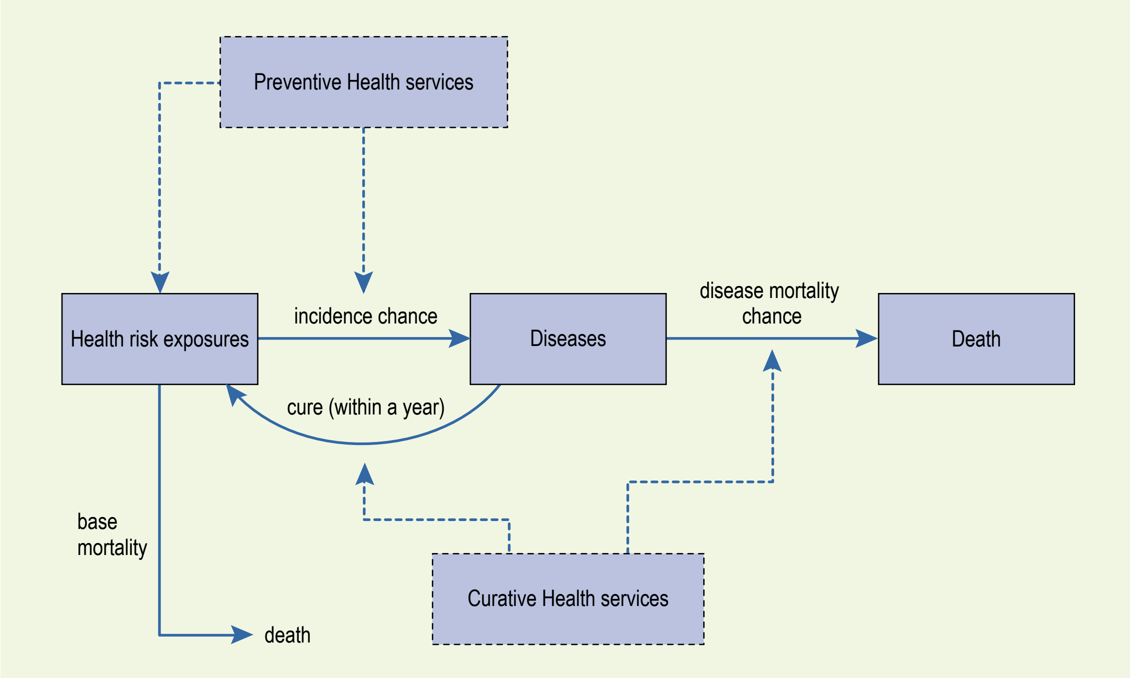

Figure 16 Multi-state disease modelling, as applied in TARGETS (Niessen and Hilderink, 1997).

is enforced by the selection of the health risks. Obviously, nutrition and starvation have to be included when describing mortality, but should be based on a clear definition, to have an empirical embedding. Other health risks seem to be more relevant for their potential effect on mortality, instead of the actual effect (war deaths), or are difficult to be found in epidemiological literature (crowding), while most modern, behavioural risks are not taken into account, at all. At the last of the approaches, is the regression technique of Evans (2001), which shows too little real-world dynamics.

The ideal methodology to apply, is a methodology which has a dynamic description of health levels, but does not heavily depend on the underlying (disease) data and stays close to empirical epidemiological data. Therefore, applying the PHOENIX approach, including a stronger connection with the WHO data on risk factors (WHO, 2000), addresses part of this. In this approach, mortality is the main outcome of the methodology. However, it also allows including morbidity levels, without having to cover disease dynamics, to the full extent. The precise formulation of the health impact module will be given in the next section.

6.4 Modelling the burden of disease

The main purpose of the health impact model is to describe the burden of disease by sex and age. The methodology which is applied, largely follows the approach as described in the World Health Report 2002 (WHO, 2002) and the Disease Control Priorities Project (DCPP) (Cairncross and Valdmanis, 2006). In these reports, the causal chains between health-risk factors and health outcomes have been studied by identifying various types of health risks.

The burden of disease is modelled through three components, for the following three elements, namely:

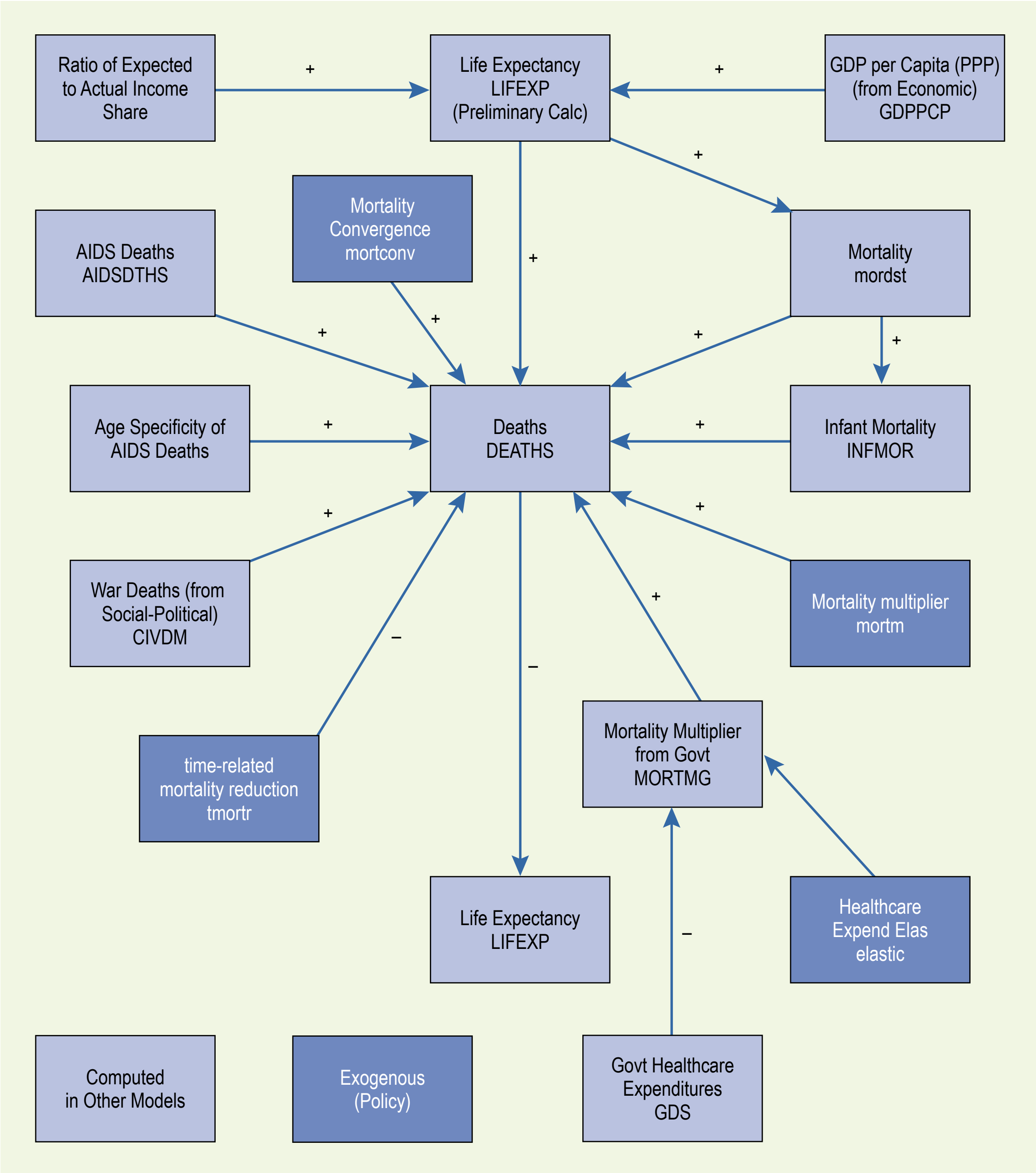

Figure 17 International Futures' Life expectancy model (Hughes, 2007).

- The *base mortality component,* representing the lowest possible levels of mortality,
- The *risk factor-attributable mortality component,* representing the burden of disease that can be attributed to health risks
- The *excess mortality component*, representing mortality that cannot be attributed to any of the distinguished health-risk factors.

$$\begin{aligned} Total\ Mortality\ Rate_{s,a} = {} & Base\ Mortality\ Rate_{s,a} + \\ & \sum_{rf=riskfactor} Mortality\ Rate_{s,a,rf} + \\ & Excess\ Mortality\ Rate_{s,a} \end{aligned}$$

where s = sex, a = age and rf = risk factor.

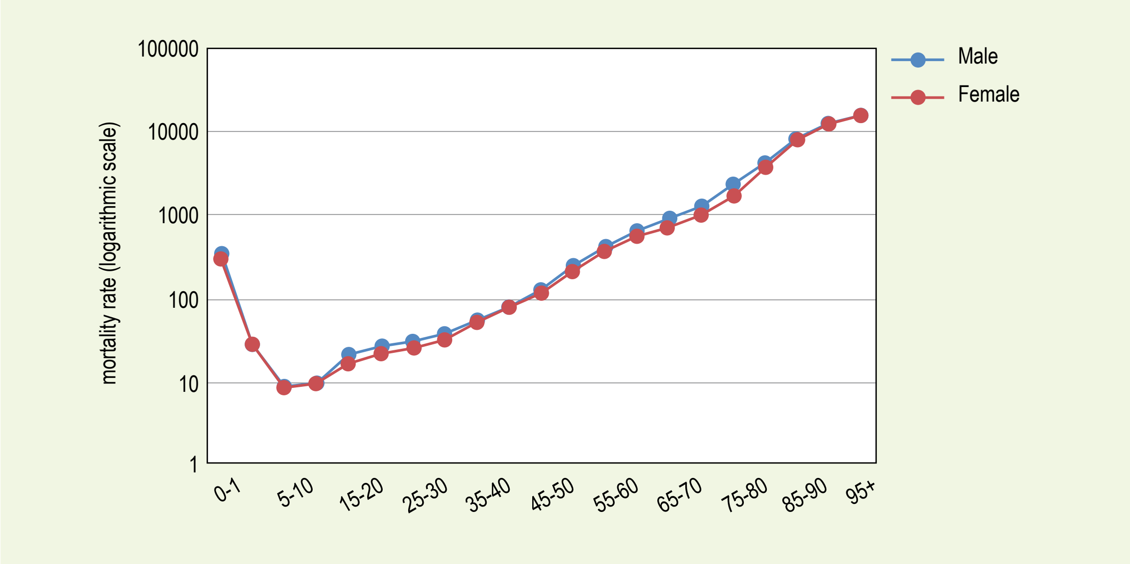

Figure 18 Base mortality rates for the distinguished age groups (Source: Olshansky et al., 1990; IDB, 1997; CBS, 1998).

Only the exposure-specific component has an explicit distinction of morbidity, in addition to mortality. The other two only describe mortality. The excess mortality component is not further specified, here. Historically, it represents the remainder of mortality not covered by the other two, and for the future this component is assumed to reduce, in line with the overall health services. The base mortality and, especially, the risk factor-attributable components require further elaboration. Finally, this section describes the modelling of health services and the final health outcomes of the model.

6.4.1 Base mortality

The base or minimum mortality level is obtained, if all health risks are eliminated and if all health services function at a maximum. This level determines the upper limit of life expectancy which a population can reach. Estimations of this upper limit of life range from 80 to 120 years (Olshansky *et al.*, 1990; Olshansky and Carnes, 1997; Oeppen and Vaupel, 2002). According to some demographers, the upper limit of life expectancy can even be prolonged up to 125 years, which might be possible because of improved knowledge and medical technology (Tabeau, 1997). However, these levels of life expectancy require changes in health practices and mortality schedules that appear to be inconsistent with what is practically achievable (Olshansky and Carnes, 1996). On the suggestion of Fries (1980), a life expectancy of 85 years for males and 86 years for females will be taken as a starting point for the upper limit of longevity. The associated mortality rates are presented in Figure 18.

A mortality reduction factor is applied to also allow projections of life expectancies that go beyond these levels. For 2050, these levels are still in line with other projections (UN, Eurostat, CBS), but, for 2100, projections even go beyond a 100 years (IIASA). The reduction factor assumes that the reduction in mortality is proportionally for all ages.

Box 1. Epidemiological Terminology (Fox, 2003)

Incidence rate: A measure of the frequency with which an event, such as a new case of illness, occurs in a population, over a period of time. The denominator is the population at risk; the numerator is the number of new cases occurring during a given time period.

Case-fatality rate: The proportion of persons with a particular condition (cases) who will die from that condition. The denominator is the number of incident cases; the numerator is the number of cause-specific deaths among those cases.

Relative risk: A comparison of the risk of some health-related event, such as disease or death, between two groups. RR ratios indicate the increased risk of exposure to a certain risk factor, with a ratio of 1 indicating no increase of risks.

Cause-specific mortality rate: The mortality rate from a specified cause, within a population. The numerator is the number of deaths attributed to a specific cause during a specified time interval; the denominator is the size of the population at the midpoint of the time interval.

6.4.2 Risk factor-attributable burden of disease

The dynamic and integrated character of the proposed methodology is represented by the risk factor-attributable mortality and morbidity. This component is strongly connected with the socio-economic and environmental domain. It is modelled based on a multi-state approach, distinguishing exposure, disease states and death. Box 1 comprises explanations for the used epidemiological terminology. Special attention is given to health services, which modify the transition rates between the various states.

The burden of disease due to exposure to risk factors, is modelled by using the following methodology:

$$Incidence\ Rate_{d,s,a} = (Base\ Incidence\ Rate_{d,s,a} + Excess\ Incidence\ Rate_{d,s,a}) * \prod((RR\ Incidence_{rf,d,s,a} * Exposure_{rf,d,s,a}) + (1 - Exposure_{rf,d,s,a}))$$

$$Case\ fatality\ Rate_{d,s,a} = (Base\ Case\ fatality\ Rate_{d,s,a} + Excess\ Case\ fatality\ Rate_{d,s,a}) * \prod((RR\ Case\ fatality_{rf,d,s,a} * Exposure_{rf,d,s,a}) + (1 - Exposure_{rf,d,s,a}))$$

To show the health effects of risk factors, diseases also have to be included, since one risk factor can influence several diseases and one disease can be influenced by several risk factors. For every disease (subscript d) a base incidence rate and a base case-fatality rate for all age groups (a) and both sexes (s) is calculated. These base levels reflect minimum levels that can only be attained by removing all exposure to risk factors and with no excess incidence or case fatality. The effect of risk factors (rf) is included by relative risk ratios (RR) on incidence rates, on case fatality rates or both. If more than one risk factor is related to a certain disease, the total effect of these risk factors is calculated in a multiplicative way. Excess incidence or case-fatality rates occur, when interregional variance still exists in risk-free rates, which are calculated by eliminating the increased risks due to risk factors. This variance can have various explanations, the most important of which is the level of health care services.

$$Mortality\ Rate_{d,s,a} = Incidence\ Rate_{d,s,a} * Case\ fatality\ Rate_{d,s,a}$$

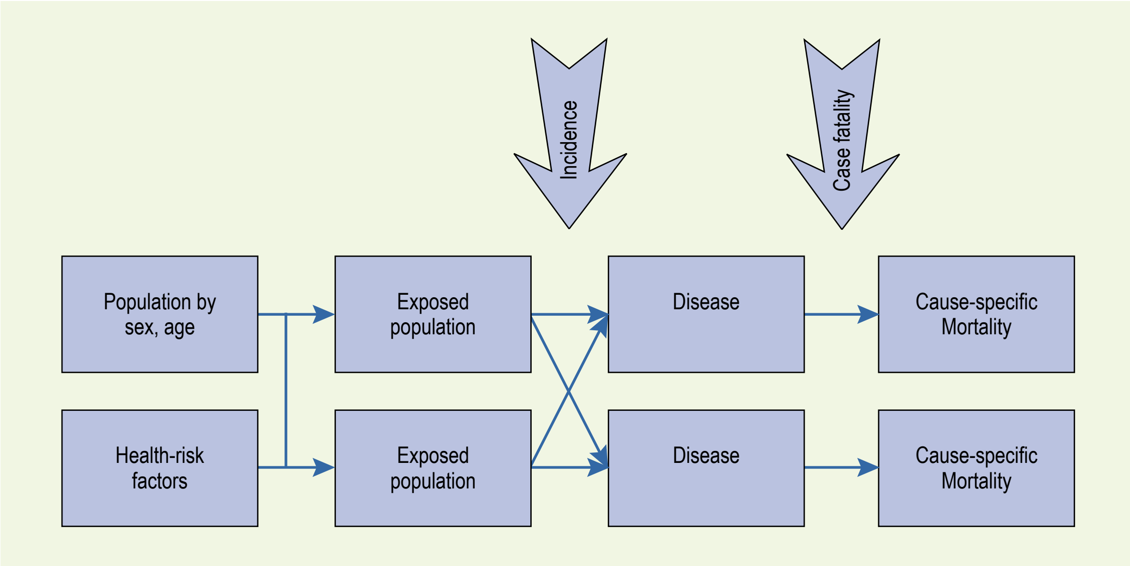

Figure 19 Multi-state modelling of cause-specific mortality.

For the included diseases, specific base mortality rates can be calculated by multiplying the disease-specific base incidence rates and base case-fatality rates. The individual effect of one of the relevant risk factors can be calculated as the *Population Attributable Fraction* (PAF) of that risk factor for a certain disease. Calculation and application of these fractions are described by Ezzati *et al*. (2002). Separate PAFs can be calculated for incidence (PAFI) and mortality (PAFM), showing the fraction of the incidence of mortality that can be averted, by eliminating the exposure to the risk factor in question. By summing these attributable mortality levels for all diseases related to a certain risk factor, the total attributable mortality due to that risk factor is calculated.

Ideally, all risk factors and their related diseases are described, according to the methodology described above. Unfortunately, not all data are available for several risk factors. For these, we have applied a simpler approach, describing exposure-specific mortality in a more direct way. For these exposure categories, a minimum and a maximum age and sex-specific range are used. This range is derived from the WHO data on risk factors and cause of death, as operationalised in the World Health Report (WHO, 2002). For most of the risk factors, the attributable mortality is given in total deaths by sex (WHO, 2002, annex Table 10). Secondly, the attributable mortality of these risk factors is linked with specific disease and/or causes of death ((WHO, 2002), annex Table 14-16). For all regions, exposure to risks factors and the sex- and age-specific mortality data are combined, resulting in (a range of) exposure-specific mortality rates. Given these ranges, the effectiveness of the health services then determines where the actual mortality rates are, between the maximum and minimum level. The final equation for exposure-specific mortality then becomes:

$$\begin{aligned} Exposure\ Mortality\ rate_{s,a,rf} = {} & Exposure\ Mortality\ rate^{max}_{s,a,rf} - \\ & Health\ Services\ Effectiveness \times \\ & (Exposure\ Mortality\ Rate^{max}_{s,a,rf} - Exposure\ Mortality\ Rate^{min}_{s,a,rf}) \end{aligned}$$

where sex (s), age (a) and exposure to risk factors (rf) and health-services effectiveness is as aforementioned.

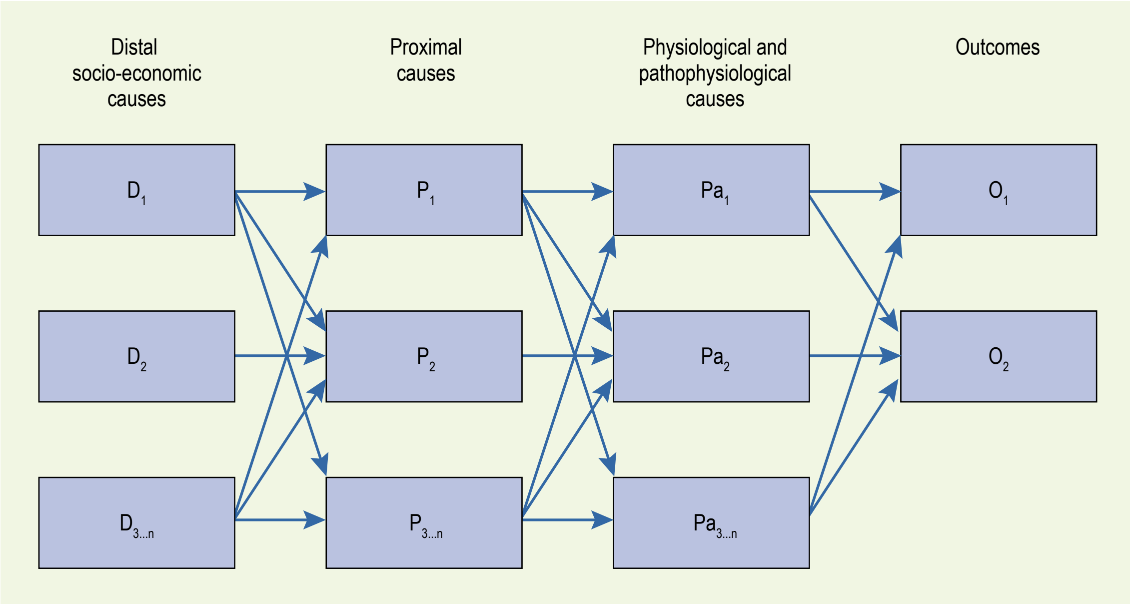

Figure 20 Types of risk factors and their causality (WHO, 2002).

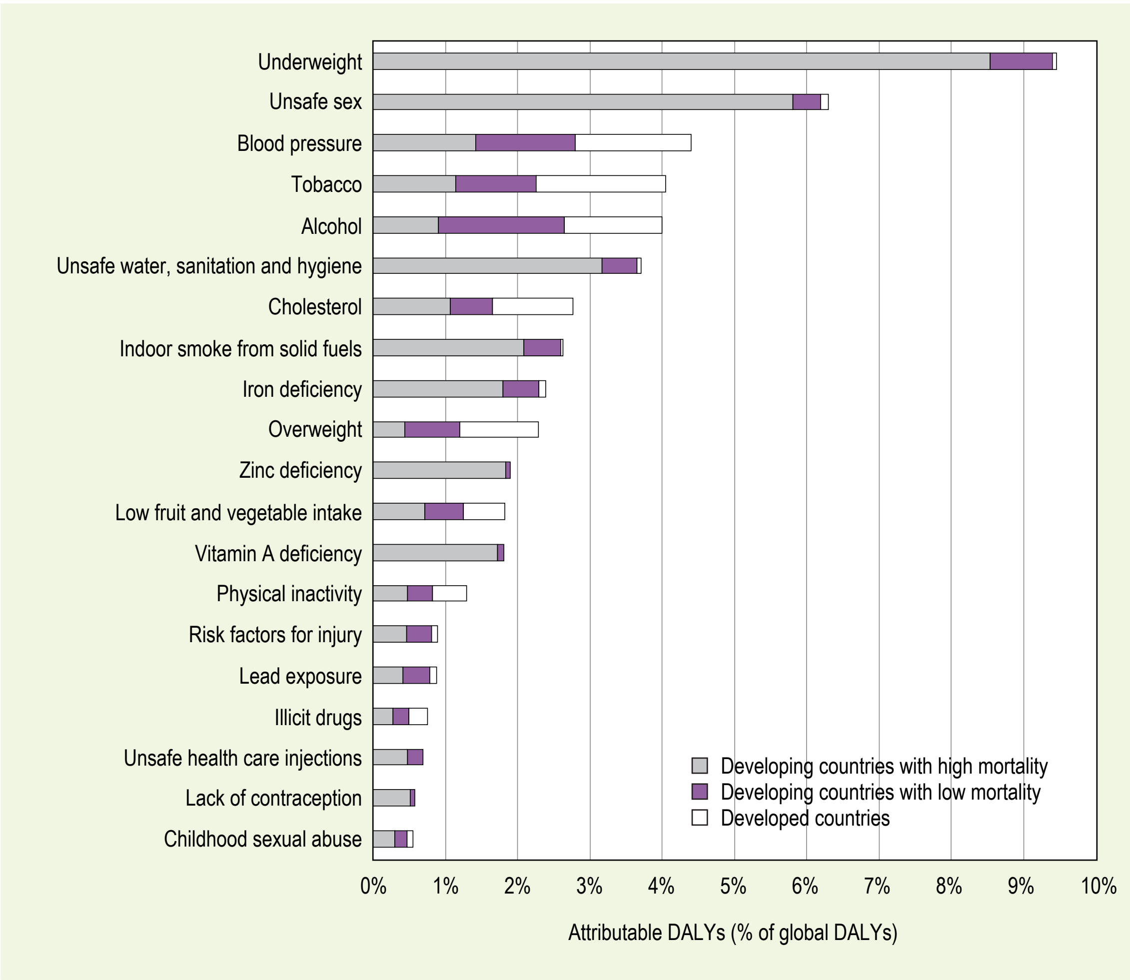

Figure 21 Global distribution of disease burden, attributable to 20 leading risk factors (WHO, 2002).

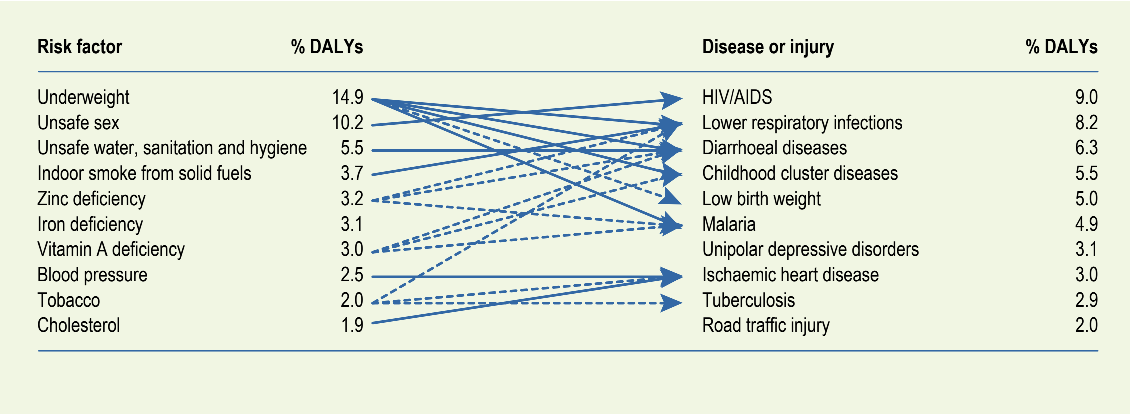

Figure 22 Leading risk factors and diseases in high mortality developing countries (WHO, 2002).

6.4.3 Health-risk factors

Risk factors can be divided in several types, according to their direct or indirect contribution to the occurrence of diseases. These types are distal socio-economic causes, proximal causes, and physiological and patho-physiological risk factors. Figure 20 (WHO, 2002) provides an overview of the chain of risk factors. The figure shows that distal risk factors influence proximal risk factors which, in turn, affect physiological causes of disease. Important to note is that a determinant can be influenced by several others, and several others can be influenced by one determinant. The outcomes in the figure refer to disease states and mortality due to specific diseases.

Selection of risk factors

The selection of risk factors is based on current shares of morbidity and mortality levels, without neglecting possible future changes in these shares. To describe the effects of risk factors and to make projections for the future, the most important risk factor-related diseases also have to be included. The relevance of a determinant, in relation to aspects of the other domains of sustainable development, has been taken into account in the selection of risk factors, as well as whether it has a distinct possibility for exploration of future trends.

Describing these risk factors with the largest attributable mortality, gives a good indication of progress in the epidemiological transition. Most of the burden of these diseases is attributable to a small number of risk factors. Another factor with large impact is the level of health-care

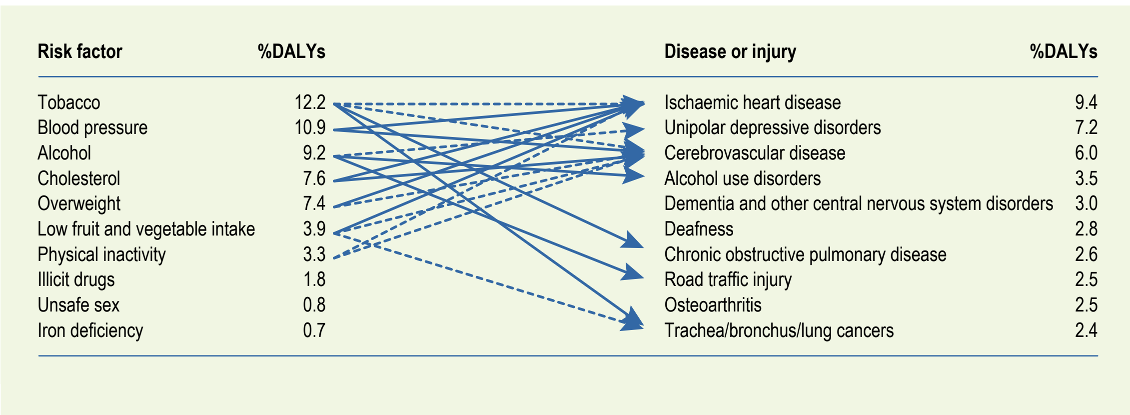

Figure 23 Leading risk factors and diseases in developed countries (WHO, 2002).

Table 1 Overview of the included distal, proximal and patho-physical determinants and diseases.

Distal / socio-economic causes	Proximal causes	Patho-physiological causes	Outcomes
Income Education Available food per capita Temperature Precipitation	Improved water supply Improved sanitation Malnourishment Traditional biomass use Poverty	Underweight	Diarrheal diseases Malaria Pneumonia / ARI

services which, although it might have a limited impact on the occurrence of diseases, it will have a large impact on the number of children who will die from these diseases.

Figure 21 indicates which risk factors cause the largest disease burden, globally. The double burden of disease becomes clear in the risk factors for developing countries, which are, on the one hand combating the effects of underweight, and unsafe drinking water and sanitation, and on the other hand, high blood-pressure levels, cholesterol levels, overweight and obesity. Figure 22 and Figure 23, published by the WHO (2002), give an adequate overview of which risk factors are linked to which diseases. To make the risk and epidemiological transitions visible, separate figures for the least en most developed regions have been included.

Included risk factors

Based on the described selection criteria, risk factors and their related diseases are selected to be included in the model. In Table 1, the already included risk factors and their outcomes are presented, divided in risk factor types. The outcomes relate to both disease burden and mortality due to the named diseases. Poverty is explicitly included in the model. However, most of the health loss due to impoverishment is related to other proximal and / or distal determinants. For instance, having access to improved sanitation or being educated is related to socio-economic status. In the remainder of this section, the already implemented risk factors and diseases are described.

Child Underweight and Malnutrition

The impact of child underweight as risk factor on health loss is very large. Globally, over 9 percent of DALYs lost are attributable to child underweight, an attribution that is in Africa even more than 40%. UNICEF (2007) estimated that 50% of all child mortality is somehow related to underweight. Being underweight leads to higher incidence rates for a number of diseases, such as diarrhoea and pneumonia, but also important is the effect on case fatality rates. The total of all health effects which are related to nutrition, is even larger, since additional risk factors related to malnutrition, such as zinc, iron and vitamin deficiency, also account for about 6%.

Child underweight is the result of chronic undernourishment. There are various ways to express underweight. Mostly, it is a combination of weight, height and age of the child. The most commonly used indicator for underweight is weight-for-age. Child underweight is defined as the number of children under the age of five, with weight-for-age more than 2 standard deviations below the standard international reference group median.

The causality between the risk-factor types, related to child underweight and malnourishment (the undernourished population) is shown in Figure 25.

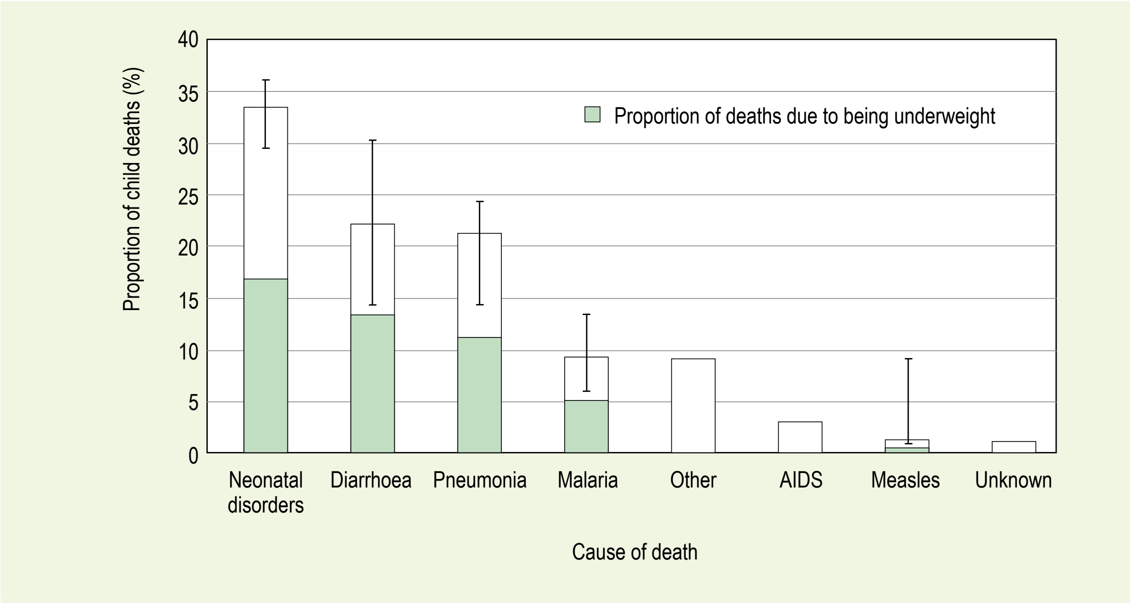

Figure 24 Distribution of global child deaths by cause (UNESCO, 2003b).

Based on a normal distribution, the total number of underweight children is divided in a mild, a moderate and a severe underweight group. Severe underweight is defined as the fraction that falls below minus three standard deviations from the median weight-for-age of NCHS/WHO reference population. Between minus two and minus three standard deviations below the median of the reference population is defined as moderate underweight, while mild underweight is defined as the population with a weight-for-age between minus one and minus two standard deviations below the median of the reference group. This methodology has also been used for the WHO Global database on child growth and malnutrition (De Onis and Blossner, 2003).

Malnourishment refers to a nutritional intake below the daily energy requirement of the human body. Malnourishment is not limited to children aged under five, as is child underweight, but it refers to the whole population. Malnourishment is defined as the number of people with a lower calorie-intake than is required to perform basic activities – which is on average around 1800-2000 kcal per person per day. Malnourishment is calculated based on a FAO methodology (FAO, 2003), comprising a log-normal distribution of food intake (in kilocalories per capita) within populations. Available food per capita is derived from the IMAGE model (MNP, 2006), which calculates food production, based on agricultural, climate and economical factors.

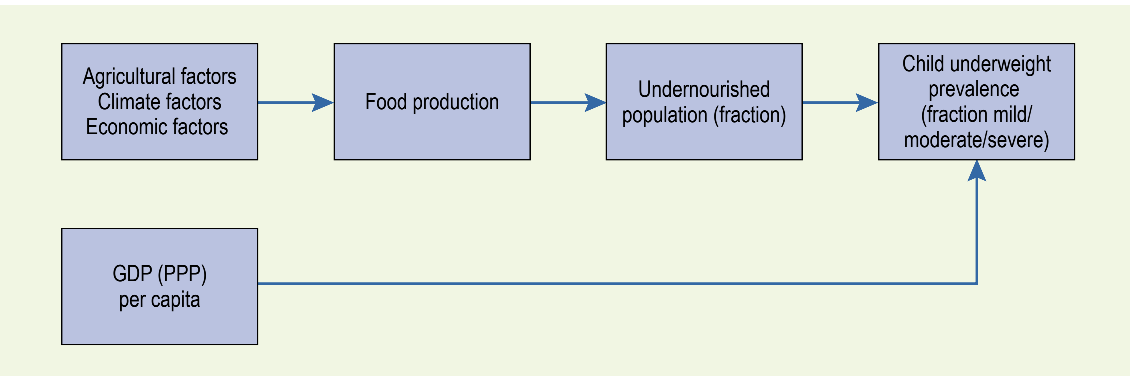

Figure 25 Conceptual overview of modelling undernourishment and underweight.

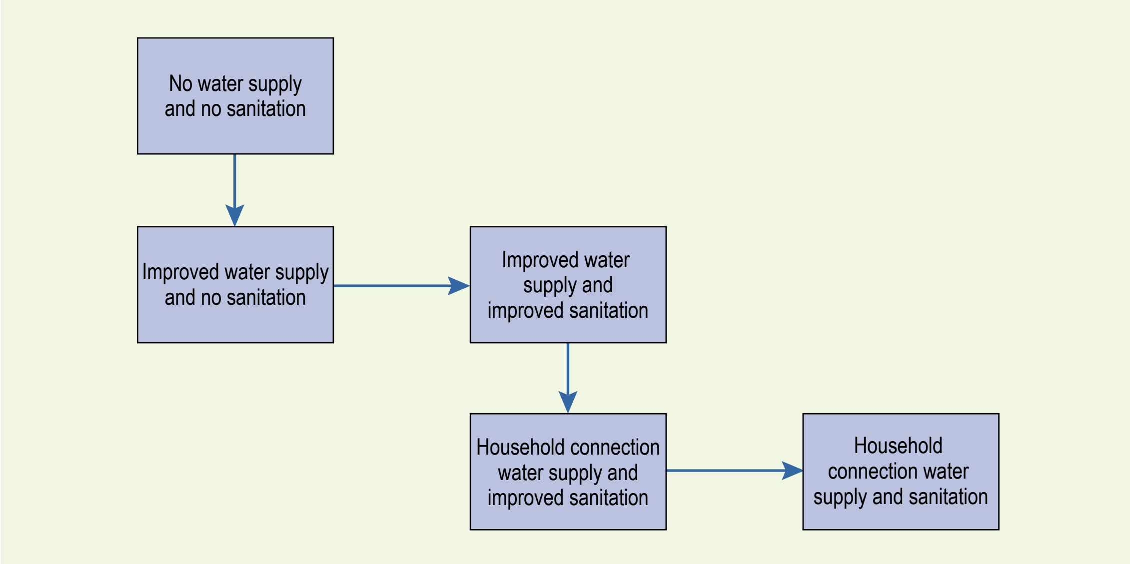

Figure 26 Various stages of the development path of water supply and sanitation.

Unsafe water supply and sanitation

Currently, 1.1 billion people have no safe water supply and 2.4 billion people even lack basic sanitation. The vast majority of these people live in Asia and Africa. Unsafe water supply and sanitation is responsible for 5.5% of worldwide DALY loss, due to diarrhoeal diseases.

To describe development in water supply and in sanitation levels, a path of development is formulated as pictured in Figure 26. These levels of development are adapted from the *Disease Control Priorities Project* (DCPP) (Cairncross and Valdmanis, 2006). It is assumed that developments in water-supply levels will be implemented ahead of developments in sanitation levels. This view is justified by data on water supply and sanitation (WSS) levels (WHO/UNICEF, 2006), from which it appears that, for almost all countries, water-supply levels are higher than sanitation levels. Separate levels of development on this path are calculated for urban and rural

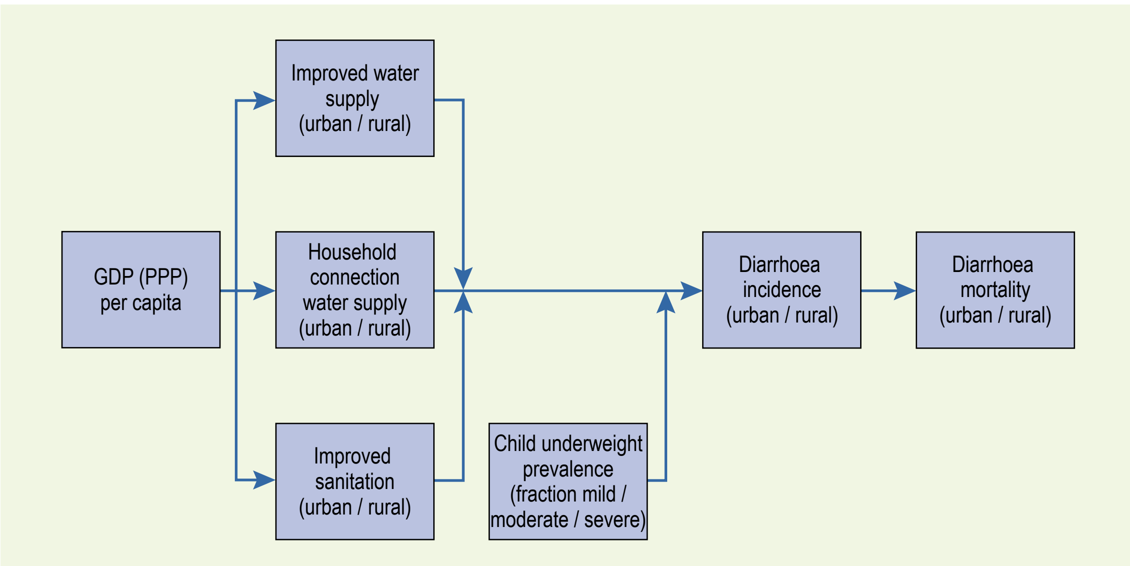

Figure 27 Conceptual overview of modelling water supply and sanitation and diarrhoeal diseases.

Table 2 Malaria suitability indices for climatic determinants.

	Suitability = 0	Suitability = 1
Monthly temperature (degrees Celsius)	< 18	> 22
	> 40	< 32
Annual minimum monthly temperature (degrees Celsius)	< 0	> 4
Precipitation (mm / month)	0	> 80

populations. This makes it possible to obtain variation between urban and rural diarrhoeal burden of disease.

Given the state of development in the regions, total relative risk ratios are calculated, based on the "realistic scenario" used in the DCPP (Cairncross and Valdmanis, 2006) to describe the health effects of this risk factor. The included causalities are shown in Figure 27.

Malaria and Climate change

Annually, more than one million people – mostly African children – die because of malaria, a vector-born infectious disease. Malaria vectors, the mosquitoes spreading the infection, can only survive in suitable climates with high average temperatures, no frost and enough precipitation. The MARA/ARMA malaria suitability model (Craig *et al.*, 1999) incorporates these climatic factors, to determine climatically suitable areas. For each climatic factor, a fuzzy suitability index is calculated. The climatic levels required for the maximum suitability of 1, and for the minimum suitability of 0, are shown in Table 2. For indicators with levels between those required for 0 and 1 suitability, a level is calculated by using s simple function (Craig *et al.*, 1999). All these factors are calculated at half-by-half degree grid level, making use of the output from the IMAGE model (MNP, 2006). Total climatic malaria suitability for each grid cell is determined by the lowest of these three indices. See Figure 28 for the year-2000 situation.

This model was originally developed for Africa, where most malaria cases and deaths occur, but for GISMO, this model is applied worldwide. Based on climatic malaria suitability, the potential population at risk of malaria is estimated. Malaria control has reduced or eliminated malaria vectors in most regions outside Africa and, therefore, needs to be included. Insecticide treated bed nets (ITNs) and Indoor residual spraying (IRS) are modelled separately, as potential policy options to intervene on. Other vector-control programmes are used to fit the estimated malaria incidence with incidence estimations at the national level.

The total malaria incidence per country is calculated, by using the WHO-methodology for calculating incidence rates (Korenromp, 2005). This incidence is distinguished for urban and rural populations, with urban populations at a lower risk of being infected. Differences in calculated numbers and available data have been attributed to vector control activities. Using available data on mortality per country, case fatality rates are estimated. Again, underweight is of importance for this disease, influencing case fatality rates.

Temperature and precipitation can also influence the incidence of other diseases. In the WHO publication *Climate change and human health – risks and responses* (WHO, 2003), the potential effects of climate change on several diseases is assessed. In addition to malaria, the impacts of climate change on health become visible through malnutrition, diarrhoea and, to a lesser extent, flooding. The effect of climate change on diarrhoea is not (yet) included. Flooding is not model-

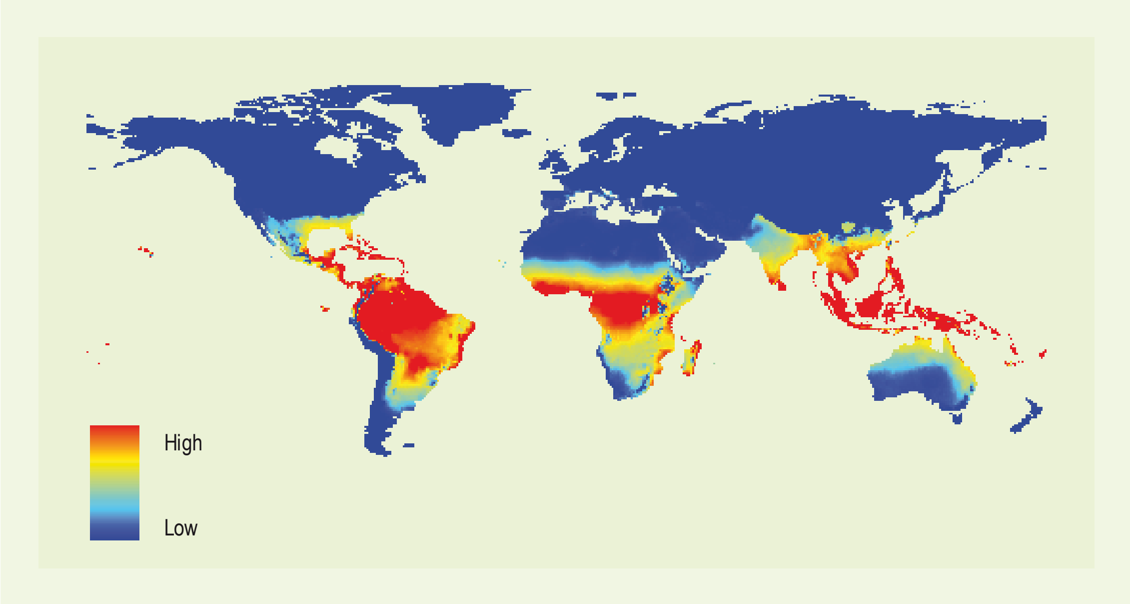

Figure 28 Average monthly malaria suitability for the year 2000.

led but also has limited relative importance. Only Latin America seems to have a high health loss caused by flooding.

Indoor air pollution

Lower respiratory infections (LRI), or pneumonia, cause over 2 million child deaths, annually (Mathers and Loncar, 2006). The main risk factor for these infections is indoor air pollution, caused by cooking and / or heating with solid fuels, and the effect is increased in children who are underweight. These solid fuels can be traditional biomass (such as wood, charcoal, dung and crop residue) or coal. Indoor air pollution not only causes increased risk of pneumonia mortality, but also of Chronic Obstructive Pulmonary Disease (COPD) and lung cancer. Other diseases are

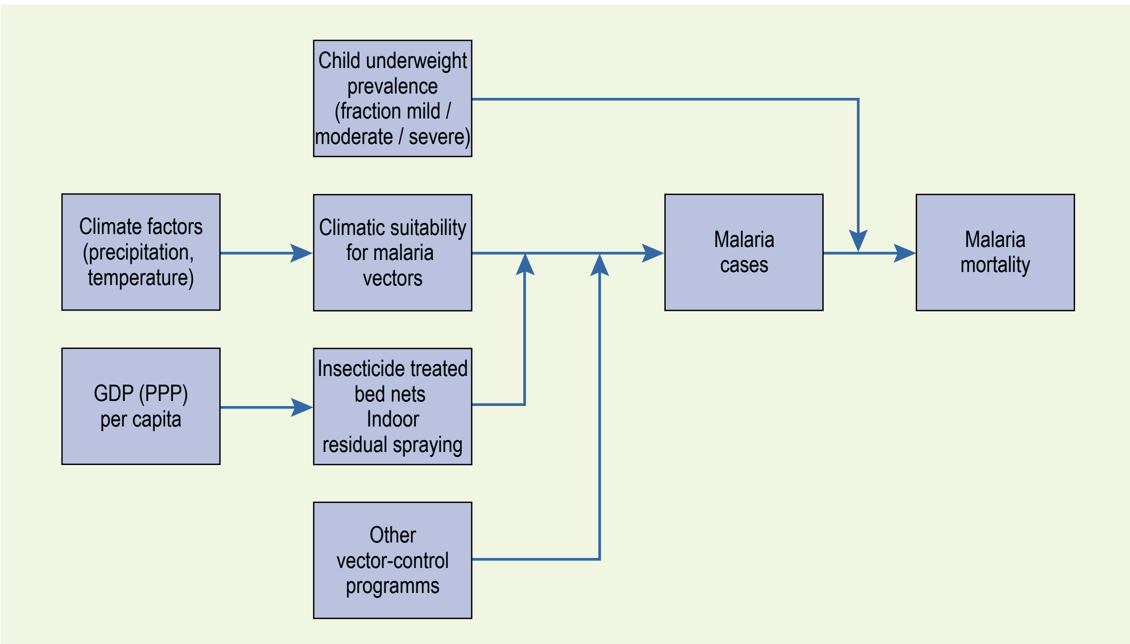

Figure 29 Conceptual overview of determinants of malaria modelling.

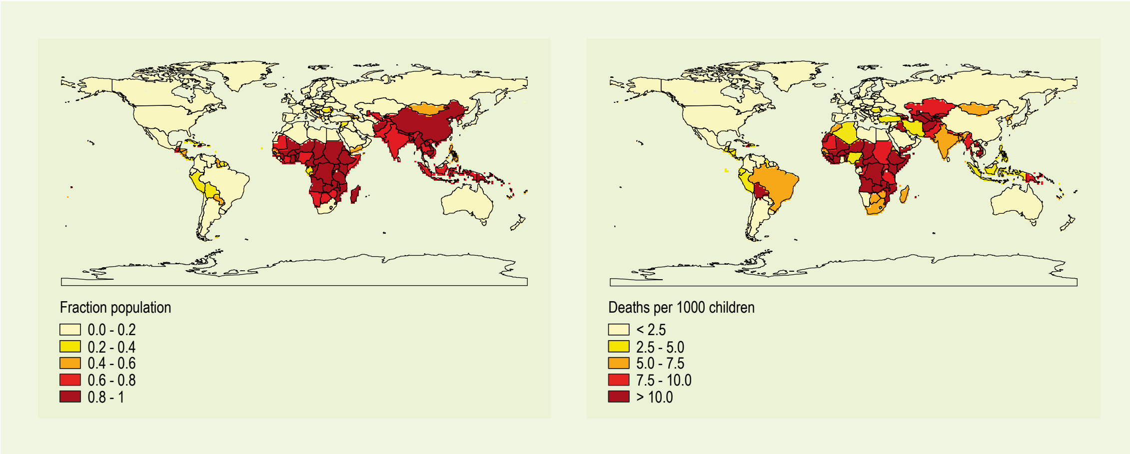

Figure 30 Population using solid fuels (left) and mortality rate due to pneumonia (right).

suspected to be related to this risk factor, but evidence for these diseases is limited and they are not included.

The number of people exposed to indoor air pollution is very high. Besides most African countries, South and South-east Asia also still have very high rates of solid fuel use. The health effects of exposure to this risk factor can, however, be lowered by proper ventilation when cooking and heating. The methodology to describe the burden of disease attributable to this risk factor, is adopted from the WHO (Desai *et al.*, 2004).

The current national levels of traditional fuel are shown in Figure 30. Dynamics in these levels are ideally derived from the TIMER model (MNP, 2006). However, since TIMER calculates energy use in joules, these numbers would have to be converted to the fraction of populations using solid fuels. However, the results of residential solid fuel use of TIMER are, at this point, not consistent with WHO solid fuel use data. Therefore, the current levels of solid fuel use are now estimated, by using a simple function which uses GDP as an explanatory variable (Mehta *et al.*, 2006). Pneumonia-related mortality can, to a large extent, be prevented by vaccination programmes. These are not (yet) included as a policy option, but when data on this issue becomes available, this can easily be adopted in the model.

Overview and interlinkages

All selected risk factors and diseases included and described above, are included in Figure 32. Linkages with the IMAGE and TIMER models become clear in this way, just as the importance of child underweight as a patho-physiological risk factor. The three diseases included, comprise 4 million annual deaths, over 40 percent of worldwide mortality among under-five-year-olds (Mathers and Loncar, 2006). Since perinatal conditions account for another 25 percent of annual mortality among under-five-year-olds, most disease or risk factor specific health outcomes are included for this age group.

6.4.4 Health services: level, coverage and efficacy

To describe the final impact of exposure to certain risk factors concerning mortality and morbidity, the effect of health services have to be taken into account. For the health services, two facets are of special importance, that is, the money spend on health services and the effect of

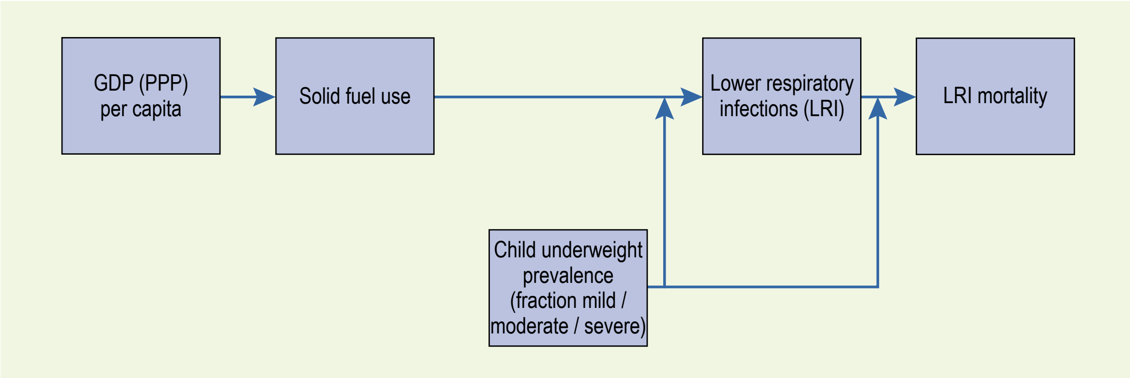

Figure 31 Conceptual overview of health outcomes due to indoor air pollution.

this spending on mortality and morbidity. These two aspects will be elaborated on in the next sections.

Level of health services expenditures

Most of the demand for health services is generated in a relatively short period, that is, just before death (Helder and Achterberg, 1997). With a changing population structure, the demand and supply of health services can be subjected to effects caused by an ageing population, which can cause a disproportional demand and supply of health services in favour of the elderly. This pattern is already noticeable in OECD countries, where people over 65 years of age spent about four times as much on health care as those below the age of 65 (Oxley and MacFarlan, 1994). Between 1960 and 1990, the average percentage of all health care in the European Union used by people above the age of 65 increased from 30% to 40%, while the proportion of people in this age group only increased from 11% to 14%, within the same period. This pattern is also clearly visible in the USA (Meara *et al.*, 2004). In general, changes in health expenditures can be attributed to the following causes (Helder and Achterberg, 1997; Pommer *et al.*, 2005): income growth, changing size and age composition of the population, epidemiological changes causing a different pattern of health services, new technical possibilities, changes in prices of health-care commodities and health-care systems design. Analyses for OECD countries show, that the factor which mostly explains the level of health services, is income (Oxley and MacFarlan, 1994). Most studies found an income elasticity of about one, or greater than one, typifying health as a 'luxury good' (Kanavos and Mossialos, 1999; Gerdtham and Jönsson, 2000).

Other factors, such as life style and technology, do not seem to have a significant effect, while private share of health expenditures and ageing have a modest effect. For example, a 10% increase in the grey dependency ratio, increased the health expenditures by about 2% (Gerdtham and Jönsson, 2000). The importance of age structure is expected to become stronger in the 21st century, when the process of ageing will reach its peak (Pommer *et al.*, 2005) These analyses are based on data for OECD countries, and might not be representative for the other 85% of the world's population. In 2000, almost 90% of the total health budget, worldwide, was spent by high-income countries, representing only 15.8% of the world's population (World Bank, 2004). In 2000, the average health services expenditures for a person living in a high-income country were around 2750 US$ per year, while South Asia and Sub-Saharan Africa only spend around 20-30 US$ per person. Worldwide, the health budget corresponds with 9.3% of the global GDP, which was still 8%, in 1990 (World Bank, 1993). In 2000, this percentage varied between countries, from 0.86% in Azerbaijan to 13.1% in the USA (World Bank, 2004). Looking at the historical trend for this percentage, the USA has always figured high, compared to other

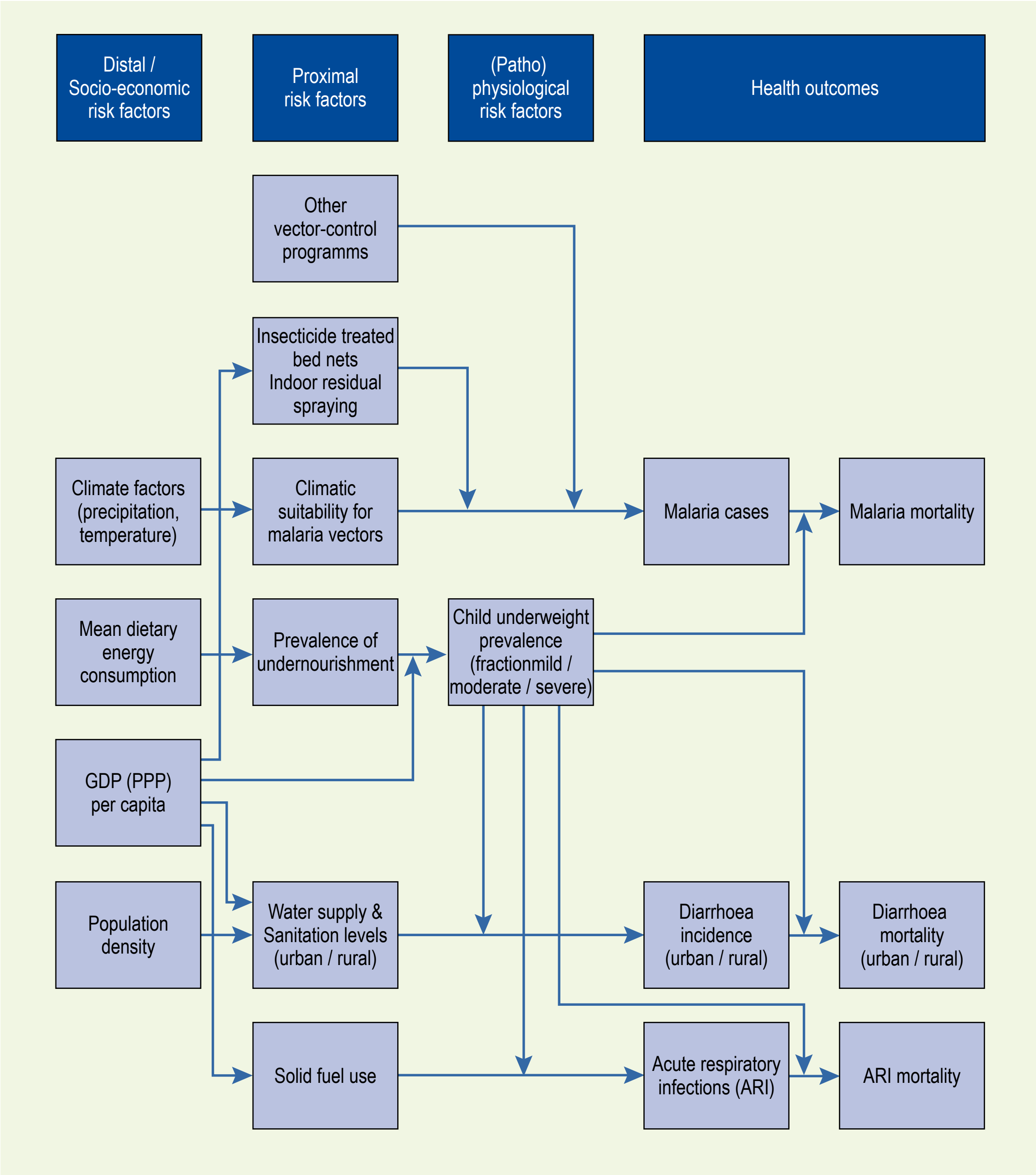

Figure 32 Overview of risk factors and health outcomes included in the model.

countries. In 1960, 5.3% of their GDP was spent on health, while Western Europe and Japan spent a relatively low percentage of 3.8% and 3.0%, respectively.

Based on available data (World Bank, 2007b), we estimated the relationship between health expenditure and income per capita, for North America, Western Europe, Japan and Oceania, using historic data (preferably back to 1960). The results for these countries are shown in Figure 33. This figure includes forecasts for higher GDP levels, using logarithmic relationships. The relationships appear to be consistent with the findings of others (Musgrove *et al.*, 2002). For Japan – clearly deviating from the other regions – another functional form of the health expenditure relationship with GDP is used, which seems to be more consistent with other regions than a logarithmic function. For all other regions, for which only a few data points were available, a general logarithmic function is used, based on a cross-sectional dataset, for the years

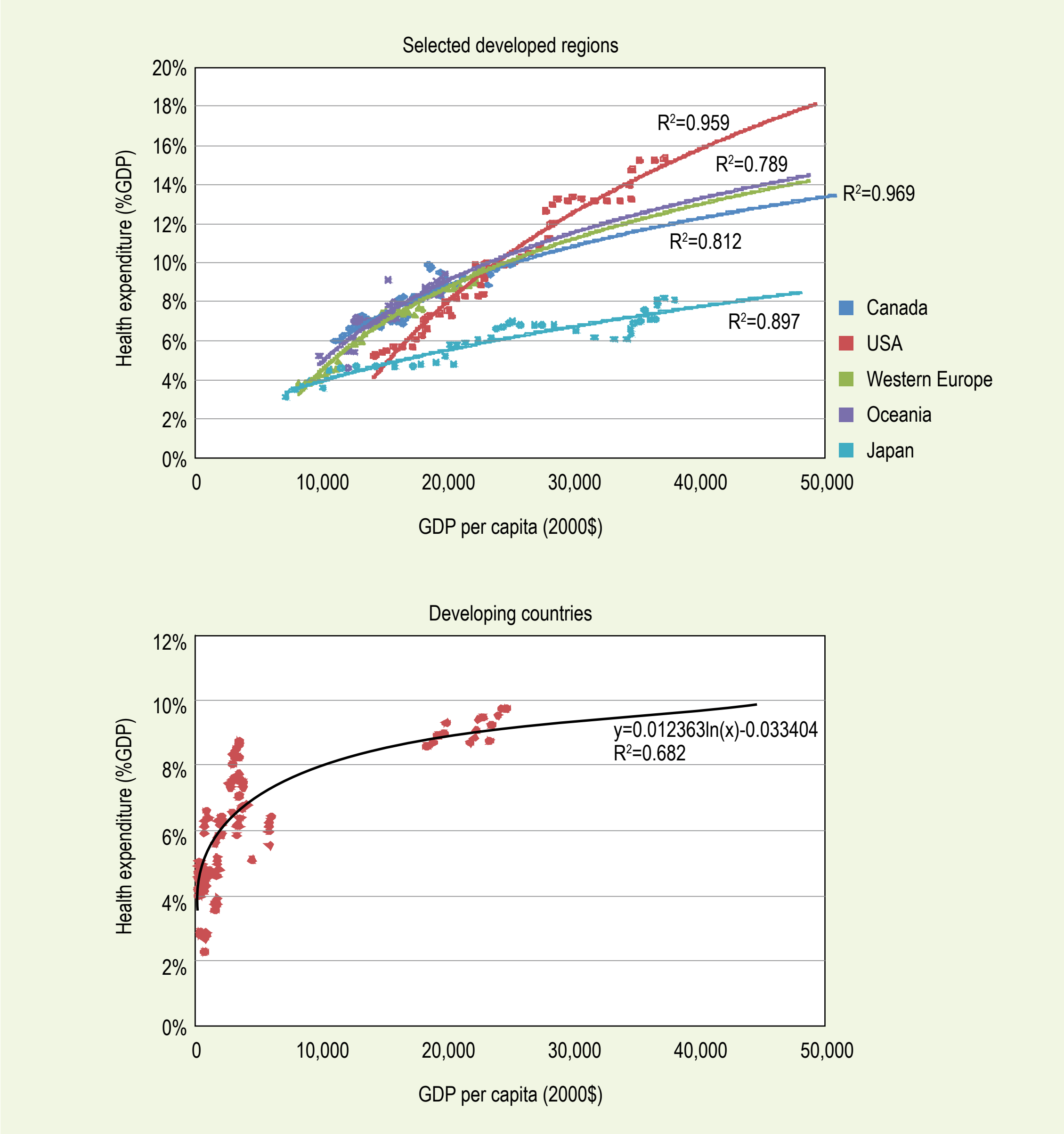

Figure 33 Cross-sectional relation between GDP per capita and health expenditure (World Bank, 2004).

2000 until 2004 (World Bank, 2007b). Outliers, such as the United States, are excluded from that analysis.

The health-care design is also a relevant factor, especially the distinction along the lines of public–private, and the line of prevention–cure-care (Niessen and Hilderink, 1997; Hilderink, 2000b). The public–private distinction addresses an important dimension, especially in the context of the ongoing debate on the role of private companies in, for example, supplying drugs or setting up specific health programmes, as part of development assistance. For the health model, the effect of both is assumed to be similar and therefore not included. However, for the economic model, it is relevant to know who is spending it, since public health services are financed by the government with a specific budget, while private spending is on the account of the overall consumption levels (see chapter on Economy). Also health spending and, especially, out-of-pocket spending, has a strong relation with poverty (Van Doorslaer *et al.*, 2006). The

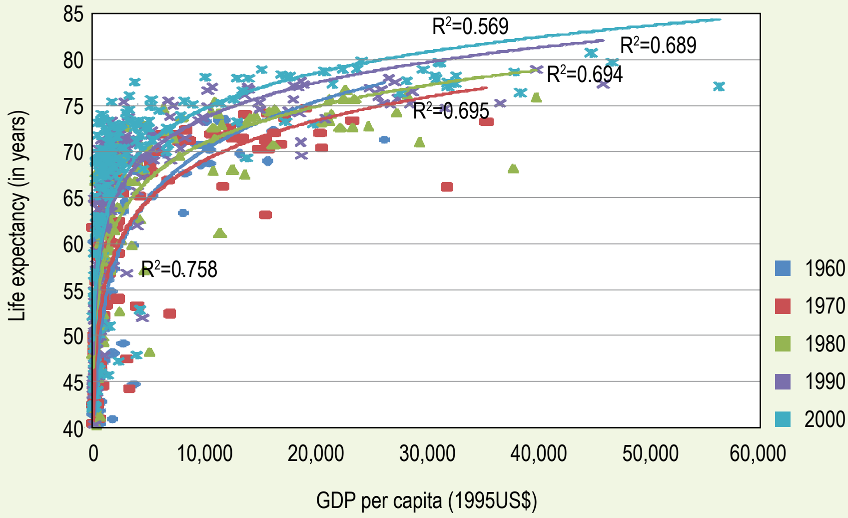

Figure 34 Cross-sectional relation between GDP per capita and life expectancy, 1960-2000.

historical share of private and public health services is derived from World Bank (2007b) and is kept constant, in the future.

Separating prevention and cure from the overall health services budget is more applicable to health modelling. In general, prevention seizes upon the reduction of the health-risk factors, while cure deals with the consequences of being exposed to these risks. However, most data are not specified for these two aspects. In practice, these expenditures are strongly interwoven. For instance, the costs of a health centre with both preventive and curative health services, are difficult to specify. There are, however, other preventive interventions that allow further specification, for example, the costs of malaria nets, vaccination programmes and water supply and sanitation, which might be explored, in future steps.

Efficacy of health services

The second facet of health services is the actual effect that the level of health services has on mortality and morbidity. By using this static function for the effectiveness of health services, the progress of medical technology is ignored. With regard to this, assumptions have to be made to estimate the effect of increased knowledge and facilities on the minimum attainable mortality levels. The World Bank has analysed the relationship between life expectancy and income, in the 1900-1990 period (World Bank, 1993). However, this relationship oversimplifies the complex field of influences, where improved overall conditions and technology play their own role. Therefore, the medical technology is represented by a more generally accepted technology factor.

We followed the health effectiveness function, as applied in PHOENIX 1.4 (Hilderink, 2000b). The effect of this spending on mortality is, subsequently, implemented in a logarithmic way, representing diminishing returns.

6.5 Discussion

We have focused on environmental health risks in global- and country-level modelling. By linking both mortality and morbidity to underlying determinants, future projections can be made of the burden of these diseases. The distinction of distal, proximal and physiological determinants, allows taking policy interventions into account in their potential of modifying these determinants. By including the major causes of death, such as malaria, lower respiratory infections and diarrhoea, more than 40% of all global child deaths and 35% of all DALY loss have been covered (Mathers and Loncar, 2006). Although the effect of undernourishment and underweight is mainly visible from other causes of death, modelling this aspect of health is an important step in covering a larger amount of disease burden, since more than half of all child deaths are related to hunger (UNICEF, 2007).

The current model has an explicit distinction into urban and rural populations for several health risks. Variation occurs among urban and rural populations in health outcomes due to variations in the risk-factors (e.g., malaria, outdoor air pollution and water supply and sanitation). Unfortunately, other factors, such as socio-economic variables and access to health services, could not be differentiated along these dimensions. Further development in within-country distribution of income and availability of facilities, can be an important improvement of the model.

In the next phase of this project, more risk factors and diseases will be included, to better describe the epidemiological and risk transition. These changes will include HIV/AIDS, as well as chronic diseases, related to smoking, alcohol use, overweight and inactivity. In addition to this, the effect of health services spending is a topic that might require more elaboration. It involves issues, such as coverage, efficacy, access and equity. The measurement of these aspects is, in itself, already subjected to huge scientific debate. Within the PHOENIX health model the effect is dealt with in a rather simplified way. The current way of health services modelling will be substituted by a modelling approach which includes factors, such as labour, medical technology and expenditures for health services infrastructure (e.g. similar to a Cobb-Douglas production function). Some case studies will be performed.

7 Education model

Education and knowledge have always been recognised as important aspects, intertwined with quality of life. In Maslow's hierarchy of needs, education is positioned at the lower levels to guarantee basic needs and capabilities, but education also plays a substantial role at the higher levels of opportunities and social structures (Hilderink, 2004). Education is included as one of the main dimensions of the Human Development Index (HDI).

7.1 The importance of education

Traditionally, education has had a strong association with labour resources and their quality through human capital (see, e.g., Becker, 1993). The OECD uses a broad definition of human capital placing it explicitly in a non-economical context: 'the knowledge, skills, competencies and other attributes embodied in individuals, that facilitate the creation of personal, social, and economic well-being' (OECD, 2001). Education is considered as an important driving force for the demographic transition, as composite of the fertility and epidemiological transition. Education is an important proximate determinant for fertility behaviour. Education levels are also important as an health determinant (Caldwell, 1979; Caldwell, 1986; Smith *et al.*, 1997). Educated people do not only live longer in developing countries – because they know better how to manage health risks, such as dealing with unsafe drinking water, adequately taking medication and gathering health information – but they also tend to live longer in developed countries. In the Netherlands, higher educated men live on average 5 years longer and women 2.6 years (Van Herten *et al.*, 2002).

Achieving universal primary education has been on the international agenda since the *Universal Declaration of Human Rights* in 1948 affirmed that elementary education was to be made compulsory and freely available to all children in all nations (UN, 1948). In 2000, the importance of education was confirmed when it was adopted in the second goal of the Millennium Development Goals (MDGs). The target for this MDG is to 'ensure that all boys and girls complete a full course of primary schooling'. Progress is measured by the net enrolment ratios in primary education, the proportion of pupils starting grade 1 who reach last grade of primary, and literacy rates of 15-24 year-olds, women and men. In 2003, the *United Nations Literacy Decade* was launched 'to renew the commitment and efforts to improve literacy around the world' (UNESCO, 2004). This takes place in the context of the *Education for All* campaign, which sets similar targets for literacy: achieving a 50% improvement in levels of adult literacy, by 2015, and equitable access to basic and continuing education for all adults.

7.2 Education indicators

The UNESCO definition of literacy is that adults, aged 15 and over, can, with understanding, read and write a short, simple sentence about their everyday life (UNESCO, 2003a). This definition has its origin in the 1960s, when illiteracy was the target of various literacy campaigns. In the 1970s, the term 'functional literacy' came into use, trying to extend the idea of literacy in a societal, historical and cultural context (Verhasselt, 2002). This was followed in the 1990s, by the introduction of the term 'basic skills', originating from the OECD's concern about the relationship between skills and workplace performance in a new global economy (Van der Kamp *et al.*,

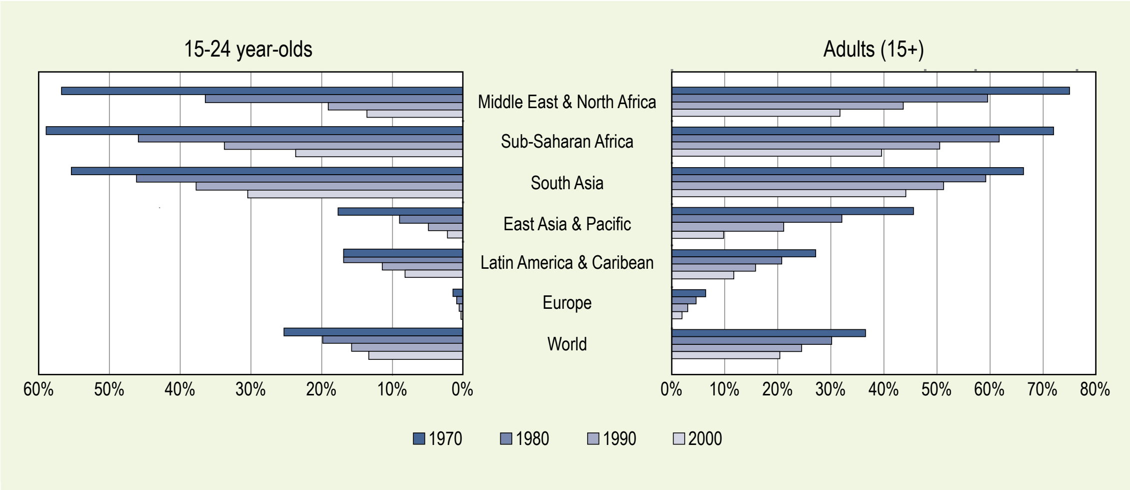

Figure 35 Trends in illiteracy, 15-24 year-olds and adults (15+) (UNESCO, 2003b; World Bank, 2003).

1995). These refinements of the literacy concept might be more useful for developed countries, in which the original definition is not an adequate indicator for a person's capabilities.

One might consider literacy as one of the outcomes of formal education. However, this relationship can easily be looked at from different perspectives. Reder (1998) describes education and literacy by using three so-called models. Next to the literacy development model, in which literacy is the effect of educational attainment, the literacy selection model is distinguished. This model assumes a reverse effect, namely that literacy directly influences educational attainment through a selection process of schools, based on literacy. The third, reciprocal effect model, assumes that literacy and education support one another although the literacy development effects seem to be stronger than the selection effects (Verhasselt, 2002).

The regression analysis, shown in Figure 37, reveals a correlation between completed primary education and literacy, although this relation is not too strong and is weakening over time.

To select other relevant indicators for describing and monitoring education, one needs to look at the underlying process of education. What determines the choices of people enrolling in schools? These decisions are, obviously, made at a micro level, although aspects, such as policy settings and education infrastructure, might be more relevant at the macro level. These decisions are an individual consideration of the costs of education versus the expected benefits from educational attainment. It is beyond the scope of this paper to model education at the micro level, but these micro aspects are important to take into account.

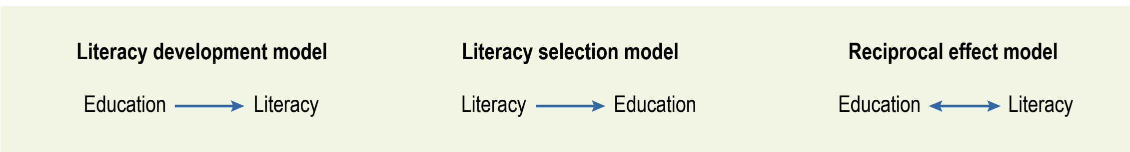

Figure 36 Three relationships between education and literacy (Reder, 1998).

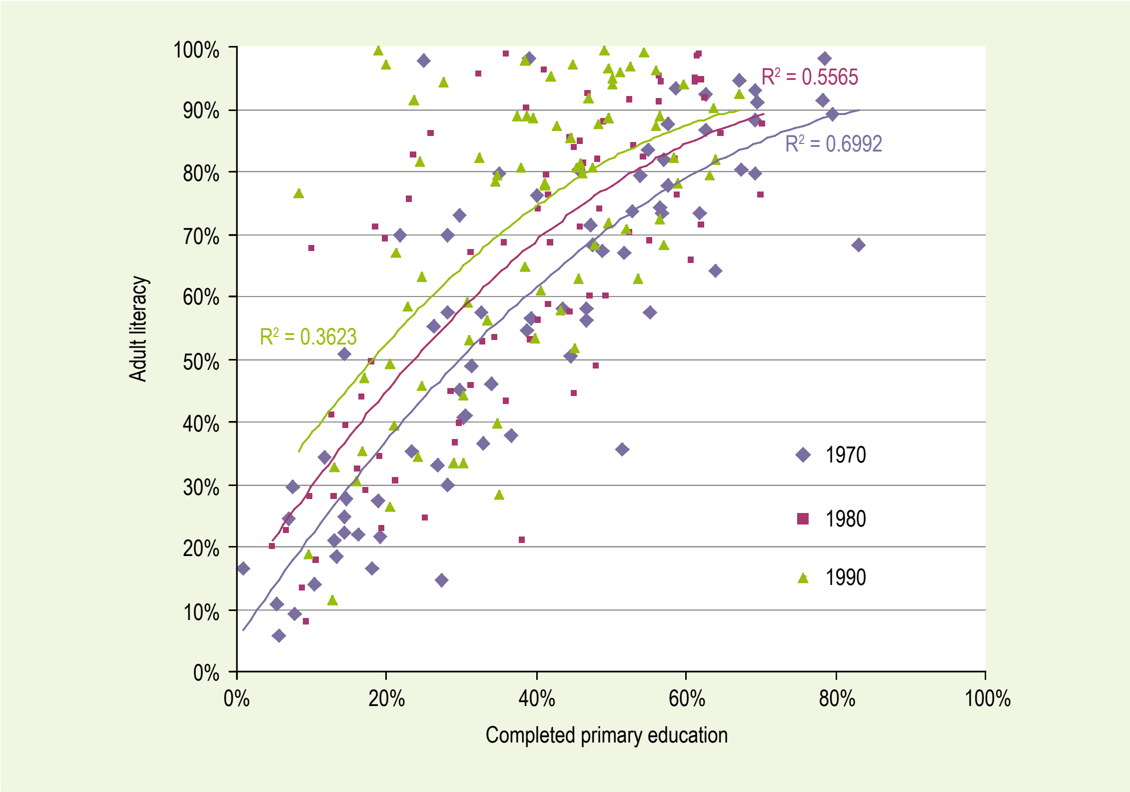

Figure 37 Correlation between completed primary education and literacy (Source: UNESCO 2003b).

The factors influencing the process of education, which have to be taken into account when modelling education dynamics, some more relevant and important than others, are:

- The entanglement with the economy goes through productivity and increase in income. The higher the education level, the higher the productivity and the economic growth – the higher the financial resources available for education, the higher the educational levels.
- The socio-economy includes, among other things, the distribution of education. A selection effect based on socio-economic status, causes a child's education to be more stimulated by higher educated parents with high incomes (Pritchett, 2004). In addition to these so-called vertical inequalities among generations, horizontal inequalities can also be seen. In Mexico and Brazil, within the poorest 10 percent of households, less than 10 percent of the young adults have completed secondary school, while in the richest 10 percentile this is 70 percent.
- Demography can be considered to be an important aspect of socio-economic inequalities. For example, structural lower education attainment by girls, provides a painful proof of gender inequalities. A second important demographic variable is age. Older people are more likely to have lower education levels than younger. It might also be more difficult to reach adults, to give them further training.
- Ethnicity is another factor which has proven to be of importance. In the USA, minority status has a significant, negative, and direct effect on literacy proficiency. In the Netherlands, 17% of the foreign population is functional illiterate against 8% of the native population (Stichting Lezen en Schrijven, 2004).
- Religion has had a strong relationship with literacy in history, but seems to be less important at present.
- Lastly, laws concerning education can have a substantial effect on educational attainment.

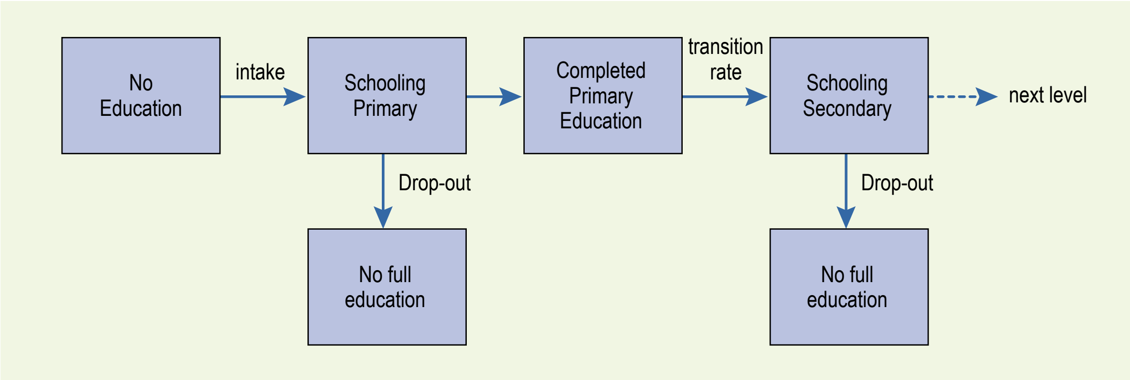

Figure 38 The basic process of education.

7.3 Modelling education

To assess future educational developments, one has to look at historical trends, as well as gaining insights into the dynamics of education. For example, the current pattern of educational attainment by a working-age population is the result of the education efforts within the last 60 years. To assess future educational patterns, this historical awareness is essential. There are several ways to take the educational levels into account and to describe the future educational patterns. Therefore, a brief overview of existing applications is given.

7.3.1 Existing applications

The *Threshold 21* model (Millennium Institute, 2004) only takes primary educational levels into account. It is a function of inflow (intake or entrance rates) and outflow (drop-outs and graduates). Unfortunately, no further specification is given of the underlying factors determining these flows, other than the population by sex, at age 6. However, the model does reveal aspects of the underlying educational system, by distinguishing the number of teachers and the amount of classrooms. These aspects are endogenously modelled, based on certain goals.

The *International Futures* (IFs) model (Hughes and Hildebrand, 2006) gives a well-documented and advanced way of education modelling. It shows similarities with T21, but simulates – next to primary – also secondary and tertiary educational levels. Based on the average GDP per capita and government expenditures on education, intake rates are calculated at the various levels. Furthermore, drop-out rates are also derived from these economic indicators. Drop-out rates are assumed to be the same for all five grades in primary and secondary education. Repeaters are not taken into account. For the tertiary level, two types of education are distinguished, namely, a more theoretically-oriented and a more professionally-oriented type. All three levels are modelled using one-year age cohorts. Additional information about teachers and classes is not included. In IFs, the education outcomes have their effect on fertility, mortality and the economy.

The third and last methodology described here, is the IIASA approach (Lutz and Goujon, 2001). As part of their multi-state cohort component population projections, education was included as an important determinant. However, only fertility levels are considered to be education-dependent, while education does not influence mortality patterns. The purpose of this approach was to improve assumptions on future fertility levels and, thereby, population projections. However, this may have resulted in the lack of an elaborate description on how education has been modelled. Furthermore, only a brief description of underlying data sources is given.

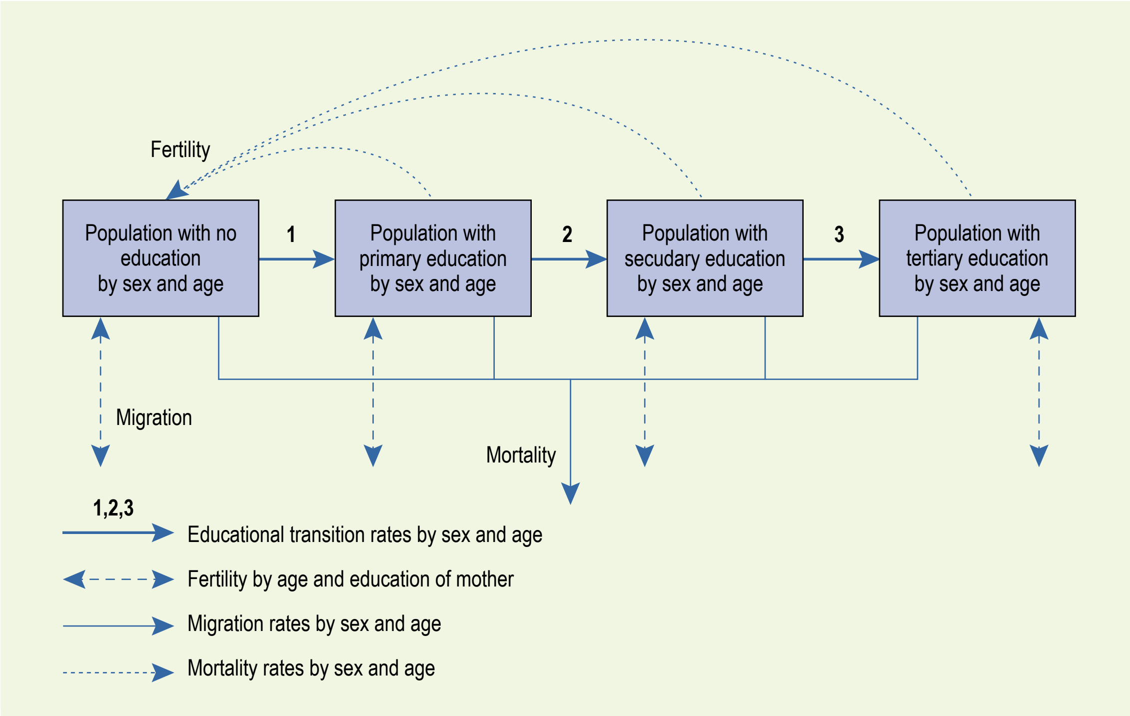

Figure 39 IIASA Education modelling (Lutz and Goujon, 2001).

7.3.2 Evaluation

All three approaches have their strengths and weaknesses. The T21 model is rather limited, as it only models primary education, where IFs takes all three levels into account. However, IFs does not include the infrastructural aspects. The IIASA approach suffers from a lack of description, although the integration of education with population projections might be an important improvement of their projection methodology. The use of five-year age cohorts in two of the three approaches might result in some slight miscalculations, which could easily be avoided by using one-year age groups. Another overall weakness is lack of validation by not reproducing historical patterns. Only future educational levels are simulated. Finally, none of these methods links education to literacy levels.

7.4 Implementation

To describe the various facets of education dynamics, an education module has been developed. The population model serves rather well as an integrative platform for education modelling, since it facilitates detailed modelling by distinction of 100 age groups and the two sexes. Furthermore, mortality and fertility processes are endogenously included, and the interaction with the economy module is taken into account, through both labour and expenditures for education, allowing the analysis of both causes and consequences of educational levels.

7.4.1 Methodology

Enrolment ratios are the combination of intake or entrance rates and drop-out rates. Ideally, the whole process of intake and then advancing from year to year should be covered. However, the availability of data on (historical) intake and drop-out rates is rather limited. Especially, the lack

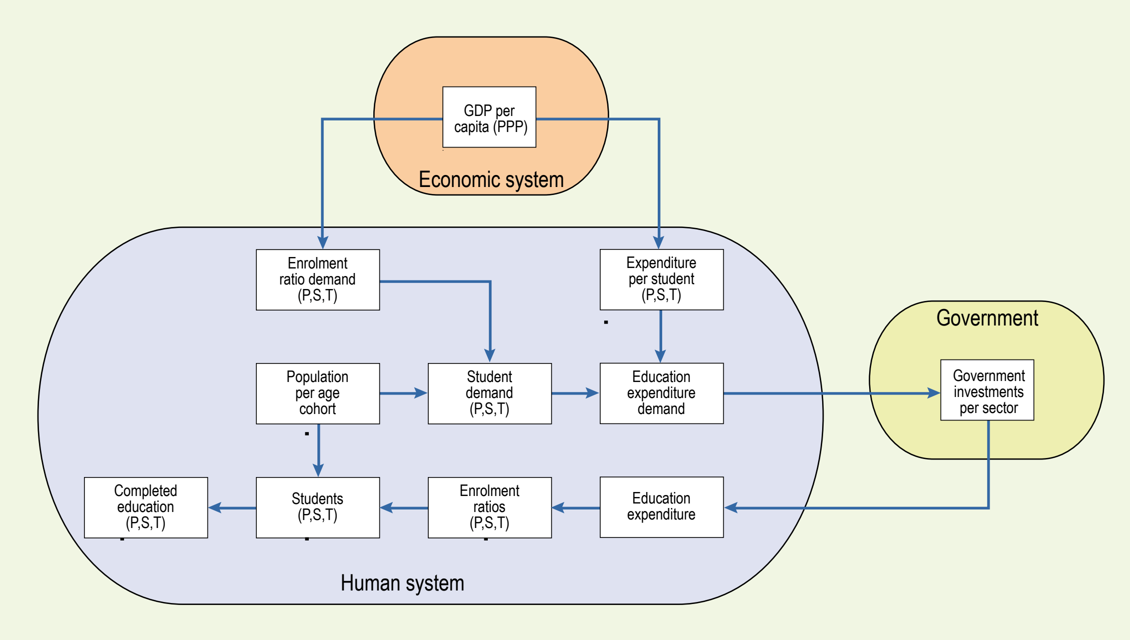

Figure 40 Conceptual overview of the education model (P=Primary, S=Secondary, T=Tertiary).

of good quality data for the different ages makes such an advanced way of modelling less applicable. Therefore, we have chosen to model the education process based on net enrolment ratios. However, a further refinement should be considered if more data becomes available.

Figure 40 gives a graphical overview of the education model. In the first step, the enrolment ratio and expenditure per student, per education level (primary, secondary and tertiary) are determined, using cross-sectional relationships with the development level (per-capita GDP in PPP terms, see Figure 41 for the equations used). Together with the total population within the education level specific age groups the total demand for educational expenditure is determined. Together with the demand for other expenditures (e.g., on health services), the government module determines how much of this demand will be fulfilled. Next, these expenditures determine the actual enrolment ratios of the different levels. Students enrol in the the subsequent time-step, and drop-outs are not taken into account. The beginning and end of all three levels of education are assumed to be equal for all regions, although we are aware that – in reality – they vary greatly between countries. Children are assumed to be attending primary education from 5 years old until they are 11, secondary education from 12 until 17 years, and tertiary education from 18 until 24 years. Furthermore, repeaters are not taken into account.

7.4.2 Gender differences

Although the gender dimension has not been distinguished in the model description given above, it is essential to take this highly relevant facet of education into account. There is still a huge gap between the educational levels of boys and girls, which should be targeted. The importance of education for girls and women is stressed by the positive effect of women's education on their family's health. Analyses show that a 10% increase in primary, secondary or tertiary female enrolment ratios could result in, respectively, a 0.9, 1.0 and 0.7 years increase in overall life expectancy (Hannum and Buchmann, 2005). For example, mortality rates for children under five years old, whose mothers have had a secondary or higher education, are more than 50% lower than for those, whose mothers have had no education (Hannum and Buchmann, 2005).

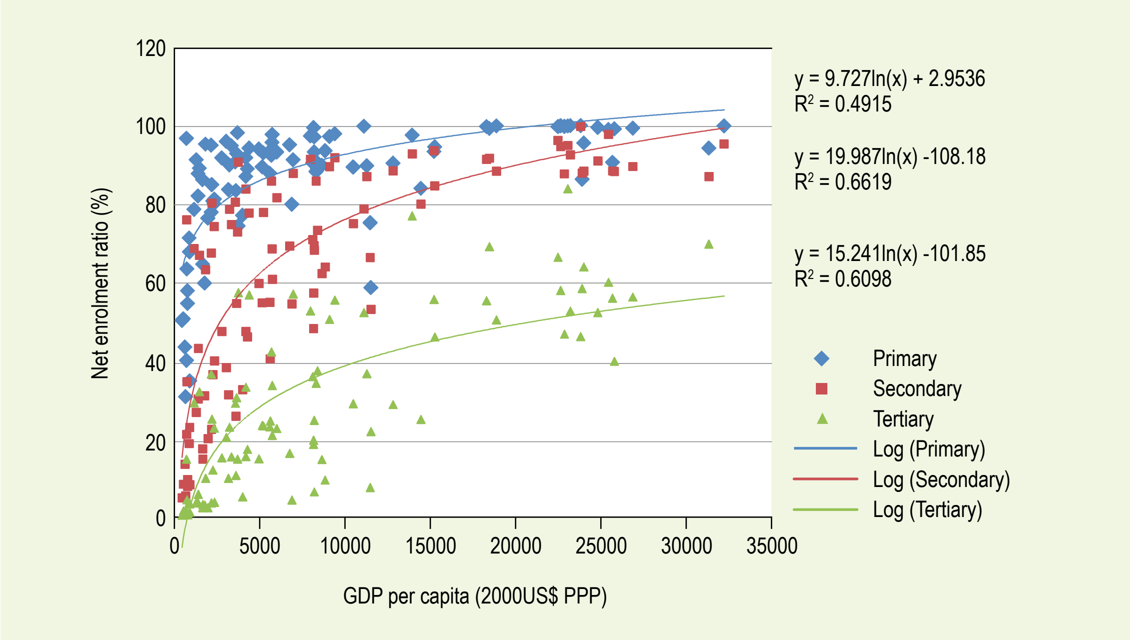

Figure 41 Correlations between GPD per capita and net enrolment ratios, primary, secondary, tertiary (World Bank, 2004).

On top of the health outcomes, women's education is usually seen as an important factor in the decline of fertility as part of the demographic transition. Educated women show lower fertility levels; the number of children they have lies closer to their personal desire, because they have access to and are capable of using contraceptives.

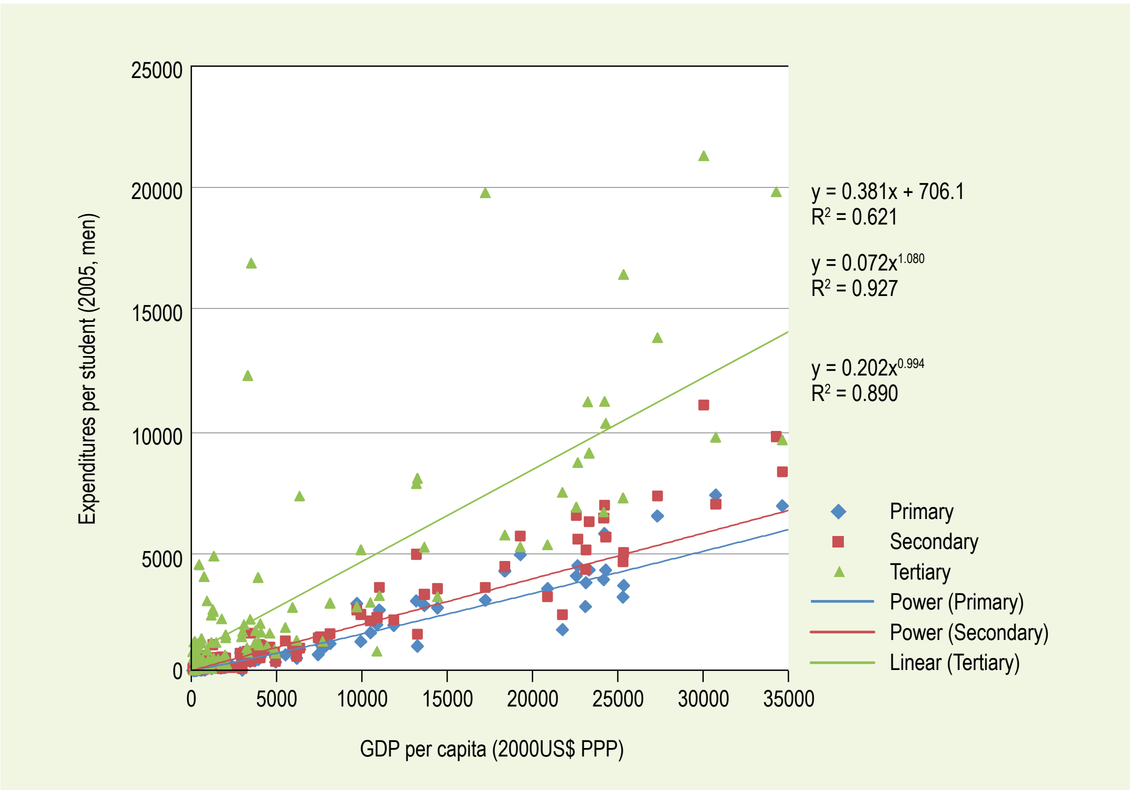

Figure 42 Correlations between GPD per capita and expenditures per student, primary, secondary, tertiary (World Bank, 2004).

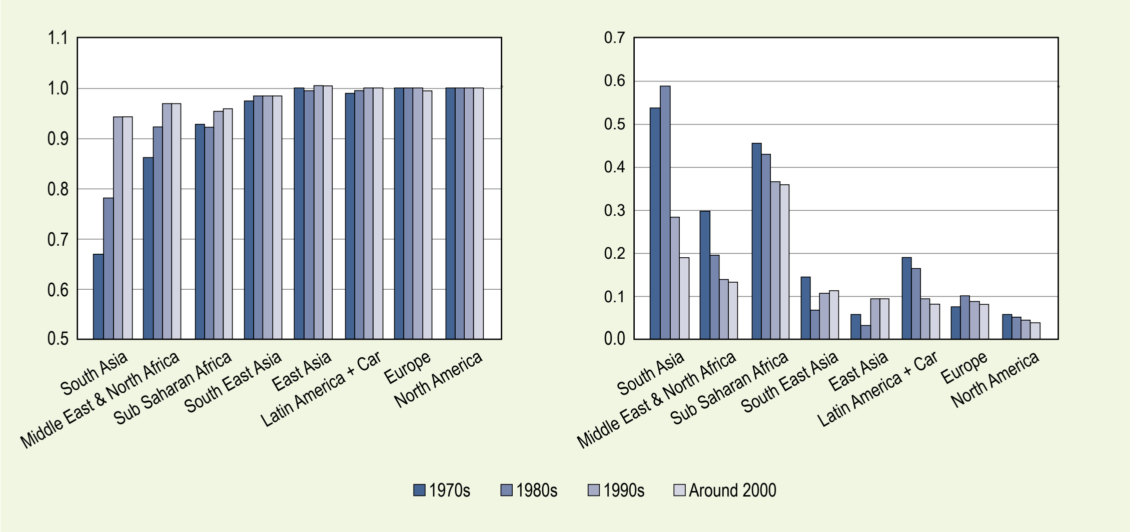

Figure 43 Enrolment of girls in primary education as a fraction of the average enrolment, and girls without education as a fraction of the total of the non-educated (World Bank, 2004).

Looking at enrolment ratios in primary education, generally, girls show lower intake rates than boys. This is especially true for South Asia, the Middle East and Africa. However, since the 1970s, girls have been catching up rapidly, and currently the enrolment of girls in primary education is 82% of that of boys (Figure 43). In East Asia and Latin America, the enrolment ratios for girls were even higher than for boys, during some periods.

The trend of girls catching up is even stronger in secondary education. In several regions, the enrolment ratio for girls is even higher than for boys. Although this trend is also clearly visible in tertiary education, at this highest level it is staying behind, compared to the other two levels. However, girls show substantially higher enrolment ratios than boys in Europe and America. In the educational model, these factors are included and combined with the overall enrolment ratios to obtain sex-specific ratios, as shown in Figure 43.

7.5 Discussion

Applying the methodology, as described in the chapter, results in the following findings and conclusions. First of all, the relation between literacy and education is weak. Illiteracy levels are, by definition, not equal to the 'no education' category, since pupils who attend only a couple of years of primary school, and who do not complete it, are also included in this category – although they might have had enough education to become literate. There might also be a more autonomous increase in literacy levels, which is not associated with formal education but is the result of informal social structures. Secondly, enrolment in primary education shows a relatively high variation among lower income countries.

The importance of primary education is not only restricted to describing the basic levels of education, for example, those associated with literacy; it is also important to the higher levels. Most of the increase in the overall education level is due to pupils moving on from primary, via secondary, towards tertiary, while people without education benefit less from the improvements in income levels.

To understand the educational dynamics, one has to take the age structure into account. The current approach, with a strong connection with the one-year age cohorts of the demographic model, captures the underlying dynamics of the educational process. The inertia of educating a population takes place through the education of children, and to reach a whole population will take between 50 to 100 years. Many of the people without education cannot be reached through normal schooling and will not receive any further education, assuming that adult education is not implemented. It will be a matter of time before these uneducated generations will be replaced by educated ones.

8 Economy model

The third pillar of the HDI, our interpretation of *quality of life*, is a decent standard of living, represented by per-capita income. To address this pillar, an economic model is required. The model should 1) serve as an integrating framework of the other models; 2) link environmental quantity and quality to production and consumption; and 3) be able to analyse economic poverty. Chapter 2 concluded that the International Futures model (Hughes and Hildebrand, 2006), and, especially, its economic module, could serve as a blueprint for model integration. Furthermore, the model includes 1) endogenous multi-factor productivity, which is important for economic growth assessments; 2) the most important economic sectors, distinguishing, among others, agriculture and energy, which spearhead PBL's strategy for global research; 3) a government sector and foreign aid flows, thereby including the most important (political) institutions; and 4) economic poverty indicators, linked to other economic outcomes. Here, we describe the main dynamics of our implementation of IFs Economy. For a more detailed description of the model, we refer to the technical documentation of IFs (Hughes and Hossain, 2005) and its help systems (Hughes, 2007). Furthermore, the entire IFs model and, thereby, also its economy module, is verified and validated in Hughes (2006). Next to the economic model, this chapter also includes the methodology for the income–poverty calculations.

8.1 The IFs Economy model

The International Futures (IFs) model is a tool for thinking about long-term global futures. The model "assists with understanding the state of the world and [helps] thinking about the future we want to see" (Hughes, 2003). For this purpose, the model includes several sub-modules, of which the population, economic, agriculture, and energy sub-models are the most advanced. IFs Economy draws upon techniques found in both econometric and system dynamics traditions. In its documentation the model is referred to as a "general equilibrium-seeking model" (Hughes, 2003). It is not a general equilibrium model in the way that all markets are cleared in a single year, using prices of factor inputs and goods and services as equilibrating intermediates, and profit maximisation for producers and welfare maximisation for consumers. In contrast, the structural base of the model has a strong accounting character, with requirements that flows balance within and across regions, as well as stocks of assets and liabilities. The model incorporates a domestic part (commodities, households, capital and government) and an international part (rest of the world). The domestic part includes production of goods and services (section 8.1.1) and sectoral demand (household, capital and government) (section 8.1.2). This domestic part is linked to other world regions through international trading, foreign aid, Foreign Direct Investments (FDI) and foreign bonds (section 8.1.3).

The domestic side uses equilibrating dynamics of two kinds: those around the goods and services market and those around the government balance. On the goods and services market, the model uses inventories as buffer stocks to provide price signals to the investment module, so that the model seeks equilibrium over time. For the equilibration of the government balance, the model keeps the relative government debt level constant in time to balance revenues (taxing) and expenditures, including consumption. Next to government consumption of goods and services, government expenditure includes education and health services, which are linked to the demand for these services and population dynamics (see chapters 5, 6 and 7), and to the total factor productivity used in the production module. On the international side, the key equilibrating

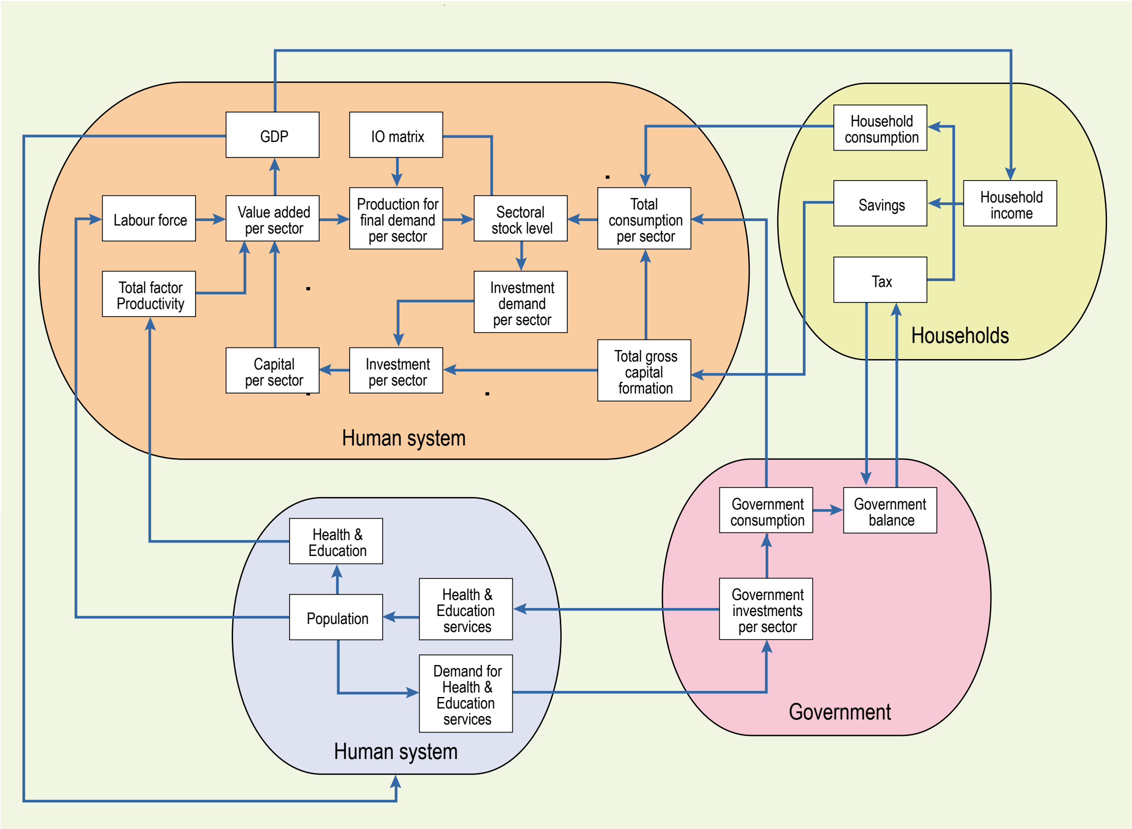

Figure 44 Schematic overview of the IFs Economy model and its link with the human system.

dynamic relates to the total international debt level. Changes in foreign reserves and short-term governmental borrowing play important short-term buffering roles, while exchange rates are the key longer-term equilibrating variable.

8.1.1 Production

The production module is a dynamic growth model of classical economics. The size of production is mainly determined by growth in labour (L), capital (K) and multifactor productivity (MFP). Five production sectors are taken into account: agriculture, energy, materials, manufactures and services. Each sector has its own Cobb-Douglas production function to determine its value added (VA_s):

$$VA_s = MFP_s * K_s^{\alpha} * L_s^{1-\alpha},$$

with labour-capital shares α. For the labour-capital shares, constant return to scale is assumed. The labour-capital shares are sector dependent functions of per-capita income (PPP), thereby incorporating the transition towards more capital intensive production when income grows. The sum of the sectoral value added is total Gross Domestic Product (GDP), which flows directly to the private households as payment for their labour and capital supply. To take account of the structure of the economy, the intersectoral flows from the input-output (IO) matrix are used to determine production for final demand. This IO matrix is dependent on the development level (per-capita income in PPP terms) and converges linearly in time from the base year matrix of the GTAP database (Dimaranan, 2006) towards a generic matrix. Nine generic IO matrices were generated (again, using GTAP data) to present the average technical coefficient pattern of regions, ate different levels of development (GDP per capita). The assumption is that regions use different types of technologies at different development levels.

Multifactor productivity
The multifactor productivity (MFP) is a mixture of endogenous and exogenous terms. The calculation is broken down in two elements: the basic productivity growth and productivity drivers for deviation around this basic growth rate (for details see Hughes and Hossain, 2005). The basic productivity growth consists of three terms: a basic growth rate, a term which represents technological catch-up with the systemic leader (identified as the United States) and sector-dependent growth rates.

The productivity drivers for deviation around the basic growth, are based on the work of Chen and Dahlman (2004). The model uses stylised facts about drivers of productivity, that have been extracted from the literature. The drivers are grouped into four categories, recognising that the categories overlap. These categories incorporate factors that can either retard or accelerate the basic productivity growth, transforming the overall formulation into one of conditional convergence. The four categories include: human capital, social capital, physical capital and knowledge creation and diffusion. Within the GISMO model, only the term human capital and the term knowledge creation and diffusion are used. The term human capital has two components – education and health – taking into account average years of education and life expectancy. The term knowledge creation and diffusion also has two components, corresponding to the creation (Research and Development expenditure of the government) and diffusion of knowledge (total trade as percentage of GDP). The model looks at typical patterns across the typology of productivity drivers, at different levels of development (using GDP per capita at PPP as a proxy for development level), and attempts to represent the impact of deviation from typical levels on productivity. These deviations include both the positive contributions, caused by an exceedance of those levels, and the penalties for productivity, imposed because of a falling behind of those levels.

Capital stocks
The sectoral capital stock is an accumulation of sectoral investments (IDS_s) and sector-specific depreciation, determined by the sector-specific lifetime of the capital stock (lks_s):

$$K_s^{t+1} = K_s^t + IDS_s - K_s^t / lks_s \quad ,$$

Changes in the pattern of investment per sector are used to maintain equilibrium over time between sectoral demand and supply. These changes are subject to changes in sectoral prices. In the model, prices are relative prices indexed around initial base-year values of 1, based on the difference between the current stock levels, relative to desired stocks levels. As these prices respond to imbalances in inventory stocks, investments by sector are actually linked to sectoral inventory stock levels. These sectoral inventory stock levels increase by production and imports, and decrease through household consumption, government consumption, consumption used for investments and through export.

Investments by sector are determined in two steps. First, investment demand for shares per sector is determined. These shares are dependent on the demand for shares in the previous year, altered in response to the inventory levels. The inventory stock levels are compared to a desired stock level, which is a fixed percentage of the stock base, that is, the sum of gross production and imports. In a second step, these investment shares are normalised and multiplied with the total level of gross capital formation, to determine absolute sectoral investments.

Labour force
Total labour supply is a function of total population and the labour participation rate. Men are assumed to participate fully. The participation rate of women in the work force is assumed to grow over time and saturates as female rates approach full participation. To divide the labour force over the different sectors, a per-capita income-dependent formula is used. This formula determines the amount of workers required in a sector to produce a certain unit output (labour-output fraction). The whole labour force is attributed.

8.1.2 Consumption

The sum of sectoral value added (GDP) flows directly to the private households as factor payments, which, together with the inwards FDI and foreign bonds, and government transfers (pensions, plus welfare transfers), determines the total household income. Part of this income is taxed, making it available for public (government) expenditure. Furthermore, part of the total household income is used for outward FDI and foreign bonds. The remainder, disposable income, can be used either for private consumption, or for household savings.

Government Revenues and expenditures
Government revenues are obtained through the taxing of private household incomes and through international channels, for example as foreign aid. Total household tax is determined in two steps. In the first step, the tax base is determined as a base-year tax share (kept constant during the whole simulation period) of total household income (excluding government transfers). During the next step, the total tax is multiplied by a government revenue multiplier that reflects the balance or imbalance in government revenues and the debt level (see later in this section). Government consumption of goods and services is determined by using base-year shares, which are kept constant during the whole simulation period.
The total of all revenues are used for government consumption and government transfers, as well as for providing foreign aid to other regions. Government consumption includes expenditures on education, health, R&D and other areas (including military spending). Expenditures on education and health are determined by investment demand from the sub-models health (chapter 6) and education (chapter 7). These investment demands can be increased or decreased by the user, by using multipliers. R&D expenditures are determined by a cross-sectional relation with per-capita GDP (PPP), which can also be altered by the user, by using multipliers. Finally, the other expenditures are kept constant, as a fraction of total GDP.

Government transfers, including pensions and welfare transfers, converge linearly in time, from their base-year value towards a cross-sectionally determined relation with GDP per capita. They are then multiplied with a multiplier that reflects the balance or imbalance in total government expenditure and the debt level (see later in this section).

The government balance increases or decreases the regional debt level. There are three options for dealing with the overall debt level. Governments can 1) converge in time towards an ‘aspired’ debt level (a cross-sectionally determined relation with GDP per capita); 2) remain constant as a fraction of GDP; or 3) remain constant in absolute terms. When the government debt is too high compared to this target, revenues (taxing) are increased and expenditures (government transfers) are decreased, by using multipliers. When government debt is below the target, revenues are decreased and expenditures are increased.

Private consumption and savings

The total disposable income (roughly total household income tax plus government transfers) is used either for private consumption, or for household savings. The model calculates private consumption, while household savings are determined as residuals compared to the disposable income. Private consumption is determined in two steps. In the first step an estimate is computed, using a cross-sectional relationship between GDP per capita and average household consumption. In this calculation, private consumption (as percentage of GDP) converges in time from its base-year value towards the analytical function estimate. In the second step, two additional factors enter the calculation. The first factor is an interest rate multiplier, using the real interest rate as the key equilibrating variable. Interest rates enter into the equation in such a way that rising interest rates depress consumption (as saving becomes more interesting), while decreasing interest rates promote consumption (as consumption becomes more interesting). The second multiplier helps to maintain the general equilibrium with the long-term savings rate. The long-term savings rate can be determined in two ways: 1) keeping the savings rate constant in time; or 2) converge to a scenario specific value.

The distribution of total household consumption across the different sectors is based on a linear expenditure system, which simulates changes in consumption patterns as household income increases. Consumption per sector of origin depends upon a minimum level of expenditure in each sector and the marginal budget share of each sector in total consumption above the sum of all minimum expenditures. The parameters for this consumption function are computed during the first time cycle of the model.

Investment consumption

Investments include gross capital formation (used to increase sectoral capital stocks) plus inventory stock changes (compared to the inventory stock levels in the previous year). Gross capital formation is determined as the investment rate in the base-year times GDP. Furthermore, gross capital formation is linked to the interest rate, using an investment rate multiplier that drives down investment, when interest rates rise, and vice versa. By definition total investments equal total savings. Total savings are defined as the sum of household savings, governments balance and foreign savings. Investments' demand on the goods and services market is determined in the same way as government consumption by origin, using constant base-year shares to divide total gross capital formation over the different production sectors.

8.1.3 International flows and their balancing

International equilibration is build around the current account balance and the capital account balance, which, by definition, are equal with opposite signs. The current account includes trade in goods and services and foreign aid. The capital account includes net FDI and foreign bonds.

International trading

Imports and exports respond to relative regional prices compared to the world average price. The world average price is determined as the sum of exchange rate adjusted regional prices, relative to their regional gross production.

Exports are responsive to both changes in production and changes in prices. The calculation starts by computing an export base, which is the share of total exports in gross production in the previous year, multiplied by the gross production. This export base is modified over time in response to 1) a fairly standard elasticity of exports to production growth; 2) an export shift parameter, which can be used by the user for scenario construction; 3) a price factor, which is dependent on the difference between regional and world prices; and 4) elasticity of trade with prices.

Imports are responsive to both changes in income and changes in prices, and are determined analogously to import capacities. Exports are tied to gross production only, whereas imports are tied to a demand base, which is the sum of gross production plus sectoral consumption. First, a basic import level is determined that grows with the demand base. This basic import level is modified over time, in response to 1) a fairly standard elasticity of imports to income growth; 2) a price factor, which depends on the difference between national prices and world prices; and 3) elasticity of trade with prices.

Since the above methodology does not by definition result in a worldwide balance between summed import and exports, actual world trade is determined as the average of the two and is used to normalise the export capacity and the import demand. For the international financial calculations, relative-priced adjusted trade is required, which is simply a multiplication of the real sectoral trade values with the relative global prices. Total foreign savings are determined as the balance between total export and import and net foreign aid.

Foreign aid
The model uses a pooled approach to foreign aid. Aid from all donors flows into the pool, and recipients draw proportions from the pool. For donors, aid as percentage of GDP in the base-year is kept constant during the whole simulation period. Summed donor aid determines the size of the aid pool. A recipient's share of the global aid pool is determined, again by using aid as percentage of GDP in the base-year, which is also kept constant during the whole simulation period.

Foreign Direct Investments (FDI) and foreign bonds
Foreign direct investments (FDI) and foreign bonds are modelled in exactly the same manner, only the cross-sectional functions are different. Therefore, only the FDI dynamics are described.

In general, FDI will be directed from relatively capital-rich regions towards relatively capital-poor ones. However, recognising that these patterns will not be universal, the algorithm that determines stocks of investment outflows builds on the historical pattern of an FDI source, but assumes convergence over long periods of time towards a generic pattern. The same is true for recipients and stocks of inflows. Next to this stylised behaviour, the overall pattern of increase or decrease in FDI flows is assumed relative to the size of the global economy.

In each time cycle, the model computes stocks of both inflows and outflows. As a first step, the expected stocks of inflows are a fraction of GDP, where the ratio gradually converges from the initial condition, for each region, to the expected pattern of global ratios as a function of GDP. Exactly the same logic applies to expected stocks of outflows. In a second step, actual stocks are computed by using a rate of growth. The user can further intervene in the stock specification with a stock-growth multiplier. The rate of FDI stock growth converges from an initial rate, tied to empirical inflows, to an exogenous rate. Again the logic is the same for outward flows and stocks.

Finally, the model makes it possible to specify a rate of global growth in FDI (including potentially sharp retrenchments in FDI) and imposes the resulting global FDI levels on the above formulations. Thereby, the above formulation is used to determine the regional stocks and flows within this global constraint. The user control over this will come in the form of a multiplier on global FDI. Once global FDI is determined, it is used to normalise the regional calculations of stocks. The changes in the ultimate values of stocks, of course, then provide gross inflows and outflows.

International financial accounting and equilibration
International equilibration is build around the current account balance and the capital account balance, which by definition are equal with opposite signs. The current account equals the trade balance of relative-price adjusted exports minus imports, plus the net outflow of foreign aid. Furthermore, the current account includes rents, interest, profits, and dividends paid on past capital inflows (FDI, foreign bonds and foreign government debt). The capital account equals the net inflow of underlying capital flows (the change in capital stocks), both in the long-term and the short-term. The long-term flows include foreign direct investments and foreign bonds, while the short-term flows include government debts. Although the current and capital accounts must balance, the balance often relies in the very short term on residual changes in capital stocks. In the longer term, exchange-rate and interest-rate fluctuations help maintain the balance by affecting the dynamics of the more slowly adjusting trade and longer-term financial flows.

The model determines the current account balance from the elements, as indicated above and described in the previous sections. This capital account purposefully excludes the two equilibrating elements of changes in reserves and short-term government compensatory borrowing. The model is not assumed to anticipate a government's relative choice between changes in reserves and changes in short-term government borrowing in order to achieve real balance between the current and capital accounts. Instead, it arbitrarily uses government debt as the buffering mechanism, set as the short-term borrowing. Exchange rates are a function of external debt to maintain relative balance with a target of zero over time. The exchange rates are used in the trade module.

8.2 Income Poverty

Average income or consumption over a specific period can be used as a proxy for economic welfare of individuals (or households). People can be considered to be living in poverty if they have an income under a certain level, comprising the so-called headcount poverty index. This level can be relative to, for example, a 50 percent line of the average income of a country, or it can be taken absolutely. Since 1990, the World Bank uses the threshold value of $1 per person per day, adjusted for purchasing parity power (PPP), as a level of so-called extreme poverty (Ravallion *et al.*, 1991). In addition, a level of $2 PPP is used as a second level of poverty.

To determine the headcount poverty index, however, average income is not enough; a notion of how this income is distributed among the population is the second requirement. There are several ways of measuring income inequality. Some simple measures include the decile ratio or the proportions of total income earned by a certain percentage of population. The Gini coefficient is one of the most commonly used indicators of income inequality. It is calculated from the Lorenz curve (Figure 45), in which cumulative income is plotted against the cumulative number

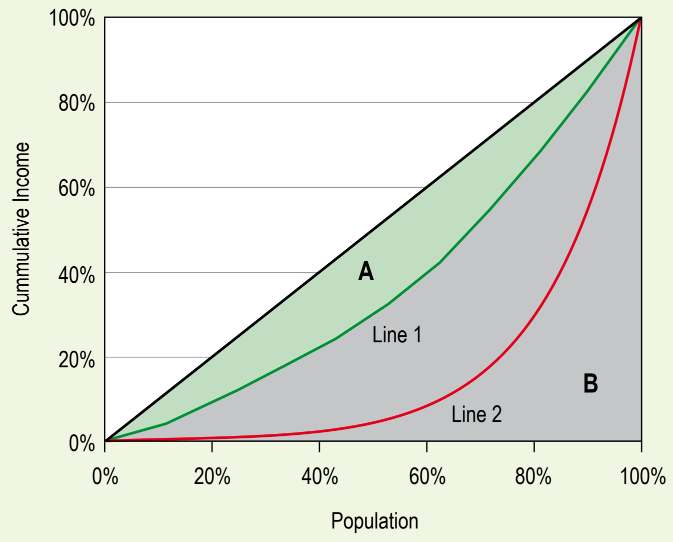

Figure 45 Lorenz curve and its relation to the Gini coefficient.

of persons or families, in the order from poorest to richest. The ratio of the area between a country's Lorenz curve (A) and the entire triangular area under the 45 degree line (A+B) is the Gini coefficient. The more equal a country's income distribution, the closer the Lorenz curve to the 45 degree line and the lower its Gini coefficient. If income were distributed with perfect equality, the Lorenz curve would be equal to the 45 degree line and the Gini would be zero (area A is zero). If income were distributed with perfect inequality, the Lorenz curve would coincide with the horizontal axis, with a steep increase at the right end of the horizontal axis to the level of 1 at the income axis, and the Gini would be one.

To forecast income poverty, the model uses functions of income (or expenditure) and distribution. These formulations are based on a cross-sectional and a log-normal analysis. The log-normal formulation is a standard approximation of empirical distributions in the applied literature (Bourguignon, 2003) and is, among others, applied in the Polestar model (Heaps *et al.*, 1998; Kemp-Benedict *et al.*, 2002). Based on the log-normal assumption, the functional form of the income (or expenditure) distribution is defined as:

$$f(y) = \frac{P}{\sqrt{2\pi}\sigma\, y} \exp\left[-\frac{1}{2\sigma^2} \left(\ln\left(\frac{y}{\bar{y}}\right) + \frac{\sigma^2}{2}\right)^2 \right],$$

where P is the total population, y is the poverty line (1\$ or 2\$ PPP per day), $\bar{y}$ is the mean income and σ is a measure of the inequality of the income distribution. This σ can be defined as a function of the Gini coefficient:

$$Gini = \frac{1}{\sqrt{\pi}} \int_0^{\sigma} dy \exp\left(\frac{y^2}{4}\right) = 2N\left(\frac{\sigma}{\sqrt{2}}\right) - 1$$

in which N(x) is the cumulative normal distribution, as described by:

$$N(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} dy \exp(\frac{-y^2}{2})$$

However, there is a basis on which to question the pure form of the log-normal curve as average income improves (even when aggregate measures like the Gini coefficient change very little). Pockets of poverty are a well-known phenomenon and often persist in remote rural areas, among disadvantaged ethnic groups, and in other sub-populations, in spite of the economic advancement of the average population. This phenomenon is chronic poverty, rather than the transient poverty that results from job loss or other changes in life status. Thus, there may be a tendency for the left-hand tail of the log-normal distribution to display some inertia with economic transformation, leaving some additional number of people at or below the poverty line. A cross-sectional formulation might be responsive to them (Hughes and Irfan, 2007).

However, it matters greatly, whether the bulk of the population below the extreme poverty line is just below, or significantly below that level. In case of the latter, the poverty is clearly more severe. Therefore, poverty head counts can be supplemented by an indicator such as the poverty gap. The poverty gap is the mean shortfall from the poverty line (counting the non-poor as having zero shortfall), expressed as a percentage of the poverty line, which includes the depth of poverty, as well as its incidence.

8.3 Discussion

The model has a system-dynamics character, which also holds for most of the PBL models which are already, or to be, incorporated in the GISMO project. This makes it easy to integrate IFs Economy with the other models into one framework. Especially the institutional economy (government expenditures in human capital and welfare transfers and international AID flows) provides handles for policy options and interventions. Furthermore, the use of multipliers (for policy interventions and scenario construction) makes user interaction easy, although this kind of interaction is very stylish and does not always represent direct, real-life policy.

In IFs Economy, consumer and producer behaviour are modelled mostly independent from each other, and the model lacks major price behaviour and overall welfare maximisation. Furthermore, many parameters and thereby model dynamics are linked to a regional welfare level, measured in terms of per-capita GDP in Purchasing Power Parity (PPP). This results in a high level of convergence of production processes (technology) and consumption behaviour, all over the world. Furthermore, the MFP includes a wide range of drivers, which makes it look very inclusive, although less transparent. The institutional and infrastructural drivers of the MFP are welfare level dependent relations, thereby creating resonance in the model without adding a lot of extra information.

Proxies of prices are used in the model, which drive sectoral investment demand, the interest rate and international trading. However, prices do not influence production patterns (intersectoral flows) and consumption choices. Furthermore, as the convergence path of the Input-Output matrix is exogenously determined, it is not possible to change firm technology due to policies; total production, though, can change. The international trading module includes price mechanisms, although it is mainly driven by overall production and consumption. Here, the lack of price behaviour, and, thereby, specific trading taxes, makes it difficult to impose policies that target price change (e.g., taxes on carbon or trade policies). A better representation of price mechanisms should therefore improve the model significantly, and expands its usability towards trade analysis.

Still, the IFs Economy model provides a nice framework for addressing long-term economic developments. Possibly, combined with exogenous economic scenarios, the earlier mentioned institutional economy provides a good base for policy analysis. Furthermore, the MFP functionality, encompassing technological change and economic development, combined with the poverty module, is of great value for addressing economic poverty.

9 Exploring future Quality of Life

This chapter presents future developments of Quality of Life using the GISMO1.0 model, consisting of the IFs Economy module, the PHOENIX population & health model and the education module. Inputs for these future developments are taken from the scenario study of the OECD Environmental Outlook (OECD, 2008) and the second Sustainability Outlook (MNP, 2007). The additional value of this GISMO1.0 projection to the OECD study is the impact of the socio-economic and environmental developments on the Quality of Life, here quantified in terms of: 1) the Human Development Index; 2) Disability-Adjusted Life Years; and 3) the Millennium Development Goals.

9.1 Scenario context and assumptions

To run a scenario with GISMO1.0, the models require various inputs. Part of these inputs is provided by other models, such as IMAGE (e.g., food intake, temperature and precipitation) and TIMER (energy consumption and emissions). These models have been used to run the baseline scenario of the OECD environmental outlook, based on a projected path of economic growth. This path of economic growth is reproduced by GISMO1.0, while other input variables were taken directly from the baseline scenario. To better understand the outcomes of the Quality of Life projections, a more detailed description of this baseline scenario is given in the next section. In addition to the inputs provided by OECD environmental outlook, assumptions for the GISMO modules have to be made, which are of importance to the Quality of Life. Among others, these assumptions relate to migration, smoking behaviour and governmental expenditures. These will also be made explicit in the following sections.

9.1.1 OECD Baseline scenario

The scenario, used to address future developments in Quality of Life, is based on the assumptions and outcomes of the baseline scenario of the OECD Environmental Outlook (OECD, 2008). This baseline scenario uses the medium population projection of the United Nations (UN, 2004), with a population of 8.2 billion people in 2030, and 9.1 billion in 2050. The long-term determinants of economic growth are the labour force, labour productivity and trade, which time-paths reflect convergence and the notion of 'no new policies'. Labour supply is determined by population size and the labour participation rate. The labour participation rate in OECD countries remains fairly constant at 60%, while non-OECD countries will all converge towards this level. Annual growth in labour productivity across the world is assumed to converge gradually to a long-term rate of 1.75%. The global average growth in GDP is approximately 3% per year between 2005 and 2030.

Agricultural production is projected to increase by more than 50% up to 2030 in order to feed the larger and much wealthier population. This requires a substantial increase in productivity, but also an increase of approximately 10% in agricultural area. Per-capita consumption levels converge towards the developed world levels in 2050, which is around 3500 kcal/cap/day, while all regions are already above 3000 kcal/cap/day in 2030. These per-capita consumption levels are used as input in the malnutrition and mortality calculations in GISMO1.0.

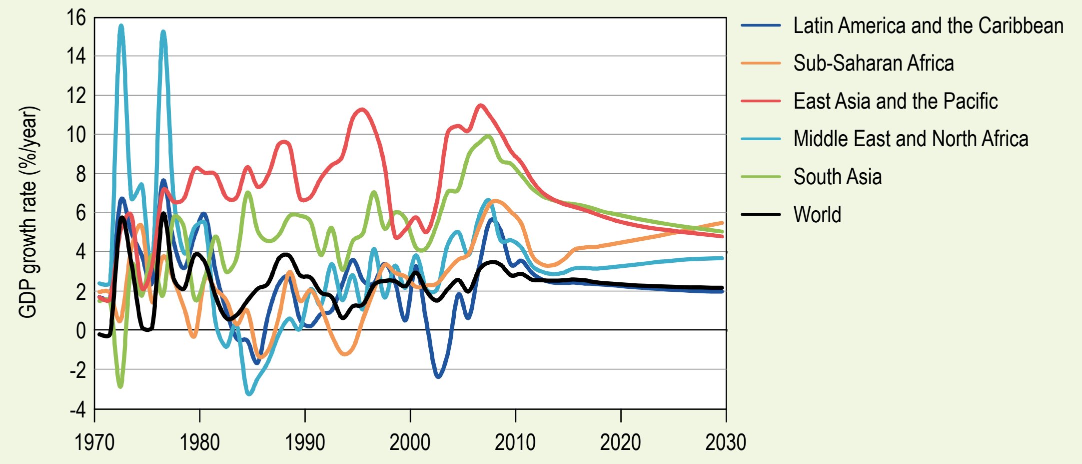

Figure 46 Economic growth for aggregated regions and the world average, 1970-2030.

The energy consumption more or less follows the 2004 World Energy Outlook (IEA, 2004), adjusted for economic growth and higher energy price trajectories adopted from IEA (2006). Together with the agricultural emissions, this leads to a global temperature increase of 1.3 ºC above pre-industrial level in 2030 and 1.9 ºC in 2050. With higher temperatures, the hydrological cycle is intensified as more water evaporates, on the whole, resulting in more precipitation. However, both temperature and precipitation effects are unevenly distributed; some areas might become dryer, while adjacent areas receive more precipitation. Changing weather patterns have, among others, large effects on agricultural yields and malaria suitability. The impacts of climate change on agricultural yields, and thereby on regional food production, are already included in the per-capita consumption levels. Temperature and precipitation patterns are used as input in the malaria model of GISMO1.0 to determine malaria suitability and related health outcomes.

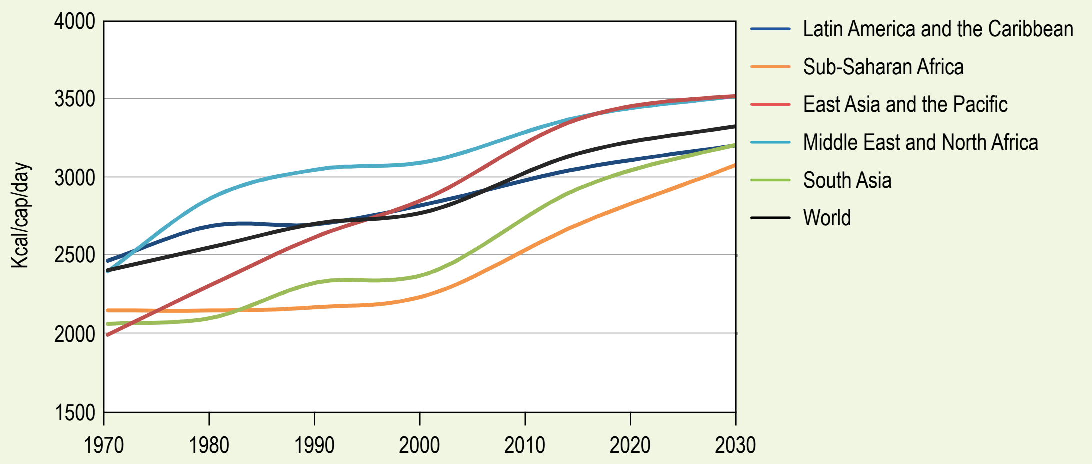

Figure 47 Food consumption in kilocalories per person, per day, 1970-2030.

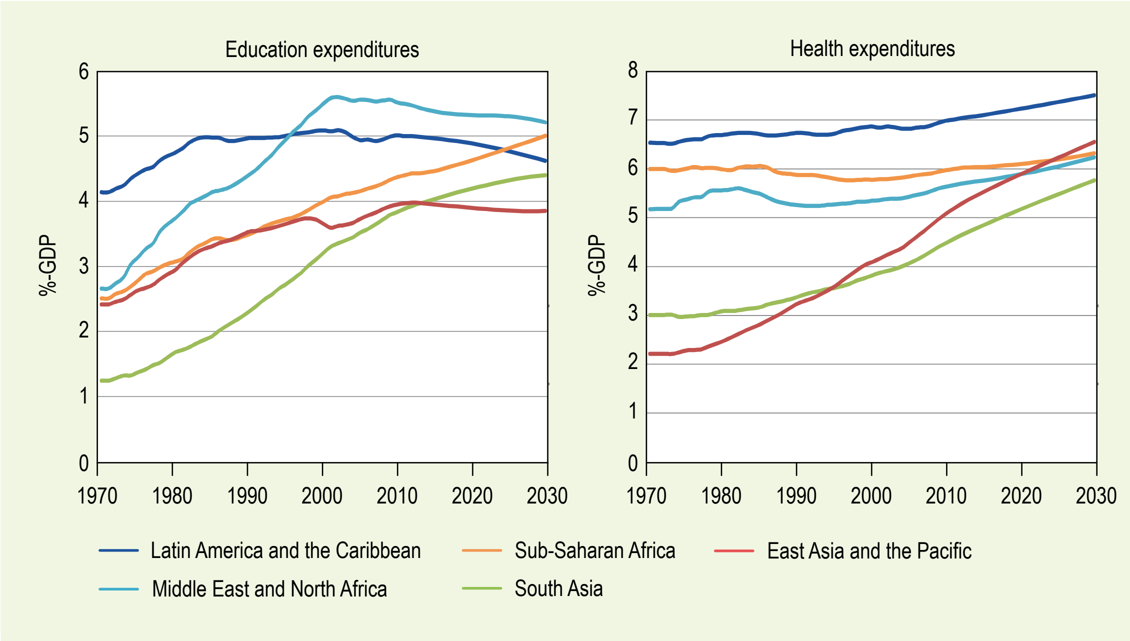

Figure 48 Government expenditures in education and health services, as percentage of GDP.

9.1.2 GISMO1.0 model assumptions

The economic developments are reproduced by the IFs-economy model using the technology as the calibration factor. Therefore, regional GDP is the same as in the OECD Environmental Outlook. The IFs Economy model determines regional poverty, using a log-normal income distribution, parameterised by per-capita income and income distribution (GINI-coefficient). The latter is kept constant during the whole simulation period. The IFs Economy model also determines government expenditures for education and health services. Education expenditures are based on the enrolment ratios and expenditures per student, both dependent on per-capita income levels. Regional health expenditures increase with increasing per-capita income, as described in section 6.4.4.

The population and health projections are provided by PHOENIX, as a result of simultaneously occurring environmental and economic changes. The health dimension was not fully represented in the OECD scenario study and population trends were exogenously chosen. Therefore, including these aspects in an endogenous, integrated way, causes differences in the numbers, compared to the OECD projection. However, due to the inertia in population dynamics, the differences in 2030 are rather small. In the longer term, our population projection turns out somewhat lower compared to the UN medium projection. The global averaged fertility level is projected to be somewhat lower than that of the UN, reaching replacement level in 2030, while the UN assumes this level to be reached in the period between 2035 and 2040. Our mortality levels are also projected to be slightly higher, while migration is directly taken from the UN and is, therefore, the same. The factors behind these mortality patterns will be elaborated on in the flowing sections. The resulting population then amounts to 8.0 billion people in 2030, and peaks at 8.9 billion people in 2060.

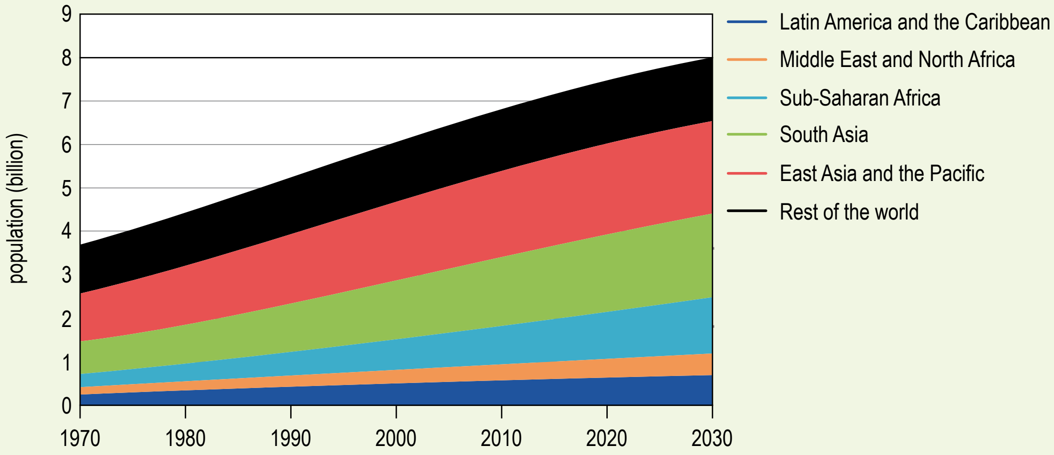

Figure 49 GISMO1.0 Global population projection for aggregated regions, 1970-2030.

9.2 Quality of Life: results from GISMO1.0

The GISMO1.0 model provides results for all 27 regions, as described in section 4.4. For the purpose of presentation, an aggregation of 6 clusters is shown, focusing on developing countries. These aggregates closely follow the clusters that the World Bank uses in their publications. Table 4 in Appendix A presents the link of the six aggregates with the GISMO regions. The time horizon for the projections is 2030.

9.2.1 Human Development Index (HDI)

The Human Development Index (HDI) has been chosen as the main representation of Quality of Life (see chapter 3.2). According to our scenario, substantial progress in development levels will be achieved in the coming decades, in all regions (Figure 50). However, Sub-Saharan Africa and, to a lesser extent, South Asia, remain behind compared to the average global improvements. Remarkable is the enormous increase in HDI value in East Asia. In 1970, their HDI value

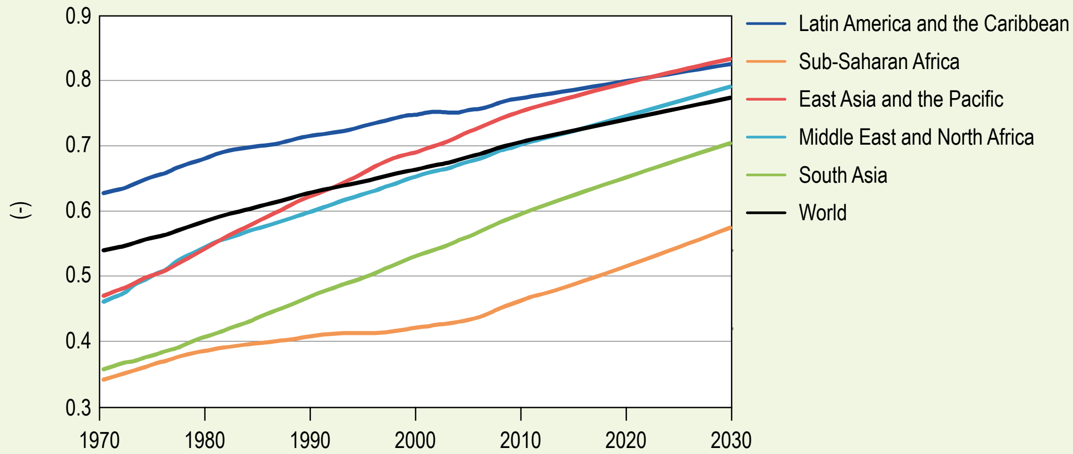

Figure 50 Human Development Index for aggregated regions, 1970-2030.

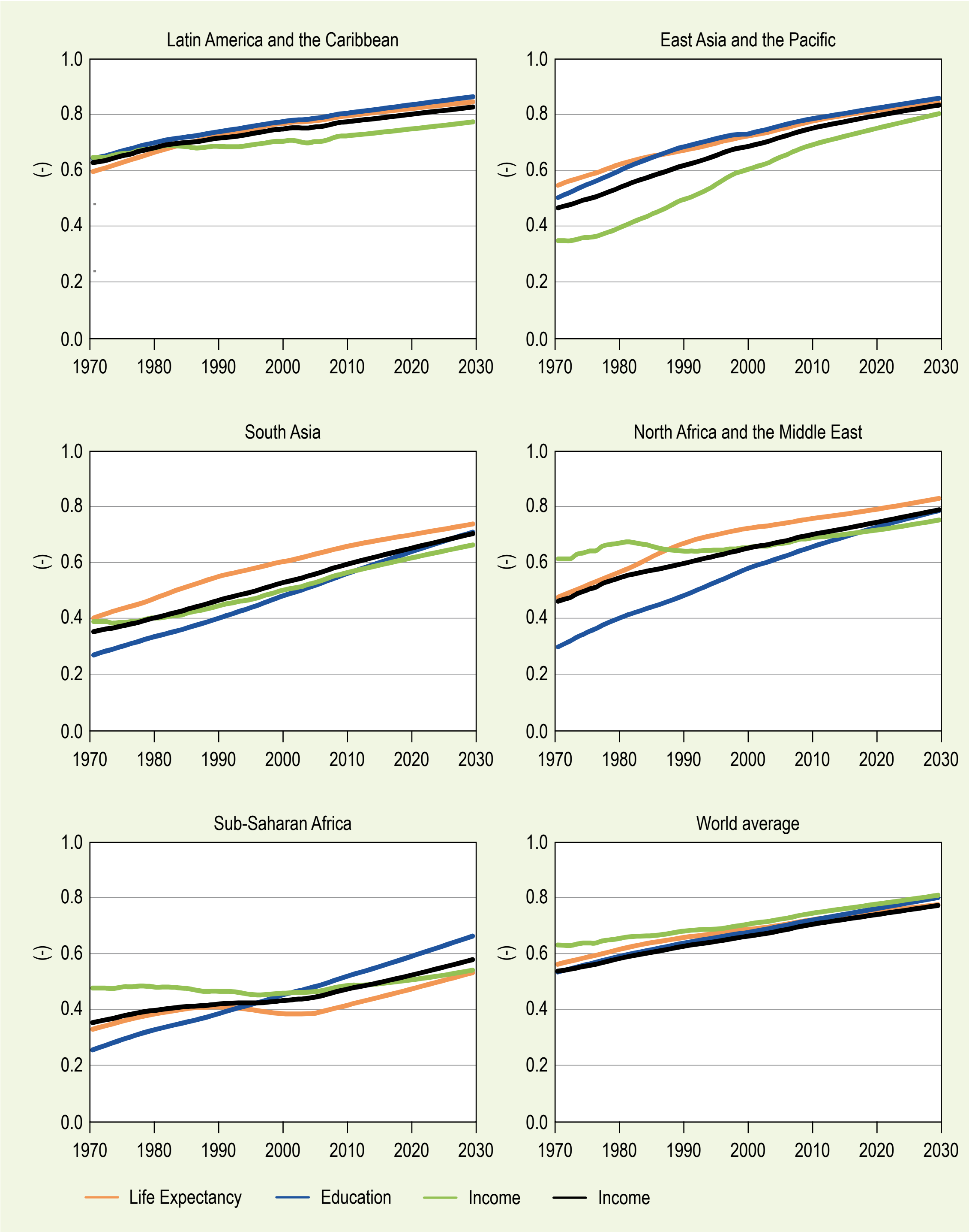

Figure 51 The three elements of the Human Development Index for the five aggregated regions and the world, 1970-2030.

was far below the world average, while in the coming decades the positive gap with the world average will be widened. To better understand these developments, a closer look will be taken at the underlying components of the HDI.

The three elements of the HDI are shown in Figure 51. Despite the fact that income is counted for in a logarithmic way, the more than sevenfold increase between 2000 and 2030, in East Asia, is responsible for most of the increase in their HDI. For Sub-Saharan Africa and South Asia and,

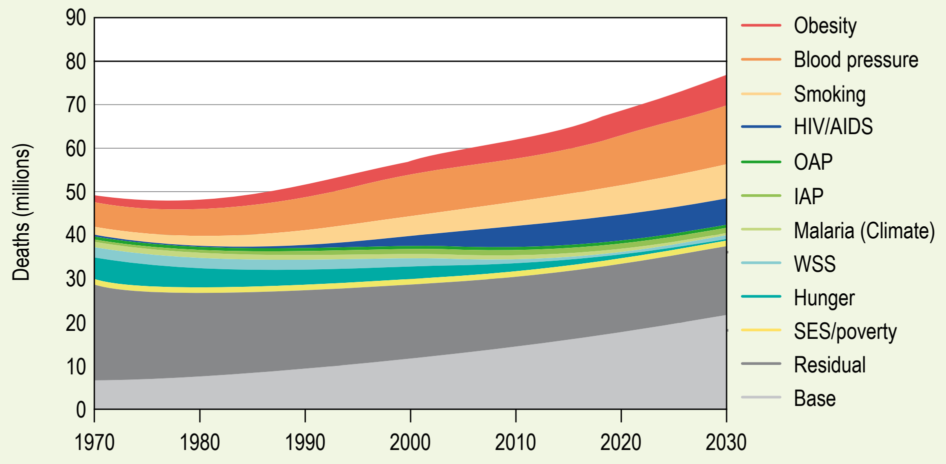

Figure 52 Global death related to 10 risk factors, 1970-2030.
SES=socio-economic status, WSS=water supply and sanitation, IAP =indoor air pollution, OAP =outdoor air pollution, malaria=only climate-related malaria (reduced by the hunger-related malaria deaths).

to a lesser extent, also for the Middle East and North Africa, a large share of the increase in HDI can be attributed to the increase in education levels. Their literacy rates increase, from approximately 30% in 1970, towards 60% to 70% in 2030. In most regions, the increase in life expectancy is moderate, and its contribution to the HDI is therefore limited, especially since some levels are already relatively high. Sub-Saharan Africa shows a decrease in life expectancy in the last 15 years, mainly due to the devastating effect of HIV/AIDS. However, for the coming decades the first signs of recovery can be observed, pushing their HDI upwards. Finally, although in 1970 Latin America and the Caribbean were far above the world average, this region shows the least progress in their HDI, due to a much lower economic growth, which also translates in lower growth in life expectancy and literacy rates.

9.2.2 Health outcomes

The health dimension of the Human Development Index (HDI) can be further analysed by taking a closer look at some specific health outcomes, such as the number of deaths and Disability-Adjusted Life Years (DALYs). Figure 52 presents the global deaths associated with 10 underlying risk factors (similar to Figure 15). These 10 risk factors are complemented by the residual mortality, representing causes of death not specifically modelled, and base mortality, representing the level of mortality if no premature deaths occur. Although the life expectancy will increase in the coming decades, because of lower mortality levels, the number of deaths will increase by almost 50%. The increase of the total number of death is mainly caused by population growth (especially in developing countries with higher traditional risk factors) and by the ageing of the population resulting in more chronic, life-style related causes of death. The mortality caused by these life-style related factors, increases with age. The prevalence of smoking is assumed to converge gradually, in all countries, to 35% and 25% for men and women, respectively. Obesity depends on the average food intake, and its impact will increase substantially given the projected increase in food consumption. The consequences of an ageing population are also shown by the increase in deaths, due to the base mortality component, which also increases with age. Furthermore, since the early eighties, mortality related to HIV/AIDS has increased signi-

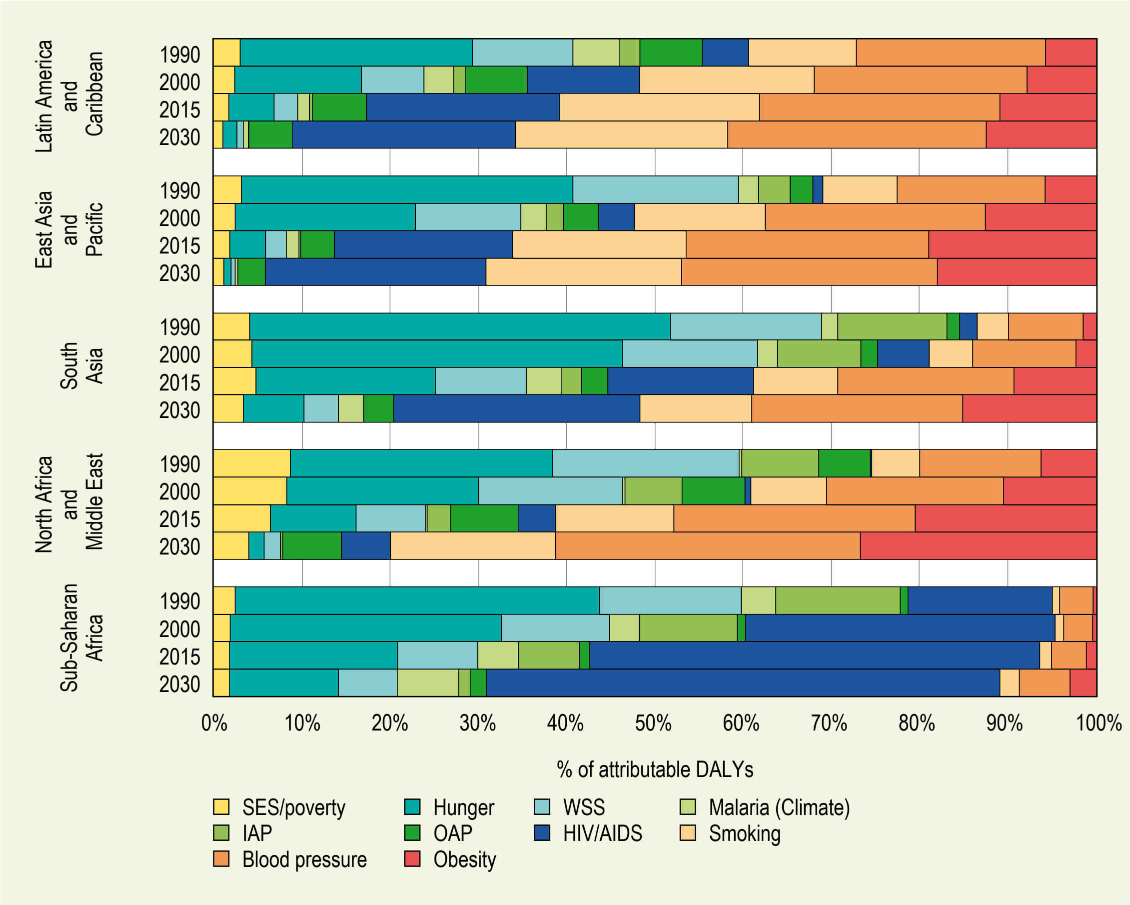

Figure 53 Relative DALYs attributable to 10 risk factors for aggregated regions, 1990, 2000, 2015 and 2030.

ficantly, and will reach a level of 15% of total attributable global deaths in 2030. Finally, the residual mortality is assumed to decrease by 2% per year, which is the average annual improvement over the period 1950-2000.

Figure 53 presents relative DALYs, attributable to 10 risk factors for the 6 regional clusters. Although the traditional risk factors gradually decrease over time, by 2030 they will still have a considerable impact on the loss of health in Sub-Saharan Africa and South Asia. In 1990, in some regions these traditional health risks accounted for around 80% of all health loss. The improvements in especially water supply and sanitation and hunger related health loss have been huge. This progress can also be observed in Sub-Saharan Africa, where the contribution of traditional health risks is reduced from 80% in 1990, to 30% by 2030; still a substantial part of health loss. However, these improvements are completely overruled by the devastating effects of HIV/AIDS. Also in other regions, such as East Asia and Latin America, HIV/AIDS demands its toll. Similar to Figure 50, the shift towards the more chronic, lifestyle-related health loss can be observed. However, this effect is less prominent in the DALYs, since these deaths usually occur at a later stage in life. The chronic, lifestyle-related years of life which are lost are fewer than those years lost because of traditional, environmental health risks, as the latter are stronger related to child mortality.

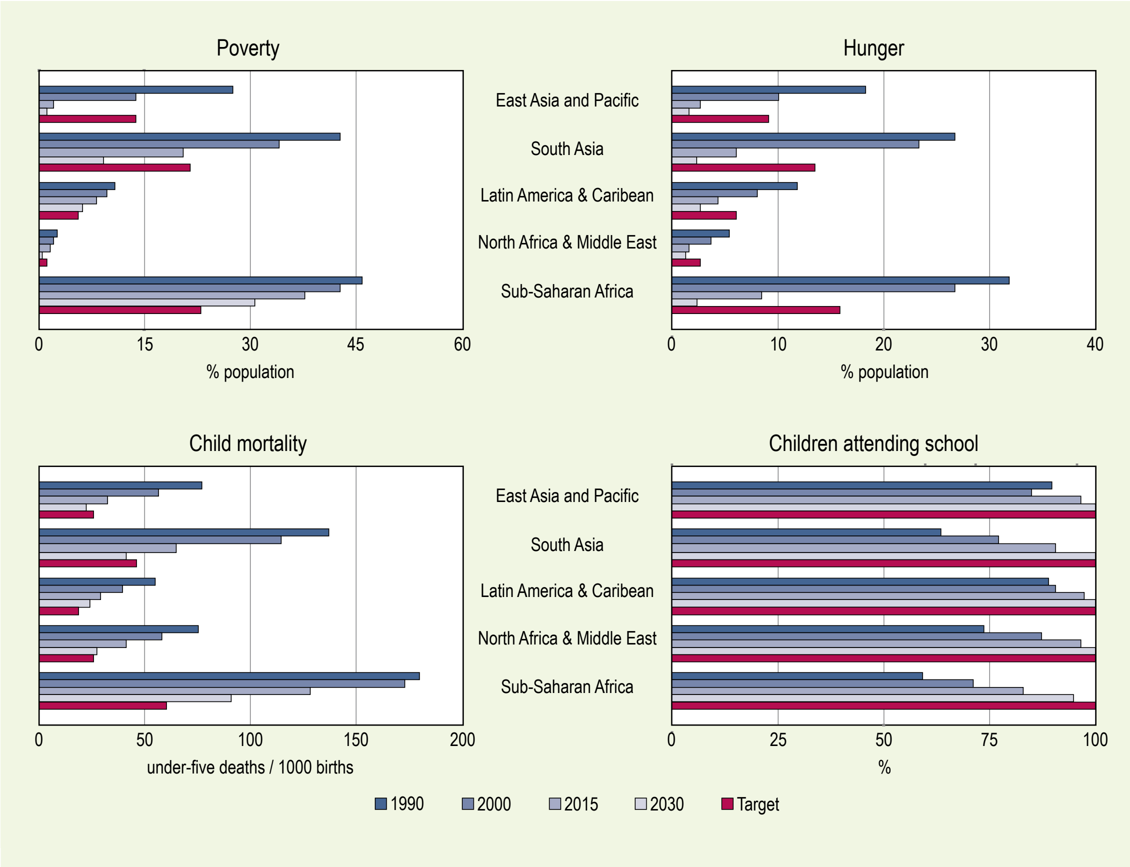

Figure 54 Four indicators of the Millennium Development Goals for aggregated regions, 1990, 2000, 2015 and 2030.

9.2.3 Millennium Development Goals (MDG)

One of the most relevant policy initiatives concerning the global development agenda is, without any doubt, the worldwide agreement on the Millennium Development Goals (MDGs). The MDGs cover the three dimensions of the HDI with a broader set of indicators tailored for development, expanding education and health coverage, but also including environmental issues. The GISMO1.0 model covers approximately two-thirds of the indicators, which are used to track the progress for the first seven Goals. MDG 8 (Develop a global partnership for development) includes several facets, which together, must bring the eradication of extreme poverty closer within reach. Among others, these facets include Official Development Assistance (ODA), enhanced debt relief for heavily indebted poor countries, access to world markets and access to affordable essential drugs and technologies. These facets are not yet included in the modelling framework and, therefore, neither in this analysis. However, they must form the basis of future policy analysis with respect to poverty reduction.

To explore future trends, a selection of four key MDG indicators is used to describe Quality of Life. These indicators include: 1) proportion of population below $1 (PPP) per day (MDG 1); 2) proportion of population below minimum level of dietary energy consumption (MDG 1); 3) under-five mortality rate (MDG 4); and 4) net enrolment ratio in primary education (MDG 2). The MDG agenda takes the year 2015 as the year by which most targets are to be achieved. As our scope is to address long-term sustainable development processes, this time horizon is extended towards 2030 in our projections.

Figure 54 presents the above described indicators for the years 1990, 2000, 2015 and 2030, as well as the MDG targets, indicated in red. The figure concludes that the poverty target could be achieved in most regions, except in Latin America and Sub-Saharan Africa. The latter will still be far behind by 2030. The hunger target is projected to be fully within reach, even for Sub-Saharan Africa. In contrast, the health target is projected to be far out of reach. The 2015 health target could be reached by 2030, in the Asian regions only, while Sub-Saharan Africa will still be far behind. Finally, the education target will be difficult to reach. The 2015 target could be reached by 2030 in most regions, while Sub-Saharan Africa will come close.

In short, East Asia and, to a lesser extent Latin America, seem to have found the pathway to development, showing the fastest improvements concerning most targets. Without additional policy, most other regions still lag behind, although they show progress for all targets. Especially Sub-Saharan Africa shows the least progress, with most targets still out of reach, by 2030.

9.3 Discussion of results

The results presented in the previous chapters are subject to uncertainties. Because the model has not yet been subjected to the full model evaluation procedure, as described in section 4.3.2, prudence is called for when using these results. However, a comparison with existing projections can put these results more into perspective and generate input for such an evaluation procedure. In this section, a comparison is done for a selection of indicators, covering poverty, life expectancy and hunger. Table 4 gives an overview of our model results, compared with projections from the World Bank, FAO and the UN, for 1990 (the MDG reference year), 2015 (the MDG target year) and 2030 (long-term projection).

The poverty projections seem to be in line with the World Bank projections (2007a). However, the overall economic growth – as reproduced from the OECD environmental outlook – is slightly higher for Sub-Saharan Africa and Asia, and slightly lower for Latin America, the Middle East and North Africa. Other differences may result from keeping the income distribution constant over time, which makes poverty reduction only dependent on average economic growth. In contrast, the World Bank projections make use of changes in real wages (by sector and skill), educational attainment and food prices, and thereby including possible changes in distribution over time. Inequality is currently rather low in Sub-Saharan Africa and Asia compared to Latin America, and on the increase in China (Chen and Ravaillon, 2007). Such an increase could also be the case for other fast-growing regions, which may result in less poverty reduction than currently projected. On the contrary, labour moving away from traditional agriculture towards industry and the service sector might increase the wages, and thereby lower overall poverty.

The hunger projections in GISMO1.0 are much lower compared to the FAO projections (2006). Both hunger projections are based on per-capita consumption levels, using standard FAO methodology as described in section 6.4.3. These per-capita consumption levels show an increase in all developing regions for both projections. However, the consumption levels from the IMAGE model, show a much faster increase in all regions, converging to developed-world levels by 2050. The FAO projections remain far below the developed-world levels, for all the developing regions. Although both projections show a large change in the long-term trend of food consumption, the projection we use is more pronounced and, thereby, influences the health outcomes. The per-capita consumption levels and their consequences should therefore be interpreted with caution.

Table 3 Comparison of the model results for poverty (World Bank, 2007a), hunger (FAO, 2006) and life expectancy (UN, 2004).

Poverty (%)	**1990**	**2015**		**2030**	
	World Bank	World Bank	GISMO1.0	World Bank	GISMO1.0
East Asia and the Pacific	29.6	2.8	1.7	0.8	0.8
South Asia	41.3	16.2	20.3	8.1	9.3
Latin America and Caribbean	11.3	6.1	8.0	4.1	5.9
Middle East and North Africa	2.3	0.7	1.3	0.2	0.4
Sub-Saharan Africa	44.6	37.4	37.6	29.9	30.5
Hunger (%)	**1990**	**2015**		**2030**	
	FAO	FAO	GISMO1.0	FAO	GISMO1.0
East Asia and the Pacific	16.5	5.8	2.5	3.9	1.6
South Asia	25.9	12.1	5.9	8.4	2.4
Latin America and Caribbean	13.4	6.6	4.4	3.9	2.7
Middle East and North Africa	7.6	7.0	1.6	5.7	1.1
Sub-Saharan Africa	35.7	21.1	8.3	12.4	2.4
Life Expectancy (years)	**1990**	**2015**		**2030**	
	UN	UN	GISMO1.0	UN	GISMO1.0
East Asia and the Pacific	66.3	72.9	72.8	75.4	75.4
South Asia	58.1	67.2	65.9	71.6	69.4
Latin America and Caribbean	67.8	74.6	73.6	77.2	75.8
Middle East and North Africa	64.8	72.9	71.5	75.9	74.9
Sub-Saharan Africa	49.7	50.4	51.7	57.0	57.1

The comparison of life expectancy with the UN (2004) shows, that our projection is lower for most regions, both by 2015 and 2030. Only for Sub-Saharan Africa it is slightly higher. It is difficult to have a proper understanding of these differences. First of all, a wide range of causes of death is responsible for the actual mortality levels, which all have their own future unfolding, such as with food and hunger. Secondly, the UN only gives overall mortality levels and does not specify more detailed causes of death. The UN projects mortality on the basis of so-called models of change of life expectancy, produced by the United Nations Population Division. This already highlights one of the major advantages of the approach in PHOENIX for modelling mortality, as this methodology enables tracing of the underlying diseases and risk factors, which all can have different future pathways for different regions. One has to keep in mind, that the assumptions concerning residual and base mortality are crucial for the overall life expectancy and have to be taken into account in the model evaluation procedure.

9.4 Conclusions

Projecting Quality of Life, using HDI, DALY and the MDGs, gives insights into the underlying determinants of development. Addressing poverty, health issues and knowledge accumulation, linked to a demographic model, gives insights into the inertia of the system, its boundaries and the possibility of linking development to environmental issues and impacts on the three domains of sustainability. Furthermore, it provides a framework for policy analyses and their effect on Quality of Life, the third objective of the GISMO project.

The projections presented in this chapter are mostly in line with projections from well-known sources, such as the World Bank and the UN. Only the hunger projections are far-off compared to the calculations of the FAO. An advantage of our methodology is the integration of all domains in one framework, including trade-offs and co-benefits within and between these domains. Where the previous mentioned studies show partial analysis – or do not include underlying determinants, as is the case with life expectancy in the UN-projections – integrating these results better addresses the claim of the MDG agenda, that improvements should take place simultaneously, for all facets (among others poverty, hunger, health, literacy). Investments in one facet (hopefully followed by improvements) can reinforce improvements in others, while failures can work the other way around.

10 Concluding discussion

The ambition level of the GISMO project is high. This report has defined its purposes to capture the broad and complex facets of sustainable development, by operationalising Quality of Life and linking it to simulation models. This helps us to understand the links between the different sustainability domains and to evaluate the contributions of different policy options and interventions to improvement of the Quality of Life and its synergies and trade offs with the environment. Traditionally, environmental modelling has been at the core of PBL's research, while the adopting of Quality of Life as the main outcome of sustainability required a broadening of PBL's modelling infrastructure. This has resulted in GISMO1.0, with the current report as its main documentation.

10.1 Main conclusions

In the GISMO project, a modelling framework has been developed, which covers various dimensions of Quality of Life, including health, education and poverty dynamics, and facilitates easy linkage to existing models, covering the different sustainability domains. Hereby, the first two objectives of the project are met. The following conclusions can be drawn:

- Although the PHOENIX population and health model already covered the human/social domain, the expansion of environment related health risk, the inclusion of an education model and the integration with an economic model, all give substantial additional value.
- The use of a widely accepted and easily quantifiable index to describe Quality of Life, such as the HDI, enables the linkage with our simulation models. The results show that using the HDI, and the possibility of looking in more detail at particular dimensions of the HDI, provide a sound entry point to capture and analyse development.
- The health model has been improved and refined. Additional health risks have been added and their effects modelled in an epidemiologically sound way. A major step forwards is the inclusion of health loss due to diseases, in addition to mortality. This allows describing morbidity levels, which are an essential component of population health measures, such as the Disability-Adjusted Life Years (DALYs).
- The IFs Economy model has a system dynamics approach and could therefore easily be integrated with our other models. The explicit distinction of the government expenditures in education and health services gives handles for policy options and interventions. Furthermore, the model addresses changing international flows and poverty analysis.
- Education, as one of the three dimensions of the Human Development Index, has been modelled in a simple but effective way. It describes the most important aspects of the schooling process, linked to demographic developments and governmental expenditures.
- The role of the environment on development is addressed through its health effects, such as malaria, hunger, water supply and sanitation and indoor air pollution. However, these links are still in their infancies, while the way in which environmental aspects play a role concerning economic developments is not covered in the current version.
- Natural resources, such as energy, fertile land and forest stocks, can add to economic growth. However, the effect of approaching – or even surpassing – physical limits on the economy and Quality of Life are still subjected to research. Furthermore, the links of climate change and biodiversity loss with Quality of Life are recognised as a potential impact and are to be taken into account in future developments.

10.2 A modelling agenda for the future

A model is always a simplification of reality. It should be as simple as possible but not simpler. However, it is difficult to determine when a model is simple (or complex) enough to reflect reality. It is mostly a matter of learning by doing. We have therefore identified several facets which are not yet adequately represented in GISMO1.0 and are good candidates for model improvements:

1. Improving the link of Quality of Life with the environmental domain through *ecosystem goods & services*
2. Capturing *urbanisation dynamics*, addressing the causes, the process itself and the consequences of urbanisation;
3. Incorporation of *Computable General Equilibrium (CGE) economy modelling,* to be able to better address price behaviour and trade;
4. Identify and improve the possibilities of *technological change* in our models;
5. Address the fourth sustainability domain: *Governance and Institutions*;
6. Applying the *Archetypes of vulnerability* approach, to address vulnerability of people and to have a better understanding of the heterogeneity within the world regions;
7. Setting up a *model evaluation* process, to address methodological aspects involved in the concept of integrated modelling and modular design;
8. Developing a *user support system,* to allow the exploration of simulation results in a transparent and flexible way.

10.2.1 Ecosystem goods & services

To make a better link between the Quality of Life and environmental changes, the concept of ecosystem goods and services should be further operationalised. These ecosystem goods and services should focus primarily on agriculture, relating to hunger but also to poverty, and energy dynamics, which relates to indoor and urban air pollution, as well as to poverty. This relates also to the underlying dynamics of price mechanisms, with respect to consumption and distribution, which should be understood better. Furthermore, physical limits, relating to climate change, biodiversity loss, soil erosion and water scarcity, should be addressed, as well as their links to food production and distribution.

For this purpose, the link with the IMAGE model and their work together with the Agricultural Economic Institute (LEI) should be intensified, to fully address the above described impacts on food prices, and to better address food consumption. Furthermore, the link with the TIMER model should be further intensified. This includes the upcoming work on household energy use, in relation to indoor air pollution, but also including the link of particulate-matter emissions from households, industry and agricultural activities with urban air pollution.

10.2.2 Urbanisation dynamics

To improve the way in which urbanisation is modelled, there is the need for a better understanding of the underlying dynamics. The focus will be on quantifying the main drivers at various levels, including both demographic and the geographic aspects. This includes the analyses of various (geo-) datasets relevant socio-economic and environmental indicators for urban and rural populations and areas. The first step in capturing urbanisation dynamics is to include an urban-rural dimension for the underlying determinants of fertility, health and migration. This requires an additional demographic component, namely the rural-urban migration flow. A second step is to translate the regional trends to a grid-level, by using various downscaling methods, ranging from simple to more advanced (see also Van Vuuren *et al.*, 2005). Addressing the spatial effects of urbanisation enables to analyse the effects of urbanisation on the Quality of Life, both positive (efficiency, services, innovation) and negative (slums, urban sprawl, pollution).

10.2.3 CGE economy modelling

At the moment, the GISMO project follows a two-track approach with respect to economy modelling. For now, the IFs Economy model (see Chapter 8) is used, which will be further equipped to address current and near-future questions. For the long term, another line of research has been initiated, in which the usability of Computable General Equilibrium (CGE) modelling will be addressed. CGE models are based on a well-funded microeconomic framework that describes the entire economy. CGE models are especially used to address bilateral trade. They allow predicting the changes in prices, output and welfare resulting from a change of policy, as well as changes in consumer behaviour, trading patterns and technology (Hertel, 1997). Within this line of research, the state-of-the-art in CGE modelling for sustainable development and poverty analysis will be assessed. In a second phase, a CGE model could be integrated into the GISMO project, as a supplement or as a replacement for parts of the IFs Economy model.

The main advantages of CGE models are:
- they describe the whole economy in a consistent manner;
- all economic agents are taken into account and their behaviour is well described by microeconomic (neo-classical) theory;
- they allow for a variety of economic policy analyses (including, e.g., taxation, economic development, allocation of goods, trade, welfare);
- agents are able to adapt (change in behaviour), due to endogenous price change;
- due to the interlinkages they show secondary policy impacts.

For the GISMO project, the *Dynamic Applied Regional Trade* (DART) model will be used as a starting point (Klepper *et al.*, 2003). DART is a multi-region, multi-sector, recursive-dynamic CGE model of the world economy. In principle, DART could be coupled to the population model PHOENIX, the energy model TIMER and the land and climate model IMAGE. The link with PHOENIX addresses the quality (human capital) and size of the labour force linked to government expenditures in health and education. The link with the TIMER model could improve the energy dynamics and addresses the secondary effects of changes in the energy sector on the rest of the economy. The link with the IMAGE model allows assessing the regional demand for agricultural commodities, based on (changes in) land availability and quality. A link between a CGE model and IMAGE is already established with the LEI model (Van Meijl *et al.*, 2006; Eickhout *et al.*, 2007).

10.2.4 Technological change

Technology is often considered a key driver for economic development and improvements in human health. Moreover, technological developments contribute to reducing a range of harmful environmental impacts. This makes the conceptual understanding of technology in the GISMO project of crucial importance for the assessment of sustainable developments and the quality of life. It requires, on the one hand a thorough understanding of driving forces behind technological development, and on the other hand insight into the effects on environmental impact reduction, human health issues, and changes in the structure and efficiency of economic production.

Such a broad conceptual assessment also implies a broad definition of what technology actually is. Rather than strictly defining technology or technological change, we can assess technology in the model by means of the approaches already taken in the current GISMO model. One distinction is that between a bottom-up approach and a top-down approach, which relates to the level of aggregation of the model. A bottom-up approach can be used to describe distinct technologies and their effects; a top-down approach takes a more aggregate approach and describes technological development through its effect, such as improved efficiency in production. The scale and scope of the GISMO model reaches for a top-down approach, in combination with a relatively aggregate level of technology incorporation, possibly at a sectoral level. A highly aggregate level has the distinct disadvantage of not showing technology as such, but a highly aggregate level may loose itself in detail, with high levels of uncertainty for scenario studies, which extent far into the future and on a large scale. A moderate meso-aggregation level could focus on technologies or technology clusters in distinct sectors, thus showing more detail than total factor productivity or efficiency improvement, without getting lost in technical details.

Another distinction for assessing technological change in modelling is between exogenous and endogenous drivers. Basically, this distinguishes whether technological development is incorporated in the model dynamics or inserted as an exogenous variable. Endogenous technological development allows for a better description of dynamics, but at the cost of increased complexity and by inserting various assumptions in the model. In either case, a thorough insight into the driving forces for technological change is required.

In GISMO1.0, the IFs module incorporates a set of drivers for multi-factor productivity (MFP), classified in four categories (see section 8.1.1). The TIMER model on energy includes several endogenous effects, most notably on autonomous and price-induced efficiency improvements, learning-by-doing, spillover and technology transfer, depletion and substitution effects (Van Vuuren et al., 2004). For a thorough assessment of interlinkages between economy, population, energy, agriculture and technology, it is essential to fully include the TIMER and the IMAGE model in the GISMO framework. However, the endogenous character of technological development in the GISMO model may pose some challenges for the interaction with other modules.

Furthermore, it is of interest to address the following conceptual issues: learning-by-doing, pullovers, path dependency and heterogeneity. Learning-by-doing reflects the empirically based idea of progress, that is, technology efficiency and effectiveness improves, as it is increasingly deployed. Spillover effects show that technology cannot easily be attributed to one country or company and show some effects of public goods. Spillover is usually modelled in terms of diffusion processes. Path dependency shows that history matters for technological development, relating developments of the past to the present, which generally leads to a technological lock-in. This emphasises that path discontinuities, or the introduction of entirely new technological systems, are exceptional and often very difficult to accomplish. Heterogeneity in firm behaviour, innovation strategies and national policies will often show diversity in technological developments for various countries or sectors. It has been argued that neglecting heterogeneity leads to a conservative representation of technological change (Bruckner et al., 2005), but it is not easy to incorporate these evolutionary processes in a highly aggregated model.

10.2.5 Governance and Institutions

To understand the effectiveness of institutions in steering society and the international system at large towards sustainability, a number of approaches have been developed within International

Relations and global environmental governance research, that potentially can be integrated into the ongoing attempts to model political developments and interventions. While these current attempts are an essential step in the direction of a further integration of institutional research into the larger community of earth system sciences, there are a number of unresolved problems that need to be overcome. In particular, the reflexivity of social sciences, the complex nature of human-environment interactions and the huge variation in social organisation, represent challenges for an integrative agenda. The key challenge is to formalise the aforementioned, usually qualitative, institutional factors, as a complementary approach to GISMO. The research will address the following questions:

- How can effectiveness of international environmental and other related regimes be measured?
- Which types of institutional design are likely to increase the effectiveness of international regimes?
- How can these criteria of effectiveness and institutional design be incorporated into computer-based modelling?

The research project will involve a two-step methodology, which is based on the idea of institutional diagnostics. In the first step, the key features of the issue and the issue-area will be identified as clearly and sharply as possible. The second step will deal with defining the nature of the institutional arrangements, needed to mitigate the problem in question or to find ways to adapt to its impacts. However, we will not aim at modelling institutions by developing stand-alone agent-based models, but rather at improving the model-based ex ante evaluations, by better incorporating the institutional dimensions into the scenarios.

10.2.6 Archetypes of vulnerability

The archetype-approach was developed and applied within UNEP's Global Environmental Outlook (GEO-IV, UNEP, 2007), to analyse and highlight the vulnerability of people and the environment to multiple stressors resulting from environmental and socio-economic changes. The approach is based on the observation that recurring patterns of vulnerability can be found in numerous different places around the world, hence the name "archetypes (AT) of vulnerability". This approach was inspired by the "syndrome approach", which looks at non-sustainable patterns of interaction between people and the environment, and unveils the dynamics behind them (WBGU, 1995; Schellnhuber *et al.*, 1997; Petschel-Held *et al.*, 1999; Lüdeke *et al.*, 2004). An archetype of vulnerability is defined as "a specific, representative pattern of the interactions between environmental change and human well-being" and its analysis reflects the different components of vulnerability analysis (see for example Turner *et al.*, 2003). An archetype does not describe one specific situation, but rather focuses on the most important common properties of a multitude of cases which are, in that sense, "archetypical". Archetypes are simplifications of real cases, to show the basic processes whereby vulnerability is produced within a context of multiple stressors. The addition to the syndrome approach was that the archetype approach more explicitly addresses the impacts for people and also includes opportunities offered by the environment, to reduce vulnerability and improve human well-being (Wonink *et al.*, 2005). Analysing archetypes of vulnerability, thereby addressing the vulnerability of human-environment systems to multiple stresses, enables to identify challenges and opportunities within and beyond the environmental policy domain. Furthermore, it provides a better understanding of the heterogeneity within the world regions.

The archetype approach proved to be a useful concept for a qualitative identification and evaluation of policy options for the reduction of vulnerability. Already during the GEO IV process, it turned out to be feasible to expand this approach further by including more quantitative tools for policy development and evaluation (see dryland cluster analysis in GEO-IV; p. 323). The applied approach is the usage of a data-based indication of the occurrence and characteristics of the ATs. By basing this on dynamic quantitative model outputs, the occurrence and characteristics of the ATs could be analysed dynamic in time to evaluate more systematically the options which potentially reduce the vulnerability.

As a follow-up, a methodology was developed for a quantitative analysis of ATs, using the linked GISMO-IMAGE modelling framework. The methodology includes a cluster analysis for the selected indicators, to identify typical indicator-combinations, that is, archetypes. Extending the cluster analysis into the future, by using scenarios from the linked GISMO-IMAGE modelling framework, can be used to analyse how the clusters and hot-spots transform over time. Furthermore, the modelling framework could be used to address specific policy interventions that can reduce vulnerability. The analysis of future scenarios and the evaluation of specific policy interventions are not yet performed and also require some further methodological work. In a next phase of the project, the methodology will be extended and used to fully analyse the following four archetypes: addressing dryland agriculture, first-generation biofuels, rapid coastal urbanisation and overexploitation of natural resources.

10.2.7 Model evaluation

The various models within the GISMO1.0 model have already been evaluated or calibrated in a stand-alone modus. However, this is not sufficient for an adequate evaluation of the integrated model, which should also be evaluated as a whole. Therefore, special attention is required for:
- Recalibration of the models if their original (stand-alone) parameter-settings are no longer representative for the integrated model (see Appendix B.4).
- Evaluation of the integrated model, including comparison of model results with observations and benchmark models, sensitivity and uncertainty analysis for the key parameters in the integrated model, and simulations of extreme situations (see Appendix B.5).
- Evaluation of the couplings between the models (see section 4.3.2).

10.2.8 User support system

The complexity of a modelling framework such as GISMO can constitute a major obstacle in communicating the model results. A crucial factor in this communication is the openness or transparency of the simulation model, which prevents the model from being regarded as a black box. For this reason, two facets will be emphasised: visualisation and the use of indicators. Visualisation techniques are essential for presentation and communication of model structures and model results, and also for interactive use of the computer simulation model. For the GISMO framework the modelling and visualisation tool MyM (Tizio, 2008) has been used to facilitate flexible visualisation and interactive model use. Apart from complexity, the enormous amount of model output can cause the loss of overview of the most relevant developments within the model. This problem can be countered by using indicators or indicator frameworks. Both aspects will be included in a user support system for the GISMO framework. This will be done by building on existing user support systems (e.g., IMAGE, PHOENIX, EUruralis). An indicator framework, such as the MDGs, may also be used as a guiding principle to design the graphical user interface. Such a design provides a clear classification of model results, which can be presented to the users in an attractive thematic way.

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Appendix A: Regional Breakdowns

Table 4 Regional clusters used for reporting.

Aggregated regions	GISMO1.0 regions
Latin America and the Caribbean	Mexico
	Central America and the Caribbean
	Brazil
	Rest of South America
Middle East and North Africa	Middle East
	North Africa
Sub-Saharan Africa	Western Africa
	Central Africa
	Eastern Africa
	Republic of South Africa
	Rest of South Africa
East Asia and the Pacific	China
	Indonesia
	Rest of South-east Asia
South Asia	India
	Rest of South Asia

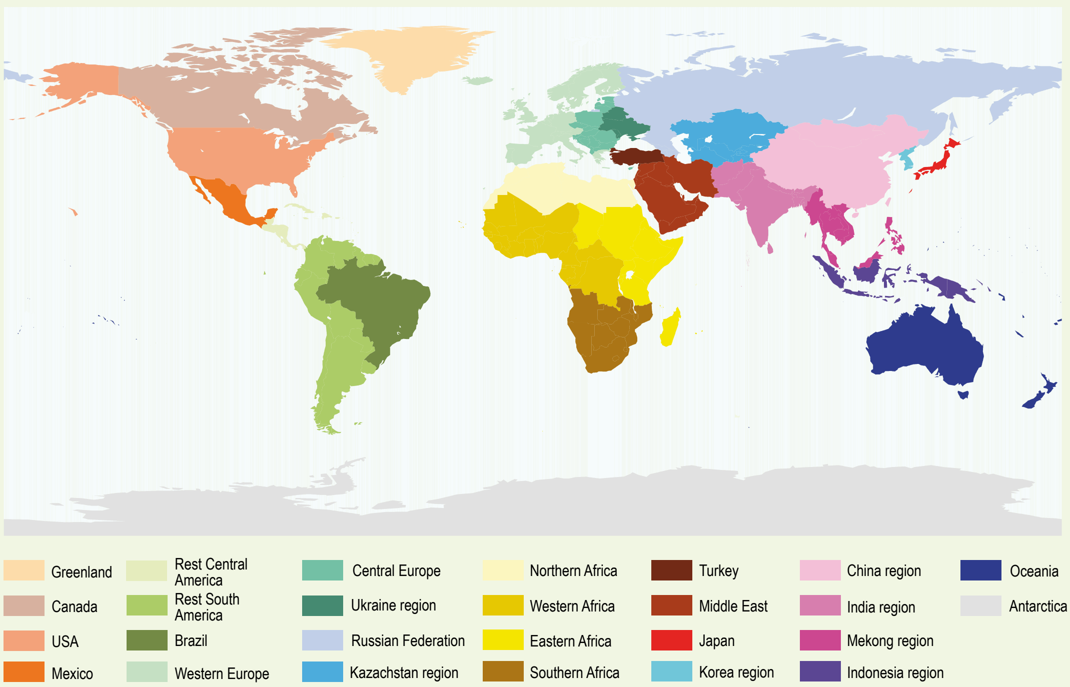

Figure 55 IMAGE regional breakdown in 26 regions (including Greenland and Antarctica)

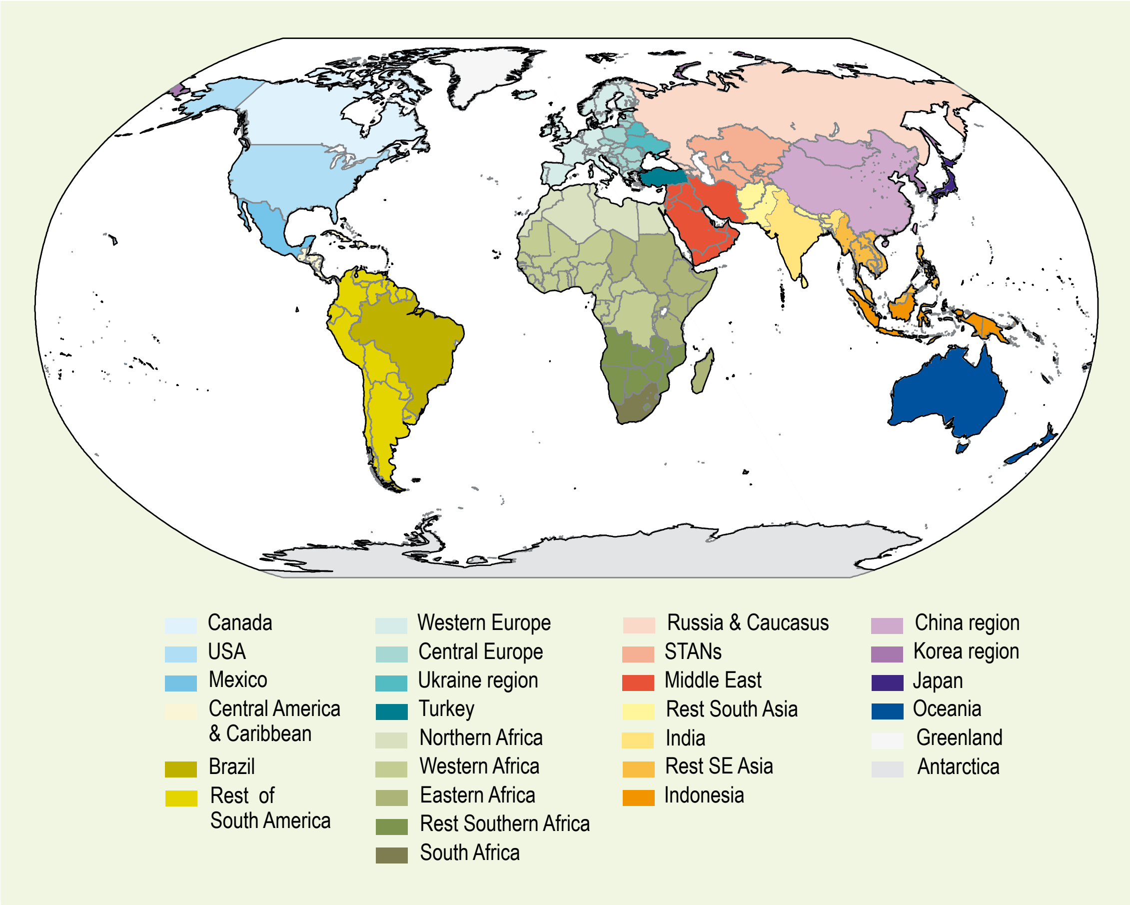

Figure 56 TIMER regional breakdown (including Greenland and Antarctica).

Appendix B: The various stages of model evaluation

In section 4.3 the various stages of model evaluation have been positioned in the context of the modelling cycle. As a supplement, Figure 57 gives a brief outline of the different evaluation issues which play a role in these stages. In this appendix, we will discuss the specific content of these stages in more detail, thus offering guidance for performing a model evaluation.

1. Model evaluation at the problem identification stage

This deals with the central question of which role the model has to play for the problem at hand. The problem-framing sets the context, and if there is a need for (computational) modelling, there will be a number of general questions which have to be addressed at the problem identification stage (NRC, 2007, page 113-114):

- What is the goal of the model?
- Which types of assessments and decisions will it support?
- Who will use it?
- Which data are available to support the model's development, application and evaluation?

Answering these questions is important for choosing the direction for further model development, and for setting the goals for the quality and quantity of information needed to build and apply the model.

2. Evaluation of the conceptual model

The modelling cycle starts, typically, with the development of a conceptual model, which concerns a qualitative working description of the characteristics and dynamics of the system under study. A conceptual model is often presented in a graphical or pictorial form, with a qualitative verbal description of the components, their characteristics and interrelations. In fact, it expresses the model builder's perception of the key processes and features for the problem at hand. Pertinent evaluation questions at this stage are:

- Is the model expected to be appropriate for the intended use?
- Are important processes or aspects missing, is the complexity of the model appropriate for the problem at hand, is the spatial and temporal scale and the level of aggregation adequate, are the chosen indicators appropriate and meaningful for the present assessment? What are the major shortcomings of the model, and what consequences has this for using the model in the problem under study?
- What is the scientific underpinning of the model? What are the strong and weak points in the underlying knowledge-base? How have controversies, alternative theories, limitations in theory/knowledge been dealt with?
- What are the key assumptions underlying the model, and what is the basis for each key-assumption? What is their potential effect on the policy-relevant advices? What alternatives are available?
- Do the quality and quantity of data support the choice of the model and its further development and use?

Typically, these questions cannot be answered to the full at the conceptual modelling stage; they can only be addressed partially and qualitatively. Often, a peer review process plays an important role in evaluating the conceptual model. In later stages of the modelling cycle, the aforementioned questions will return and can be evaluated in a more extended and quantitative way (e.g., using comparison with data, benchmark models, sensitivity and uncertainty analysis etc.).

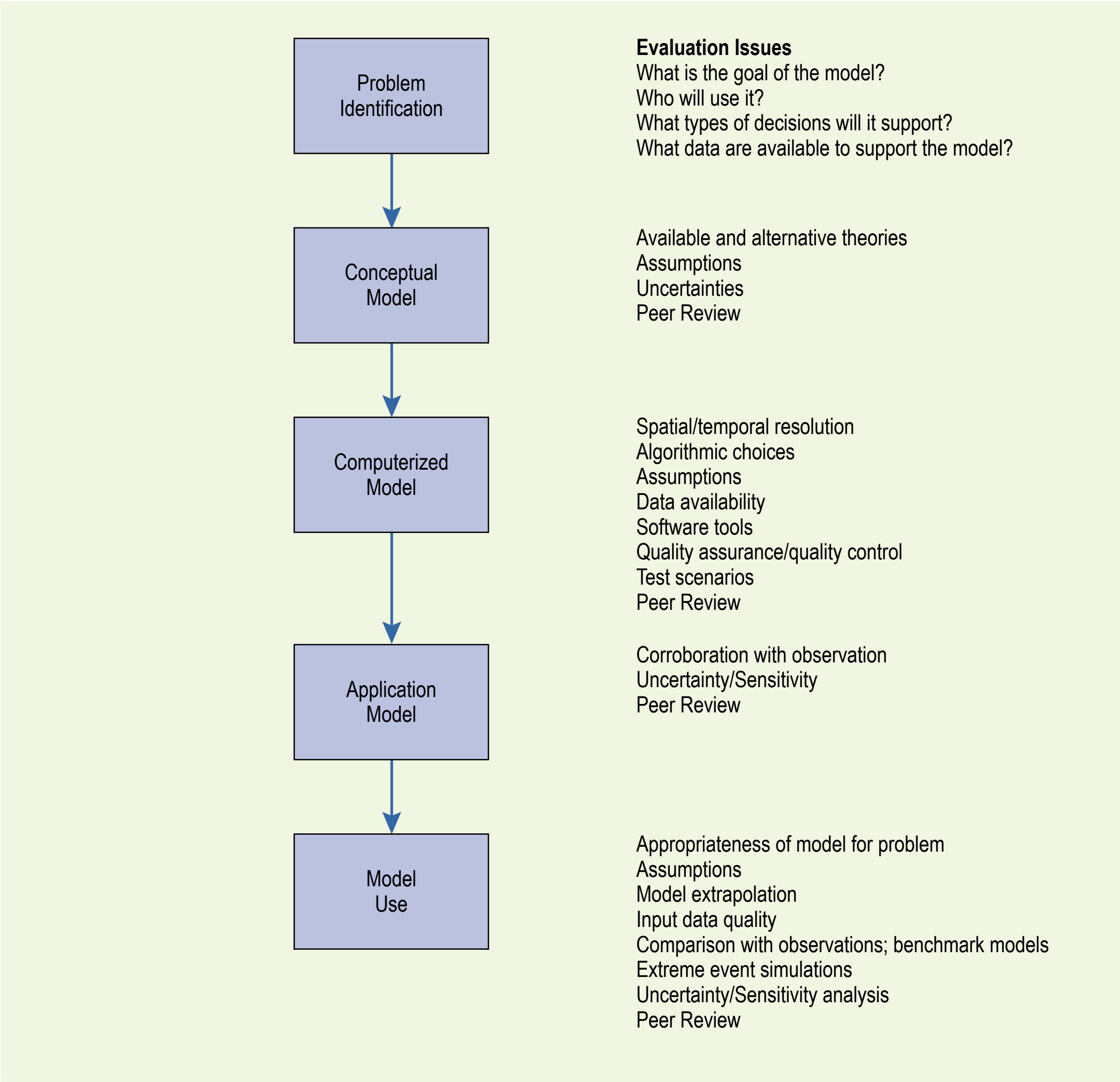

Figure 57 Stages of a model's life cycle, with associated evaluation issues (adapted from NRC, 2007)

3. Evaluation of the computerised model

The process of developing and implementing the conceptual model into a computerised model runs often through various intermediate stages, where the qualitative conceptual description first is formalised, resulting in a more formalised model, in terms of mathematical equations and decision rules. The subsequent translation of this formalised model into computer code, typically involves selecting computational methods (choice of numerical solvers, numerical optimisation routines), as well as a software implementation. The following evaluation questions reflect this process:

- How has the translation of the conceptual model into the formalised (mathematical) model been established?
- What assumptions and approximations are involved, and what is their scientific basis? What is the choice of temporal and spatial resolution? What mathematical forms are used for modeling the processes and their interactions (feedback, couplings)? How well-established and generally accepted are these choices? Are there feasible alternatives for these choices, and have they been considered?

- Are the approximation and round-off errors in the selected computational methods acceptable, in terms of the required accuracy for the application at hand? This is an issue of numerical precision, accuracy, stability, convergence, efficiency and robustness of the computational algorithms)? Are artificial effects and inconsistencies introduced by the computational methods (e.g., non-negative concentrations; no mass-conservation; numerical chaos), and how problematic can this be? Are their effects limited?
- How reliable is the software implementation? How has the syntactical correctness of the code been tested? Is the code portable to other soft- and hardware configurations, and does it render the same computational results? What kinds of QA/QC checks and procedures have been performed during the development, testing and maintenance of the code? Have these tests been documented? What audits took place or are planned?

The extent to which these issues will be addressed depends partly on the character of the model involved, for example for mechanistic models this will be more than for mpirical models, where some of these issues can be skipped, but come more into play in the next stages.

In fact, the evaluation at this stage re-addresses the questions posed in the beginning: the degree to which the model is based on generally accepted science and computational methods, whether the model fulfils its designed tasks and how well its behaviour approximates that observed in the system being modelled, and discusses them from the perspective of the coded model.

4. Evaluation of the parameterised model

Setting a model up in a more definite form for its intended application requires the setting of the parameters involved and collecting/selecting adequate input-data etc. In situations where model parameters refer to physically meaningful and directly measurable quantities, their settings can be directly inferred from observations. Also, values from literature can serve as a source for specifying parameter values. In other situations, parameter setting requires an explicit tuning or adjusting of model parameters within physically defensible ranges, until the resulting model outcomes give an adequate fit to observed data. This process is called calibration or parameter estimation, and involves decisions on which to adjust parameters, how to adjust them, and how to decide on the acceptability of the results, also including an assessment of the accuracy/uncertainty of the obtained parameter estimates. It is obvious that calibration should be performed with the intended application of the model in mind. In cases where the application context changes (i.e. other data, other settings) and where the old parameterisation is no longer expected to be adequate, re-calibration should be considered. The evaluation issues at this stage are:

- How has the model been parameterised? Has model calibration (for the application at hand) been performed and, if so, how has this been established? Has the calibration process been documented, and is this process and its results reproducible? Is information provided on the accuracy of the obtained parameter estimates?
- How and to what extent has the parameterised model been tested, and what were the conclusions of these tests? Which quantitative and qualitative methods have been used for testing how model results match observations, benchmark model results or stylised facts? What acceptance criteria have been used to judge the model as being properly parameterised?
- How representative are the data used for calibrating and testing the model for the situation in which the model will be applied?

5. Evaluation of the application model

The parameterised application model is subsequently used in the study of the problem at hand. Evaluation of its use comes down to addressing the following central questions:

- Has the application model the desired performance for the intended application, that is, are the relevant situations, processes and events adequately described by the model, with sufficient accuracy? This first requires a more explicit formulation of which performance is desired for the application at hand, including the required accuracy of the model. Next, quantitative and qualitative testing is needed to assess the extent to which the model and its data meet these conditions. This testing can consist of:

    - Explicit comparisons of model results with observations and with results of benchmark models. Central question is whether these data and benchmark models are representative for the application at hand.
    - Performing a model analysis (sensitivity and or uncertainty analysis), which renders information on model behaviour, important components and relationships, including accuracy of the model results.
    - Performing simulations of extreme situations/events and comparing these with knowledge on these results. Studying the effects of important feedback processes (e.g., stability analysis etc.).
    - Model reviews
- Have the objectives set for quality assurance been met when applying the model. For example, have adequate tests and checks on input-data, model runs, and model output been performed and documented?
- Has a peer review been performed of the application model and its results?

6. Evaluation of data

Related to the previous stages and activities in the evaluation process, is the ongoing process of checking the availability, suitability and quality of the data used for model building, calibration, application and also model evaluation. Aspects like the representativeness, actuality, appropriateness and accuracy of the data have to be dealt with. Moreover, issues like the preprocessing, the treatment of missing values, the use of up/downscaling procedures, and the effects of all this on the outcomes, have to be discussed and reported explicitly.

The extent to which the above mentioned evaluation activities will be realised, in practice depends on the specific performance requirements of the model, as well as on the present state of knowledge, the availability of time, expertise and data, and will therefore be very situation dependent. It is important to explicitly document the results of these various steps of evaluation, and to indicate what further testing or improvement of the model should be done. In appendix C, a proposal of a concise format is given for documenting the main results of an evaluation. A clear exposition of what has or has not been done (and why) is mandatory: model evaluation has to be a transparent, traceable, reproducible and well-considered activity.

Appendix C: A concise format for reporting the results of model evaluation

Inspired by Sargent (2003), below a format is presented which can be used for reporting the most important results of the model evaluation process.

Evaluation topics	Overall conclusions	Justification of conclusions	Confidence[a] in conclusions
Model evaluation of problem identification			
Evaluation of Conceptual model			
Evaluation of Computerised model			
Evaluation of Parameterised model			
Evaluation of Application model			
Evaluation of Data			

[a] This column contains meta-information which can be used to indicate how well the conclusions are motivated (e.g. vague hunch, reliable or hard information). Also it should be indicated for which issues the (expert) opinions diverge.

Strengths →	
Weaknesses →	
Important points of attention →	(in order of importance)

	Overall conclusions	Justification of conclusions	Confidence in conclusions
Summary of model evaluation →			

Towards a Global Integrated Sustainability Model

GISMO1.0 status report

Sustainable Development deals with the link between the environment and development issues. This link is very complex, including many interrelations between social, economic and environmental developments. The Global Integrated Sustainability MOdel(GISMO) addresses the trade-offs between these developments. The GISMO-project is part of the strategic research programme of the Netherlands Environmental Assessment Agency (PBL).

The project takes the distribution, continuation and improvement of Quality of Life as the main outcome of sustainable development, with health, poverty and education as its main pillars. It addresses Quality of Life in relation to the three sustainability domains. This report presents the GISMO1.0 model, as well as the rationale behind the project and the methodological aspects.

The GISMO1.0 model is especially applicable for addressing the inertia in the system, for example the demographic transition and education dynamics. Furthermore, it is very useful for analysing trade-offs between energy, agriculture and socio-economic developments. The model provides a promising framework for analysing the effects of specific policies on human development, and their interaction with the environment.

Netherlands Environmental Assessment Agency, November 2008