

Final report on calculations of a sustainable national income according to Hueting's methodology

Harmen Verbruggen (editor)

O-00/10

October 2000

IVM

Institute for Environmental Studies

Vrije Universiteit

De Boelelaan 1115

1081 HV Amsterdam

The Netherlands

Tel. ++31-20-4449 555

Fax. ++31-20-4449 553

E-mail: secr@ivm.vu.nl

Copyright © 2000, Institute for Environmental Studies

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without the prior written permission of the copyright holder.

Contents

Preface	v
1. Introduction	1
2. Accounting for the Environment: an overview and assessment of approaches	3
2.1 Introduction	3
2.2 National accounting and economic welfare	5
2.2.1 Theoretical contributions	6
2.2.2 MEW	7
2.2.3 ISEW	8
2.2.4 GARP	9
2.2.5 Conclusions	9
2.3 National accounting and sustainability	10
2.3.1 Theoretical contributions	10
2.3.2 Natural Resource Accounts	11
2.3.3 Genuine savings	13
2.3.4 SNI	14
2.4 Non-monetary satellite accounts	17
2.4.1 Introduction	17
2.4.2 Natural Resource Accounts	18
2.4.3 Indices	18
2.4.4 NAMEA	19
2.5 Conclusions	21
3. Environmental valuation and sustainable national income according to Hueting	27
3.1 Introduction	27
3.2 The concept of environmental function	28
3.3 Demand and supply method (DSM) for valuation of environmental functions	33
3.3.1 Valuation on the basis of revealed preferences and known elimination costs	35
3.3.2 Extension with assumed preferences for environmental functions	39
3.3.3 Generalisation in dynamic environmental economic theory	40
3.3.4 Practical model system	42
3.4 Ins and outs of a green and a sustainable national income calculation	43
3.4.1 Environmental functions not scarce	43
3.4.2 Relatively weak but perfectly expressed preferences for the environment	45
3.4.3 Strong but poorly expressed preferences for the environment	47
3.4.4 Strong and perfectly expressed preferences for the environment; absolute optimum	47
3.4.5 Strong and perfectly expressed preferences for the environment; feasible optimum	52
3.4.6 Strong and perfectly expressed preferences for sustainability; absolute optimum	53

3.4.7 Basic assumptions for practical calculation of SNI	56
3.5 Sustainability standards	56
3.6 Conclusions	62
4. Assessment of sustainability standards	71
4.1 Land use	71
4.2 Fossil fuel depletion	71
4.3 Enhanced greenhouse effect	73
4.4 Depletion of the ozone layer	77
4.5 Smog formation	80
4.6 Fine particles in air	82
4.7 Eutrophication	83
4.7.1 Air	83
4.7.2 Soil	84
4.7.3 Surface water	86
4.7.4 Total emissions and standards	86
4.8 Acidification	87
4.9 Toxic substances in surface water	88
4.10 Dehydration	90
4.11 Soil contamination	90
4.12 Summary of standards	91
5. An applied general equilibrium model to calculate a Sustainable National Income for the Netherlands	97
5.1 Introduction	97
5.1.1 Context and overview	97
5.1.2 Applied General Equilibrium Modelling	98
5.2 General set up of the SNI-AGE model	98
5.2.1 A static comparative analysis	98
5.2.2 Counting SNI	100
5.2.3 The environment and the modelling of pollution abatement	101
5.2.4 Additional operational choices	103
5.3 Detailed set up of the model, version 1.1	107
5.3.1 On agents and markets	107
5.3.2 Individual behaviour; the use of nested CES structures and indexes	109
5.3.3 Producers	111
5.3.4 International trade	115
5.3.5 Consumers	118
5.3.6 Market equilibrium	124
6. Calibration of an applied general equilibrium model for the Netherlands in 1990	133
6.1 Introduction	133
6.2 Data for the initial SAM	133
6.2.1 Introduction	133
6.2.2 Economic data	134
6.2.3 Environmental data	136
6.3 The impulse	139

6.4 Values of elasticities	140
6.5 Abatement cost curves for various environmental themes	140
6.5.1 Introduction	140
6.5.2 Methodology	141
6.5.3 The cost curves of the environmental themes	145
6.5.4 Possibilities for constructing abatement cost curves for 1995	157
6.5.5 Final remarks	158
References	159
Appendix 6.I Elasticity data	163
Appendix 6.II The incorporation of abatement data	165
7. Calculations of a sustainable national income: four variants	171
7.1 Introduction	171
7.2 Operational choices and additional assumptions	171
7.3 Abatement cost curves for various environmental themes	179
7.3.1 Introduction	179
7.3.2 Methodology	180
7.4 Results	181
7.4.1 Mechanisms	181
7.4.2 Macro-economic results	186
7.4.3 Sectoral results	189
7.4.4 Environmental results	191
7.5 Final remarks	193
References	194
Appendix 7.I Some additional exercises with the AGE-SNI model	197

Preface

Frank den Butter, Chairman of the Steering Committee

The aim of the present study is to investigate the possibilities to operationalise Hueting's methodology of calculating a Sustainable National Income (SNI), by applying it to the Netherlands. The study, which took two years, has been conducted by a research team from the Institute for Environmental Studies (IVM) at the Vrije Universiteit Amsterdam, and the calculations are based on sustainability standards that have been provided by Hueting's team. The research project has been commissioned jointly by the Ministry of Economic Affairs and the Ministry of Housing, Spatial Planning and the Environment. During the study, several aspects of the implementation of the methodology and the specification of the general equilibrium model which was used for the application of the methodology have been subject of lively discussions in a Steering Committee. This Committee consisted of experts in the field of environmental economics and environmental sciences and representatives of the commissioning ministries. Its broad composition guaranteed that many shades and differences of opinion on how to calculate a sustainable national income were represented and were heard during the discussions on how to proceed with the project.

Members of the Steering Commission were Professor F.A.G. den Butter, Vrije Universiteit, chairman, Mr. H.K. van Tuinen, Statistics Netherlands (CBS), Mr. C.J.J. Eijgenraam (halfway replaced by Dr. C.C. Koopmans), Netherlands Bureau for Economic Policy Analysis (CPB), Dr. W. Slooff (halfway replaced by Mr. K. Wieringa), Institute for Public Health and the Environment (RIVM), Professor E.C. van Ierland, Wageningen University, Professor L. Reijnders, University of Amsterdam and Professor J.W. Velthuis, Foundation for Economic Research (SEO). On behalf of the ministries which commissioned the project, Dr. Th. Roelandt and Dr. E.J. Bartelsman (halfway replaced by Mrs. T. Laske-Aldershof and Mr. R.E. van Hell) of the Ministry of Economic Affairs and Mr. C. Vijverberg of the Ministry of Housing, Spatial Planning and the Environment have also been members of the Steering Committee.

The Steering Committee had three main tasks in providing guidance to the project, namely:

1. To guard the scientific quality of the research and to monitor that the research generates new scientific knowledge and insights;
2. To see to it that the method of calculating the actual value of a SNI for the Netherlands was as much as possible in accordance with Hueting's methodology;
3. To co-ordinate the research efforts of the teams involved in the project, to see to it that the teams kept their time tables and to clarify the separate responsibilities of the teams.

Although at the start of the project the Steering Committee agreed on a procedure in case of disagreement, serious disagreements never occurred as most discussions in this Steer-

ing Committee on the practical implementation of Hueting's method finally always have resulted in some kind of workable consensus. This is not to say that the Steering Committee also shares a common view on the meaning and usefulness of Hueting's SNI for environmental policy. On that question, opinions still differ.

Obviously, the calculation method of this report contains a number of open ends and concessions, which have to be accounted for when interpreting the results. This comes as no surprise and it is quite natural when a theoretical methodology is put to practice. So, not all relevant environmental themes are adequately covered, and data sets can still be further improved. Pollution abatement is modelled rather uniformly across sectors. The interaction between environmental themes still poses problems. A drawback of the calculations is that not all feasible substitution possibilities could be taken into account. Finally, it became clear the SNI calculations are rather sensitive to the stringency of the sustainability standards.

An important aspect of the present calculation method is that the general equilibrium model only compares the level of national income in an equilibrium without sustainability standards with an equilibrium value of income in case strict sustainability standards with respect to various environmental themes would have pertained. There is no time dimension in the comparison of these two equilibrium values. The major question in this respect is in what manner environment saving technology would have been developed and implemented in a dynamic path towards the equilibrium under the sustainability standards. To what extent is the present difference between the SNI and the actual national income biased due to the neglect of dynamics in the modelling exercise? However, an answer to this question of dynamics would imply a long-lasting new project where a dynamic version of the general equilibrium model has to be built. Maybe such a research project would even be too ambitious and surpass the present state of the art of modelling.

Apart from these remarks the Steering Committee believes that the research teams have accomplished a major task and have been most successful in applying Hueting's methodology to the Netherlands. This research really contributed to the enhancement of academic knowledge on environmental economics.

1. Introduction

Harmen Verbruggen

‘It is easier said than done’, the saying goes. And this especially refers to the many attempts to improve or supplement the traditional national income figure to arrive at a more complete and less misleading indicator of social welfare. One of these attempts is extensively dealt with in this study, namely the correction of national income for environmental losses. To be more precise, the aim of this study is to investigate the feasibility of calculating a national income that takes the environment as a welfare generating economic good into account, according to the methodology so strongly advocated by Hueting. This methodology would result in a so-called Sustainable National Income (SNI). In other words, the aim of this study is to put Hueting’s methodology to the test.

After this introductory chapter, Chapter 2 provides an overview and assessment of the various approaches to assess changes in environmental quality and the depletion of natural resources in a national accounting framework. Herewith, Hueting’s methodology is placed in a wider perspective. Chapter 3 puts Hueting’s methodology and the lines of thought from which it is derived, into writing. Chapter 4 extensively deals with the setting of sustainability standards, which are so essential in estimating the corrections of the traditional national income figure, because these standards function as a reference for sustainability, and hence, the calculations of a SNI. The computable general equilibrium model for the Dutch economy, which is used to perform the alternative SNI calculations, is explained in Chapter 5. Attention is paid to the general characteristics of the model, its specific features that are required to facilitate SNI calculations, as well as the more technical model specifications.

Chapter 6 discusses the data requirements, presents the available data and provides a calibrated version of the model for 1990. This chapter also presents and briefly discusses the so-called abatement cost curves. These curves are essential in estimating the cost of correcting the traditional national income figure. Chapter 7 presents and tries to interpret the first outcomes of alternative SNI calculations. Four variants, based on different assumptions and model specifications are discussed. It is important to note that Chapter 7 is written as a self-containing chapter and is easily accessible for a non-technical reader.

Notwithstanding the great efforts made by the research teams of the Institute for Environmental Studies (IVM), Vrije Universiteit, and the Statistics Netherlands (CBS), to develop a well-founded calculation procedure and present credible results for a SNI, the numerical outcomes should be interpreted with care. As yet, there is no widely accepted standard procedure, the model calculations can still be improved and the data base is far from complete. But the first important hurdles are taken.

Finally, this report is made up of chapters that are written by different (groups of) authors. Each and every (group of) author(s) is only responsible for the chapter which

heads his or their name(s). Notwithstanding this separate author's responsibility, it has been attempted to achieve internal coherence and avoid mutual inconsistencies.

2. Accounting for the Environment: an overview and assessment of approaches

Onno Kuik

2.1 Introduction

The interest in the size and composition of national income or national dividend dates back a few centuries. The interest was to a large extent driven by a practical motivation: to assess the economic base for taxation. Sir William Petty (1623-1687), one of the pioneers in this field, expressed it as follows:

“..for not knowing the Wealth of the people, the Prince knows not what they can bear; and for not knowing the Trade, he can make no Judgement of the proper season when to demand his Exhibitions.” (quoted in Roll, 1973).

The ancient regime’ physician-economist François Quesnay made the famous comparison between the economic system and the human blood circulation in his “Tableau œconomique” which represented the circulation and annual reproduction of the “produit net”. It was not until the twentieth century, however, that accounting concepts and statistical techniques were developed to such an extent that consistent and accurate assessments could be made on a regular basis. Conceptual breakthroughs were made by Irving Fisher in the beginning of the century. Early “modern” assessments of national income include those of Bowley and Clark for the United Kingdom and those of Coats for Canada.¹ The incidence of the Great Depression and the writings of Keynes with their promise of active macroeconomic management, gave a new impetus to national accounting. Finally, the war made it essential for the UK government to have speedy and accurate assessments of the country’s economic resources. The Central Statistical Office was set up to produce central statistics of national income and product. In other countries this example was soon followed. In the Netherlands, national income statistics were calculated by the Central Bureau of Statistics (CBS). The United Nations played an important role in the harmonisation of national accounting systems.

Modern national accounting is based on the standard national accounting identity that equals total income (wages paid for services of labour, rent for the use of land, interest for the use of borrowed capital, and profit for capital invested) to total expenditures (household and government expenditures, investments, and net export spending). To the extent possible, all measurements are based on observable transactions in the market.² The national accounts and their main aggregates, such as gross domestic product (GDP),

¹ Irving Fisher, *Nature of Capital and Income*, 1906; Bowley, *The Division of the Product of Industry*, 1920; Clark, *The National Income 1924-1931*, 1932; R.H. Coats, *National Wealth and Income of Canada*, 1919.

² Notable exceptions are food and fuel produced and consumed by farm families and the rental value of owner-occupied dwellings.

gross national product (GNP) or national income (NI), record the level and nature of economic activity in a country in the accounting period.

Two lines of critique have developed concerning this accounting practice. The first line of critique argues that aggregates such as GDP (and especially growth of GDP and GDP per capita) are often used as measures of economic welfare and that such a use is incorrect, may provide the wrong signals to policy-makers and the public and may thus lead to “wrong” policies. One important fallacy of GDP as a welfare measure is that it fails to take account of external disutilities generated by economic activities, for example in the form of environmental pollution and natural resource degradation.

The second line of critique argues that the concept of (net) income as currently defined in the standard accounting identity is misconceived as it includes an element of natural capital consumption that is not accounted for. Reductions in the stocks of renewable and non-renewable natural resources in the accounting period can be regarded as capital consumption or depreciation of the capital stock. The net revenues of resource extraction are added to GDP but no allowance is made for their depreciation, i.e. for the fact that their current use diminishes their future productivity. Another way of putting this is that the income as assessed by the national accounts is not sustainable. In the environmental critique of current national accounting both lines of critique are often (though not always) combined.

Solutions to both kind of perceived fallacies have been suggested along two broad approaches:³

1. the development of supplementary statistics alongside the conventional national income accounts; in the environmental field often called “satellite accounts”;
2. the adjustment of the central statistics of the national accounts; e.g. “green” GDP or sustainable national income.

The idea of environmental and resource accounting has been considered by academics for over twenty five years. Official interest in the matter is more recent. In 1993, the United Nations Statistical Office presented its views on environmental and resource accounting in a handbook on *Integrated Environmental and Economic Accounting* (1993). The position of the UN is that integrated environmental and economic accounts should be presented in a satellite format and should be seen as a complement to, rather than a substitute for, traditional accounting practices (at least for the foreseeable future). The *System for Integrated Environmental and Economic Accounting* (SEEA) complements the current system of national accounts in two respects: (i) depletion of natural resources in production and final demand, and (ii) changes in environmental quality. Accounts can be presented in physical units, in monetary units or in a combination of the two. In transforming physical data to monetary units SEEA suggests a number of approaches including (i) market valuation, (ii) direct methods, and (iii) indirect valuation. The terminology is somewhat confusing, but ‘direct methods’ include all methods that aim at revealing individual preferences for environmental services (either directly by survey methods, e.g. Contingent Valuation, or indirectly by methods that assess the value of environmental services from their association with market goods, e.g. Hedonic Pricing and Travel Cost methods). ‘Indirect valuation’ in the terminology of SEEA values environmental services

³ See, for example, Hamilton *et al.*, 1994.

by the costs (expenditures) that actually *have been* made to maintain these services (pollution control expenditures), or that *should be* made to maintain environmental services at an undisturbed or sustainable level.

This paper surveys some of the recent approaches to assess changes in environmental quality and the depletion of natural resources in a national accounting framework. We distinguish between adjusting national income for changes in environmental quality (section 2.2) and adjusting national income for depletion of environmental and natural resources (section 2.3). We also present some work on environmental and resource accounting in non-monetary units (section 2.4). Section 5 offers some conclusions.

2.2 National accounting and economic welfare

It has long been realised that national income or national product do not measure economic welfare. Nonetheless, the critics argue, everyone is using it in a way as if it did.⁴ There are several reasons for the fact that national income may be a poor approximation to economic welfare. The main reasons may be grouped as follows.

1. The treatment of non-marketed good and services and leisure time. Non-paid household labour is an often quoted example. Non-paid housekeeping provides services to the members of the household. These services are not recorded in the present national accounts. The number of working hours in a week have gradually fallen over the last century. We may assume that the additional leisure time is valued positively by most workers. This amenity is not recorded in national income accounts, however.
2. The treatment of consumer durables. Consumer durables provide services to their owners over their lifetimes. Current accounting practice, however, treats them as final consumption in the year of their purchase only. This may lead to foolish paradoxes as the implication that deliberate efforts to make goods more perishable raise national output.⁵
3. Equity. The aggregate measure of national income or national income per capita is silent about the distribution of this income. If the distribution of income is an argument in the social welfare function, a change in national income may be a poor approximation of its effect on welfare.
4. Instrumental, regrettable or defensive expenditures. Some of the expenditures that are currently classified as final output could be regarded as intermediate expenditures. The reason is that certain activities do not yield direct utility but are regrettably necessary inputs to activities that yield utility. Pollution control expenditures by governments and households could be classified as intermediate rather than as final output. Some authors, go much further than this and would classify a whole range of expenditures that are related to the “necessary overhead costs of a complex industrial nation-state” as instrumental or defensive.⁶

⁴ Stockhammer *et al.*, 1997:19.

⁵ Nordhaus and Tobin, 1972:6.

⁶ *ibid.*, note 5; Leipert, 1989.

5. Environmental damage costs. Environmental externalities from economic activities produce economic 'bads' such as environmental pollution and natural resource degradation that are not recorded in national accounts.

A rise in the aggregate output of an economy as measured by national income or national product may give a false indication of the change in welfare or utility that consumers experience if this rise in output is accompanied by a reduction in non-marketed activity or leisure time, a reduction in the lifetime of consumer durables, a less equitable distribution of income, an increase in instrumental or defensive expenditures or an increase in environmental damage costs.

Several solutions have been presented and are developed to either adjust the main National Income statistics or to extend the national accounts with additional statistics on aspects of welfare. In this section (and in the following section) we will first discuss important theoretical or formal contributions (section 2.2.1) and then discuss a number of applications (sections 2.2.2, 2.2.3 and 2.2.4). Section 2.2.5 presents some conclusions.

2.2.1 Theoretical contributions

Mäler (1991) has considered the subject of green accounting from a welfare-theoretical perspective. Mäler discusses corrections on net national product (NNP). Apart from his treatment of labour, which is not relevant for the present discussion, his four main conclusions are that:

- 1) the value of environmental services to households and the direct use of natural resources by households should be included in NNP, valued at households' marginal valuation. If the value of environmental services is thus included in NNP, defensive expenditures must not be deducted to avoid double-counting;
- 2) the value of environmental services and natural resources to firms is already accounted for in NNP through the value of the output of firms;
- 3) the value of input goods to increase environmental quality should be deducted from NNP; they are intermediary goods. (Note that input goods that are used by firms for this purpose are already treated as intermediary in conventional NNP);
- 4) the value of the change in environmental and natural resource stocks should be included in NNP, valued at its (discounted) future value to households and production.

Mäler's conclusions emphasise the difference for accounting purposes of environmental services to households on the one hand, and to production on the other hand. This is clear after a moment's reflection. The value of environmental services to production, and also its inverse, the environmental damage to production, is already accounted for in the value of production. If due to air pollution (e.g. ozone) the value of crop production is less than would have been the case without pollution, then NNP (or GDP) is also less than would have been the case without pollution. Deduction of this damage from NNP would thus be double-counting.

Defensive expenditures must not be deducted from NNP if the value of environmental services is included in NNP. Given the state of the environment, defensive expenditures must increase welfare (otherwise they would not have been undertaken). In conventional NNP defensive expenditures are credited without environmental damages being debited.

If, however, environmental damage is debited (as proposed by Mäler), then it would be technically wrong not to credit defensive expenditures.

An important entry in Mäler's accounts is the volume of environmental services, valued at households' marginal valuation. Mäler does not elaborate on the feasibility of this entry. Hamilton (1994) and Atkinson (1995) suggest that where households are able to make defensive expenditures in response to environmental degradation, the value of these expenditures might be an indicator of the value of environmental services (Atkinson 1995: 5). These defensive expenditures by households are already accounted for in NNP: they are included in household expenditure. The correction that Atkinson and Hamilton propose comes down to deducting net pollution,⁷ valued at households marginal valuation, from NNP. This solution, although practical, rests of course on the heroic assumption that defensive expenditures are a proxy to the marginal value of environmental services.

The change in environmental and natural resource stocks must be valued at their future (discounted) value to households and production. In a theoretical model with perfect foresight, such as Weitzman's,⁸ this poses no special problems. In the real world however, the future is uncertain. To use only one example, it is quite unclear how a loss of biodiversity today will affect future production possibilities and household utility. Because of an often fundamental lack of knowledge of the future, both at the ecological and economic levels, the value of stocks can only be speculated upon. In Chapter 2.3 we will return to the issue of accounting for losses of environmental and natural resource stocks.

2.2.2 MEW

In the late 1960s, current lifestyles, inherited values and norms, and the "consumption society" in general were questioned. In this general mood of revolt against "old and rusted" institutions, values and norms, and economic growth as measured by Gross Domestic Product or one of its variants, became object of protest and rejection. In the United States some argued that negative growth elements, manifested by a massive deterioration of the physical and social environment, had eaten away all apparent GDP growth in the recent past. In response to these views, Nordhaus and Tobin (1972) developed the *Measure of Economic Welfare* (MEW) to better understand the relationship between economic growth and welfare.⁹

The MEW includes corrections of conventional Net National Product (NNP) in the areas of:

- Non-market activities and leisure time. The authors valued these activities and leisure time at their presumed opportunity cost, the money wage rate. The imputation of non-paid activities and leisure time more than doubles NNP.

⁷ Net pollution is defined as emissions of pollutants generated by production and consumption less the dissipation of pollutants in the environment in a given time period. (Atkinson 1995: 3).

⁸ See Section 2.3.1 for a discussion of Weitzman's model.

⁹ Nordhaus and Tobin define welfare as real household consumption.

- A reclassification of government final expenditures into intermediates, consumption and net investment, and a reclassification of some household expenditures. Education, medicine and public health expenditures are considered gross investments that raise productivity or yield household services.
- Consumer durables. The treatment of consumer durables as capital goods turns out to have little quantitative effect.
- Instrumental or defensive expenditures. Among these expenditures are classified: costs of commuting to work, and government services such as police, sanitation, road maintenance and national defence.
- Disamenities of urbanisation. This category which includes the environmental damage costs of environmental pollution is valued by a “disamenity premium” that is estimated as the income differential between people living in densely populated locations and people living in rural locations. The “disamenity premium” is estimated to be about five percent of GDP.

Nordhaus and Tobin (1972) calculated the MEW for the period 1929-1965. In this period, per capita MEW grew slightly slower than per capita NNP (1.1 percent for MEW as against 1.7 percent for NNP). Although the MEW is, according to the authors “primitive and experimental” (and we will not deny that), the MEW has been a source of inspiration for some attempts to calculate a “green national income”, for example Leipert (1989) and Daly and Cobb (1989). Daly and Cobb’s Index of Sustainable Economic Welfare (ISEW) is described below.

2.2.3 ISEW

The Index of Sustainable Economic Welfare (ISEW) by Daly and Cobb (1989) is partly based on the MEW, and partly on other work (e.g. Zolotas, 1981). Some of the differences with the MEW are a different approach to the calculation of the net capital stock¹⁰, another approach to non-market activities (it omits leisure time and values household activities differently), and a different definition of defensive expenditures (including, for example, expenditures on national advertising and car accidents). The most important difference for our purposes is the explicit attention for environmental damage costs and natural resource depletion, and the explicit attention for the distribution of income.

Daly and Cobb stress that income distribution is an argument in the social welfare function. They do not, however, examine this issue at great length. They use a statistic on the pre-tax (!) income distribution in the U.S. to develop a rather ad-hoc index of “distributional inequality” with which aggregate personal income in the accounting year is weighted.

In contrast to Nordhaus and Tobin’s MEW, the ISEW does take environmental damage and natural resource depletion explicitly into account. The ISEW distinguishes between water pollution, air pollution, noise pollution, loss of wetlands, loss of farmland, and long-term environmental damage. Assessments of environmental damages for specific years are taken from literature (especially Freeman, 1982) and arbitrarily extrapolated to

¹⁰ One of the most amusing, but also troubling, aspects of the Index is that it treats foreign capital as unsustainable per definition.

other years. The depletion of mineral and fuel resources is valued at their *total* production value. Long-term environmental damage includes climate change and depletion of the ozone layer. As no reliable estimates of future damage were available at the time of construction of the ISEW, this damage is arbitrarily set at \$ 0.50 per barrel of oil (or its equivalent, including nuclear energy) consumed. Notwithstanding its completely arbitrary valuation, long-term environmental damage accounts for more than 60 percent of total environmental damage and natural resource depletion in 1986.

Over the period 1951-1986 growth in GDP per capita almost doubled (1.9 percent annually). The growth in welfare over that period was only 20 percent, however (0.53 percent annually). The development of ISEW over time shows that per capita welfare increased during the 1950s and 1960s, levelled off during the 1970s and decreased during the 1980s (growth of per capita ISEW during 1980-1986 is -1.26 percent per annum).

Since its publication some attempts have been made to improve the ISEW and to apply it to other countries (e.g. Stockhammer *et al.*, 1997).

2.2.4 GARP

The Green Accounting Research Project (GARP) is concerned with the monetary and physical estimation of the environmental impacts of economic and social activities, with the objective of including such impacts within an EU-wide environmental accounting framework. The project covers four case study countries: Italy, Germany, the Netherlands and the United Kingdom. (Markandya and Pavan, 1999). The valuation methodology is the 'pathway approach' in which pollutants are followed from source to receptor and where the effects on receptors are valued using willingness-to-pay approaches. The first results of the project showed that the GARP methodology is applicable to some extent¹¹ but that large differences in data availability exist between environmental problems on the one hand and countries on the other hand. The GARP project has no ambitions to produce a measure of green GDP. Rather it seeks to report changes in human welfare through estimation of damage costs on a (willingness-to-pay) welfare basis. Integrating these estimates into national accounting aggregates is not advocated because of technical problems with the estimation techniques and because of methodological questions.

2.2.5 Conclusions

Both the MEW and the ISEW were developed to prove a point. The MEW was developed to prove that GDP was not such a bad indicator of economic welfare after all: GDP and MEW changed in the same direction, although MEW changed at a slower rate. The ISEW was developed to prove the opposite point: that economic progress as measured by GDP actually decreased welfare. Both measures could easily prove their points due to their 'subjective' approach in gathering and interpreting data and their ad-hoc methodologies. Later attempts to 'refine' the ISEW methodology (e.g., Stockhammer *et al.*, 1997)

¹¹ In the first phase of GARP valuation was restricted to energy-related air pollution and noise. For air pollution, damages to human health, materials and crops were assessed. In the second phase of GARP the analysis was extended to damages to water, land and ecosystems. Moreover, in this second phase damages were attributed to sources.

have not been convincing. It seems that overall attempts to measure welfare in one indicator have not yet been very successful.

The GARP project has been more modest in its objectives. In an extensive attempt to value environmental damages in four EU countries for one base year in a systematic way, the GARP project showed that coverage of damage categories is still far from complete and that for those damages that have been quantified and valued, uncertainties remain substantial.

2.3 National accounting and sustainability

This section discusses 'sustainable' national income. Paragraph 2.3.1 reviews some theoretical literature on this subject. Paragraphs 2.3.2, 2.3.3 and 2.3.4 discuss applications, among which is Sustainable National Income by Hueting (paragraph 2.3.4).

2.3.1 Theoretical contributions

A number of authors have examined the assessment of sustainable national income measurement from a theoretical perspective.¹² Many of the analyses start with a reference to Hicks' definition of income as the maximum value that a man can consume in one period without impoverishing himself (Hicks, 1948).

The theoretical basis for the correction of national income accounts for environmental losses was provided by Weitzman (1976) and Hartwick (1977, 1992). Weitzman demonstrated that in a dynamic general equilibrium framework, under specific assumptions (e.g. perfect foresight), net domestic product (consumption plus net investment) is the correct measure of sustainable consumption, i.e. a consumption level that can be sustained forever. Formally, he shows that the maximum welfare attainable along a competitive trajectory is exactly the same as what would be obtained from a hypothetical constant consumption level equal to net domestic product. For this conclusion to hold (at least) two major assumptions need to be fulfilled. The first is that the current economy is in competitive equilibrium, i.e. actual prices are equal to optimal shadow prices. The second is that net investment is measured in such a way that it includes (the change in) all the capital items that affect future consumption. Weitzman, in this respect, already referred to exhaustible natural resources and human capital (Weitzman, 1976: 157). Other authors have extended Weitzman's model to explicitly include natural resources and the environment. Hartwick (1977) showed that for the economy to be on a path of sustainable consumption, the value of depreciation of natural resource stocks must be invested in reproducible capital. If the stock of natural resources is (optimally) reduced in the accounting period, the value of this reduction should be subtracted from net national income. Note, however, that this value is measured as the volume of reduction multiplied by the *shadow price* of the resource.^{13,14} Withagen (1997) points out that actual prices of

¹² Mäler, 1991; Hartwick, 1977, 1992; Withagen, 1997, Zeelenberg *et al.*, 1997.

¹³ The shadow price is society's willingness to pay (in utility or consumption terms) to possess one additional unit of the resource.

¹⁴ Note that we assume an optimal path of natural resource extraction (Hotelling's rule), and the investment of the net revenues of resource extraction in man-made capital assets (Hartwick's rule).

natural resources are commonly determined on world markets, on which the economy under consideration may have little influence. Actual prices may therefore have little relationship with optimal shadow prices. Accumulating environmental pollution (for example CO₂ emissions) can also be considered reductions of the capital stock. The shadow prices of pollutant emissions have no market equivalents, and are difficult to assess. Apart from these difficulties, Withagen (1997) argues that Weitzman's result also breaks down with non-constant time preference, exogenous technological change and distortionary taxes.

There is some paradox in these theoretical contributions. They show us how to calculate sustainable income, assuming a dynamically optimal economy: no externalities and other distortions, an optimal path of resource extraction, etceteras. But the very reason for constructing a sustainable national income measure is that it is believed that the current economy and current policies are far from optimal. Aaheim & Nyborg (1995) remark that the assumption that the economy is on an optimal path "corresponds rather badly to the starting point of the whole debate on "green national product": namely that a lot of people are concerned about the environment because they believe it is over-exploited." (Aaheim & Nyborg, 1995: 59). In sum, *in practice* it seems impossible to calculate a theoretically 'correct' measure of sustainable income (Withagen, 1997; Zeelenberg *et al.*, 1997; Aaheim & Nyborg, 1995).

A related issue in the debate on sustainable national income concerns the theoretical distinction between 'weak' and 'strong' sustainability. In the weak sustainability paradigm different types of capital are distinguished such as man-made capital, human capital, natural capital and even social capital. The operational definition of sustainable development in the weak sustainability paradigm is that the total stock of capital should be maintained as a necessary (though possibly not sufficient) condition for the sustenance of future well-being (Pearce *et al.*, 1998). The sufficiency of the weak sustainability paradigm hangs on the extent to which different types of capital can be substituted for each other. Pearce *et al.* (1998) give a number of arguments (irreversibility, uncertainty, and thresholds /discontinuities) why the substitution possibilities between man-made and natural capital may be less than perfect.

In the strong sustainability paradigm the possibility of substitution between natural and man-made capital is assumed limited or at least it is advocated that given the uncertainties about the future it would be prudent to act *as though* these possibilities would be (very) limited.¹⁵ In the strong sustainability paradigm natural and environmental resources should remain intact to be enjoyed by future generations. If the strong sustainability approach is adopted it makes sense to estimate the costs of enforced sustainable use of environmental and natural resources (Gerlagh *et al.*, 1998).

2.3.2 Natural Resource Accounts

Natural resources such as deposits of minerals and oil, forests, fish in the sea, fresh water, and agricultural land can be used as factor input in the production of marketable goods and services. They can be regarded as (natural) capital. In the calculation of net national income, the consumption (depreciation) of man-made capital is accounted for.

¹⁵ See, for example, Hueting and Reijnders, 1998.

No such provision is presently made for natural capital. While it is undisputed that the present practice of not accounting for the consumption of natural capital in national income accounting is not correct, its inclusion presents some accounting difficulties which are discussed below.

In this section, the focus is on natural resources as distinct from environmental resources. The main distinction between the two is that natural resources are used to produce marketable goods and services, while environmental resources supply goods and services that are not traded in markets, such as clean air, a stable climate, biodiversity, and natural amenities. Notice that certain natural resources, such as forests, are both used as an input in production - forestry, producing timber - and at the same time produce amenity values such as climate regulation and watershed services and provide habitat services for wildlife. In this section, only the "commercial" values of these resources are taken into account.

The best-known natural resource accounting study was done by the World Resources Institute for Indonesia (Repetto *et al.*, 1989). Accounts were constructed for oil, forests and soil. Repetto *et al.* found that a substantial part of the apparent income growth in Indonesia in the period 1971-1984 should be classified as natural capital consumption. Repetto *et al.* suggest that a fuller accounting of natural resource depletion might conclude that in many years during the period depletion exceeded gross investments, implying that natural resources were being depleted to finance current consumption expenditures, an unsustainable course of action (Repetto *et al.*, 1989: 6). A few years later, the World Resources Institute carried out a similar accounting study for Costa Rica, this time accounting for deforestation, soil erosion, and overfishing. In the period 1970-1989, the annual natural resource depreciation averaged 5 percent of Costa Rica's GDP (Solórzano *et al.*, 1991).

The World Resources Institute calculates annual depreciation of natural resources such as mineral and energy deposits, forests and fish as the net change in physical stocks (additions minus reductions) multiplied by the average net price of its extracted commodities. The net price is the difference between a commodity's world market price (F.O.B.) minus the factor costs of its extraction and transportation. Soil erosion is valued by the present value of estimated losses in future productivity.

El Sarafy (1989) has argued that for the case of non-renewable resources, particularly subsoil assets, the depreciation approach of the World Resources Institute (using the net price method) or other approaches (deducting total receipts) underestimates the amount of true income that such a resource can generate. The resource rent (revenue minus costs) can be divided in two parts: an income part and a capital part. The income part can be consumed, provided that the capital part is invested to create a perpetual stream of income both during the life of the resource, as well as after the resource has been exhausted. El Sarafy provides a simple formula to calculate, under certain assumptions, the ratio of true (perpetual) income to the total rent of the resource (El Sarafy, 1989: 13). El Sarafy suggests to deduct the "user costs" (the capital part of the rent) from GDP instead of deducting them from some net measure of National Income.

In general, the problems with natural resource accounting are threefold:

- measuring;

- classification; and
- valuation.

Measuring the net changes in resource stocks in an accounting period is relatively easy for some natural resources such as oil and gas deposits, but relatively difficult for natural resources such as fish stocks, forest reserves or topsoils. Some of the measuring problems in constructing natural resource accounts were reported by Bartelmus in his study on Papua New Guinea (Bartelmus *et al.*, 1993). There was only sketchy information on the stock of certain natural resources such as fish; the rate of regrowth of forests was largely unknown; certain information was confidential, such as the sales revenues and extraction costs in the mining industry.

Classification poses serious conceptual problems. The World Resources Institute uses the net change in resource stocks as the physical basis for valuation. This implies that additions to the stock, such as discoveries of new reserves of minerals, are counted income in the year of discovery. It has been suggested that such discoveries can be better classified as investments, generating income in later years. There are other controversies, for example the question whether corrections should be made to gross or net measures of national income.

Valuation poses the most serious problems. What should be measured in principle is the (capitalised) loss of future income because of the present use of the resource. This is a shadow price also known as “user costs”. User costs can be derived from theoretical dynamic models of optimal resource extraction, but they can not be derived from observable data in the accounting period. Approximations such as Repetto’s net price method or El Sarafy’s user cost formula are arbitrary. The problems with pricing are exacerbated by the huge price fluctuations which characterise world markets of natural resources (and are largely unrelated to fundamentals of the economy under investigation). These price fluctuations strongly influence depletion in value terms and make the necessary “adjustments” to national income highly unstable. This common feature in practical applications of natural resource accounting poses serious questions on the usefulness of an adjusted national income figure for policy purposes. This point is further discussed in Section 2.5.

2.3.3 Genuine savings

Most proposals for adjustments to national accounting focus on income or product accounts, such as GDP, NDP or national income. Pearce *et al.* (1998) propose an indicator of “weak” sustainability that focuses on capital formation: they call it a measure of “genuine savings”. In the weak sustainability ‘paradigm’ different types of capital are distinguished such as man-made capital, human capital, natural capital and even social capital. The operational definition of sustainable development in the weak sustainability paradigm is that the total stock of capital should be maintained as a necessary (though possibly not sufficient) condition for the sustenance of future well-being (Pearce *et al.*, 1998). The sufficiency of the weak sustainability paradigm hangs on the extent to which different types of capital can be substituted for each other. Pearce *et al.* (1998) give a number of arguments (irreversibility, uncertainty, and thresholds/discontinuities) why the substitution possibilities between man-made and natural capital may be less than perfect. However, Pearce *et al.* argue, while an indicator based on weak sustainability may

not necessarily tell us what development is sustainable, it certainly tells us what development is not sustainable. Persistent negative genuine savings rates must lead to non-sustainability in the sense that the welfare of the country will eventually decline.

The Genuine Savings indicator measures aggregate net savings in a country that takes account of the depletion of natural resources and the accumulation of pollutants. The problems of *measurement* and *valuation* of natural resource depletion and accumulation of pollutants are basically the same as in other approaches to adjust national income.

2.3.4 SNI

In Hueting's approach to sustainable income accounting, a sharp distinction is made between sustainability and the sustainable use of environmental functions on the one hand and society's subjective preferences for such a use on the other hand. Environmental functions can be defined as the set of possible uses of the biophysical environment. If the use of one function is at the expense of other functions or of its own future use, the function is scarce, i.e. its use entails an opportunity cost - a "price" (Hueting, 1974). Sustainability requires such a use of environmental functions as to assure their indefinite availability. Note that this definition of sustainability does not necessarily require the conservation of all environmental assets. If an environmental function can be performed by several environmental assets, substitution between these assets is allowed in principle. For example, the function "resources for energy production" can be performed by fossil energy resources such as coal, oil and gas, but also by renewable energy resources such as solar, wind, and hydro. For a sustainable use of the function "resources for energy production" the depletion of the stock one kind of asset (e.g. oil) is no problem as long as its depletion is accompanied by an equivalent increase in the stock of substitute assets (e.g. solar).

Is sustainability, i.e. the sustainable use of environmental functions, desirable? Does society want to preserve all environmental functions indefinitely *at all costs*? The answer to these questions can only be given on the basis of society's subjective preferences for the use of environmental functions. Hueting stresses the point that, in general, society's subjective preferences for environmental functions and therefore its "demand" for these functions is not (completely) observable. It is difficult to derive individual preferences for environmental functions based on observed behaviour. There are no markets for environmental functions. Although some information on the demand for environmental functions can be inferred from defensive expenditure and financial damage, this information is incomplete and often does not address the most vital functions such as the functions of the life-support systems of our planet. Alternative valuation techniques such as contingent valuation are not very accurate and are not always applicable. Moreover, none of these techniques can provide reliable data on society's preferences for a liveable environment for future generations. In a word, whether or not we want to become "sustainable" is not known. Hueting therefore strictly separates the "objective" concept of sustainability (the indefinite availability of environmental functions) from the question whether or not society really wants to achieve such sustainability (Hueting and Reijnders, 1998).

Given the lack of knowledge of subjective preferences, SNI shows the correct measure of national income only if one *assumes* that society's preferences for the sustainable use

of the environment are absolute, i.e. independent of their costs. Hueting argues that there are as many green national incomes as there are assumptions on subjective preferences for environmental services. These subjective preferences include preferences for future availability of environmental functions, thus affecting the discount rate at which future benefits and costs are assessed. This situation will persist as long as we are unable to correctly measure subjective preferences for the current and future use of environmental functions. In this unfortunate situation it is necessary to be explicit about one's assumptions. Sustainable National Income represents the maximum level of income that can be derived from that level and composition of economic activity that leaves environmental functions available, now and in the future, given the state of technology in the year of reporting. Whether Sustainable National Income, thus defined, correctly measures welfare or utility is another question altogether. An important assumption is that society's preference for the sustainable use of environmental functions is absolute, i.e. independent of the cost of achieving this sustainable use. Hueting stresses the point that this assumption cannot be accepted or refuted on empirical grounds. Another important issue regards the role of future technological improvement in the efficiency of use of environmental resources. Hueting, deliberately, does not take this factor into account. He acknowledges that such future technological improvement could in principle lessen the tension between economic growth and environmental degradation, but he does not want to speculate on it. In fact, he is sceptical on the chances that as yet not implemented an unknown technology can safeguard the environment for future generations in the face of ever-increasing population and production (Hueting, 1996). SNI assesses the *distance* between the present and the sustainable level of production and consumption, given today's technology. When the calculation of SNI is repeated in later years it can be assessed whether technological improvement has indeed reduced this distance.

Hueting further assumes that conditions for the sustainable use of environmental functions can be determined by science and can be expressed in the form of physical standards. The sustainability standards should be in the form of "no more pollution should be allowed than can be naturally assimilated by the environment", or "so many fish may be caught that the stock does not diminish". At this moment sustainability standards for several environmental themes have been proposed by CBS (see Chapter 4) and are under review by the Netherlands Institute of Public Health and Environment (RIVM). SNI is directly dependent on the sustainability standards. When there is large scientific uncertainty on the maximum sustainable use of environmental resources, there will be a corresponding uncertainty in any estimated SNI.

SNI assesses the maximum level of economic activity that can be developed within an accounting period that respects the sustainability standards. All the costs that need to be made to meet the standards of pollution and resource use in order to prevent the sustainability standards to be exceeded, irrespective whether they are to be made by industry, government or households, are considered to be intermediary expenditures and should therefore not count as income. To put it simple, SNI is the difference between standard national income and the expenditures that need to be made to respect the sustainability standards. The following diagram illustrates these ideas.

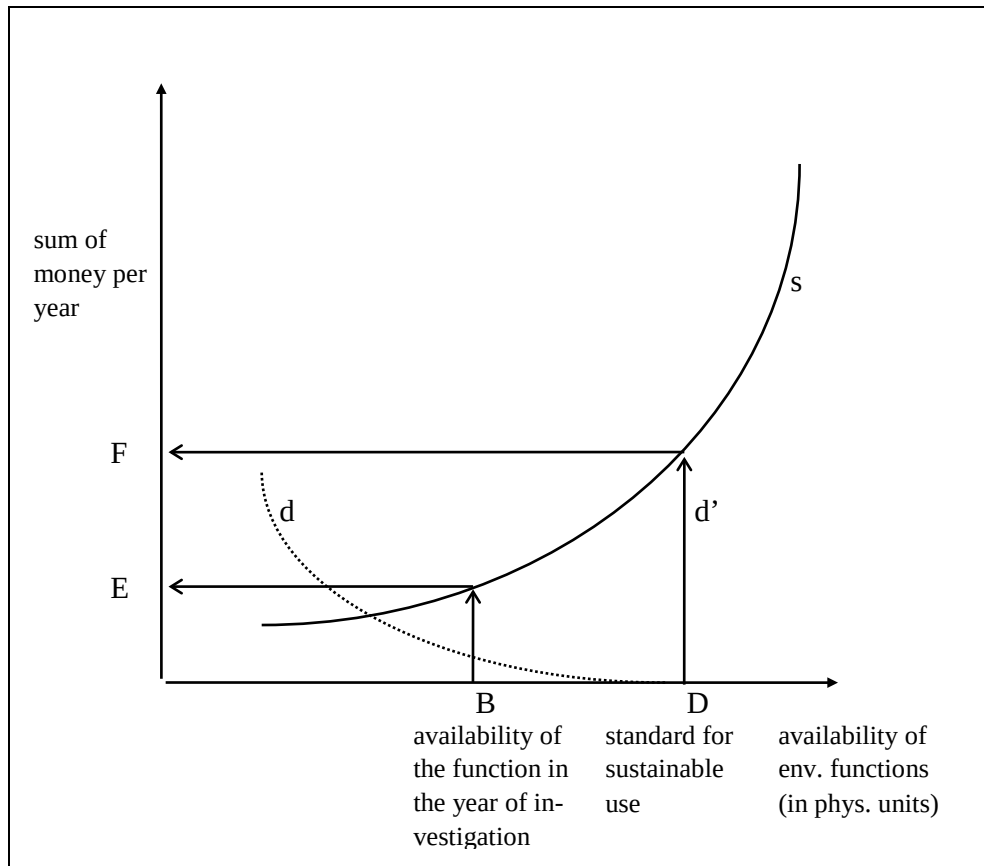


Figure 2.1 Demand and supply of environmental functions. Source: Hueting *et al.* (1995).

s = supply curve or elimination cost curve d = incomplete demand curve based on individual preferences (revealed from expenditures on compensation of functions, etc.);

d' = demand curve based on assumed preferences for sustainability;

BD = distance that must be bridged in order to arrive at sustainable use of environmental functions;

EF = costs of the loss functions, expressed in money.

The arrows indicate the way via which the loss of environmental functions recorded in physical units is translated into monetary units.

The X-axis depicts the level of an environmental function, e.g. the cleanness of air, the integrity and size of natural habitats, the stock of fish in the sea, all expressed in physical dimensions. The Y-axis depicts money. Curve s is the supply curve for the environmental function or the elimination cost function. It shows the costs of sustaining a certain level of the environmental function. The social demand curve for the environmental function is d . Hueting *et al.* (1995) argue that a complete demand curve for environmental functions (such as d), based on individual preferences, cannot be determined. Many governments, however, including the Dutch, have adopted 'sustainable development' as official government policy. If this is taken seriously, one may assume that society has collectively expressed an absolute preference for the preservation of (certain) environmental functions. This absolute preference is depicted in the *assumed* 'collective' de-

mand curve d' . Demand for an environmental function is then equal to the sustainability standard, and it is completely inelastic. Now assume that the present level of the environmental function on the X-axis is B. To reach the sustainable level at D, elimination costs of the magnitude of EF have to be made. If this exercise is repeated for all environmental functions that have to be sustained, then the sum of all EF's is the money-difference between the standard national income and the SNI.

In the SNI approach abatement cost or elimination cost curves play a central role. An abatement cost curve indicates the relationship between the level of an environmental function and the social costs that are needed to restore and maintain this level. In the SNI methodology costs can accrue from three different sets of actions. The first set of actions comprise technical measures to reduce pollution from a given economic activity. These technical measures can be 'end of pipe' measures, process changes, or the development of alternatives for non-renewable resources. Abatement cost functions for the depletion of fossil fuels, climate change, depletion of the ozone layer, acidification, smog formation, eutrophication, zinc emissions, dispersion of toxic substances to water, fine particles to air, aridification, and local soil pollution have been estimated (de Boer, 2000a, 2000b, Dellink *et al.*, 1997, van der Woerd *et al.*, 2000). The second set of actions comprise volume reductions in the polluting or extracting economic activities themselves. In a macro-economic or general equilibrium framework such volume reductions would amount to structural shifts in the sectoral composition of an economy¹⁶ - that is a shift away from environment burdening towards less-burdening activities. These sectoral shifts should be carried out when technical measures alone are not sufficient to reach the sustainability standards or when these technical measures are too expensive. The third set of actions concerns actions to reduce the level of population (through family planning) if the actions of the first two sets would lead to an unacceptably low level of per capita income. It should be noted that these actions are all analysed in a comparative-static exercise in which time plays no role.

The measures from one or more of these sets of actions will typically affect more than one sector of the economy, and possibly all. The effects of the implementation of technical measures, sectoral shifts and family planning on the level of national income should therefore preferably be evaluated in an integrated multi-sector framework (De Boer, 1997; Zeelenberg *et al.*, 1997). A computable general equilibrium model that is able to capture these effects is discussed in Chapter 5. The objective of this model is to assess the indirect, macro-economic effects of package of technical and structural measures that are necessary to reach the sustainability standards for the various environmental pressures that are (or will be) included in the calculation of SNI.

2.4 Non-monetary satellite accounts

2.4.1 Introduction

In a series of articles, den Butter and Verbruggen (den Butter, 1992; den Butter and Verbruggen 1997a, 1997b) reviewed green accounting approaches and assessed their poten-

¹⁶ In commonly-used sectoral classifications (e.g. SBI code in the Netherlands), the shifts would almost certainly also take place within sectors (Huetting, 1996).

tial use for policy making. They identify a number of problems with the various proposed approaches that are caused by a lack of knowledge on both the technical relationships between environment and economic development and on societal preferences. They question the possibility of developing a non-hypothetical green national product. They argue, however, that macroeconomic policy making in modern countries is not based on one indicator such as national product or income only. As a rule, a number of indicators are used jointly in the decision-making process, such as employment, the external trade balance, inflation, government finances and income distribution issues. In such a multi-attribute decision-making process, it is not necessary that every indicator is expressed in the same unit (although it would be helpful, of course). Given this multi-attribute decision-making process, den Butter and Verbruggen argue that a small but comprehensive set of environmental indicators expressed in their natural dimensions that are linked to conventional entries in national accounts would be as useful for policy making as green national accounts, if not more useful. In this section, a number of approaches towards integrating physical environmental indicators in the system of national accounts are discussed.

2.4.2 Natural Resource Accounts

Norway has a relatively advanced (physical) accounting framework for its natural resources. The Norwegian Resource Accounting System (NRA) includes accounts for air pollution¹⁷, energy (oil, gas, hydropower), fisheries, minerals and forests. The accounts include information on reserves and stocks (opening stocks, changes in physical units due to discoveries and natural growth, extraction, and revaluations) and on flows (extraction, import/export, conversion and use). In addition, a number of indicators in physical units have been constructed. Norway has no intention to integrate its NRA in its SNA.¹⁸

2.4.3 Indices

Since it is understood that conventional national income statistics have some major deficiencies in showing welfare or sustainability, the search is for better indicators of sustainable development (Kuik and Verbruggen, 1991). In its Agenda 21, UNCED calls for the development of indicators of sustainable development (UNCED, 1992). The search for appropriate adjustments to national income statistics is but one approach to meet this objective. Another approach is the development of indices that point at specific aspects of economic development. There are several attempts in this direction. The Statistical Office of the European Union is developing Environmental Pressure Indicators as a re-

¹⁷ We would classify air pollution or "clean air" as an environmental resource.

¹⁸ The Central Bureau of Statistics of Norway argues: "In preparing an environment-adjusted domestic product as an aid to integration of economic and environmental policies, the persons preparing the statistics have to make a long series of subjective assessments of values. This implies that the statistics may contain a number of political evaluations, which will not necessarily be obvious to those who are to use the data. Thus it is possible that the conditions which require a balance of different considerations may become more obscure. On the basis of the above considerations, CBS has chosen not to recommend the preparation of an environment-adjusted domestic product." (CBS Norway, 1992, quoted in Hamilton *et al.*, 1994: 41).

sponse to the priority expressed in the European Commission's Fifth Environmental Action Programme (European Commission, 1996).

Another attempt is the Human Development Index (HDI) of the United Nations Development Programme (UNDP). The concept of human development regards the consumption of commodities and the accumulation of wealth as means rather than ends of development and progress. "The real objective of development should be to create an enabling environment for people to enjoy long, healthy and creative lives" (UNDP, 1998). The emphasis should be on the widening of people's choices and the level of their achieved well-being. According to UNDP, critical aspects of its development concept include health and longevity, education, a decent standard of living, political freedom, human rights and self respect.

The Human Development Index (HDI) is an attempt to create an indicator which measures the achievement of human development across countries. It combines indicators for life expectancy, educational attainment and income. The HDI sets a minimum and a maximum for each dimension and then shows where each country stands in relation to these scales - expressed as a value between 0 and 1. Since the minimum adult literacy rate is 0% and the maximum is 100%, the literacy component of knowledge for a country where the literacy rate is 75% would be 0.75. Similarly, the minimum for life expectancy is 25 years and the maximum 85 years, so the longevity component for a country where life expectancy is 55 years would be 0.5. For income the minimum is \$100 (PPP) and the maximum is \$40,000 (PPP). Income above the average world income is adjusted using a progressively higher discount rate. The scores for the three dimensions are then averaged in an overall index.

UNDP also develops indices that point at distributional aspects of development: the Human Poverty Index (HPI), the Gender-related Development Index (GDI) and the Gender Empowerment Measure (GEM).

In its 1998 World Development Report, UNDP emphasises the negative consequences of today's consumption patterns for tomorrow's human development; it stresses the present environmental unsustainability of present consumption patterns and calls for the reversal of this trend through a seven-point agenda for action (UNDP, 1998). Unfortunately, however, it has not developed an indicator which points specifically at the sustainability aspect of development, nor does it, surprisingly perhaps, argue for the need of such an indicator.

2.4.4 NAMEA

Another approach to environmental accounting is the presentation of environmental stocks and flows in non-monetary units in so-called "satellite accounts". The Statistical Bureau of the Netherlands has developed an accounting framework, the National Accounting Matrix including Environmental Accounts (NAMEA), in which monetary information on the economy and physical information on the environment have, to some extent, been integrated (Keuning, 1993).

NAMEA combines the economic accounts of the National Account Matrix (NAM) with environmental indicators. Table 2.1 presents the main structure of NAMEA in schematic form. The *economic* accounts of NAMEA are: the goods and services account (1), con-

sumption account (2), production account (3), income generation account (4), distribution and use account (5), capital account (6), financial balances (7), tax account (8), and rest of the world (ROW) accounts (9 and 10). For each account the receipts are presented in rows and outlays are presented in columns. Each account balances total receipts and total outlays. Important balancing items are: net domestic product (4,3), net generated income (5,4), net savings (6,5), surplus or deficit on the current account of the balance of payments (9,10).

NAMEA contains two *environmental* accounts: an account of substances (11), and an account of environmental themes (12). These accounts are expressed in physical units, therefore they do not influence the monetary row and column totals of the economic accounts (1-10). The row sums of the environmental accounts correspond with the totals in the columns. The substances account (11) contains 13 substances: CO₂, N₂O, CH₄, CFCs and halones, NO_x, SO₂, NH₃, P, N, solid waste, waste water, natural gas, and oil. The columns reflect the origin of the substances, the rows reflect their destination. Polluting substances are generated by households (2,11), firms (3,11) and other sources (6,11). Stocks of natural resources (natural gas, oil) can change (6,11). Transboundary pollution is presented in the ROW accounts; imports of pollutants (9,11) and exports of pollutants (11, 9). Finally, a number of emitted polluting substances is absorbed in production processes, e.g. the purification of waste water or the incineration of wastes (11,3).¹⁹

The themes account (12) presents indicators of the following environmental themes: the greenhouse effect, depletion of the ozone layer, acidification, eutrophication, the accumulation of waste, waste water, and the depletion of natural resources, i.e. fossil fuels. The substances of account (11) are weighted with theme-related environmental stress equivalents and then aggregated column-wise by theme (11,12). The environmental theme indicators (in theme-equivalents) are presented in the column of the capital account (12,6).

NAMEAs for the Netherlands are annually published in the National Accounts.

The Office for National Statistics (ONS) of the United Kingdom is developing environmental accounts (UKENA) that follow the Dutch NAMEA system quite closely (Vaze and Balchin, 1996).

¹⁹ The emissions from activities such as waste water purification and waste incineration are presented in the production account (3,11).

Table 2.1 The main structure of NAMEA.

	Good and services	Con- sumption	Pro- duction	Capital	ROW current account	Substances	Themes	Total
	1	2	3	6	9	11	12	
1								
2						emissions by consumers		
3						emissions by producers		
6						other emis- sions and in- crease of natu- ral resources		
9						emissions from ROW		
11			absorp- tion of sub- stances		emissions to ROW		contribu- tion of sub- stances to themes	destina- tion of sub- stances
12				theme- equiva- lents				theme- equiva- lents
Total						origin of sub- stances	theme- equiva- lents	

2.5 Conclusions

It is widely acknowledged that the current measure of national income is not a perfect indicator of welfare. Losses of environmental services go largely unrecorded, while it is undisputed that these losses do in fact, in many cases, reduce the economic well-being of households. While there is good progress in the assessment of environmental damage in monetary terms, the estimates are generally still far from complete and imprecise. Moreover, as we saw above, even if we were able to correct national income for the value of environmental damages, this would not exhaust the potential for adjustments. The problems that one is likely to encounter then seem insurmountable. Nonetheless, specific welfare indicators such as the HDI are very useful, if only to point at the deficiencies of GDP.

But even if we accept the fact that national income is not a good indicator of welfare it can be argued that current accounting practices do not even measure 'income' correctly. Income, as we understand it, is the amount a person can consume without impoverishing himself. If the person saves, he or she plans to be better off in future. If the person lives beyond his or her income, he or she may expect to be worse off. What is true for an individual income is also true for the aggregate of all individual incomes in a country: National Income. Because of the systematic neglect of natural resource depletion and the accumulation of polluting stocks, current calculations of national income overestimate the amount that can be consumed without future impoverishment; that is, current calculations overestimate true national income.

The question then is: can true national income be measured correctly and how important is this for the conduct of everyday economic affairs, including environmental policies? It

should be realised that Hicks's central definition of income is an *ex ante* definition –it is concerned with what a man can consume in a period and still *expect* to be as well off as he was at the beginning of that period (Hicks, 1948: 178). Income is then a guide to prudent conduct, precisely what we would like it to be in the context of sustainable development. However, in this definition nothing is said about the *realisation* of these expectations. Individuals may hold different expectations and they may or may not be realised and they may or may not be consistent with each other. The income that is measured by the national income accountant is typically an *ex post* income, the income that can be measured after all expectations have materialised in the accounting period. As such, this *ex post* income is not a guide for (future) conduct but a historical datum. Historical data are interesting but they tell little about the future. In an illuminating paper on the interpretation and applicability of green accounting with respect to Norway's oil reserves, Aaheim and Nyborg (1995) argue that an economic policy that is based on the idea that a consumption level equal to a green national income (adjusted for the depreciation of oil reserves) can be sustained may prove to be fairly disastrous. The reason is that the price of oil and the *expectations* of future prices (and thus the capital value of the resource) have swung so violently that the 'deterministic' factors to changes in the wealth of the oil reserves (extraction and expected return: the factors that are included in the calculation of green national income), were negligible compared to the effect of uncertain factors (prices and resource estimates: factors that are not included in green national income). So, if the Norwegian authorities had encouraged a consumption level equal to the estimated 'sustainable' income level in the early 1980s, with no regards of uncertainty, "this would certainly have caused grave problems for the Norwegian economy in the years to follow" (Aaheim and Nyborg, 1995: 65).

The main point is that if the future were known with certainty, it would be relatively easy to calculate 'sustainable' national income, but likewise it would also be relatively easy to formulate a sustainable economic policy. If the future is uncertain, which it is, then it is difficult to calculate sustainable national income, and this *ex post* sustainable national income figure is not necessarily a good guide to (future) economic (and environmental) policy.

The SNI method appears to avoid some of the problems of the other approaches. *Assuming* society's preference for sustainability it avoids estimating subjective preferences for environmental functions. The arguments above indicate that this is a very strong point of the SNI methodology, especially in a dynamic context. However, 'costs' are essentially also an expression of individual preferences. The economic or opportunity costs of 'hypothetical' measures cannot be observed. The necessary cost calculations for the SNI method can therefore only be made in a (necessarily simple) model of the economy. This necessarily implies that the outcome of any calculation is sensitive to various modelling assumptions. If this sensitivity is high, the "reliability" of the estimated SNI will be relatively low. Moreover, SNI is strongly dependent upon the scientific sustainability standards. To the extent that these standards are uncertain, SNI will be uncertain too.

Nevertheless, the modelling exercise as such can be very useful to provide at least an indication of the (relative) costs of various sustainability standards that may or may not be adopted in environmental policy. SNI can then be regarded as a tool of policy analysis. And this would seem a very practical purpose, perfectly in line the general purpose of

national accounting, which, as we saw in Section 2.1, has always been driven by practical motivations.

In general there would not seem to be any controversy between monetary and non-monetary approaches. Non-monetary accounts are an essential input to any monetary accounting exercise. Non-monetary accounts such as NAMEA also have a very important information function on their own.

References

- Aaheim, A. and K. Nyborg (1995). On the Interpretation and Applicability of a "Green National Product". *Review of Income and Wealth*, 41, pp. 57-71.
- Atkinson, G. (1995). *Social Accounting, Genuine Saving and Measures of Economic Welfare*. Centre for Social and Economic Research on the Global Environment (CSERGE), University College London and University of East Anglia.
- Bartelmus, P., E. Lutz and S. Schweinfest (1993). Integrated Environmental and Economic Accounting: A Case Study for Papua New Guinea. In: Lutz, E. (ed.), *Towards Improved Accounting for the Environment*, World Bank, Washington D.C.
- Daly H.E. and J.B. Cobb (1989). *For the Common Good*. Beacon Press, Boston, pp. 401-455.
- de Boer, B. (1997). *Verschuiving van milieubelastende naar milieuvriendelijke productie: methoden voor benadering van het effect op het nationaal inkomen* (Shift from environment burdening to less-burdening production methods: methods for the approximation of the effect on national income, in Dutch). Internal Memo, Statistics Netherlands, Voorburg.
- de Boer, B. (2000a). The greenhouse effect. *Mimeo*, Statistics Netherlands, Voorburg.
- de Boer, B. (2000b). Depletion of the ozone layer. *Mimeo*, Statistics Netherlands, Voorburg.
- Dellink, R.B. and K.F. van der Woerd (1997). *Kosteneffectiviteit van milieuthema's* (Cost effectiveness of environmental problems, in Dutch), IVM-R97/10, Institute for Environmental Studies, Vrije Universiteit, Amsterdam.
- den Butter, F.A.G. (1992). The Mirror of Cleanliness: on the construction and use of an environmental index. In J.J. Krabbe and W.J.M. Heijman (eds.), *National Income and Nature: Externalities, Growth and Steady State*, Kluwer Academic Publishers, Dordrecht, pp. 49-75.
- den Butter, F.A.G. and H. Verbruggen (1997a). Milieu en Economische Groei. *Milieu*, 9, (1), pp. 1-11.
- den Butter, F.A.G. and H. Verbruggen (1997b). De waardering van het Milieu voor het Milieubeleid. *Milieu*, 9, (2), pp. 49-56.
- El Serafy, S. (1989). The Proper Calculation of Income from Depletable Natural Resources. In: Y.J. Ahmad, S. El Serafy and E. Lutz (eds.), *Environmental Accounting for Sustainable Development*, Report of a UNEP - World Bank Symposium, The World Bank, Washington D.C., pp. 10-18.
- European Commission (1996). *Environmental Indicators and Green Accounting. Practical steps towards the implementation of the Communication from the Commission to the Council and the European Parliament on Directions for the European Union on Environmental Indicators and Green National Accounting*, (COM(94) 670 final), Brussels.
- Freeman A.M. (1982). *Air and Water Pollution Control – A Benefit-Cost Assessment*. John Wiley & Sons, New York.
- Gerlagh, R., R.B. Dellink and M. Hofkes (1998). *Some notes on sustainable income*, Mimeo, Institute for Environmental Studies, Vrije Universiteit, Amsterdam.

- Hamilton, K. (1994). *Pollution and Pollution Abatement in National Accounts*. Centre for Social and Economic Research on the Global Environment (CSERGE), University College London and University of East Anglia.
- Hamilton, K., D.W. Pearce, G. Atkinson, A. Gomez-Lobo and C. Young (1994). *The Policy Implications of Natural Resource and Environmental Accounting*. CSERGE Working Paper, GEC 94-18, London and Norwich.
- Hartwick, J.M. (1977). Intergenerational equity and the investing of rents from exhaustible resources. *American Economic Review*, 67, (5), pp. 972-974.
- Hartwick, J.M. (1992). Deforestation and National Accounting. *Environmental and Resource Economics*, 2, pp. 513-21.
- Hicks, J. (1948). *Value and Capital: an inquiry into some fundamental principles of economic theory* (2nd ed.). Oxford University Press, London.
- Hueting, R. (1974). *Nieuwe Schaarste en Economische Groei*. Amsterdam. Published in English as *New Scarcity and Economic Growth*. North-Holland, Amsterdam (1980).
- Hueting, R. (1996). Three Persistent Myths in the Environmental Debate. *Ecological Economics*, 18, pp. 81-88.
- Hueting, R., P. Bosch and B. De Boer (1995). *The Calculation of Sustainable National Income*, IDPAD Occasional Papers and Reprints, The Hague/New Delhi.
- Hueting, R. and L. Reijnders (1998). Sustainability is an Objective Concept. *Ecological Economics*, 27, pp. 139-147.
- Hueting, R., P. Bosch and B. De Boer (1995). *The Calculation of Sustainable National Income*. IDPAD Occasional Papers and Reprints, The Hague/New Delhi.
- Keuning, S.J. (1993). An Information System for Environmental Indicators in Relation to National Accounts. In: W.F.M. de Vries, G.P. den Bakker, M.B.G. Gircour, S.J. Keuning, A. Lenson, *The Value Added of National Accounting: Commemorating 50 years of national accounts in the Netherlands*. Netherlands Central Bureau of Statistics, Voorburg, pp: 287-305.
- Kuik, O.J. and H. Verbruggen (eds.) (1991). *In Search of Indicators of Sustainable Development*. Kluwer Academic Publishers, Dordrecht.
- Leipert, C. (1989). National Income and Economic Growth: The Conceptual Side of Defensive Expenditures. *Journal of Economic Issues*, 23, (3).
- Mäler, K.G. (1991). National Accounts and Environmental Resources. *Environmental and Resource Economics*, 1, pp. 1-15.
- Markandya, A., M. Pavan (eds.) (1999). *Green Accounting in Europe - Four Case Studies*. Fondazione Eni Enrico Mattei/Kluwer Academic Publishers, Dordrecht/Boston/London.
- Nordhaus, W. and J. Tobin (1972). Is Growth Obsolete? In: *Economic Growth*, National Bureau of Economic Research, General Series No. 96, New York, pp.1-80.
- Pearce, D.W., G. Atkinson and K. Hamilton (1998). The Measurement of Sustainable Development. In: J.C.J.M. van den Bergh and M.W. Hofkes (eds.), *Theory versus Implementation of Sustainable Development Modelling*, Kluwer Academic Publishers.
- Repetto, R., W. Magrath, M. Wells, C. Beer and F. Rossini (1989). *Wasting Assets: Natural Resources in the National Income Accounts*. World Resources Institute, Washington D.C.
- Roll, E. (1973). *A History of Economic Thought*. Faber and Faber Ltd., London.
- Solórzano, R., R. de Camino, R. Woodward, J. Tosi, V. Watson, A. Vásquez, C. Villalobos, J. Jiménez, R. Repetto and W. Cruz (1991). *Accounts Overdue: Natural Resource Depletion in Costa Rica*. World Resources Institute, Washington D.C.
- Stockhammer, E., H. Hochreiter, B. Obermayr and K. Steiner (1997). The Index of Sustainable Economic Welfare (ISEW) as an Alternative to GDP in Measuring Economic Welfare. The

- Results of the Austrian (Revised) ISEW Calculation 1955-1992. *Ecological Economics*, 21, pp. 19-34.
- UNCED (1992). *Rio Declaration and Agenda 21*. Report on the United Nations Conference on Environment and Development, Rio de Janeiro, 3-14 June 1992, UN doc. A/CONF.151/26.rev1 (Vols I-III).
- UNDP (1998). *World Development Report 1998*. United Nations Development Programme.
- UNSO (1993). *Handbook on Integrated Environmental and Economic Accounting*. United Nations Statistical Office.
- van der Woerd, K.F., E.C.M. Ruijgrok and R.B. Dellink (2000). *Kosteneffectiviteit van verspreiding naar water*. IVM-E00/01, Institute for Environmental Studies, Vrije Universiteit, Amsterdam.
- Vaze, P. and S. Bachlin (1966). The Pilot United Kingdom Environmental Accounts. *Economic Trends*, April 1996, HMSO, London.
- Weitzman, M.L. (1976). On the Welfare Significance of National Product in a Dynamic Economy. *Quarterly Journal of Economics*, 60, pp. 156-162.
- Withagen, C. (1997). *Groen en Duurzaam Nationaal Inkomen*. Mimeo, Vrije Universiteit Amsterdam and Katholieke Universiteit Tilburg.
- Zeelenberg, K., B. de Boer, and R. Brouwer (1997). *Sustainability in Growth Models*. Statistics Netherlands, Research Paper no. 9744, Voorburg.
- Zolotas, X. (1981). *Economic Growth and Declining Social Welfare*. New York.

3. Environmental valuation and sustainable national income according to Hueting

Roefie Hueting and Bart de Boer, Statistics Netherlands

(Translation: Nigel Harle)

3.1 Introduction

Hueting's notion of sustainable national income (SNI) has a relatively long history going back to the mid-1960s. Much of this work has appeared in print and reference to these publications will be made as appropriate, allowing us to restrict ourselves to the principal issues here. Estimation of SNI rests on four pillars. (1) The formal or indifferent concept of welfare, as introduced probably by Rosenstein-Rodan (1927) and elaborated further by Robbins (1932, 1952) and particularly by Hennisman (1940, 1962, 1995), from which it follows immediately that if there exist strong preferences for the environment, conservation measures will lead to a decline in the standard national income and an increase in welfare (Hueting, 1974a). (2) The concept of environmental function, introduced by one of the present authors (Hueting, 1969, 1974a); see Section 3.2. (3) The position that sustainability is an objective, scientific concept that must be clearly distinguished from whether or not there exist preferences for such, implying that it is indeed possible to establish sustainability standards, even though these may sometimes be bracketed within high margins of uncertainty. This position also implies that no distinction can be made between 'weak' and 'strong' sustainability; see Section 3.5. (4) The position that there exist certain 'blockages' as a result of which preferences for environmental conservation are *incapable* of being fully expressed through market and budget mechanisms; see Section 3.3.

Point (4) justifies the assumption that there exist stronger preferences for the environment than presently find expression in standard national income. As Hueting (1996) emphasises, this assumption can be neither accepted nor refuted on empirical grounds. This opens the door for estimating green national incomes, of which, *ergo*, as many manifestations exist as assumptions can be made vis-a-vis preferences. One of these is the SNI, which is based on the assumption of virtually absolute preferences for the future availability of those environmental functions that are vital to humanity. See Section 3.4.

The environment is defined as our biophysical surroundings, on which we are entirely dependent and which can be described as a set of possible uses or functions. The environment falls outside the system of national accounts (Tinbergen and Hueting, 1991). Producing is defined as adding value to the biophysical surroundings by labour; see Section 3.2. From this view it follows that in moving from the standard national income to the SNI or some other green national income *only* negative corrections can be made. See Section 3.3.

Because the bulk of national income growth is generated precisely by those production (and consumption) activities that are most burdensome to the environment, a shift from environmentally burdensome to less burdensome activities will have a negative effect on the volume of the standard national income (Hueting, 1981; Hueting *et al.*, 1992a). This effect can be expressed by working with the prices arising after internalising the costs of the required elimination measures when making the step from standard to sustainable national income; see Section 3.4. Although shifts from meat to beans, say, or from car to bicycle or plane to train are the most essential from the environmental angle, the sectoral subdivisions available at Statistics Netherlands (CBS) are not sufficiently detailed for such shifts to be introduced into the model. Instead, shifts less essential from the environmental point of view have been incorporated.

As a very rough estimate of sustainable world income Tinbergen and Hueting (1991) arrive at a figure of 50 per cent of current standard world income. The provisional results of the study on an SNI for the Netherlands reported here justify the conclusion that this rough estimate is by no means extreme (Verbruggen *et al.*, 1999). We are concerned here with a comparative static exercise in which time plays no role. A transition to a lower, sustainable level of economic activity free of shock to the social fabric will require considerable time. The transition route to a sustainable level must itself also be sustainable, i.e. involve no irreparable damage to vital environmental functions. See Section 3.4. This quest obviously lies outside the scope of the SNI study.

3.2 The concept of environmental function

The notion of possible human use of the environment or 'environmental function' was introduced by Hueting (1969, 1970a,b). In all, 16 basic functions of nature for humanity are distinguished; these include oxygen production, waste removal, gene pool for improving and creating crops and livestock, supplier of medicines (vaccines, antitoxins), supplier of natural products (timber, fish, skins, ivory, etc.), hydrological regulation, erosion prevention and maintenance of biological equilibrium. The economic value of these functions is determined in an approach comprising, *inter alia*, the following elements: (1) estimate of expenditures on replacing the function (replacement costs) when the latter falls short of existing wants due to overload (up to this point it was a free good with zero value); (2) estimate of expenditures on measures to compensate for loss of the function (compensation costs); (3) estimate of expenditures incurred in going ever further to enjoy nature, such as travel expenses. This approach underwent substantial modification between 1970 and 1974, as discussed in the next paragraph. We mention the approach adopted in 1969, since this came to lead a life of its own and is still being used today.

In Hueting (1974a,b) a fundamentally different approach is taken, the principles of which have not changed since. Compared with the 1969 approach the differences are as follows.

Firstly, use is now made of a supply and a demand curve, because in any process of valuation preferences (demand) and costs (supply) are inseparably linked (see Section 3.3). The supply curve is made up of the (rising) costs of the at-source measures required to eliminate the environmental burden, leading to restoration of functions. These are termed the elimination costs. One of the reasons for this choice is that the functions (or services) provided by ecosystems, say, cannot in fact be replaced, or only temporarily so. Restora-

tion of functions by means of elimination is always possible, however, as long as the functions have not been irreversibly damaged of course (as in the case of species extinction, for example). The demand curve is made up of the expenditures actually made as a result of loss of function(s). These can be seen as revealed preferences for the various environmental functions. They include the following: expenditures on measures to compensate for loss of function, including, *inter alia*, the replacement costs of the 1969 approach; expenditures on restoring damage due to loss of function (floods due to forests losing their 'hydrological regulation' function, for example); and expenses incurred in travelling ever further to enjoy nature. To a limited extent, but specifically not for the most essential functions, willingness-to-pay and similar estimates are also taken on board as revealed preferences, thereby avoiding double-counting (Hueting, 1974a, 1989, 1992b, 1995).

Secondly, in discussions among the multidisciplinary team that one of us had meanwhile formed at Statistics Netherlands for setting up environmental statistics and for adjustment of the standard national income for environmental losses, it proved impossible to satisfactorily demarcate the concept of 'nature' for statistical purposes. This resulted in a definition of 'environment' as the non-manmade (bio)physical surroundings, or elements thereof, on which humanity is entirely dependent in all its doings, whether they be producing, consuming, breathing or recreating. This (bio)physical surroundings encompass water, soil, air, natural resources, including energy resources, and plant and animal species. It is true that our observable surroundings are largely human-built. However, houses, roads and farm crops are the result of two complementary factors: labour and elements of the biophysical surroundings as here intended. Our crops, for example, have been bred or manipulated from genetic material taken from natural ecosystems; this material was not created by human beings and sooner or later we shall most probably have to fall back on it. We therefore continue to be dependent on the functions of the biophysical surroundings as here intended, including the functions of 'gene pool' (or: 'gene reserve'), 'habitat for biological species', 'water as raw material for drinking water', 'air for the physiological functioning of human beings, animals and plants', 'soil for cultivating crops' and the many functions of non-renewable natural resources.

Producing is defined, in accordance with standard economic theory, as the adding of value. This value is added to the physical elements of our environment. In this process one good is transformed into another in order to satisfy wants. The values are added by labour, i.e. hands and brains, with the brains guiding the hands, so that we are concerned ultimately with two factors: labour (technology) and environment. Thus, both consumption goods and capital goods embody a combination of the physical elements of the environment, on the one hand, and labour, accumulated or otherwise, on the other. In this view, labour and environment are the two factors with which humanity has to make do in securing a desired level of consumption. If environmental functions are lost we are left literally empty-handed. Environment and labour are thus complementary. Annual production as measured in the standard national income is therefore accompanied by a *physical flow of goods*. Put differently, regardless of whether the products are actually physical, in production and consumption there will always be an interaction with the biophysical environment and consequently always a physical burden on that environment. This environmental pressure is, obviously, a form of environmental use.

All this may seem obvious, but apparently it is not so to everyone. In the first place, production is still frequently taken to mean material welfare, a confusing *contradictio in terminis*, and the environment, immaterial welfare. Second, in recent publications on environmental valuation the distinction is neglected between the *possibilities* offered by the environment for direct use (e.g. breathing), for production and for consumption on the one hand, and the addition of value(s) to the environment, i.e. production, on the other (De Groot, 1992; Costanza *et al.*, 1997; Opschoor, 1997; Nentjes, 1997). These authors establish the value of an environmental function such as 'water as a habitat for fish' on the basis of the market value of fish, for example, thereby ignoring the fact that economically speaking a fish swimming is not the same good as a fish caught. The difference is brought about by the value added by labour. The market reflects only this value added and precisely *not* the value of the environmental function. By 'environmental services' these authors do not mean the *possibilities* of catching fish, cropping timber and so forth: the possible uses or functions which may or may not get lost, and restoration and maintenance of which requires sacrifices (opportunity costs). Rather, they take such 'services' to be the fish and timber themselves. How environmental functions are to be valued will be discussed in the following section.

When use of one function is at the expense of another or the same function, or this threatens to be so in the future, there is competition of functions. As an illustration, once certain water pollutant thresholds have been exceeded, use of the function 'dumping ground for waste' may come to compete with the function 'drinking water'. In the case of overfishing, similarly, the function 'habitat for (one or more) species or ecosystems' comes to compete with itself, and the function may consequently get lost; many species and ecosystems of which they were a part, in other words many functions, have indeed already been lost. The function 'soil for cultivating crops' may be damaged by unsustainable use of the function 'supplier of timber', leading to loss of the function 'hydrological regulator' and subsequent erosion; it may also be in conflict with itself, when unsustainable farming methods lead to erosion and salinisation of the soil. The many functions of natural resources that threaten to get lost as a result of exhaustion of the source are in competition with themselves.

Competing functions are *by definition* economic goods. If, at a given level of technology, use of function A is at the expense of use of function B, greater availability of function B will lead, one way or another, to reduced availability of function A; conversely, more of A will lead to less of B. An alternative will always have to be sacrificed (opportunity costs) and consequently both A and B are scarce - and consequently economic - goods. Here, 'use' obviously also includes passive use such as designation of an area as a nature reserve, which thereby excludes other uses, following recognition of the right of other species to exist; the sacrificed use, or sacrificed alternative, constitutes the opportunity cost. Competing environmental functions, defined as environmental goods, form the theoretical backbone of the Sustainable National Income and its estimation.

In this way the environment, and environmental losses, acquires a central place in economic theory, in contrast to an approach whereby these losses are viewed as external effects. The subject matter of economic theory can then be formulated as follows: the problem of choice with regard to the use of the scarce, alternatively applicable, dead and living matter of our biophysical surroundings for the satisfaction of classifiable wants. Or, very briefly: arranging the dead and living matter of the environment according to

our preferences. This is argued in Hueting (1974) and, more extensively, in Hueting (1992b, 1995). One of the arguments can be stated succinctly as follows. In the literature external effects are defined, briefly, as unintended side-effects outside the market affecting third persons, non-market parties; for a more extensive definition, see Hennipman (1968). However, when a road is built through a nature reserve, or a sewer to a river, estuary or sea, and all citizens make equal use of the road or sewer, the same citizens nonetheless lose important functions, in part or *in toto*.

The availability of environmental functions is the degree to which those functions can be used for a given end. This depends on two factors: one objective and measurable, the other subjective and not directly measurable. *On the one hand*, the availability of functions depends on the quality, quantity and spatial extent of environmental elements such as water and soil, which are largely amenable to measurement in physical units, and on the likewise measurable functioning of systems, including, specifically, ecosystems and life support systems²⁰, or in other words on the state of the environment. Through (over-) use of a certain function the state of the environment may be altered, leading to reduced availability of other functions or of the same function: competition between functions. Whether this happens, and to what extent, depends on the preferences of the economic subjects. The availability of functions is thus also dependent, *on the other hand*, on subjective preferences, which are not directly measurable. In Hueting (1974) this is expressed in a system of co-ordinates with on the horizontal axis the availability of functions expressed in terms of a physical variable (parameter) and on the vertical axis the preferences and costs associated with restoration and maintenance of functions (see Section 3.3). *In this way the relationship is established between subjectivist economic theory and the measurable physical environment, or ecology.*

Three categories of competition between functions are distinguished: spatial, quantitative and qualitative. Spatial competition occurs when the amount of space is inadequate to satisfy existing wants, or threatens to be so in the future. For example, in many residential areas there is inadequate space to allow transport systems to operate and at the same time children to play in the street. Use of space for a wide variety of purposes, be it roads, agriculture or urban development, is at the expense of the function 'space for the existence of natural ecosystems'. Spatial competition is probably the main cause of species extinction, through loss and fragmentation of habitats. Everything points to this process continuing in accelerated tempo unless drastic measures are taken. Conservation of natural species is a key criterion for estimating the SNI according to Hueting (see Section 3.5).

²⁰ Life support systems are understood as the processes that maintain the conditions necessary for life on earth. This comes down to maintaining equilibria within narrow margins. The processes may be of a biological or physico-chemical nature, or a combination thereof. Examples of biological processes include the carbon and nutrient cycles, involving the extraction of such substances as carbon dioxide, water and minerals from the abiotic environment during biomass creation, and the return of these substances to the abiotic environment during biomass decomposition. Examples of physico-chemical processes include the water cycle and regulation of the thickness of the stratospheric ozone layer. As the examples show, there is interaction between the processes, with the possibility of equilibrium being disturbed. The water cycle, for example, may be disturbed by large-scale deforestation.

In the case of quantitative competition, it is the amount of matter that is deficient or threatens to be so in the future. We are here concerned with natural resources such as oil, copper and groundwater, which are exhaustible and non-renewable on a human time scale or which cannot increase in quantity, such as water.

With qualitative competition, it is always one and the same function, the function 'dumping ground for waste', or much more accurately: 'addition or withdrawal of species and matter' which is in conflict with other possible uses such as 'drinking water', 'physiological functioning' and 'habitat for species'. The introduction of agents into the environment (water, soil and air) or their withdrawal from it, in the course of a given activity, alters the quality of these environmental media, and as a result other uses of them may be disturbed or rendered impossible. Here, an 'agent' is defined as an a-biotic or biotic element or amount of energy (in whatever form) introduced into or withdrawn from the environment that can cause loss of function. Thus, agents may be chemical substances, plants, animals, heat, ionising radiation and so on.

Competition between functions is a manifestation of the finite nature of the environment, and to trace this competition in appropriate matrices is to expose the underlying conflicts. This has been done by Hueting (1974a). The conflict proves to lie almost entirely in the use of environmental functions for production and consumption, and growth thereof, in the here and now, at the expense of other desired uses and of future availability of environmental functions, including those functions necessary for production and consumption. In other words, the conflict boils down essentially to a question of sustainable versus unsustainable use of environmental functions. An elaboration for the use of the functions of a rainforest has been published by Hueting (1991).

For a proper understanding of the economic aspects of the environment it is instructive to compare the concepts outlined above with the concepts traditionally used in economic theory. This is no more than a metaphorical exercise, however, as the two categories of concepts are ultimately incompatible. Thus, some functions of the biophysical surroundings can be seen as consumption goods. Examples include: 'air for physiological functioning (breathing)', 'water as raw material for drinking water' and 'swimming water'. Other functions can be viewed as production means, such as 'water for irrigating crops' and 'gene pool for breeding and modifying crops and livestock'. However, 'normal' consumption goods and production means have to be reproduced over and over again, while environmental functions remain, in principle, freely available. Only if they come to compete, with each other or with themselves, e.g. if certain thresholds are exceeded, does their continued availability require a sacrifice. Finally, what was termed 'the non-manmade biophysical surroundings' in Hueting (1974) is now often referred to as 'natural capital'. This, too, is instructive, but once again there is an anomaly: 'normal' capital goods wear out, but natural (or environmental) capital does not, in principle. Below, we shall use the two terms synonymously, however.

These differences in terminology make no difference when it comes to the valuation method elaborated below, in Section 3.3. After all, capital goods derive their value from the value of the consumption goods they are used to produce, and thus ultimately from preferences for these goods. Similarly, environmental capital, or the biophysical surroundings, derives its value from the value of its possible uses, the environmental functions, and thus from preferences for these functions. The elimination measures are of

course always aimed at conserving water, air, soil, ecosystems, etc., and thus at natural capital as the vehicle of the functions.

3.3 Demand and supply method (DSM) for valuation of environmental functions

In Hueting (1974a, 1992b, 1995) and Hueting *et al.* (1992, 1998) the view is defended that there can in principle be only one method for the valuation of environmental functions and their loss. It is argued that what are presented as different valuation methods are in fact valuation techniques that form parts of this one method. The method may yield widely varying results, however, mainly because assumptions must generally be made regarding preferences (the demand side). If these assumptions are made explicit, environmental valuation can yield comprehensible and valuable information. If they are not, as is all too frequently the case, the widely varying results will probably not be taken seriously by serious people. On the cost (supply) side there may be differences too, but these are generally made ‘automatically’ explicit in the presentation of cost estimates; here, the degree of difference is less dramatic. This position has been further elaborated by Hueting and De Boer (1999), in a parable of a carpenter who measures the area of a room, using different methods, with results varying by a factor of 10, 50 and more, as is the case with the various methods currently in sway for valuing the environment. The reasoning can be summarised as follows.

Environmental functions start out as free goods, available in abundance with regard to existing wants and consequently of zero value. The emergence of competition between functions marks a juncture at which functions start to fall short of meeting existing wants. The availability of functions or, in the terms of the System of National Accounts (SNA), their volume, decreases from ‘infinite’ (abundant) to finite (shortfall). Use that was initially free comes to require the sacrifice of an alternative. As a result, the shadow price of environmental functions rises, and with it their value, defined as price times quantity, from zero to positive. A *new category of scarce goods* has come into being. As the availability of environmental functions declines further, their shadow price continues to rise. This real increase in price and value reflects an increase in scarcity and thus a rise in costs or in other words: a decrease in wealth. After all, a rise in real prices reflects an impoverishment or, in terms of the SNA, a decrease in volume. A decrease in real prices reflects an increase in wealth or, in terms of the SNA, an increase in volume. The concept of ‘volume’ has two aspects, quantity and quality; in the elucidation below, for the sake of brevity we shall consider only the former.

Increases in volume are the result of increases in labour productivity, due in turn to technological progress: a greater volume of goods can be produced per unit labour, and the real price per unit product consequently falls. Conversely, a decline in volume results from a decline in productivity, measured in terms of produced goods, which is what follows from internalising the costs of the measures taken to restore unaccepted loss of environmental functions (see Section 3.3.1). From this it follows that, in the view presented here, any adjustment of national income for losses of function will comprise only subtractions, and no additions. This is for a simple reason: losses of function are not written off when they originate, so restoration (and compensation, etc.) may not therefore be written on, for this would result in asymmetric entries, rendering inter-year comparison

impossible. Environmental functions fall outside the SNA (Tinbergen and Hueting, 1991). As long as these are free or virtually free goods (see above), neither can they indeed be entered in the accounts, because their shadow price is zero, or approximates zero. In the SNA, and in fact throughout the economy, it holds that the sum total of values (added to the biophysical surroundings; see Section 3.2) equals the sum total of revenues equals the sum total of costs. Evidently, this holds likewise for environmental functions. Because the environment falls outside the SNA, however, so too do losses of function (costs) as well as the restoration and maintenance thereof (revenues). The unrecorded losses of function (costs) can be incorporated in the national income by way of entering the opportunity costs required for restoring that part of the loss of function that is not accepted; what loss is deemed unacceptable depends on the preferences (see Section 3.3.1). In this way a 'green' national income comes into being alongside the standard national income. In accordance with the aforementioned basic rule, the revenues in the form of restoration of functions are equal to the costs of restoration, but remain invisible, because the environment remains outside the system. These *are* recorded in physical terms, however; see Figure 3.1 in Section 3.3.1. We shall return to this point in Section 3.4.4.

As long as one form of use of our biophysical surroundings is not hampering another, an insufficiency of labour (intellect) is the sole factor limiting sustained production growth. As soon as one use is at the expense of another, though, or threatens to be so in the future, a second limiting factor is introduced. Labour is then not only reducing scarcity, but is also creating new scarce goods: formerly free, or less scarce, environmental functions. Similarly, consumption is then not only satisfying wants, but is also cancelling out such satisfaction. Labour and consumption, besides having a positive effect on welfare (more produced goods), also have a negative effect (diminished environmental functions). These losses are not entered in the System of National Accounts (SNA), nor in the majority of cost-benefit analyses (CBA). Over and against the unentered costs stand the revenues (more produced goods), which *are* entered. The question arises: what is the result on balance?

In the view presented here, the answer is given in four steps, in which the calculation is gradually built up, without suggesting any sequence of calculation. The first two steps constitute a partial approach and are described essentially in Hueting (1974a). Additions introduced in later publications are included in the following brief review. The third step embodies a macro-approach based on environmental economic growth theory as developed by Stiglitz (1974), Hartwick (1977, 1978) Dasgupta and Heal (1979) and others. Step four is the setting up of a system of reliable, and thus reasonably detailed, inter-linked environmental economic models with which to carry out valuation based on the principles deduced in the previous steps. The third and fourth steps have been elaborated and discussed in a number of internal Statistics Netherlands papers, correspondence with colleagues and several publications (De Boer *et al.*, 1994, 1995, 1998; Brouwer and O'Connor, eds., 1997).

The basic point of departure is the same for all four steps. If there are no preferences for a good, its value is zero, irrespective of how important, or even indispensable, that good may be for humankind. If a good can be obtained without sacrificing an alternative, its value is likewise zero. In valuing environmental functions, both preferences and costs must be quantified. These are therefore two inseparably linked elements of the valuation of environmental functions and their loss. This is why the method is known as the De-

mand and Supply Method, or DSM, a name adopted only late on in its development (in 1996). Valuations that are, ultimately, estimates of only preferences (demand) or costs (supply) are here viewed as techniques forming part of the single valuation method presented here.

With respect to the economics of the environment we are concerned almost always with the choice between produced goods and environmental functions. If valuation is to be of use in making such choices, the two categories of goods must be expressed in the same unit. For environmental functions this requires the construction of shadow prices comparable with the market prices in which produced goods are expressed, that is shadow prices without a consumer's surplus. To establish the total economic value of the two categories, given by BCGR in the Figure 3.1, below, which does include the consumer's surplus, requires very extensive survey campaigns, for both categories. Overall, the results of such an exercise are of dubious reliability. This holds particularly for the vital necessities of life such as food, drink and medical care, for the intramarginal utility of these goods includes the utility of the first slice of bread, the first sip of water, and the saving of a life (Hueting, 1974). It holds in equal measure for the vital environmental functions (Hueting, 1989, 1992b, 1995; Geurts *et al.*, 1994; Hoevenagels, 1994). In practice, therefore, we consider it necessary to define value as (shadow) price (marginal utility) times quantity, determination of which requires data on both preferences and costs.

3.3.1 Valuation on the basis of revealed preferences and known elimination costs

As a *first step* in the chain of reasoning, the line is taken that all preferences for environmental functions can be expressed in the marketplace or, as a complement to this, be discovered by means of surveys. On a system of co-ordinates function availability is recorded on the horizontal axis, in physical units, with the preferences and annual costs of the measures to restore functions being plotted on the vertical axis. See Figure 3.1. Two cost curves are constructed. The reduction of the costs plotted on the one curve constitutes the benefits accruing from the increase of costs plotted on the other; see below. The aim, now, is to find the minimum total cost, or in other words the point where the difference between benefits and costs is maximum.

The first of these two cost curves consists of the sum total (without double counting) of all expenditures, actually made or yet to be made, by whatever party, resulting from loss of environmental functions and of the expenditures that people state they are willing to make to regain these functions (willingness to pay and to accept surveys, i.e. contingent valuation). As stated in Hueting (1974a, 1989, 1992b, 1995), surveys prove to yield unreliable results for precisely the most vital functions. The costs actually incurred fall into four categories. (1) Expenditures on measures to compensate for loss of function, such as the raising of dykes as a result of disruption of various functions regulating hydrology and climate, or on preparing drinking water as a result of over-use of the function 'dumping ground for waste'. These are the compensation costs. (2) Expenditures, actually made or yet to be made, relating to damage, such as housing damage and harvest losses caused by flooding due to loss of the function 'hydrological regulation' of forests and soil, and production losses and medical costs ensuing from, say, loss of the function 'air for physiological functioning'. This is the financial damage. (3) Travel expenses incurred

in going ever further to enjoy nature. (4) Ricardian rent paid via the price of raw materials.

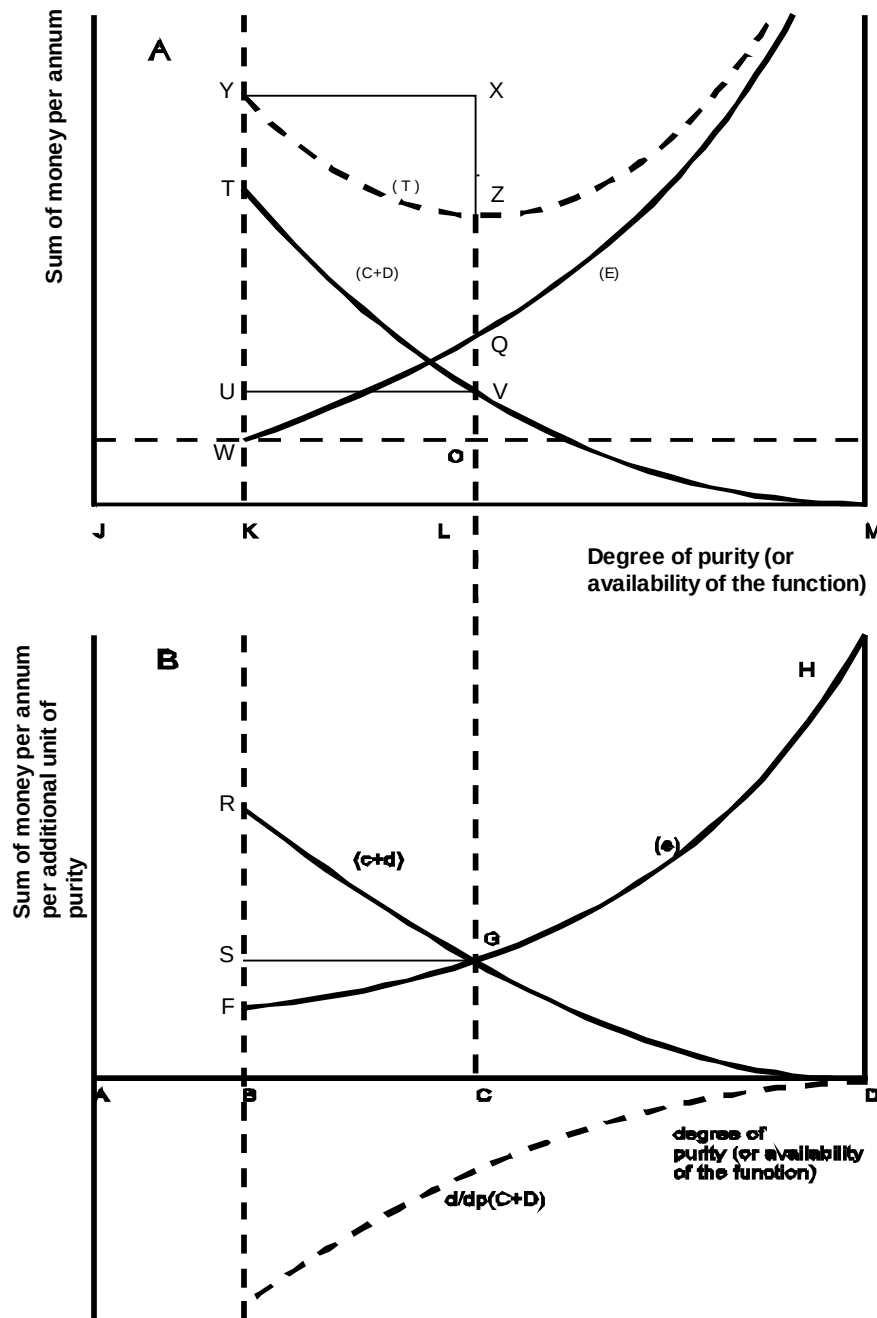


Figure 3.1 Cost of elimination and revealed preferences for an environmental function. Above: total curves; below: marginal curves. *E*, elimination costs, $(C+D)$, compensation and (financial) damage costs, *e*, marginal elimination costs, $(c+d)$, marginal compensation and (financial) damage costs. Taken from Hueting (1974a).

All these amounts can be interpreted as expressing revealed preferences for the original functions, so that the negative first derivative of the cost curve built up from these amounts can be seen as a collective demand curve for environmental functions (see Figure 3.1): the first derivative lying in the fourth quadrant is reflected to the first quadrant [$-(d/dp)(C+D) = +(c+d)$, where the symbol p represents purity]. For category (2) this is based, strictly speaking, on the assumption that those suffering damage through loss of a function are prepared to pay at least the amount required to restore that damage in order to achieve restoration and lasting availability of the of the function in question. The curve has the same shape as a normal demand curve. With decreasing availability of the function, progressively more compensation measures must be taken and progressively more financial damage occurs: the price (and thus the marginal utility) increases.

The second cost curve is built up from expenditures on measures, to be taken by whatever party from the year of investigation onwards, which increase the availability of the original functions. This can only be achieved by eliminating the cause of loss of function and, where necessary and feasible, by neutralising the accumulated impact of earlier environmental burdening *in situ*. For this reason this curve is referred to as the elimination cost curve (or abatement cost curve). The measures involved thus eliminate the source of the loss of function, i.e. the environmental burden, permitting partial or complete restoration of the function in question. They are, of course, arranged in order of increasing cost per unit of environmental burden eliminated. The measures consist of: (1) technical measures, including process re-engineering, redesign and developing and applying (renewable) substitutes for non-renewable resources (e.g. solar energy, glass fibre), (2) direct shifts from environmentally burdening to less burdening activities (reallocation), (3) a shrinkage of economic activity, with employment remaining unchanged (more leisure time) and (4) a decrease in the size of the population. No pronouncement is made as to the time frame within which these measures are to be implemented, as will be clear from their nature. Whether, and to what extent, they are indeed implemented depends on the preferences, in other words on the position of the demand curve. The cost curve to emerge from this procedure may be considered as a supply curve, because the measures act to make available, or supply, environmental functions. From how the curve is built up it follows that it is a collective supply curve. The sum of the elimination costs is equal to the sum of the prices of the production factors that must be withdrawn, by a variety of routes, from the production of consumption goods and budget goods in order for functions to be restored. The curve rises progressively from bottom left to top right. The further a function is to be restored, the more efficient the measures must be. This is generally accompanied by progressively rising (marginal) costs per unit avoided environmental burden.

As we move further up along the elimination cost curve, we automatically move further down the curve of compensation and other costs: as the original functions once again become more available, the necessity of such expenditure decreases. It is this reduction in compensation and other costs that constitutes the benefits accruing from the expenditures made on elimination measures. By summing the two curves a U-curve is obtained; see Figure 3.1. The minimum of this U-curve reflects the position of optimum function recovery, for here the total social costs are minimum while the difference between total benefits and costs is maximum. The minimum of the U-curve corresponds to the point of intersection of the first derivatives of the two curves, i.e. of the marginal supply and de-

mand curve. This point of intersection would reflect the shadow price that we are seeking and that can be compared directly with the market prices, *provided* all preferences for environmental functions were reflected in the demand curve constructed as described above. The shadow price (CG in Figure 3.1) simultaneously determines the value of the environmental function as well as the unaccepted costs of function loss. The residual function loss, recorded in physical terms, reflects the costs that *are* accepted: the associated increase in production (which is entered in the national accounts) is valued more highly. Like any price, the shadow price of an environmental function is an indication of its marginal utility.

To value is to compare. In economics, there is no such thing as an absolute value; a good can only be worth more or worth less compared to another good. Because what is always at stake is a conflict between the environment and produced goods, as we have seen above, the value BCGS (or BCGF; see below) in Figure 3.1 gives us precisely what we need for making the inevitable choices involved in this conflict. At the same time, shadow prices that can be compared directly with market prices are also a necessary precondition for adjusting the Standard National Income for environmental losses. BCGS (or BCGF) comprises no consumer's surplus, for example, just like market values. Other conceptions of the valuation of environmental functions exist, however, and these will be discussed below.

Now consider Figure 3.1 again. The shadow price (partial, see above), directly comparable with the market price of a produced good, equals CG. The cost that must be incurred to achieve the optimum, and thus the value of the function, is given by BCGF, corresponding with the line OQ. BCGF simultaneously indicates the value of the function, comparable with the market value of produced goods. As stated in Section 3.2, value should be shadow price times quantity, or in other words the area of BCGS. In Hueting (1974a), from which Figure 3.1 is taken, the producer's surplus was neglected. This is not essential, however. Now, the total value or benefits is equal to the increase in monetised total utility as one moves from B to C = BCGR = line section TU. *This thus includes BCGF as well as BCGS.*

FGR = monetised net increase of utility gained as the availability of a function increases from B to C = line section ZX. This net increase equals the total increase in utility BCGR minus the costs BCGF. This must always be a positive number, because there is a change from sub-optimal to optimal.

Further on in the aforementioned exposition of Hueting (1974a) a second step is made: the demand curve ($c+d$) in Figure 3.1 moves to the right and is then termed ($c+d+x$); x is not shown in Figure 3.1. If x is large (but unknown; *ergo* x) and ($c+d$) is situated far below ($c+d+x$), then the bulk of FGR (after neglecting the producer's surplus) consists of what can be called the consumer's surplus, although we would rather refer to FGR as 'net benefit' or, because x represents an assumption about preferences for a function, as 'meeting an assumed demand'.

Erroneously, some authors (e.g. Costanza *et al.*, 1997; Opschoor, 1997) refer to FGR as 'the value'. Erroneously, because net increase in utility after reallocation (of resources and capital goods) and value are of course two entirely different things, while it is clearly 'value' that these authors are after. Certainly, comparison of FGR with costs may be a useful tool for deciding whether or not to go ahead with a given project - if a reliable demand curve is available, that is, for that is often not the case. But that 'value' is a very different concept

can be readily understood with reference to a produced good with a very low consumer's surplus and a high price; few people will hold that surplus to be the value of the good.

3.3.2 Extension with assumed preferences for environmental functions

The *second step* in the reasoning behind our method is the following. It can be plausibly argued, for a variety of reasons, that preferences for environmental functions can be expressed only very partially through the mechanism of the market and that questionnaire-type surveys cannot provide reliable answers when it comes to the most vital functions, i.e. those on which the lives of future generations are dependent (Hueting, 1974a, 1989, 1992b, 1995; Bateman and Turner, 1992; Hoevenagel, 1994a-c; Geurts *et al.*, 1994; De Boer *et al.*, 1995). As an example of compensation costs (as revealed preferences) there is no point in creating new forests or lakes so long the process of acidification has not been halted by elimination measures. Erosion-driven soil loss cannot be compensated. Much of the damage resulting from loss of functions will take place in the future; cases in point are damage due to disruption of climatic stability and to the loss of the functions of natural ecosystems such as rainforests and estuaries. No financial damage or compensation expenditures can therefore arise in the present. Choosing a discount rate, for instance the market interest, for calculating the net present value of future damage boils down to making an assumption about preferences for future environmental costs and benefits (Hueting, 1991). This does not, therefore, resolve the basic problem of preferences being unknown. We cannot base ourselves on observed individual behaviour, furthermore, given the working of the Prisoner's Dilemma. In practice, individuals do not switch to environmentally sound behaviour, because they doubt whether others will do the same, as a result of which the effect is thought to be negligible while the individual concerned causes him or herself detriment. The same holds at a meso and macro scale. If one company takes measures to protect the environment but others do not, it will price itself out of the market. If a given country adopts measures and others do not follow, that country will suffer damage, while the effect of those measures will be insubstantial. *All these aforementioned factors, which make it impossible and very difficult respectively to fully express preferences for environmental functions, we shall call blockages.* These blockages play an important role in Section 3.4.

The shadow prices we are seeking thus remain largely unknown. This has two consequences. First, the value (or relative scarcity or marginal utility or correct price) of the goods produced and consumed at the expense of scarce environmental functions remains likewise unknowable; this value differs from product to product, moreover (Hueting, 1974a). Second, we cannot escape from making *assumptions* about the urgency of the preferences for present and future availability of environmental functions (e.g. Hueting *et al.*, 1992, 1995, 1998; Hueting and Bosch, 1994). This obviously holds in equal measure for cost-benefit analyses as well as for adjustments of national income for environmental loss. *When making such assumptions, the optimum described above is once again valid, as is the shadow price that is directly comparable with market prices, at the point of intersection of the supply and demand curves.*

In practice, an assumption regarding preferences can take the form of standards for the availability of environmental functions. We can imagine certain situations in which such is indeed the case. If there is some kind of 'survival minimum' for the function, the de-

mand curve will become very steep near the minimum. It makes no difference, in principle, whether this minimum is below or above the current level of the function. If prices are high, however, the demand curve must bend towards the vertical axis, because it is impossible to sacrifice more income (goods) than is produced. The further to the right the urgently desired level lies, therefore, the shorter the vertical section of the curve will be. If it is plausible that the steep section of the curve will intersect the supply curve (marginal cost function), the demand curve can be replaced by a simple standard at the point of the urgently desired function level; this does not affect the outcome. Something similar holds if the demand curve is simply not well known but a reasonable assumption can be made about the position of the optimum and thus also of the optimal level of the function. That function level then becomes the standard. A special case arises if preferences for consumption and use of the environment in the future are far more urgent than those for consumption and use of the environment now (*cf.* the discussion of sustainability, below). In theory, the optimal function level is a characteristic of the sustainable path that can be found by optimising a dynamic macro-economic model; in practice, however, this is a calculation that is well nigh impossible to perform. Fortunately, the position of the optimum can be estimated (see third step, below).

From the above it follows that there are as many values for environmental functions as there are assumptions regarding preferences and, *ergo*, as many green national incomes, too. We understand 'green national income' to mean the national income in a situation in which preferences for environmental functions and produced goods are fulfilled as satisfactorily as possible. By this we mean that welfare is limited only by the technological state of the art in the year for which calculations are being made, and not by the aforementioned blockages; these are assumed to have been entirely overcome²¹. We thus base our calculation of an SNI on the assumption of preferences existing for the continued availability of vital environmental functions; an SNI is therefore a special case of a green national income. As long as the assumptions are made clear and explicit, the ensuing valuation exercise can yield valuable and comprehensible information.

3.3.3 Generalisation in dynamic environmental economic theory

As a *third step*, the theory presented above is generalised in a macro-economic sense by taking a systems approach. This step is necessary because the measures occurring in the calculation of green national income cause such a large change in the pressure on the environment that all variables change as a result, including the prices of market goods, budget goods and environmental functions. In other words, the *ceteris paribus* condition of the previous steps no longer pertains. The applied systems approach starts from the notion that all relevant interacting processes in society and the environment can, at least in principle, be modelled as mathematical relations between variables that can be combined in one comprehensive model. Meadows (1972), Stiglitz (1974), Solow (1974), Weitzman (1976), Hartwick (1978), Dasgupta and Heal (1979), Mäler (1990), Asheim (1994), Pezzey (1994) and Vellinga and Withagen (1996) are among those who have led the way in this approach.

²¹ Another, frequently employed definition of green national income is the monetary welfare measure corresponding with the assumed preferences and is related to the green national income as we define it. We shall return to this point later.

This step leads to a generalised model of an economy consisting of a series of production activities and groups of consumers, each using both short-lived and long-lived (i.e. capital and durable) goods and services and each using the environment. These actor groups apply technical measures to reduce pressure on the environment and slow down or halt its deterioration. These measures require labour, capital goods, matter and energy flows. Outputs and consumption activities are dependent on all these inputs.

The assumption that (partly assumed) preferences are fulfilled in the best possible way, given the other data, relations and assumptions of the model, is often formalised in economics as the concept of all people maximising their welfare. A person's welfare is not a physiological or psychological quantity amenable to direct measurement, but a theoretical internal model variable in which the products and environmental functions the person uses are weighted according to his or her (estimated or assumed) preferences. In calculating a person's welfare, allowance is made for the fact that the weight someone assigns to a product or function is influenced by the available quantities of all other goods and functions. The calculation of an individual's welfare from the quantities of products and environmental functions that he or she uses and wants to use in the future is described in a mathematical relation called the individual welfare 'functional'. It follows that individual welfare merely reflects the ranking of the combinations of products and functions considered in order of their desirability to the person in question. Consequently, all individuals are assumed to maximise their welfare.

We simplify matters and consider society as a whole, maximising so-called social (or collective) welfare, or welfare in short, which reflects the ranking of the packages of products and functions that are used by the sum total of individuals in a society. Like individual welfare, social welfare is of course not directly measurable²². When the model is solved and the model variable called welfare is used as an outcome, it cannot therefore be anything but a welfare *indicator*.

As both present and future product flows and function levels are weighted in the welfare indicator, this is sometimes referred to as 'intertemporal welfare' as opposed to 'instantaneous welfare'. These terms may be confusing. 'Intertemporal' welfare at any given time may instantaneously rise (because people 'feel' instantaneously better) if a future risk is judged to have become smaller than it was. Here, 'instantaneous' denotes an aspect of 'intertemporal' welfare. From now on, however, we shall distinguish 'instantaneous welfare' in any given year from welfare in the general sense in that year; this may be somewhat inelegant, but it is in accordance with the literature. Instantaneous welfare at a particular moment in time is the result of weighting all product flows and functions levels that are *used at that moment*, provided this weighting can be isolated from the intertemporal weighting. Welfare in the general sense is in that case the result of the

²² From a systems theory point of view, personal or social welfare is 'observable' in most models, that is, it can be reconstructed from the model's input and output variables, like an individual's or society's actions, respectively. Therefore, 'observable' welfare can also be reconstructed from data on these variables. In reality, data are only available for actually measured (observed) environmental economic development and therefore only allow reconstruction of the small Section 3. of the welfare 'functional' in the neighbourhood of the data. The result of this 'functional' is still an ordinal quantity, reflecting the fact that it cannot be directly measured.

weighting of the instantaneous welfare levels in the present and all future moments, i.e. intertemporal weighting.

Like welfare, production output is described as non-linearly dependent on inputs. Though it is questionable whether all non-linearities in the production functions hold in the long run, the general form is non-linear.

In general the model is dynamic, as it describes the effects of changes of economic and environmental stocks on other parts of the system. Economic stocks consist mainly of capital goods and durable consumption goods, while environmental stocks are quantities or concentrations of environmental resources and levels of pollutants, biota, available land and so on. The magnitudes of these stocks are so-called state variables and how they develop in time largely determines the solution of the model. The processes described by the model influence how these stocks vary, thereby producing patterns of inertia that are characteristic of the model. One result is that realistic model solutions as responses to sudden man-made changes are always gradual, and therefore always follow continuous *paths* in the space of the state variables (state space). Each set of assumptions concerning the representation of real processes in the model, parameter values and input data produces a path. Welfare is maximised by determining the ways in which controllable human actions depend on time and this process selects one optimal path for each set of assumptions, parameters and input data applied. For our purpose, it suffices to plot such a path in terms of certain characterising variables, such as a welfare indicator, or benefits and costs, just as Figure 3.1 presents these variables for different static (i.e. time-independent) situations.

Several of the aforementioned authors have sought welfare indicators that can be related to national income. Brouwer and O'Connor (1997), Zeelenberg *et al.* (1997) and De Boer *et al.* (1995, 1998 and in preparation) have reviewed their efforts. We shall elaborate this subject in Section 3.4.

3.3.4 Practical model system

In the previous section the calculation procedure is described in generalised terms, proceeding from standard economic theory. For such a calculation to be reliable, a large dynamic model is required that comprises all the relevant processes in both the economy and the environment. Welfare must be maximised within this complex model, yielding an optimal path, in our case a sustainable path. This appears to be an impossible task, given the capacities of standard computing hardware and software. We therefore opt for an approach using a set of interlinked models rather than one all-embracing model; this is our *fourth step*. The economic activities of production and consumption are represented in one model, and additional models constructed for each of the various environmental problem areas. Ideally, information should then be transferred back and forth between the models in a process of iterative exchange. To avoid tedious iterations with the total model set, we have reduced these interactions to one-way information flows, i.e. to one-time operation of each model for a given period. This means that the overall optimum, i.e. the optimal path, can be calculated only approximately, as opposed to the case with the theoretical comprehensive model. We have opted to achieve a reasonable approximation by assuming that the optimal function levels of the theoretical model (*cf.* 5.3) can be formulated in words and/or roughly quantified. It is further assumed that the levels of the

state variables of the environment (quantities, qualities such as concentrations, space) corresponding to the assumed optimal function levels can be estimated, at least to within some range, on the basis of expert opinion or by using appropriate standards for the state of the environment. These standards are then entered as constraints in the model of each environmental problem, and standards for allowable environmental pressures (emissions and so on) are then derived by iteration. These pressure standards may be functions of time. However, the pressure levels associated with overall sustainability must be capable of being maintained forever and therefore these (constant) levels are independent of time (cf. 6.5 and 6.6). The standards are then entered as constraints in the economic model. In this step it is decided which technical measures, which direct production shifts and which levels of production shrinkage and population reduction are to be taken to arrive at the standards and, subsequently, what national income results from these actions at the time of interest, i.e. the year of investigation.

3.4 Ins and outs of a green and a sustainable national income calculation

Four main subjects are reviewed in this section. First it is explained that each different set of assumptions regarding preferences for environmental functions and blockages preventing their expression forms a specific case, for which the model (or model set) computes an optimal development path of the economy and the environment. Second, we show that two significant *welfare indicators* and a *green national income* can be calculated for each path, and how they are related. Third, we argue why we opt for green national income as a practical welfare-related indicator. Finally we focus on a special case: sustainable national income.

We work towards these goals by discussing a series of cases of increasing relevance to our problem: (1) preferences for environmental functions are unimportant because functions are abundant; (2) functions are scarce and preferences are such that the optimal path (computed by the model) approximates the actual path; (3) preferences for the environment are stronger than in the second case, but there are blockages preventing their full expression; (4) preferences are as strong as in the third case, but the blockages have been overcome; and (5) the special form of the last case in which preferences for sustainability are general and dominant. These cases are considered in Sections 3.4.1 to 3.4.5, respectively.

This staggered approach also enables several other issues to be explained: the difference between the welfare indicator on the actual and the optimal path; the difference in national income on the two paths, i.e. the opportunity costs; the part played by technical measures, production shifts and other measures in these costs; the prices to be used in calculating these costs; the nature of sustainability; and the existence of feasible transition paths to - for instance - sustainability. We shall discuss only the main features of these issues, referring for details to the literature as appropriate. De Boer *et al.* (forthcoming) gives a mathematical exposition of the argumentation.

3.4.1 Environmental functions not scarce

Consider an imaginary country (or a real country in the distant past) where people value the present and future availability of environment functions, but where these functions

are abundant. The situation is then relatively simple. As explained in Section 3.3.3, a welfare indicator can in theory be calculated using a model of the economy including its interaction with the environment. This indicator, which we shall call v , depends in this straightforward case only on present and future consumption of man-made goods and services. Welfare must, of necessity, be maximal in both the actual and the model economy. The actual and the model path consequently roughly coincide. If the model is 'correct', therefore, maximisation of its welfare indicator will result in a model solution, or model path, that approximately reconstructs the actual development of the economy in this imaginary country. In particular, this means that the quantities of selected groups of man-made goods consumed in a series of historical years should be 'adequately' approximated by the model's consumption variables over these years. As a by-product, the welfare indicator is calculated in a fashion entirely consistent with the adopted assumptions on preferences.

In this case several convenient simplifications can be made. Calculation of the welfare indicator including the future (in the welfare 'functional') generally involves the use of different discount rates for different consumption goods. These rates may even depend on the length of the period between the future and the present year, i.e. on time. If *the same discount rate* is used for all consumption goods, the welfare indicator *on the optimal path*, in this case the current path of the economy, may be written as a sum of various kinds of terms. The consumption of produced goods (c) in the year of investigation is represented by the instantaneous welfare term, evaluated for that year. The consumption of products in the future is represented by the increases in the stocks of produced capital goods in the present year (dk/dt), each stock change weighted with its own 'welfare shadow price'. Additional terms occur if parts of the model are explicitly dependent on time, i.e. on time-dependent influences from outside the model ('exogenous' or input variables), such as a climate variable or a measure of technological progress. Some of these time dependencies can be avoided by making the influence an 'endogenous' variable, i.e. by extending the model such that the influence is the result of an internal process. The corresponding terms in the welfare indicator formula then disappear, being incorporated in other terms. Other time dependencies are often assumed away. We therefore concentrate on the terms due to immediate and future consumption, expressed in the consumption flows c and the rates of change of the capital stocks dk/dt , respectively.

A monetary welfare indicator proportional to the welfare indicator v can be computed by dividing the latter by the marginal welfare of some marketed product in the year of investigation. The outcome is entirely arbitrary, as it depends on the arbitrary reference level and units of the welfare indicator itself and the arbitrary choice of market good. Consequently, this result cannot be compared with national income. If there were a unique way of doing this, one would obtain the macro-economic equivalent of such monetary welfare measures as the 'real economic value' and consumer's surplus of a good. We assume this to be impossible and follow the literature in that the term in c , the instantaneous welfare function, is linearised. Thus an approximate welfare indicator is obtained in which the flow of each consumption good and the change of the stock of each capital good is represented by a separate term. Replacing the marginal welfare coefficients in all the terms by the prices arising from the model exercise (which approximate the market prices) yields an approximate monetary welfare indicator or 'monetary welfare measure', which we denote as w . We call these prices shadow prices. It is important

to note that, as a result of linearisation and expression in market prices, the macro-equivalents of the consumer's surpluses have disappeared from both the immediate consumption terms and the stock change terms of the welfare measure. The respective terms of this measure still constitute the contributions of present and future consumption to welfare in a given year. These terms now sum to the macro-totals of *consumption* plus *net investments*, in other words to *net national product* (or income): y on the model's optimal path (Weitzman, 1976). As a formula: $w = p(c + dk/dt) = y$. This model-calculated national income is a good approximation of real standard national income as calculated in the national accounts, provided the model and its optimal path are fair approximations of the present economy and its development. This implies that the prices are 'real' prices, insofar as they are free of inflationary or deflationary tendencies.

3.4.2 Relatively weak but perfectly expressed preferences for the environment

In a more realistic case than the last, the production and consumption of goods leads to direct or delayed damage to environmental functions, which consequently become scarce. Here, however, only moderate preferences for environmental functions are assumed, to such a degree that the model's optimal path ('*business as usual*', b in Figure 3.2) is a fair approximation of the current economic and environmental path ('*actual*', a). Although there are blockages preventing full expression of these preferences (Section 3.3.2), these are assumed to have a negligible effect. The national income computed by the model under the assumed preferences is formally a green national income, but is in this case a good approximation of standard national income; see Figure 3.2.

If the same discount rate is taken for all consumption goods and all environmental functions in the welfare function, the welfare indicator v calculated for this optimal path may be broken down into terms, as indicated in 6.1. Some of these terms may be explicitly time-dependent (see above). Some of the latter may now also stem from environmental sub-models. Both are again not discussed. Now the available quantities of both produced goods and environmental functions contribute to the welfare indicator. The available levels of consumption goods (c) and environmental functions (ϕ) in the year considered (the year of investigation) both contribute to the instantaneous welfare term. The rates of change of the modelled stocks, viz. of stocks of produced capital goods (dk/dt) and of levels of environmental functions ($d\phi/dt$), appear in the welfare indicator as well. Each change rate is weighted with its own factor that can be expressed in terms of marginal welfare. These stock changes represent the safeguarding of the consumption of produced goods in the future and the deterioration of the future potential for using the environment, respectively.

Having linearised the instantaneous welfare term in the welfare indicator v , we can once again obtain an approximate monetary welfare measure w , following the procedure described in 6.1. However, w now consists of the weighted sum of the available quantities of consumption goods (c) and environmental functions, and the rates of change of both the stocks of produced capital goods and the levels of the environmental functions; the weights are the *monetary shadow prices* (see 6.1). The expression for the welfare measure can be rearranged in such a way that the equality to net national income plus environmental terms becomes apparent. The latter are the contributions to welfare of available environmental function levels (ϕ), their rates of change ($d\phi/dt$) and several cost terms (these costs do not

cover all elimination, restoration and compensation costs and financial damage; for the sake of brevity we refer to De Boer *et al.*, forthcoming). The terms expressed in the function levels and the associated costs stand for the immediate use of environmental functions, as the term in c stands for the immediate consumption of products. Likewise, the terms in dk/dt and $d\phi/dt$ stand for the consumption of products in the future and the use of functions in the future, respectively. The latter term, consisting of the changes in environmental stocks, weighted with shadow prices, is analogous to the net investments term expressed in dk/dt and is therefore often referred to as the rate of change of ‘natural capital’.

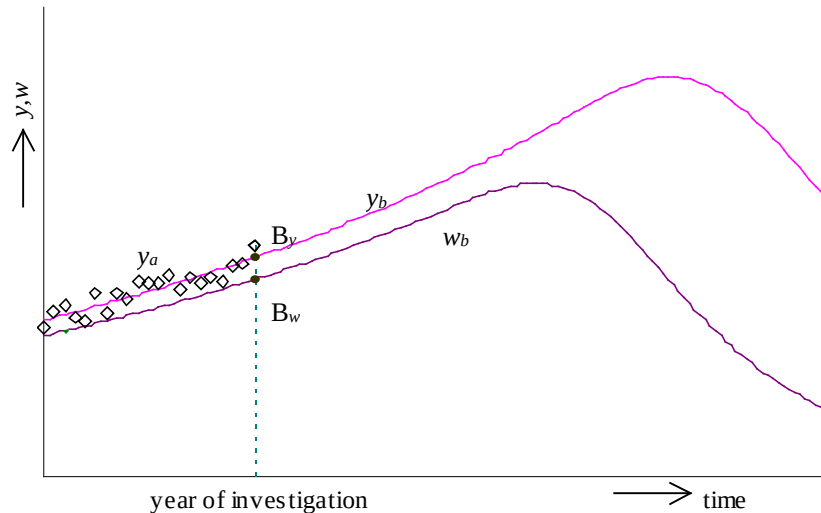


Figure 3.2 Standard national income (y_a) as measured in the System of National Accounts and its approximation and extrapolation on a ‘business as usual’ path (y_b) as computed with an environmental economic model with relatively weak but not blocked preferences for the environment, for a fictitious case; w_b is the welfare level on the ‘business as usual’ path. The collapse appears earlier in w_b than in y_b because in w_b the future is taken into account. The points B_y and B_w indicate the levels of national income y and the welfare measure w in the year of investigation.

After these simplifications, the shadow prices of the produced goods (c, k) used in the indicator are the model’s market prices of those goods. As the model’s *business as usual* path (b) is an approximation of the actual development (a), the model’s market prices are in this case approximately equal to the real market prices. Consequently, the model’s national income approximates standard national income as provided by the national accounts. If net national income is increasing at the expense of the environment, the shadow prices of the declining environmental function levels ϕ are positive and increasing, because the functions are becoming scarcer. The derivatives of the function levels with respect to time, $d\phi/dt$, are often negative because the functions are frequently on the decline, but their shadow prices are positive; see 5.3. This approach is proposed by Repetto *et al.* (1989, 1991), Mäler (1991), Landefeld and Carson (1994a,b), Hamilton (1995) and probably several other authors.

It may well be realistic to assume relatively weak preferences for the environment and to accept the correspondingly small difference between the monetised welfare measure and national income, as has been done in this case. This choice means assuming that people are either not aware of the possibility of serious losses of environmental functions in the future, or do not care. From 5.2 it follows that stronger preferences for environmental functions are equally plausible. Cases built on this assumption are elaborated below.

3.4.3 Strong but poorly expressed preferences for the environment

In this case, people are assumed to have stronger preferences for environmental functions than appear from the actual development of the economy; yet the model is considered realistic. This discrepancy is explained by the existence of blockages in society that prevent people's preferences for environmental functions from being completely expressed in their actions, as discussed in 3.3.2 and referred to briefly in the introduction of Section 3.4. These blockages can be modelled as additional constraints on welfare optimisation. The resulting optimal path is the '*business as usual*' path (*b*) that was also found as the optimal solution of the case presented in the former section, but which may now be referred to as the '*blocked path*'. Again, it approximates actual economic development and might be extrapolated into the future as an economic forecast (Figure 3.2). In this case, however, the national income associated with the path is *not* a green national income, because society's preferences for the environment are not expressed completely and immediately. We nonetheless prefer the procedure for calculating path *b* presented here (strong preferences, blocked expression thereof), because it allows us to keep the assumption on preferences the same, which allows this path to be compared with that from which our indicator is taken. This latter path is introduced in the next section.

3.4.4 Strong and perfectly expressed preferences for the environment; absolute optimum

The blockages preventing people from expressing their preferences for the environment in their actions can probably be overcome by a persistent, dedicated and broad policy, of which price instruments and awareness-raising are important constituent components. This may well be a lengthy process. Subsequently, social, production and consumption processes must be adapted to match the preferences. These adaptations will take the form of technical measures, production shifts, production shrinkage and measures to reduce population, as discussed in Section 3.3.1. Implementation of these measures will, again, take considerable time. Once the measures are in place the various pressures on the environment will be reduced. After delays that may again be substantial for some environmental processes, the state of the environment will return to more stable levels that under the assumed preferences form an optimal mix with the consumption and investment packages.

As the indicator we seek should be as transparent as possible, we make it independent of assumptions regarding the dynamics that determine the time lags in the adaptations just discussed. We assume – in a manner of speech – that these adaptations are started and completed all at once in the year of investigation. The result is an unfeasible 'leap' from the blocked path *b* to the unfeasible path *s* on which the assumed *strong preferences for the environment are perfectly and immediately expressed*, so welfare is absolutely max-

imum, given the technical possibilities at the present and as expected in the future (Figure 3.3). Despite the unfeasibility of the leap, this path is of great interest because it has a strong signal value, as a statistical orientation point or 'beacon' to head for when devising (environmental) economic policy, since it indicates the direction of perfect fulfilment of assumed preferences for the environment. The national incomes associated with the paths of this type are the *green national incomes* corresponding to the assumed (unblocked) preferences.

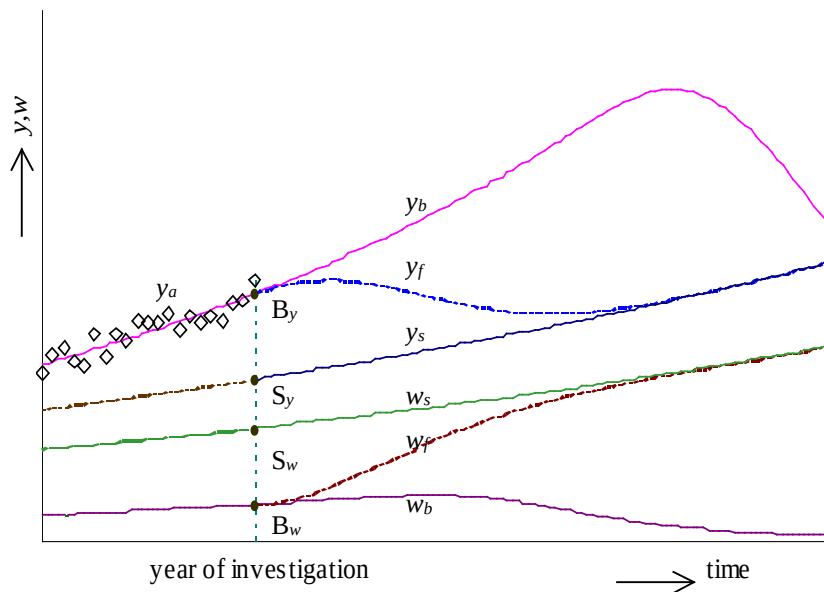


Figure 3.3 Actual standard national income observations (y_a , fictitious example) compared with the net national income (y) and a welfare indicator (w) on three optimal paths, calculated with a dynamic environmental economic model. The blocked path (index b) approximates the actual path (index a) by assuming incomplete expression of preferences for the environment. These preferences are assumed to be completely expressed on the unfeasible unblocked path (index s) and the feasible unblocked path (index f). The points B_y and B_w indicate the levels of national income y and the welfare measure w on the blocked path b in the year of investigation; S_y and S_w are the corresponding points on the unfeasible unblocked path s .

The stronger the assumed preferences for the environment, the lower the resulting green national income will be. It goes without saying that the green national incomes resulting from unblocked preferences are lower than the green national incomes resulting from blocked preferences. An example in which weak and blocked preferences for the environment are assumed is the analysis of Mäler (1991). The path of which 'our' SNI is a characteristic is one of the unblocked paths discussed here. This SNI path distinguishes itself from the other unblocked paths because adjustment of the standard national incomes in the successive years of investigation is based on the technology available in the respective year of investigation. This precludes the risk of extrapolated technological progress subsequently proving unattainable, with the attendant possibility of a collapse at some time in the future; cf. y_b in Figure 3.3. The SNI according to Huetting is lower than the other green

and sustainable national incomes and the unfeasible ‘leap’ is therefore greater - and substantially so. This is because the path to which this SNI belongs does not involve cheaper solutions to environmental problems being anticipated in the future, as with the other *s*-paths, so that the opportunity costs are higher. Nonetheless, this path is not the lowest conceivable, for - entirely in line with the notion of sustainability - this path is concerned solely with maintaining vital environmental functions. Noise nuisance (function: ‘silence as freedom from noise’) is thus not included, for example, to the extent that it does not damage health, because noise does not accumulate and does not therefore undermine the living conditions of future generations.

The path *s* is found in theory by assuming that the blockages of the preferences have been overcome (i.e. have disappeared) and by optimising the sizes of the modelled stocks in the year of investigation along with the measures that need to be taken in later years to maximise welfare²³. The stocks in the modelled production, consumption and social processes consist of capital goods, durable consumer goods, employment allocation and population size. The differences between these stocks on the blocked path *b* and the unblocked path *s* in a given year are caused by the *measures available in that year*, required to reach *s* from *b* outright in that same year. The consequence of the assumption of blockages being overcome from the year of investigation onwards is that technology on path *s* in the year of investigation must be the same as on path *b* in that year.

In theory, the environmental stocks at each point on path *s* are the result of welfare maximisation, as mentioned above. In practice, standards are derived or set for these stocks and related pressure standards are derived; the measures are selected on the basis of cost minimisation; see Section 3.3.4.

As just stated, welfare on path *s* is greater than on any other path. Figure 3.4 illustrates this point. The welfare indicator *v* and its monetary approximation *w* have the properties discussed in Section 3.4.2. Under the simplifying assumptions discussed there, the monetary welfare measure *w* is again equal to national income on the path, plus terms due to the immediate use of environmental functions in the year of investigation, plus terms due to their use in the future. The environmental terms take the form of the modelled environmental stocks and their rates of change, respectively, both valued at the model’s marginal prices, analogous to market prices, plus the costs of elimination and restoration measures, to the extent that these directly increase environmental function levels. The costs are a negative term of course. On the unblocked path *s*, the total term for future use of the environment, expressed in the rates of change of environmental stocks, is greater than on the blocked path *b*, while the total term for immediate use is probably of the same order of magnitude on both paths. Future use of the environment gains in importance if stronger preferences for the environment are assumed. On path *s*, the welfare indicators *v* and *w* are dominated by future use of the environment; this group of terms is related to the elimination costs. If these costs decrease with time, through technological progress, for example, the welfare indicators and national income increase, and vice versa. Comparing paths in any one year, however, for instance in the

²³ The unblocked path can be thought of as a rough approximation of the course economic development would have hypothetically taken if society had overcome its blocked preferences at the (likewise hypothetical) moment in the past when the environmental functions grew scarce, with technological development following the actual historical course, which is hypothetical indeed.

year of investigation, shows that national income decreases while welfare increases, and vice versa (Figure 3.4). This can be explained using the terms of the monetary welfare measure, as was done in Section 3.4.2.

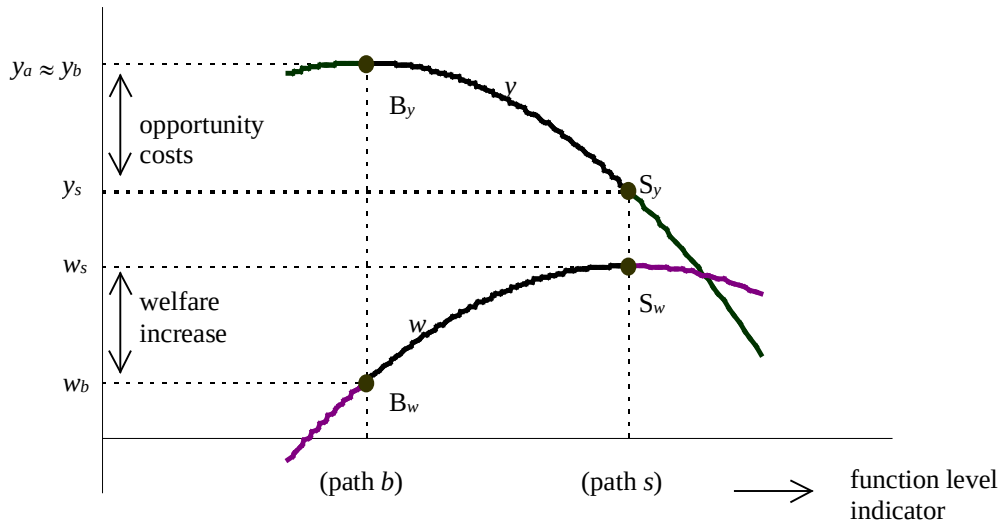


Figure 3.4 Net national income (y) and the welfare indicator (w) in a (historical) year of investigation on the blocked optimal path (b) and the unfeasible unblocked path (s); y_a is the observed standard national income in that year. The points B_y , B_w , S_y and S_w correspond to those in Figure 3.3.

Welfare measure versus green national income

Unfortunately, the simplifying assumptions under which the welfare indicators behave so obligingly do not always apply. More important, the comprehensive dynamic environmental economic model required to perform a sufficiently realistic calculation is so complex that we are obliged to use a set of co-ordinated models instead of one comprehensive model, which, strictly speaking, makes welfare maximisation impossible. Consequently, standards for function levels cannot be obtained from the optimum but have to be approximated; see Section 3.3.4. Although it is, in principle, feasible to subsequently calculate the monetary welfare indicator w using the solution of this model system, this is still a complex task, while it probably cannot be checked whether the presented indicator really represents the maximum for the calculated path.

Another problem stems from our goal, which is to include the environment in national income in order to make this a more complete welfare indicator and one that can be compared with standard national income. This indicator consists of standard national income plus appropriate environmental terms. Comparing the values of this indicator on the blocked path b (w_b) and the unfeasible unblocked path s (w_s) does not involve any direct comparison with standard national income, however. Standard national income on the actual path a (y_a) or its modelled approximation on path b (y_b) can only be compared with national income on path s (y_s), i.e. with the green national income corresponding with the assumed preferences. Green national income y_s is lower than standard national income y_b , because of the opportunity costs of the required measures (see Figure 3.5).

Welfare increases as a result of the ‘leap’ from path b to path s . Comparing the two paths b and s at any given time, a decrease in national income is found to be accompanied by an increase in the welfare indicator. The comparison shows the gap between the two paths in terms of the opportunity costs; this is a very important measure in practice, which is relatively easy to explain. This discrepancy does not exist on the optimal path, because there the mix of environmental functions and produced goods is optimal.

These considerations lead us to the conclusion that the calculation of a green national income as proposed by Hueting (1974a) and Hueting *et al.* (1992, 1995) is the best practicable approach for our present purpose.

Prices with and without measures

The theory discussed above makes clear that the welfare indicators v and w for path b or s at a given instant in time are expressed in shadow prices valid for the same path and the same instant (see 6.1). In other words, v_s and w_s on the ‘indicator path’ s are expressed in the shadow prices arising *after* implementation of what were referred to in Section 3.3.1 as elimination and compensation measures and subsumed under the headings technical, shift, shrink and population. Above, however, the welfare indicators v_s and w_s were abandoned in favour of green national income, i.e. national income on the unfeasible unblocked path s (y_s). In comparing (approximated standard) national income on the blocked path b (y_b) and (green) national income on path s (y_s) in the year of investigation, the comparison must be between points B and S in Figure 3.5.

Bearing in mind the close relation between the welfare indicator and national income, there are now grounds for concluding that this comparison of real income should be done on the basis of the prices arising *after* implementation of the measures (point S in Figure 3.5). The prices resulting after internalisation of the costs of the measures (including levies) reflect the relative importance of the environmental functions better than the prices in the actual situation on path b : the ‘new’ price ratios are those on the sustainable path s . Shifts to more environmentally friendly production, particularly, are weighted more appropriately in this way, provided the model used computes all relevant production shifts.

This point can be elucidated as follows. It follows from Hueting (1981) and Hueting *et al.* (1992) that the bulk of national income growth is generated by industries that cause the greatest losses of environmental functions, both in production and in consumption. The increase in productivity in these industries, measured in terms of goods produced, is much greater than elsewhere in the economy, so the real prices of these products decrease strongly (see Section 3.3) and, with them, the price ratio between environmentally burdening and less burdening products. As a result, any shift to environmentally

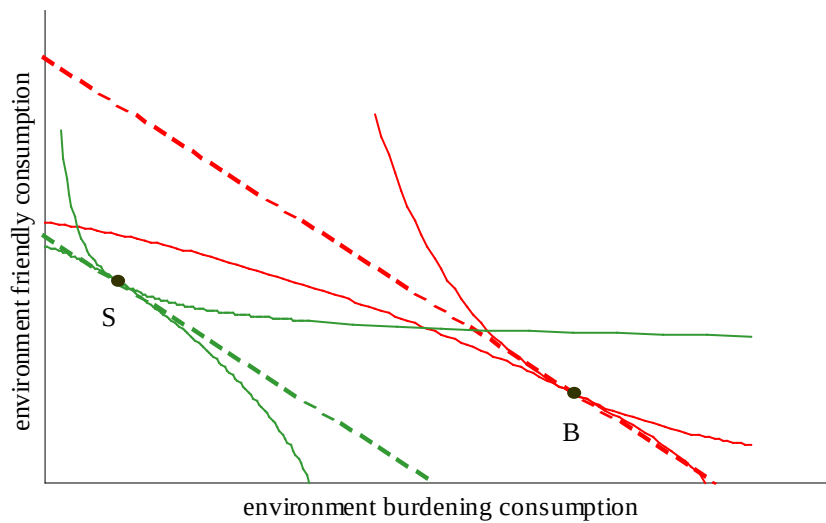


Figure 3.5 The optima B and S discussed in the text, as calculated by an environmental economic model under the assumptions made on preferences and blockages. In point B, approximating the actual situation in the study year, blockages prevent key preferences for the environment from being expressed. In S, these blockages have been overcome. The (convex) indifference curves through these optima reflect the different forms of the welfare function under the respective conditions. Each optimum lies on a different boundary of production possibilities (concave lines), determined by the different availability of environmental functions. The dashed lines indicate the levels of consumption at both optima, using the prices at the optimum with blockages overcome (point S); these levels represent the standard national income (through point B) and the green or sustainable national income (through point S).

friendly products has a negative impact on the volume of national income (Huetting *et al.* 1992). This impact can be approximated by weighting using the (new) prices on path *s*, in which the costs of function restoration are internalised; as a result, the real prices of environmentally burdening products increase, as does the price ratio between environmentally burdening and friendly products. The latter price ratios reflect the situation on the sustainable path better than the price ratios on the actual path. This clarifies and improves the original concept of calculating the cost involved in production shifts.

3.4.5 Strong and perfectly expressed preferences for the environment; feasible optimum

As indicated in Section 3.4.4, adaptation of the modelled stocks in production, consumption, social and environmental processes to 'removal' of the blockages may take a long time. From this perspective, large instantaneous changes in these stocks are unfeasible. If this restriction is respected, welfare maximisation results in a feasible unblocked path *f*, which starts in the actual situation as observed in the year of investigation. In that year

the stock variables in the environmental and the production and consumption parts of the model have the same values on path f as on the blocked path b , and consequently approximately the same values as in reality. The first part of the feasible unblocked path f is a *transition* phase, in which measures are being implemented, environmental functions are recovering, national income is falling and welfare is rising. This transition is followed by a more stable phase in which these variables are more or less consolidated; in this phase the path comes to approximate the unfeasible path s , which obviously becomes feasible by that time. In Figure 3.3, path f is assumed to approach path s asymptotically.

The feasible unblocked path is included in Figure 3.3 for clarification because it is a vital element of understanding the indicator, especially when the indicator is presented to the public. Calculation of the feasible unblocked path is obviously not part of our research effort. Nonetheless, an indication of how such a path can be constructed is given in De Boer (1999) for the case of global warming. The standard is illustrated by comparing it with a feasible unblocked emission path. A dynamic model of the factors blocking preferences is not available, and so these blockages are assumed to be overcome outright in the year of investigation. The storage of carbon and heat in the oceans enables the feasible greenhouse gases emission path to lag centuries behind without causing losses of function that would otherwise prevent the long-term, optimal, stable emission value from being reached.

3.4.6 Strong and perfectly expressed preferences for sustainability; absolute optimum

This is a special case of that discussed in Section 3.4.4. Thus, we again assume that the blockages on preferences are overcome outright and that the measures required to reach the preferred path s are all implemented at once in the year of investigation, in an unfeasible ‘leap’, so to speak. In this case, though, we assume absolute preferences for sustainability, which we define loosely as the minimum availability of *vital environmental functions* that can be sustained forever in the future, either at a *constant* or at an *ever-increasing* level. In theory ‘the future’ is infinite, but in practice we limit it to the time span in which the influence of geophysical processes on the environment is unlikely to exceed human influence, say several millennia or longer. Moreover, we proceed from the special form of the definition that is limited to minimum *constant* levels of environmental functions; these represent our ‘sustainable levels’. By ‘absolute preferences for sustainability’ we mean that people’s preferences for the sustained availability of environmental functions far exceed their preferences for the availability of consumption goods or environmental functions in the year of investigation, or in any other isolated year.

The theory discussed in the previous sections can be applied to the problem of sustainability. See, among others, Stiglitz (1974), Dasgupta and Heal (1974, 1979), Hartwick (1977, 1978), Pezzey (1994) and Gerlagh (1999); Zeelenberg *et al.* (1997) provide a short overview. This theory indicates that an absolute preference for sustained availability of environmental functions implies sustained availability of consumption goods. The reverse statement, that an absolute preference for sustained availability of consumption goods implies sustained availability of functions, can probably be proven, because production is impossible in the absence of environmental functions. Although these two statements look very similar, they reflect the fact that sustainability can be defined in

several ways, leading in turn to differences in the ensuing paths s . In every definition of sustainability, a distinct group of variables directly influencing welfare or directly related to welfare is kept constant forever: the welfare indicator v or w , environmental function levels, levels of actual use of the environment, flows of consumption goods, aggregate consumption, or net national income. Sustaining one of these variables at a maximally attainable level is at the expense of the other variables, although these are sustained as well. This trade-off also occurs if a group of variables, such as function levels, use levels or consumption flows, are sustained at maximally attainable levels. This requires multi-objective optimisation, leading to a set of possible outcomes (paths). However, welfare maximisation under assumed absolute preferences for sustained instantaneous welfare, or for sustained aggregate consumption, or for sustained national income, leads to a unique and different result each time, viz. a maximum feasible sustainable level of, respectively, instantaneous welfare, aggregate consumption, or national income. The model solution is a different *sustainable path* (s again) for each of these cases. The function levels remain constant on each sustainable path, despite the fact that this was not explicitly assumed as the goal of the preferences, but these levels are in general different for each sustainable path. All model variables on such a sustainable path remain constant, it should be added, with the notable exception of stocks and extractions of non-renewable resources. Their function levels are sustained as well, however; see Section 3.5.

Sustainable function levels can therefore be found in theory; they follow from the process of welfare maximisation in a comprehensive environmental economic model, under the assumption of strong preferences for sustainability. By adopting a single given definition of sustainability, the function levels are determined uniquely. We seek the maximum net national income at which the environmental functions are sustained. According to our theory as just discussed, the functions are then sustained at approximately minimal levels. The goal, consistently, is to ensure that *possible* (potential) future uses of the environment are not lost. Future generations can then decide for themselves whether they wish to step up their level of usage. This approach thus involves minimum sacrifice for the present generation.

In practice, as explained in Section 3.3.4, the comprehensive environmental economic model required to compute maximum welfare and the corresponding sustainable function levels is far too complex to perform such optimisation, even more so because a sustainable optimal path is not only an optimum but a limit case as well. Studies using simple environmental economic models that do allow for such optimisation (Pezzey, 1994; Gerlagh, 1999) lead us to make the following observations. First, the sustainable levels of use of environmental functions may be interpreted as the regeneration capacities of nature for these types of use. Second, in theory these sustainable levels constitute the sustainability standards to be applied in the practical calculation using linked models (Section 3.3.4). Third, no attempt has yet been made to derive realistic standards from simple environmental economic models, but if one were to do so, these standards would probably turn out to allow lower activity levels than the standards we establish in our practical approach. The difference is due to the use of optimisation in the simple models on the one hand and the application of the precautionary principle, some additional plausible assumptions and the more detailed environmental models of the practical approach, on the other. This approach is explained in Section 3.5.

Within the theory discussed up to now, it appears to be possible to find a sustainable path at a low enough but still positive rate of technological progress: vital environmental functions are maintained and (real) production and consumption increase without ever collapsing. Generally, technology on the sustainable path s progresses more slowly than on the blocked path b . For each year of investigation an optimal sustainable path is found ($s_1, s_2, \dots, s_n$), starting in that year with technology equal to that on the unblocked path b , but with diverging technology in all later years. Only the level of y_s at the starting point of each path is taken as SNI for the respective year of investigation. For later years of investigation, new sustainable paths with ever-higher levels of y_s at their starting points will most probably be found, as a result of technological progress. Connecting the starting points of the sustainable paths *ex post* yields the realised development of the sustainable national income or SNI (as well as the realised developments of the other model variables under sustainability). This process is elucidated in Figure 3.6.

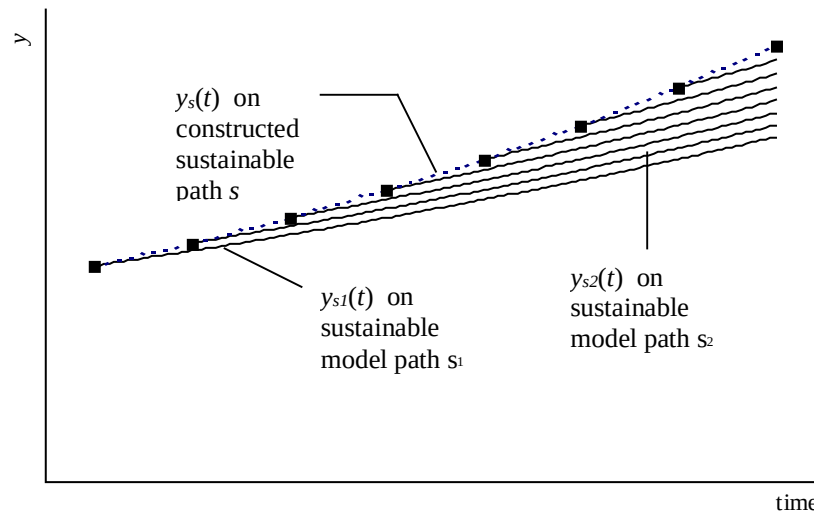


Figure 3.6 Construction of the unfeasible sustainable path s and the corresponding sustainable national income y_s . In the calculation of the sustainable national income according to Hueting, technological progress is *ex ante* assumed zero on each model path. Consequently national incomes on these paths ($y_{s1}(t)$, $y_{s2}(t)$ et cetera) are constant and their graphs are horizontal lines. National income on the *ex post* constructed sustainable path s , however, may still rise due to technological progress.

This procedure may be theoretically sufficient to arrive at a sustainable income, but it involves the risk of the theory proving erroneous, in that the projected technological progress needed to preserve the environmental functions may in the long run not be realised and a collapse may occur at some time in the future. Compare y_b with y_s in Figure 3.3. While some of the authors mentioned in this section accept this risk or just acknowledge it without taking the consequences, others, like the present authors, deem the risk too high. We therefore consider it appropriate to calculate the sustainable national income for each year of investigation (n) under the assumption that technological progress on the corresponding sustainable path (s_n) is zero (except for non-renewable resources; see Sec-

tion 3.5). As before, connecting the starting points of the sustainable paths s_n *ex post* yields the realised development of sustainable national income y_s as we advocate it (SNI according to Huetting). It may rise in the course of time, as a result of actually realised technological progress, not anticipated in the model paths $s_1, s_2, \dots, s_n$.

3.4.7 Basic assumptions for practical calculation of SNI

Huetting *et al.* (1992) give a number of basic assumptions required for practical estimation of a country's SNI. See also Chapter 6. We mention the most important of these here; some have already been discussed.

- The transition to sustainable activities is made in every country in the world simultaneously and in the same way. This prevents the transfer of burdening activities from one country to another.
- Sustainability standards for environmental pressures are set for the region in which they affect functions, i.e. national, regional or global. A given country's contribution to meeting a regional or global standard is equal to its contribution to regional or global pressure.
- Transition costs are not taken into account.
- The employment rate is kept constant
- Technology is kept constant.

3.5 Sustainability standards

As we saw in Sections 3.3 and 3.4, assumptions regarding preferences for the availability of environmental functions may lead to the application of standards. Similarly, assumed absolute preferences for sustained availability of functions can take the form of sustainability standards for these functions. The demand curve of Figure 3.1 is then replaced by a vertical line; see Figure 2.1 in Chapter 2.

Under such preferences for sustainability, the optimal function levels are sustained forever and the green national income to be calculated is turned into the (maximally attainable, *ad infinitum*) sustainable national income. As it is difficult to estimate or even quantify these levels, it is assumed that their existence is guaranteed by three slightly more practical conditions. The first is that *the extinction of biological species at the global level may not be accelerated by human influence*; see below. The second condition is that *any changes in the state of the environment may have only a minor, acceptable impact on human health*. Health is generally described in the modern literature as a state of well-being extending beyond the mere absence of illness. Nonetheless, most 'maximum acceptable risk' levels in force for environmental state variables are construed with the aim of preventing illness. We identify the second condition with the latter goal. The third condition is that *the elements of the environment that people must be able to observe for these elements to fulfil their functions, must be situated within reasonable travelling distance*. We take this distance as 200 km for nature areas in general, but require additionally that at least one nature area is located within cycling distance, say 10 km.

These conditions must be satisfied in the present and in the future. Each one imposes bounds on the acceptable variation in the state (quality) of the environment, however imprecise. From these limit values, *sustainability standards* for the various forms of environ-

mental pressure can be derived as discussed above, i.e. with the aid of environmental models, and subsequently the sustainable national income can be calculated by imposing these standards on the economic activity model (see Section 3.3).

Generally, limits set for different environmental problem areas (or themes) have to be tuned to each other in order to minimise combinatorial (synergetic) effects. They probably cannot be avoided completely and this is not necessary either, as long as sustainability is (likely to be) warranted. Two kinds of combinatorial effects prevail.

The first effect is the way in which land use influences the admissible concentration levels. Whatever conditions to land use are put forward as a sustainability standard, areas used for different purposes impose different bounds on the concentrations of various substances in air, local soil and local surface waters. If the processes determining the concentrations vary on roughly the same spatial scale as the adopted sustainable land use pattern, and the emissions locations may be changed on this scale, the nation-wide sustainable emission standards may be set to less strict levels than would be found otherwise. This is the case for acidifying, eutrophication, hazardous and some other substances in soil and surface waters. Hazardous substances, however, are treated in another way in this study. It is assumed that sustainability is warranted if the sustainable concentration limits of these substances are exceeded in only 10% of the soils or surface waters (on area basis) nation-wide. This assumption is not validated and may constitute a source of uncertainty.²⁴

Secondly, the concentration levels of different substances influence each other's effects on the health and survival of species, including humans. Concentrations of hazardous substances therefore have to comply with so-called *negligible risk levels* instead of the less strict but scientifically better underpinned maximum permissible levels, which are intended for single substances only (Crommentuin *et al.*, 1997). Other interactions belonging to this category occurs between nitrogen and phosphorus nutrients limiting primary production on land or in water, and between the factors limiting ozone formation in the air, more specifically NO_x and volatile organic compounds. These cases are discussed in the relevant sections of Chapter 4.

We hold that sustainability standards can be scientifically established. See Hueting *et al.* (1992) and Hueting and Reijnders (1998) for several examples and Bosch (1994), De Boer and Bosch (1995) and Dellink and Van der Woerd (1997) for a number of quantified standards. Thus sustainability, defined as the situation in which vital environmental functions remain available *ad infinitum*, is an objective concept, to the extent that the natural sciences can be deemed objective (Hueting and Reijnders, 1998). As Costanza and Patten (1995) and Hueting and Reijnders (1998) have argued, in the context of the interaction between human activity (loosely referred to as 'the economy') and the environment, criteria for sustainability are to be regarded as assumptions. Scientifically, therefore, it can only be established *ex post* whether the measures taken to fulfil these criteria, or standards, were indeed adequate.

As argued earlier, the availability of environmental functions depends on the quality, quantity and spatial capacity of the environment (or (bio)physical surroundings or environmental capital), which is after all the vehicle or carrier of these functions. Environ-

²⁴ This location-dependent approach must have effects on the cost effectiveness curves as well, but these effects have been neglected so far.

mental functions remain available for as long as this environmental capital (in a broad sense, see p.8) remains intact. Sustainability standards can thus relate to the qualitative, quantitative and spatial aspects of the biophysical surroundings, and environmental models then used to translate these standards into standards for human activities: emission or withdrawal of substances, heat, species, etc. into or from the environment (see Section 3.2), for example, or land use, or use of raw materials such as crude oil or copper. State variables are related to pressure variables using environmental models. The elimination measures mentioned in Section 3.3.1 reduce the pressure variables to the permitted or sustainable level of environmental burdening. In doing so, a distinction is made between renewable and essentially non-renewable (i.e. very slowly forming) resources.

Sustainability aims to maintain the functions of environmental capital provided by nature (in a broad sense, see p.8). As rightly pointed out by Goodland, this definition of sustainability goes beyond 'sustainable yield', a notion that is current in fishery and forestry circles. Sustainability applies to aggregate natural capital, not just to a few species of fish or timber trees (Goodland, 1995). In the case of forestry, for instance, it includes biodiversity, ecosystem integrity, water source and water moderation values and contributions to geochemical cycles (including the carbon cycle) and climate. Apart from this, a level can be established above which a (plant or animal) species can be harvested sustainably (see below). Thus there is obviously a level, defined as a number of individuals of a species, below which the species is threatened with extinction; arriving below that level is unsustainable, remaining above that level is sustainable. Together with the condition that harvesting a species should not disrupt the ecosystem of which it forms a part (see Odum, 1971), this yields the sustainability standard for the species.

In establishing sustainability standards, we have taken as the basic point of departure the natural regeneration capacity of the environment: as long as this remains intact, environmental functions will remain available. The following examples illustrate how this quantity and the acceptable, i.e. sustainable burden can be established. It can, for instance, be established that the rate of erosion of topsoil may not exceed the rate of formation of such soil due to weathering. Similar consumption standards can be set for other natural resources. With respect to how sustainability relates to species, then, the standard holds that the rate of human-induced extinction should not exceed the rate at which new species come into existence. This boils down to preserving all the species still alive today, for it is assumed that during the past several thousand years conditions have been such that, leaving aside drastic human intervention for the moment, the number of new species must certainly have at least equalled the number of species lost to extinction (Raup, 1986; Hawksworth, 1995). However, in contrast to the situation prior to human intervention, the rate at which natural species are becoming extinct is today at least a factor 10,000 higher than the rate at which new species are evolving (Raup, 1986). In the absence of drastic human intervention, the quantity and quality of renewable natural resources such as groundwater or biomass (including wood) generally show a substantial degree of constancy. In the absence of human intervention, environmental capital is thus characterised by a substantial degree of constancy or even increase.

With regard to pollution, too, criteria can be established. Acid precipitation, for example, should not exceed the neutralising capacity of the soil. Likewise, there should be no exportation of risks to future generations through pollution of groundwater that is to serve as a source of drinking water for those generations. In many cases, the accompanying

environmental burden can be determined with great accuracy. There is a wealth of data on the rate at which new fertile soil is naturally formed and on the neutralising capacity of natural soils, and these data enable a precise indication to be given of the admissible environmental burden due to erosion and acid rain (Reijnders, 1996). In other cases we have insufficient knowledge to make firm pronouncements. For example, at present we can do no more than give a rough indication of the conditions under which plant and animal species are able to survive (Hawthornthwaite, 1995; Den Boer, 1979). On the basis of the best available global circulation models it can be calculated that worldwide emissions of carbon dioxide must be reduced drastically to achieve stabilisation of the global warming process, but an exact percentage cannot be given (De Boer, 1996). Similarly, shortcomings in our toxicological knowledge mean that we cannot fully analyse the risks associated with polluted groundwater. However, this does not detract from the fact that improved scientific knowledge can lead to more precise establishment of standards for sustainability.

All in all, it is feasible to establish scientifically the environmental burden that is 'admissible' on the basis of the objective of sustainability. Hueting and Reijnders (1999) describe how the precautionary principle can be employed if there are uncertainties and inadequate knowledge in the context of sustainability.

In the case of very slowly forming natural resources such as crude oil and copper, which are to all intents and purposes non-renewable, 'regeneration' can take three forms: efficiency improvements, recycling and, over the longer term, substitution of one form of environmental capital by another that can provide the same functions. Familiar examples of substitution include solar power and glass fibre for crude oil and copper wire, respectively.

This can be expressed as follows in a numerical value. Sustainability of non-renewable natural resources means that in a given period only as much may be withdrawn from the stock as substitutes for the resource are expected to be developed in the long run as well as new potential for recycling and conserving the resource (improvement of efficiency). In this way the functions of a resource available in the year of investigation are maintained at the same levels in the future. In practice this can be worked out by, for instance, taking from a period in the past the quantity of possible uses (e.g. heating, transportation, etc., expressed in effective energy) that has become available through efficiency improvement, substitution and recycling and then assuming that the relative rates of efficiency improvement, substitution and recycling will be the same in the future.²⁵ There follows from this a maximum permissible annual rate of extraction that can be used as sustainability standard. In a formula: $e(t_0) \leq r(t_0) \cdot S(t_0)$, in which $e(t_0)$ is the extraction rate in year t_0 , $r(t_0)$ the relative rate (or rate coefficient) of reduction of consumption of the resource (resulting from substitution, etc.) at a constant level of activities, and $S(t_0)$ the stock in year t_0 (Tinbergen, 1990).

²⁵ This involves an assumption about technological progress in the fields of substitutes and recycling. This exception to the point of departure that the estimation should be based on the technology that is operational in the year of investigation, or shortly thereafter, is the only way to arrive at a sustainability standard for non-renewable resources. The only other option, to pass on stocks untouched to future generations, is unfeasible and also makes no sense, because this would then have to be carried through *ad infinitum*.

This formula is applied at the global level. Standards for individual countries can be subsequently derived by applying the general rule, given in Section 3.4, that a country's share in meeting the global standard should be equal to its share in total extraction.

In practice, the factor $r(t_0)$ is determined mainly by efficiency improvements, as substitution and recycling have still made only a very minor contribution in recent years. The aforementioned assumption that the line recording use of the resource in the past can be continued into the future with, basically, a constant annual rate of efficiency improvement, implies that as time progresses the same material output can be achieved at a fraction of current resource use. In a study on the development of energy efficiency, Tinbergen (1990) found a practical value of 1.67 per cent for this improvement rate. From this it follows that in 60 years' time the *present level of production* can be achieved with 37% and in 315 years' time with 0.5% of current fossil fuel consumption: $S(315) = (1 - 0.0167)^{315} * S(0) = 0.005 * S(0)$. Such enormous efficiency improvements (63% and 99.5%, respectively) seem rather unlikely. In the context of sustainability, 315 years is a very short time. The probability that mankind will sooner or later have to manage without the functions of the non-renewable natural resources, if no substitutes are found, is comparable to the certainty that mankind will sooner or later have to manage without the functions of the soil in those areas where the degree of erosion is higher than the rate of soil formation.

Because efficiency improvements alone are thus inadequate to achieve sustainability, it has been proposed that, in the calculation of SNI, additional measures must be taken for the development of substitutes (Tinbergen and Hueting, 1991). We here adopt this proposal, applying the following procedure. For each resource, statistical data are used to establish the rate at which substitution (the ultimate solution) has taken place over the past 10 to 20 years and the annual cost this has entailed. It is then calculated how long it would take, at this rate, to completely replace the resource (1). Next, it is calculated how long it will take for the resource to be depleted, at the *current* level of production (2). Then (1) divided by (2) yields a rough approximation of the required 'acceleration factor' for the development of substitutes in time for them to replace the functions of the resource when it is depleted. This factor multiplied by the statistically established annual cost of substitute development yields the sum that needs to be reserved for this purpose.

The figures thus found can be no more than rough estimates, of course. In the context of non-renewable natural resources, though, this is an approach that does justice to the principle of sustainability, which is the point of departure of our estimates. The approach would be comparable with that of Solow (1974), Hartwick (1977, 1978) and others, if the latter were to exclude unfeasible substitution of natural resources by other resources and by capital (see below), i.e. if they were to abandon their faith in the extreme areas of formal production functions.

When using the concept of environmental function, the only thing that matters in the context of sustainability is that vital functions remain available. What does the conservation of vital functions imply for the distinction between renewable and non-renewable resources and for the distinction between strong and weak sustainability?

As for renewable resources, functions remain available as long as their regenerative capacity remains intact. Regeneration in relation to current use of 'non-renewable' resources such as crude oil and copper that are formed by slow geological processes is

close to zero. 'Regeneration' then takes the form of efficiency improvement, recycling and, in the final instance, developing substitutes. The possibilities for this are hopeful (Brown *et al.*, 1998; Reijnders, 1996). So, economically speaking, there seems to be no essential difference between the two types of resource: sustainability is attained if their functions remain available.

Advocates of 'weak sustainability' take the line that all elements of the environment can ultimately be substituted by man-made alternatives, implying that restoration of lost elements can be postponed in anticipation of cheaper substitutes provided by future technologies. However, the life support systems (see note 2) of our planet, on which a number of vital functions depend, are not substitutable at all (Lovelock, 1979; Roberts, 1988; Reijnders, 1996). The same holds for most of the functions of natural ecosystems, especially in the long term (see, for example, the remark on the function of 'gene pool' in Section 3.2). Consequently, there can be no such thing as 'weak sustainability' for the functions of these systems.

Advocates of 'strong sustainability' hold it to be impossible for humanity to substitute many of the elements of the natural environment. In its strictest form, however, this implies that stocks of non-renewable resources should remain fully intact, an unrealistic aim, as already discussed. Consequently, strong sustainability for non-renewable resources seems to be impossible.

In conclusion, there seems to be only one kind of sustainability, whereby non-renewable resources must gradually be substituted by other elements of our physical surroundings in order to guarantee the availability of functions, and substitution of a large class of renewable resources is impossible, particularly life support systems, including ecosystems.

The question is often asked whether sustainability standards should be applied locally or globally. This depends on the scale at which the functions in question should be substituted. For instance, preservation of the function 'soil for growing crops' requires local application of the standard for erosion (the erosion rate may not exceed the soil formation rate; see above), because exceeding the standard at one place cannot be compensated by remaining under this standard elsewhere. Crude oil, on the other hand, is a global resource, so in this case the sustainability standard, effectuated through efficiency improvement and substitute development, should be applied worldwide.

If an environmental problem exceeds the national scale, the sustainability standard for the environmental pressure related to the problem is converted to a sustainability standard on national scale. Given the assumed absolute and general preference for sustainability, the pressure reduction measures are distributed optimally among the countries involved in the environmental problem, if total costs are minimal, and thus if marginal abatement costs are equal in the countries involved. The cost effectiveness curves for the environmental problem are specific for a country, but are generally not known in each country. It is therefore assumed that the countries within the area affected by the environmental problem reduce their environmental pressure proportionally, that is, proportional to their contributions to the total environmental pressure. Because this approach is sub-optimal, the standard for a country thus calculated might be too strict or too mild. Both the cost-effective solution as the approximation employed here will probably result in comparable emission reductions domestic and abroad. The influence of border crossing transport of substances through the environment on the state of the environment, and

thereby on the sustainability standard for the pressure, is therefore neglected. However, it is recommended to perform a sensitivity analysis on the importance of this assumption.

3.6 Conclusions

1. The SNI according to Hueting is the maximal income that can be sustained forever if technological development is not taken into account, except where it is inevitable to sustain environmental functions, which in turn are essential for sustaining income. This can only be realised if a vast majority of the subjects have an absolute preference for sustainability. The concept is theoretically sound as well as operational, although it involves considerable statistical effort. Its theory is in line with so-called general growth theory.
2. The provisional results for the Netherlands obtained in the study by the Institute for Environmental Studies of the Vrije Universiteit, Amsterdam, reported in Chapter 6, justify the conclusion that the rough estimate of an SNI by Tinbergen and Hueting (1991) is not extreme. This estimate was 50 per cent of standard world income. Assuming there to be preferences for sustainability, welfare will increase by pursuing as rapidly as possible, but without undue shock to society or irreparable environmental damage, a path which leads to a (substantially) lower standard national income, which will then eventually approximate a meanwhile probably higher SNI.
3. While the cost of measures to restore and sustain vital environmental functions (supply) can be estimated, this is only partially true of preferences for such measures (demand), for there exist blockages that make it impossible or very difficult for these preferences to be expressed. This is particularly true of preferences for maintaining vital environmental functions in the future, i.e. for sustainability. This justifies the assumption that there are stronger preferences for environmental protection and conservation than are (capable of being) expressed through market and budget mechanisms.
4. The pronounced quantitative differences between the SNI according to Hueting and other green national incomes can be traced back largely to different views vis-a-vis the position of the optimal path of the economy and thus to different assumptions regarding the strength of preferences for the environment and the associated question of recognition, or otherwise, of the blockages referred to under 3. Authors such as Repetto (1989, 1991) and Mäler (1991) assume that preferences for the environment are fully expressed in actual expenditures on compensation for and elimination of loss of function and in the financial damages incurred as a result of such loss. According to these authors, then, society is on the optimal path and there are no blockages on preferences for the environment. The standard national income is then corrected for the aforementioned costs, to the extent that these are actually incurred by government and private households. By applying this correction, a better measure is obtained of changes in the volume of scarce goods, being one of the factors influencing welfare. Others, such as Stiglitz (1974), Hartwick (1977, 1978), Pezzey (1994), Asheim (1994) and Pezzey & Withagen (1995) recognise that the optimal path is a sustainable path if strong preferences for sustainability are assumed. Comparison of the sustainable national income associated with this path with the standard national income associated with the actual path is hampered by the fact that the paths are cal-

culated using different welfare functions, however. We therefore consider it more logical to consistently assume preferences for the environment to be strong enough for the optimal path to be sustainable. In our perspective, the existence of the sub-optimal path in the real world is explained by the blockages preventing these preferences from being expressed; this in contrast with the sustainable path, where these blockages have been overcome. The pronounced differences in outcome are thus explained mainly by major differences in assumptions regarding preferences for the environment, with other theorists either denying the existence of blockages or, if blockages are indeed recognised, assuming far weaker preferences for the environment than we do. In our interpretation, the latter holds *inter alia* for El Serafy (1989, 1995). Under the assumption of strong preferences for sustainability, application of the theory of such authors as Stiglitz, Hartwick, Pezzey, Asheim and Withagen will yield an SNI of similar magnitude as the SNI according to Hueting.

5. Sustainability standards for environmental pressure are — in theory — the levels of environmental pressure on a sustainable development path of the economy, including the environment. These standards reflect the regeneration capacity of the environment with respect to the various forms of environmental pressure and, with the exception of those relating to the consumption of non-renewable resources, are constants.
6. In practice it is (yet?) unfeasible to compute the sustainability standards, the costs associated with attaining these standards and the SNI in the theoretically correct way, i.e., with a single, comprehensive, dynamic environmental-economic model. Instead, the standards are calculated with the aid of environmental models and the SNI according to Hueting with a general economic equilibrium model. This requires introduction of additional rules as well as several ad hoc choices. The principal rule is the assumption that sustainability is guaranteed if human activity and the resultant environmental pressure do not accelerate the extinction of biological species at the global level. Because of these rules, the practical sustainability standards for environmental pressure and the practical SNI are probably lower than their theoretical counterparts, were they to be computable.
7. At the maximum feasible SNI (the SNI according to Hueting) vital environmental functions are sustained at minimum levels and the sacrifices required to attain the sustainable path in question are minimum. An SNI calculated with future constant function levels chosen as high as possible will probably be zero.
8. Sustainability standards can, in principle, be established scientifically. Choosing to assume preferences for sustainability is obviously subjective, and the same holds for the choice of models and the rules and choices referred to under 7. These are the choices (albeit often rationally argued ones) of the researcher or policy analyst, however, not those of the economic subject. Furthermore, standards for sustainability must be sharply distinguished from subjective preferences for attaining such standards, or for not doing so.
9. When applying the concept of ‘environmental function’, the distinction between weak and strong sustainability cannot be made: non-renewable resources must gradually be substituted by other elements of the environment, whereas substitution of a

large class of renewable resources is impossible, particularly life support systems, including ecosystems.

10. If the underlying assumptions are rendered explicit, environmental valuation and green accounting can yield valuable and comprehensible information. If they are left undeclared, these disciplines will become discredited because of the incomprehensibly wide range of quantitative outcomes they yield.

References

- Asheim, G. (1994). Net national product as an indicator for sustainability. *Scandinavian Journal of Economics*, 96: pp. 257-265.
- Bateman, I.J., and R.K. Turner (1992). *Evaluation of the environment: the contingent valuation method*. Centre for Social and Economic research on the Global Environment, GEC Working Paper 92-18.
- Bosch, P.R. (1994). *Energiedragers*. Draft report, Statistics Netherlands, Voorburg, The Netherlands.
- Brouwer, R., and M. O'Connor (1997). *Methodological problems in the calculation of environmentally adjusted national income figures*. Study for the European Commission, Directorate General XII, Contract No. EV5V-CT94-0363, Brussels, 2 volumes.
- Brown, L.R., C. Flavin and H. French (1998). *State of the World 1998*. W.W. Norton, New York.
- Costanza, R., and B.C. Patten (1995). Defining and predicting sustainability, *Ecological Economics*, (15), pp. 193-196.
- Costanza, R., et al. (1997). The value of the world's ecosystem services and natural capital. *Nature*, 15 May, pp. 387.
- Crommentuin, T., M.D. Polder and E.J. van de Plassche (1997). *Maximum Permissible Concentrations and Negligible Concentrations for metals, taking background concentrations into account*. Rijksinstituut voor Volksgezondheid en Milieu, Bilthoven, the Netherlands, Report no. 601501001.
- Dasgupta, P.S. and G.M. Heal (1974). The optimal depletion of exhaustible resources. *Review of Economic Studies*, symposium issue, pp. 3-28.
- Dasgupta, P.S. and G.M. Heal (1979). *Economic theory and exhaustible resources*. Nisbet/Cambridge University Press, Welwyn/Cambridge.
- de Boer, B. (1995). *Klimaatverandering*. Draft report, Statistics Netherlands, Voorburg, The Netherlands.
- de Boer, B. (1996). Calculation of sustainable national income in the Netherlands: some results. Paper prepared for the workshop *Valuation Methods for Green National Accounting: a Practical Guide*, organized by The World Bank, U.N. Statistical Office and Ecological Economics, Washington, D.C., March 20-22.
- de Boer, B. (1999). Assessment of sustainability standards, this report.
- de Boer, B., M. de Haan and M. Voogt (1994). What would Net Domestic Product have been in an environmentally sustainable economy? Preliminary views and results. In: *National accounts and the environment*, Papers and Proceedings from a Conference, London, England, March 16-18, 1994, Statistics Canada, Ottawa, Canada.
- de Boer B., R. Brouwer and C. Zeelenberg (1995). *Milieu en nationaal product in de economische groeitheorie*, Centraal Bureau voor de Statistiek, Voorburg.

- de Boer, B. and P.R. Bosch (1995). The greenhouse effect: an example of the prevention cost approach. Paper prepared for the *2nd meeting of the London group on national accounts and the environment*, Washington, March 15 – 17, 1995.
- de Boer, B., R. Hueting and M. de Haan (1998). Green accounting in The Netherlands. Paper presented at the workshop *From research to implementation: policy-driven methods for evaluating macro-economic environmental performance (Greenstamp)* at Eurostat, Luxembourg, 28-29 September 1998, European Commission, DG XII, Brussels.
- de Boer, B. et al. (forthcoming). *Theoretical and practical steps towards a sustainable national income*. Statistics Netherlands, Voorburg, The Netherlands.
- de Groot, R.S. (1992). *Functions of nature, Evaluation of nature in environmental planning, management and decision making*. Wolters Noordhoff.
- den Boer, P.J. (1979). Het overleven van soorten. *Intermediair*, 15, (48), pp. 7-13.
- den Butter, F.A.G. and H. Verbruggen (1994). Milieu en economische groei. *Milieu*, 9, pp. 1-11.
- Dellink, R.B. and K.F. van der Woerd (1997). *Kosteneffectiviteit van milieuthema's*. IVM-R97/10, Institute for Environmental Studies, Vrije Universiteit, Amsterdam.
- El Serafy, S. (1989). The proper calculation of income from depletable natural resources. In: Ahmad, Y.J., S. El Serafy and E. Lutz (eds.), *Environmental accounting for sustainable development*, The World Bank, Washington D.C.
- El Serafy, S. (1995). Depletion of natural resources. In: Dieren, W. van, (ed.), *Taking nature into account, A report to the Club of Rome*, Springer-Verlag, New York.
- Gerlagh, R. (1999). *The efficient and sustainable use of environmental resource systems*, Proefschrift Vrije Universiteit, Thela Thesis, Amsterdam.
- Geurts, P., R. Hoevenagel and A. van der Veen (1994). *Het domein van Contingent Valuation*, Faculteit Bestuurskunde, Universiteit Twente, Enschede.
- Goodland, R. (1995). The concept of environmental sustainability. *Ann. Rev. Ecol. Syst.* 26, pp. 1-24.
- Hamilton, K. (1994). Pollution and pollution abatement in the National accounts. Paper prepared for the *IARIW conference* in Baden.
- Hamilton, K. (1995). *Pollution and pollution abatement in the national accounts*. CSERGE, University College London and University of East Anglia, Norwich.
- Hartwick, J.M. (1977). Intergenerational equity and the investing of rents from exhaustible resources. *American Economic Review*, 66, pp. 972-974.
- Hartwick, J.M. (1978). Investing returns from depleting renewable resource stocks and intergenerational equity, *Economics Letters*, 1, pp. 85-88.
- Hawksorth, D.L. (ed.) (1995). *Biodiversity, Measurement and Estimation*. Chapman & Hall, London.
- Hennipman, P. (1940). *Economisch motief en economisch principe*. Amsterdam.
- Hennipman, P. (1943). Nut, nuttigheid en gebruikswaarde. *De Economist*, 1943, pp. 433-438.
- Hennipman, P. (1962). Doeleinden en criteria. In: *Theorie van de economische politiek*, Leiden.
- Hennipman, P. (1968). De externe effecten in de hedendaagse welvaartstheorie, *Economisch-Statistische Berichten*, 20 March 1968.
- Hennipman, P. (1995). *Welfare economics and the theory of economic policy*. Hartnolls, Cornwall.
- Hoevenagel, R. (1994a). *The Contingent Valuation Method: scope and validity*. Vrije Universiteit, Amsterdam.

- Hoevenagel, R. (1994b). An assessment of the contingent valuation method. In: R. Pethig (ed.), *Valuing the environment, Methodological and measurement issues*, Kluwer Academic Publishers, Dordrecht.
- Hoevenagel, R. (1994c). A comparison of economic valuation methods. In: R. Pethig (ed.), *Valuing the environment, Methodological and measurement issues*, Kluwer Academic Publishers, Dordrecht.
- Hueting, R. (1967). Welvaartsparadoxen. Paper for the *National Centre of Administrative Studies*, The Hague.
- Hueting, R. (1969). Functions of Nature: Should Nature be Quantified? Paper prepared for the *World Wildlife Fund*.
- Hueting, R. (1970a). Functions of nature: Should nature be quantified?, *Economisch-Statistische Berichten*, 21 January (in Dutch).
- Hueting, R. (1970b). *What is nature worth to us*. A collection of articles from the years 1967-1970 (in Dutch).
- Hueting, R. (1974a). *New Scarcity and Economic Growth*, Dutch edition: Agon Elsevier, Amsterdam, Brussel, 1974, English edition: North-Holland Publishing Company, Amsterdam, New York, Oxford, 1980.
- Hueting, R. (1974b). A Statistical System for Estimating the Deterioration of the Human Environment. Paper prepared for the *Symposium of the International Association for Statistics in Physical Sciences (IASPS)* at Harvard University, August 10-20, 1971. In: John W. Pratt (ed.), *Statistical and Mathematical Aspects of Pollution Problems*, Marcel Dekker Inc., New York, 1974.
- Hueting, R. (1981). Some comments on the report 'A Low Energy Strategy for the United Kingdom', compiled by Gerald Leach *et al.* for the International Institute for the Environment and Development (IIED). Paper prepared for the *Working Party on Integral Energy Scenarios*. The Hague, 20 May 1981.
- Hueting, R. (1989). Correcting national income for environmental losses: towards a practical solution. In: Y. Ahmad, S. El Serafy, E. Lutz (eds.), *Environmental accounting for sustainable development*, The World Bank, Washington, D.C.
- Hueting, R. (1991). The use of the discount rate in a cost-benefit analysis for different uses of a humid tropical forest area. *Ecological Economics*, pp. 12.
- Hueting, R. (1992a). Correcting National Income for Environmental Losses: A Practical Solution for a Theoretical Dilemma. In: R. Costanza (ed.), *Ecological Economics, The Science and Management of Sustainability*, New York, 1991. Also published in: J.J. Krabbe and W.J.M. Heijman (eds.) *National Income and Nature: Externalities, Growth and Steady State*, Kluwer Academic Publishers, Dordrecht, Boston, London, 1992.
- Hueting, R. (1992b). The Economic Functions of the Environment. In: P. Ekins and M. Max-Neef (eds.), *Real-Life Economics*, Routledge, London and New York, 1992. Also published in: L.L. Boyer (ed.), *Proceedings of the 5th International Conference on Underground Space and Earth Sheltered Structures*, Delft University Press, Delft, 1992.
- Hueting, R. (1995). The economic functions of the environment - valuation of environmental effects. In: *Evaluation of Environmental Effects of Transport*, Report of an International Roundtable organised by PTRC Education and Research Services Ltd., The Hague, 19-20 June 1995. London, 1995.
- Hueting, R. (1996). Three Persistent Myths in the Environmental Debate. *Ecological Economics*, 18, (2), pp. 81-88.
- Hueting, R. (1997). Groei van de produktie is gevaar voor milieu. *NRC Handelsblad*, 2 August, 1997.

- Hueting, R., P.R. Bosch and B. de Boer (1992). *Methodology for the calculation of sustainable national income*, Statistics Netherlands, Voorburg, SDU/Publishers, The Hague, Statistical essays, M44. Also published as WWF International report, Gland, Switzerland, June 1992.
- Hueting, R., and P. Bosch (1994). Sustainable National Income in The Netherlands: the calculation of environmental losses in money terms. In: D. Pearce and S. Vaucheux (eds.), *Models of sustainable development. Exclusive or complementary approaches of sustainability?*, Université du Pantheon-Sorbonne, Paris, pp. 43-56.
- Hueting, R., P. Bosch and B. de Boer (1995). The Calculation of Sustainable National Income, *Occasional Papers and Reprints*, IDPAD OP&R 1995-2. Indo-Dutch Programme on Alternatives in Development IDPAD, New Delhi, The Hague.
- Hueting, R., B. de Boer, P.R. Bosch and J.P. van Soest (1995). Estimating sustainable national income. In: W. van Dieren (ed.), *Taking nature into account, A report to the Club of Rome*, Copernicus, Springer-Verlag, New York.
- Hueting, R. and L. Reijnders (1996a). Duurzaamheid is een objectief begrip. *Economisch-Statistische Berichten*, (1996), pp. 425-427.
- Hueting, R. and L. Reijnders (1996b). Duurzaamheid en preferenties, *Economisch-Statistische Berichten*, (1996), pp. 537-539.
- Hueting, R., L. Reijnders, B. de Boer, J. Lambooy and H. Jansen (1998). The Concept of Environmental Function and Its Valuation. *Ecological Economics*, 27, (1), pp. 31-35.
- Hueting, R., and L. Reijnders (1998). Sustainability is an objective concept. *Ecological Economics*, 2.
- Hueting, R., and L. Reijnders (1999). Uncertainty and Sustainability. *Ecological Economics*, 29, (1).
- Hueting, R., and B. de Boer (1999). The Parable of the Carpenter. *International Journal of Environment and Pollution*, Special issue on Natural Systems Valuation, forthcoming.
- IUCN, UNEP and WWF (1980). *World Conservation Strategy: Living Resource Conservation for Sustainable Development*. Gland, Switzerland.
- IUCN, UNEP and WWF (1991). *Caring for the Earth. A Strategy for Sustainable Living*, Gland, Switzerland.
- Landefeld, S., and C.S. Carson (1994a). Accounting for mineral resources: Issues and BEA's initial estimates. *Survey of Current Business*.
- Landefeld, S., and C.S. Carson (1994b). Integrated economic and environmental satellite accounts. *Survey of Current Business*, pp. 33-72.
- Lovelock, J.E. (1979). *Gaia, A New Look at Life on Earth*. Oxford University Press, Oxford.
- Mäler, K.-G. (1991). National accounts and environmental resources, *Environmental and Resource Economics*, 1, pp. 1-15.
- Meadows, D.L. (1972). *The limits to growth, A report for the Club of Rome Project on the Predicament of Mankind*, Universe Books, New York.
- Nentjes, A. (1997). *Personal communication*.
- Odum, E.G. (1971). *Fundamentals of Ecology*, third edition, Philadelphia (Penn.), pp.223 et seq.
- Opschoor J.B. (1997). *Correspondence with R.Hueting in 1997 and 1998*. Available on request.
- Pezzey, J. (1994). *Theoretical essays on sustainability and environmental policy*. PhD-thesis, University of Bristol, Bristol.
- Pezzey, J., and C. Withagen (1995). *Single-peakedness and initial sustainability in capital-resource economies*. Report, University College/Eindhoven University of Technology, London/Eindhoven.

- Raup, D.M. (1986). Biological Extinction in Earth History. *Science*, 231, pp. 1528-1533.
- Repetto, R., W. Margrath, M. Wells, C. Beer and F. Rossini (1989). *Wasting assets, Natural resources in the national income accounts*. World Resources Institute, Washington D.C.
- Repetto, R., W. Cruz *et al.* (1991). *Accounts overdue: natural resource depreciation in Costa Rica*. World Resources Institute.
- Reijnders, L. (1996). *Environmentally Improved Production Processes and Products*. Kluwer Scientific Publishers, Dordrecht.
- RIVM *et al.* (1997). *Natuurverkenning 97*. Rijksinstituut voor Volksgezondheid en Milieuhygiëne, Informatie- en KennisCentrum Natuurbeheer, DLO-Instituut voor Bos- en Natuuronderzoek, DLO-Staring centrum, Samson H.D. Tjeenk Willink BV, Alphen aan den Rijn.
- Robbins, L. (1952). *An essay on the Nature and Significance of Economic Science*, 2nd edition, London (1st edition 1932).
- Roberts, F. (1988). Modern Cassandra's. *Resource Policy*, 14, pp. 306-307.
- Rosenstein-Rodan, P.N. (1927). Grenznutzen. In: *Handwörterbuch der Staatswissenschaften*, 4. Auflage, Vierter Band, Jena, pp. 1195 *et seq.*
- Solow, R.M. (1974). Intergenerational equity and exhaustible resources. *Review of Economic Studies*, symposium, pp. 29-45.
- Stiglitz, J.E. (1974). Growth with exhaustible natural resources: efficient and optimal growth paths. *Review of Economic Studies*, Symposium, pp. 123-137.
- Tinbergen, J. (1990). Bepalen van omslagpunt is van essentieel belang. *NRC-Handelsblad*, 16 October 1990.
- Tinbergen, J. and R. Hueting (1991). GNP and Market Prices: Wrong Signals for Sustainable Economic Success that Mask Environmental Destruction. In: R. Goodland, H. Daly, S. El Sarafy and B. von Droste (eds.), *Environmentally Sustainable Economic Development: Building on Brundtland*, United Nations Educational, Scientific and Cultural Organization, Paris, 1991. Also published in: R. Goodland *et al.* (eds.), *Population, Technology and Lifestyle, The Transition to Sustainability*, Island Press, The International Bank for Reconstruction and Development and UNESCO, Washington, D.C., 1992. Also published in: R. Goodland *et al.* (eds.), *Environmentally Sustainable Economic Development: Building on Brundtland*, Environment Working Paper No 46, The World Bank, Washington, D.C., 1991.
- Vellinga, N., and C. Withagen (1996). On the concept of green national income. *Oxford Economic Papers*, 48, pp. 499-514.
- Verbruggen, H., R.B. Dellink, R. Gerlagh and H.M.A. Janssen (1997). *Duurzaam nationaal inkomen volgens Hueting: Voorstudie voor berekeningen en analyse en Aanvulling op het projectvoorstel*, Institute for Environmental Studies, Vrije Universiteit, Amsterdam.
- Verbruggen, H., R.B. Dellink, R. Gerlagh, M.W. Hofkes and H.M.A. Jansen (1999). *Alternative calculations of a sustainable national income according to Hueting*. IVM-O99/08, Institute for Environmental Studies, Vrije Universiteit, Amsterdam.
- Weitzman, M.L. (1976). On the welfare significance of national product in a dynamic economy. *Quarterly Journal of Economics*, 90, pp. 156-162.
- Wilson, C.L. *et al.* (1970). *Man's Impact on the Global Environment. Assessment and Recommendations for Action*. Cambridge, Mass.
- World Commission on Environment and Development (1987). *Our Common Future*, Oxford, New York.

Zeelenberg, K., B. de Boer and R. Brouwer (1997). *Sustainability in Growth Models*. Statistics Netherlands, Division of Research and Development and Division of Agriculture, Manufacturing and Environment, Voorburg, Research paper no. 9744.

4. Assessment of sustainability standards

Bart de Boer, Statistics Netherlands

4.1 Land use

Where land and water area are used intensively for different purposes, these kinds of use of space (functions) do not only compete mutually, but also with other environmental functions. The functions of habitat for biological species generally are among the most threatened. It is for example obvious in the tropics, but also in the Netherlands. In the sustainable national income calculation, the natural habitat functions are assumed to be sustained on minimal available levels by devising a sustainability standard for other types of land use (reserving land as habitat for other species than man, e.g. for 'natural' ecosystems, is land use too).

In this study, the Ecological Main Structure (Tweede Kamer, 1990; RIVM *et al.* 1997) is taken as sustainability standard for the Netherlands. The EMS is a system of interconnected areas with a - to some extent - natural flora and fauna, designed to enable species to migrate and thus to substantially increase the number of species that maintain vital populations in the Netherlands as a whole (RIVM *et al.*, 1997). Adopting this structure as a sustainability standard means in the first place that we assume the system - contrary to the present collection of Dutch nature areas - contributes to a necessary European and global ecological structure that creates sufficient conditions for all (historically and present) endemic species to maintain vital populations. Secondly, we assume that the system supports the scenic and recreational functions that correspond with the social sustainability optimum, with respect to visual diversity, surface area and accessibility, among other things. This means that the levels of these variables are sufficient to satisfy the needs of the subjects in the perspective of their assumed absolute preference for sustainability (Section 3.4.6). The EMS is not applied as an independent sustainability standard in this interim stage of the study yet. However, it has great influence on the sustainable emission standards for environmental agents that have lower sustainable concentration limits within the structure than without it. This is most apparent if the emission locations may be altered and the resulting concentration patterns have the same scale as the land use standard, or a smaller scale. By optimising the emission quantities and locations, less strict national emission sustainability standards for the substances involved are found than if the mentioned spatial patterns were not taken into account. This is the case for eutrophication, acidifying and hazardous substances. See Sections 3.5, 4.7.1, 4.8 and 4.9.

4.2 Fossil fuel depletion

The depletion of non-renewable resources is a great problem in terms of sustainability. In this research, we decided to include only fossil fuels as non-renewable resources in the calculation, as it has great importance for production and consumption. It is also chosen because of its relations with other environmental problems, specifically climate

change, ozone layer depletion, acidification and eutrophication via the causing activities and the technical measures.

The depletion of a non-renewable resource is a global environmental problem. The most basic sustainability standard therefore concerns the global rate of extraction and use of the resource. This standard is the maximum level of the extraction and use of the resource that results in a volume of national income that can be sustained forever, by (1) gradually using the resource more efficiently and (2) substituting it more and more till it is substituted completely. Both the extraction standard and the national income may be lower than is actually observed. Thus a constant service level of the function of the resource is warranted. The standard is that the rate of extraction, e , may not exceed the production of substitutes for the resource on the long run, i.e. after the resource is practically depleted. However, the standard for e is based on short run variables, namely the stock size of the resource, S , and the relative rate (or rate constant) of decrease of the intensity of the use of the resource in production and consumption, r , both observed in the year of calculation, t_0 :

$$e(t_0) \leq r(t_0) \cdot S(t_0)$$

The rate constant r can also be defined as the relative decrease rate of the resource use rate at a constant volume of national income. It is the result of (1) efficiency improvement in the application of the resource, including the development of possibilities for recycling the resource and (2) the development of substitutes (Tinbergen, 1990). To account for the necessary acceleration in the development of substitutes on the middle long run, an extra rule is included.

The precautionary principle, which seeks to avoid risks in case of uncertain outcome, is a key element of the calculation of the sustainable national income. It excludes the extraction standards being based upon speculative stocks of the resource; instead, proven reserves have to be used. If exploration activities contribute to an increase in proven reserves, this will result in a larger standard for admissible use of the resource if it is determined in a later year.

The foundations of the standard and the accelerated substitute development rule are discussed to more length in Section 3.5; Bosch (1995) gives an in-depth explanation and mathematical derivation.

Bosch estimated the rate constant r for the decrease of the overall *fossil fuel* energy intensity from literature to be 0.8% per year in the year 1990 on a global basis. His data sources did not allow for separate rate constants for crude mineral oil (petroleum), natural gas, (hard) coal, brown coal (lignite) and peat. Their values would probably not diverge largely anyway. The proven world reserves S in 1990, expressed as combustion heat, are listed in Table 4.1, together with the actual extractions e and the sustainable extractions on a global scale in that year, $r \cdot S$. See Bosch (1995) for caveats.

About 75% of the large reserves of solid fossil fuels consist of coal. Due to this extent, the sustainable extraction of coal is far beyond the actual extraction. If a shift to an all-coal economy would be possible with the technology of 1990, no energy savings would be required in order to be sustainable, that is, according to our rule. The contrary is closer to reality. Substitution of petroleum and natural gas by coal is only possible to a limited extent using 1990 technology. In setting the standards, we therefore neglect this pos-

sibility for substitution. The consequence of this assumption is that the standards for liquid, gaseous and solid fossil fuels are independent of each other, which means that the limit values given in Table 4.1 are correct, as far as the Tinbergen rule is correct for one resource. Substitution by coal is not discarded, but will appear in the set of technical measures used to comply with the sustainability standards for the extraction of petroleum and natural gas, once this theme is included in the SNI calculation.

Table 4.1 Reserves, actual extractions and sustainable extractions of fossil fuels, world, 1990.

	Proven reserves (PJ)	Actual extraction (PJ/a)	Sustainable extraction (PJ/a)	Extraction reduction (PJ/a)	Extraction reduction (-)
Petroleum	5.662.190	125.545	45.298	80.247	64%
Natural gas	5.023.520	75.093	40.188	34.905	46%
Coal, lignite, peat	45.740.070	95.569	365.921	0	0%
Total, no shift to coal	56.425.780	296.207	181.055	115.152	39%
Total, shift to all-coal	56.425.780	296.207	365.921	0	0%

The global standard is converted into a standard for the Dutch use of oil and gas. Bosch (1995) applied the global extraction reduction percentages for oil and gas, 64% and 46% in 1990, to the Dutch oil and gas extractions and converted the results into standards for the domestic use of these resources. Thus he stayed in line with the first stage of the SNI calculation presented by Hueting *et al.* (1992). The present study directly arrives at the second stage of their set-up, in which the standards and the costs of the measures to meet the standards concern the intermediate and final used quantities of the resources in the nation. Application of these standards in the calculation means that each country bears the cost of reducing their domestic extraction and their imports of fossil fuels for their own use. The costs of the reduction of exported products are born by other countries (see Section 3.5). The sustainability standards for the use of fossil fuels in the Netherlands therefore imply that the used quantities should be reduced by the fractions mentioned above. The use of crude oil must therefore be reduced from 975 to 623 PJ in 1990 and the use of natural gas from 1290 to 600 PJ.

The standards have not been applied in the present model study. However, as far as we can see the standards are completely met by measures taken to reach the tentative standard for climate change in the present study, so the impact of their omission on the preliminarily calculated SNI is nil or negligible.

4.3 Enhanced greenhouse effect

Some natural components of the earth's atmosphere, especially water vapour, carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) absorb short wave radiation of the sun such as light and emit the captured energy in the form of longer wave heat radiation, that increases the temperature of the atmosphere. This so-called greenhouse effect is a natural phenomenon with of vital importance for life as we know it: without these gases being permanently in our atmosphere, it's average temperature would probably be almost 20 degrees Celsius lower than it is now (Houghton *et al.*, 1990 and 1992). Man's

economic activities have lead to rapidly rising emissions of CO₂, CH₄ and N₂O and other so-called greenhouse gases, such as chlorofluorocarbons or freones (CFCs) and bromochlorofluorocarbons or halones. As a consequence, the concentrations of these substances in the atmosphere have increased and following these events, the atmosphere's mean temperature has risen more than half a degree Celsius. Nowadays scientific evidence is growing that the temperature rise must be attributed, at least for a substantial part, to the increased abundance of greenhouse gases in the atmosphere. Several other changes in the global climate, such as the increased occurrence of storms and heavy gales, of are often suspected to be related to the temperature rise. This cluster of processes and effects is generally referred to as the enhanced greenhouse effect, global warming or climate change.

If no measures will be taken in the near future to further reduce the emissions of greenhouse gases, an increase of global average air temperature by several degrees Celsius and consecutive other serious climate changes are likely to occur in the next century (Houghton *et al.*, 1992). Important consequences will probably be the movement of moderate and sub-boreal climate zones towards the poles and of lower mountainous climate to higher mountainous regions. This in turn will lead to partial melting of tundra permafrost and polar ice shields, the latter resulting in a rise of the sea level. Melting permafrost may release methane rather quickly, thus accelerating the global warming process. Thus, boreal, alpine, lowland and corral reef species may become extinct because their habitats disappear. These and some other not yet expected effects of the enhanced greenhouse effect might lead to the loss of environmental functions. A temperature change is therefore defined sustainable if its effects do not result in loss of functions (Section 3.4.6), many of which are furnished by life-support systems. Assuming that functions remain available at the least self-supporting levels as long as no species become extinct globally due to man's actions (Section 3.5), the temperature should not increase more than 1.0 to 2.0°C (Sprengers *et al.*, 1995 and Vellinga and Swart, 1991, respectively) at a rate not exceeding 0.01°C per year (Jäger, 1988, RIVM, 1992 and Rotmans, 1990a). The results reported here are based on assumed sustainability limits of 1.5°C for the final temperature increase and 0.01°C per year for the rate of change of the temperature. See De Boer (2000b) for a more detailed review of the arguments considering the choice of these standards.

Using these limits as constraints in a dynamic model of global average the enhanced greenhouse effect derived from IMAGE version 1 (Rotmans, 1990b) yields a range development paths of the economy related to sustainability, as discussed in Section 3.4.4 – 3.4.6. Each emission trajectory is an element of a certain development path of the economy. It turns out that the emissions of greenhouse gases have to diminish instantaneously in the reference year (1990) and have to decrease further in a gradual manner within a certain time span in order to comply with both constraints now and in the future. The instantaneous drop serves to reduce the rate of temperature increase to the standard, as the temperature rate of change limit is already violated since the early 1970's, according to both global averaged observation data and model outcomes. The functions of the environment being maintained, that is according to our assumptions, one could call these paths sustainable. However, we call paths of this type 'sustainable transition paths', because national income drops during the period in which the emissions are reduced, until stable emission levels and a stable income level are reached, that is, provided technology

is kept constant. (Technological development for the development of substitutes for non-renewable resources is a necessary exception to this rule; see Section 3.4.5.) The name 'sustainable transition path' distinguishes this type of feasible path from the infeasible 'sustainable paths' that exhibit a national income that is constant forever under constant technology. The latter type of path is probably infeasible in reality in the sense that it cannot be reached at once, but it is computable and it is imaginable as a reality that could have been. The optimal sustainable path is defined as the path with the highest possible sustainable national income, which is the SNI, again with constant technology. (The general case with developing technology is more complex but builds on the scheme summarised here; see Section 3.4.6 for further explanation.)

Infinitely many sustainable transition paths are feasible, like there are infinitely many sustainable paths with constant national income. As well as there is only one path with a maximum sustainable national income (given the environmental economic model), there is a unique sustainable transition path with maximum though declining national income, in other words with minimal costs. The behaviour of the greenhouse gas emissions on this transition path would give insight in the possibilities of sustainable development. Because the overall environmental economic model is very complex, it is probably impossible to calculate this transition path, at least with present computing technology (Section 3.3.4). Even if only the enhanced greenhouse effect was considered as an environmental problem, calculation of the least cost transition path is still a complex task.

An approximation of the emissions on the sustainable transition path with minimum cost was made, however, just to get an impression of the path. It was assumed that costs (effects on national income) due to changes in the structure of economic activities, caused by technical emission reduction measures and shifts towards environmentally less burdening production, can be approximated by simply extrapolating the technical cost curves for the different emissions outside their ranges. Thus the costs of technical measures are only approximated roughly, while the costs of production shifts and shrinkage are probably over-estimated. Further it was assumed that costs are minimised if each emission follows a reduction path with its own characteristic form, as described by its own time constants, which follow from the climate change model. This assumption was based on the theory and practice of dynamic optimisation, see for instance Takahashi (1966a,b); for details see De Boer (2000b). Thus, only the initial and final levels and some other parameters of the emissions are left to be optimised. Incorporating these idealised cost functions and emission reduction time functions in the (rather schematic) global the climate change model made it possible to calculate the approximate minimum cost sustainable transition path in time, as far as the emissions are concerned.

The approximated least-cost sustainable transition path is still further simplified by employing only the limit of 1.5°C to the average temperature increase, thus accepting a violation of the temperature rate of change limit (0.01°C per year) during 25 years before and 40 years after the reference year. Again, this is motivated by the solely illustrative purpose of the 'sustainable' transition path. The produced quantities of CFCs and halones on the path are reduced almost completely in the reference year (1990). The methane emission starts to diminish from 0.37 Gt (gigatonnes) in 1990 along an exponential curve with a reduction rate of 5% per year and approaches its final (equilibrium) level, 0.21 Gt/a, which is 57% of the 1990 level, around the year 2100. This pattern is mirrored

by the nitrous oxide emission. It drops instantaneously and completely from 5.0 billion kilograms ($5.0 \cdot 10^9$ kg) in 1990 to nil in the same year and subsequently rises exponentially (rate 5% per year) up to a level of 4.1 billion kilograms per year by the end of the 21st century, which is 82% of the 1990 level. The cause of this result is the emission reduction cost curve for nitrous oxide being lower than the cost curve for methane, except for high nitrous oxide emissions. The carbon dioxide emission in 1990, 28.0 Gt, is composed of 22.4 Gt from fossil fuel combustion and 5.6 Gt due to deforestation. The CO₂ emission diminishes exponentially on the transition path from this level to 0.78 Gt per year within more than 1000 years, following an exponential curve with a reduction rate of about 0.4 % per year. This rate corresponds to the large lag time, about 250 years, caused by the buffering of carbon dioxide in the oceans. The remaining CO₂-emission of 0.78 Gt (or 0.21 Gt C) per year may be emitted almost indefinitely, as it is balanced by the net carbon uptake in terrestrial and oceanic soils. Almost, because this uptake is influenced by the increased carbon dioxide concentration in the atmosphere and the total carbon concentration in the oceans on a time scale in the order of 10 000 years or more. In the very long run this uptake in the soil will therefore decrease, together with the carbon contents of the oceans and the atmosphere. This is all theory, of course, as laid down in the applied the climate change model.

The equivalent emission of all greenhouse gases together is calculated using so-called global warming potentials (GWPs) as weights; these are derived from the model, for the quasi-equilibrium occurring in about 1000 years. The equivalent emission on the sustainable transition path starts with an initial drop from 40.0 Gt CO₂ (45.6 Gt including deforestation) in 1990 to 35.5 Gt CO₂ (41.1 Gt CO₂ respectively) in the next year, due to the immediate reductions of the nitrous oxide emission and the production of CFCs and halones in 1990. The equivalent emission diminishes rather fast to 59% of the 1990 emission year 2100, and continues to drop more slowly until it approaches its final level of 9.2 Gt CO₂ per year after more than 1000 years (22.9% of the 1990 level). This equilibrium level is a lot higher than the final sustainable carbon dioxide emission of 0.77 Gt CO₂ per year (0.21 Gt C per year), because of the considerable residual levels of the methane and nitrous oxide emissions. The final emission level is exclusive of deforestation, because complete reforestation in the 21st and 22nd century is part of the simulation. All emission levels mentioned are further exclusive of substitution of CFCs and halones by substances such as HCFCs and HFCs by some of the technical measures considered. The costs of these substitution measures are accounted for in estimating the least cost sustainable transition path; the costs of reforestation are not, as these costs are temporary.

As stated above, the SNI is defined as the maximum attainable national income on a sustainable path with constant technology. This infeasible path is characterised by constant and minimum availability of environmental functions and, as far as renewable resources are concerned, constant pressure on the environment. An approximation of the path in which only the greenhouse gas emissions are sustainable can be found by minimising the cost of greenhouse gas emission reduction under the condition that the emissions are constant. This, a smooth transition from the actual situation to a sustainable equilibrium is excluded. The obtained equilibrium levels are equal to the just discussed final levels of the transition path. The standard is therefore the corresponding equilibrium value of the equivalent emission, 9.2 Gt CO₂ per year, where the equivalent 'emission' is calculated applying the proper long run GWPs to the emissions of carbon dioxide, methane and ni-

trous oxide and the production quantities of CFCs 11, 12, 113, 114, 115 and halones 1211 and 1301.

The temperature of the atmosphere on the sustainable path does not just comply with the level and rate standards; it does not even reach them. Because the temperature is in equilibrium with the emissions, so to speak, all are constant and the temperature never gets the chance to build up above the initial level of the computation, which is the temperature of the reference year, 1990. The temperature being constant forever, its rate of change is zero. This peculiar phenomenon is caused by the 'conservative' properties of carbon in the atmosphere and the oceans, as it is only removed at a constant rate (0.21 Gt C per year), within the time scale of interest, that is.

This result can be generalised for all state variables that influence environmental functions directly, to the effect that sustainability limits for these state variables exist. If these state variables are reduced (dissipated) by processes that do not depend on the state variable itself, directly or indirectly, the sustainable path, where the national income is constant and maximum (the SNI), lies 'within' those sustainability limits.²⁶ With this is meant that the path complies with the state limits, but does not reach them, i.e. each of the concerned state variables complies with its sustainability limit at any time, but none of these state variables ever becomes equal to the limit. On the sustainable transition path, on the contrary, this may happen.

The uncertainties in the input data and in the model, as well as the sensitivity of the model outcomes to both are hard to estimate. However, on the basis of calibration of the model output to measurement data and experiences during these exercises, the relative confidence margin of the equivalent emission standard is estimated $\pm 20\%$.

The global emission standard is converted into the national emission standard by multiplying the global standard with the ratio of the actual national emission and the actual global emission in the *first* reference year, 1990. All emissions should include the substitutes for CFCs and halones such as H(C)FCs, as well as not modelled substances such as sulphurhexafluoride. Deforestation is excluded for reasons mentioned above. The thus found national emission standard must be converted into a standard for the smaller set of gases which are abated in the calculation, i.e. gases included in the cost curves. The equivalent total of the emissions of CO₂, CH₄ and N₂O and the production quantities of CFCs and halones in The Netherlands was 0.251 Gt CO₂ in the year 1990, and the standard for The Netherlands was calculated as 0.0533 Gt CO₂, with a roughly estimated confidence interval of 0.043 to 0.063 Gt CO₂. The standard calls for a 78.8% reduction of the combined equivalent emission and production in 1990.

4.4 Depletion of the ozone layer

Ozone is a normal component of the atmosphere, but in the stratosphere (height 10 to 50 km) the concentrations are much higher than elsewhere. This ozone layer is maintained

²⁶ Although the reserves of non-renewable resources belong to this type of state variables, the discussed result does not apply for these resources. The standard for the use of the resource is based not only on the reserve, but also on an expectation concerning the development of efficiency improvement, recycling and substitution technology. Therefore the standard is not a constant and the use of the resource is always equal to the standard.

because ozone continuously composed and decomposed. Ozone is formed after photolysis of oxygen driven by sunlight; it disintegrates by photolysis through ultraviolet-B radiation (wavelength 280 to 315 nm) and by chemical reactions in which reactive compounds of hydrogen, nitrogen, chlorine and bromine act as catalysts. The ozone layer acts as a filter against ultraviolet-B radiation and thus protects life from it (Van der Woerd and Slaper, 1992).

Since the forties chlorofluorocarbons (CFC), halones and some other volatile halogenated hydrocarbons have been produced in large quantities that lead to the depletion of stratospheric ozone. These substances were and are used as propellants in spray cans, cooling fluids, cleansing agents et cetera. After their use, these substances evaporate and are transported through the troposphere, where they have long lifetimes. In the stratosphere they are broken down through the influence of high-energetic radiation and radicals. These reactions yield reactive forms of chlorine and bromine, which catalyse ozone decaying processes; the decomposition of ozone is intensified. Although additional ultraviolet radiation is adsorbed in these processes, the quantity of ozone in the stratosphere decreases in the process, since 1978 roughly with 3% per year, which on the contrary leads to greater intensities of ultraviolet radiation passed to ground level. The stronger ultraviolet-B radiation inflicts different forms of damages to several life forms. A higher number of people suffer from sunburn more often and more seriously, which will probably lead to a higher incidence of forms of skin cancer and to a weakening of the immune system with an increased number of individuals. Increased numbers of algae and plants suffer from increased damage to epidermal cells and the photosynthesis systems. Genetic damage occurs more often in various plant and animal species than before. Effects on the populations of these species and other species in the involved ecosystems cannot be excluded in the future if the depletion of the ozone layer goes on (Van der Woerd and Slaper, 1992; UNEP, 1989 and 1991). This suggests that the most sensitive species might become extinct under these circumstances.

The levels of ultraviolet-B radiation at which the first species may disappear are very difficult to assess, because the latter phenomenon was not observed yet, which does not mean that it did not happen. If it happens, it will probably be in global regions which are most exposed to increased ultraviolet-B radiation, i.e. the alpine and boreal regions, lying close to the polar ice shields. Detrimental physiological effects to species have been observed in both boreal and moderate zones, in terrestrial as well as aquatic ecosystems. Effects on the population sizes of species have, as far as we know, only been observed clearly in marine ecosystems. The effects are most prominent in the Antarctic seas, where the irradiation during the annual ozone hole period is high. Observations indicate that phyto- and zooplankton and larvae of fish and crustaceans are among the most vulnerable. Adaptation of the gene pool of plankton species to the relatively slow increase in ultraviolet-B irradiation cannot be taken into account, for as far as we know from literature, it is not observed as yet.

Reviews made by UNEP (1989 and 1991) refer to marine research indicating that 9% ozone depletion, leading to 20% increase of ultraviolet-B, results in an 8% reduction of the annual anchovy larvae population. With 16% ozone depletion 5% decrease in primary production and 6 - 9 % reduction of fish yield have been observed. Again at 16% ozone depletion, 50% mortality was reached in about 50% of the *examined* zooplankton species at a depth of 1 meter in temperate pelagic waters within less than 5 summer days.

Part of this mortality is normal; the extra mortality due to ozone depletion is probably lower than the figures indicate. Now assume that our basic standard, that no species shall die-out due to environmental pressure, complies with an LD90 of ultraviolet-B of the most sensitive species, and that these species are among the zooplankton of the upper layer of temperate seas. Assume further that this LD90 is reasonably well approximated by the observed LD50 of ultraviolet-B for less than 50% of these zooplankton species. Then the latter would be the sustainability standard, corresponding with 16% ozone depletion.

The same researches show that increased mortality is also present at 7.5% ozone depletion and it is even suspected that the extinction of some species cannot be excluded at this degree of ozone depletion, maybe not even at 1%. These preliminary findings and guesses must be compared to the natural variations in the ozone column, on global average about $\pm 15\%$ around the yearly average (Eggink *et al.*, 1995). The species are naturally adapted to this regime, but appear to be sensitive to deviations of the yearly pattern, especially when the periods of enhanced ultraviolet radiation come to interfere with their reproductive stages (Häder *et al.*, 1989, 1990). Yet the organisms survive the natural longer lasting cycles of ultraviolet radiation, such as the 11 years' cycle caused by the sun's oscillation, which has an amplitude of $\pm 10\%$ of the long run average. The standard for the avoidance of the extinction of the most sensitive marine species is therefore suspected to lie between 1% and 10% ozone depletion, roughly estimated at $5\% \pm 2\%$.

We did not find indications in literature for standards for ozone column depletion serving to guard off the extinction of fresh water organisms. Research results on physiological effects on both wild and agricultural terrestrial plants were found, as well as on shifts in the species composition of terrestrial ecosystems (e.g. in Tevini *et al.*, 1989, and Teramura *et al.*, 1991), but the data were considered too sparse to base a standard on.

The increase of human mortality by three types of skin cancer in relation to the dose of ultraviolet-B radiation received during a person's life can be estimated on the basis of data. This was done for instance by Slaper *et al.* (1992) in the so-called 'chain model' of the RIVM, who found a relation between the average lifetime ultraviolet-B dose and the consecutive increase in death rate. The question is, however, how many additional deaths are accepted in society. The annual death rate related to a highly appreciated and widely used achievement of technology, the motor vehicle system, is 80 to 90 per million inhabitants per year in The Netherlands. If this considered as an indication for accepted technology-related death, perhaps 10 to 50 deaths per million inhabitants per year might be accepted in relation to loss of environmental functions. Then 1 to 10 deaths per million inhabitants per year could be deemed acceptable as an effect of ozone layer depletion.

A third limit to ozone depletion could be derived from the ozone depletion process itself. As stated, the process is caused by increased levels of chlorine and bromine in the stratosphere. In total the average concentration amounts to circa 4 ppbv chlorine equivalents at present. In order to close the 'holes' in the ozone layer, it is at least necessary to return to the concentrations occurring before the first detection of the Antarctic 'ozone hole', i.e. 1.5 to 2.0 ppbv (Van der Woerd and Slaper, 1991). Although the average natural background concentration of 0.6 ppbv would be the most fundamental sustainability standard in this respect, we regard 1.5 to 2.0 ppbv as a preliminary sustainability limit aimed at the prevention of 'ozone holes'.

A rough equilibrium analysis was performed with the dynamic model of Slaper *et al.*, which causally couples the following key variables as a chain: emissions of ozone depleting gases – equivalent chlorine concentration – ozone column depletion – ultraviolet-B radiation – incidence of human skin cancers – skin cancer related deaths. It follows that the approximate standard of 3 to 7% ozone depletion for the protection of marine species boils down to an equivalent global emission of 80 to 186 million kg CFK 11 per year. Compared to the 1990 emission, 1170 million kg CFK 11, this entails a reduction of 84 to 93% in 1990. The standard for the limitation of skin cancer deaths to 1 to 10 deaths per million inhabitants translates into an equivalent world emission of 49 to 246 million kg CFK 11 per year. And the approximate limit 1.5 to 2.0 ppbv for the equivalent chlorine concentration for the prevention of the formation of ‘ozone holes’, would mean a reduction of the world emission to 96 to 149 million kg CFK 11 per year. Taking the most prudent lower and upper estimates of these limits, we arrive at 50 to 150 million kg CFK 11 per year as the approximate sustainability standard for the equivalent global emission of ozone depleting gases. The equivalent emissions are calculated with ozone depletion potentials (ODPs) mainly taken from WMO (1998), Nimitz and Skags (1992) and Kindler *et al.* (1995).

The emission standard for The Netherlands is in proportion to the world emission standard as the Dutch emission to the global emission, so the equivalent emission standard for ozone depleting gases in The Netherlands is computed as 0.95 ± 0.45 million kg CFK 11 per year. The equivalent emission in The Netherlands in 1990 was 10.4 million CFK 11 per year, so the standard calls for an emission reduction of 87 to 95% in that year. The standard, 0.95 ± 0.45 million kg CFK 11 per year, also holds for the use of these gases in various applications such as spray cans, plastic foams, refrigerators, cooling and air conditioning systems, fire extinguishers and cleaning, despite the delay times between the different types of use and the consecutive emissions. However, only a selection of the gases is represented in the economic model calculation. It is assumed that the non-represented emissions are not abated; therefore, the standard for the emission of abated gases in The Netherlands is set to 0.6 million kg CFK 11 per year. The required emission reduction in 1990 would be 94%. The steps leading to the standard are discussed in detail by De Boer (2000a).

4.5 Smog formation

“Summer smog” or “photochemical smog” is a type of air pollution in which so-called oxidants are formed; these substances have negative effects on life. The smog type often occurs on sunny summer days with low wind velocities in regions where volatile organic substances (VOS, including methane, CH_4), carbon monoxide (CO) and nitrogen oxides (NO_x) are emitted. The presence of these gases and sunlight in the lower 12 km of the atmosphere (troposphere) enables a complex of reactions to occur, in which NO and NO_2 are essential catalysts, VOS and CO are oxidised and oxidants like ozone and some radicals are formed. Incomplete oxidation yields more complex oxidants. The oxidant reaching the most damaging levels is ozone. The reactions may occur throughout the year, producing increased background levels of oxidant concentrations. Under summer smog conditions, quick oxidation of other volatile organic substances than methane (non-

methane VOS, NMVOS) dominates and high oxidant concentrations may be reached (De Leeuw, 1992).

Continuously increased ozone concentrations damage natural and agricultural vegetation. The peak levels occurring at summer smog conditions have a negative influence on the respiratory organs, irritate the mucous membranes of eyes, nose and throat of humans and probably many animals, and cause visual damage to plants. Loss of function is apparent; physiological effects on humans and plant and animal species play a key role. The Dutch standard for the average of the 98 percentiles of the ozone concentration at ground level over the growing season, from April to September, designed for the protection of ecosystems is exceeded by 13% in 1990, while the standard for this variable aimed at the protection of human health is exceeded by 3,5% in this period (RIVM, 1995).

Applications of a detailed model on continental scale (De Leeuw en Van Rheineck Leyssius, 1991) to the summer of 1980 allow us to set up a rough emission standard. It appears, namely, that the combinations of the relative reductions of the total continental emissions of NO_x and NMVOS must stay below a certain curve to reach a 13% reduction of the growth-seasonal average of the ozone peak concentration in that year. We use this curve as the sustainability standard for the annual NO_x and NMVOS emissions. The curve is explained in the next paragraph. As far as we can see, doing this boils down to assuming that 1980 was a representative year for the weather conditions for summer smog formation in the long run, and that the uncertainties in the model and the two-dimensional function fitted through its outcomes are acceptable. The assumption on the weather type has to be validated yet, and the consequences of this validation for the standard have to be worked out.

The NMVOS emission into air in the Netherlands in the years 1980, 1990 and 1992 amounted to 525, 440 and 422 million kg, while the respective NO_x emissions were 585, 574 and 564 million kg, as given in NAMEA 1986-1992 (CBS, 1996). The 1980 emissions are an extrapolation of the NAMEA figures proportional with related emissions in the Environmental Statistics for the Netherlands 1986 (CBS, 1997). The preliminary standard curve requires that at least one of the emissions be reduced in each of these years. If the NO_x emission would be reduced to 280 million kg in 1990 or to 300 million kg in 1992, which figures could be reached by satisfying the sustainability standard for acidification or eutrophication, a reduction of the NMVOS emission would not be required. If, on the other hand, the NO_x emission would not be reduced, the NMVOS emission should be reduced to about 240 million kg in 1990 and 250 million kg in 1992, with a confidence interval of 210 to 310 million kg/year. In the research stage reported here, the higher relative emission reductions of NO_x and NMVOS required for the year 1980 (100% and 61% or 48% and 100%, for instance) have been applied to the emission of the 1990, giving slightly exaggerated results. If this is really exaggerated remains to be seen, as the medium term goal for the NMVOS emission of the National Environment Policy Plan 2 for the year 2010 is stricter: 117 million kg per year (VROM, 1994). The causes of this difference have to be pointed out yet.

The NO_x emission is reduced in the SNI calculation in order to comply with the emission standards for acidification and eutrophication; in these standards, too, the admissible emission levels of NO_x depends on the emissions of other substances standards. The

overall optimum of the emissions of acidifying, eutrophication and ozone forming substances in the air depends on the standard functions and the costs of attaining the standards, ultimately determined by the general economic equilibrium model. Most probably the NO_x emission will be so much reduced to comply with the acidification and eutrophication standards, however, that the NMVOS emission would not need to be reduced in our calculations at all.

4.6 Fine particles in air

The effects of fine particles occurring in the air depend on their size and composition. Irritation of mucous membranes may occur at high dosages. Dust from sources like road traffic has carcinogenic components such as polycyclic aromatic hydrocarbons (PAH) and asbestos. The smaller the particles are, the higher doses of these compounds they carry and the easier they are inhaled into the lungs. Policy is therefore addressing fine dust in particular, by which particles smaller than a few micrometers are meant nowadays. The emissions and standards used in this study still concern particles up to $10\text{ }\mu\text{m}$ (PM-10).

Fine dust moves through air on such a small time scale that its dispersion can for our purposes be approximated statically. For the same reason, dust emissions jeopardise only the present availability of a number of functions of air, only regionally, and probably in a reversible way. Yet, interpretations of sustainability that include the present state of the environment are at stake. A sustainability standard for fine dust is therefore assessed.

Limit values to the concentrations of fine dust in air have been proposed, aiming to reduce the health risks (Eerens, 1992). The limit for the yearly average of the PM-10 concentration is $40\text{ }\mu\text{g}/\text{m}^3$ (RIVM, 1995 and 1996). Eerens estimated the concentration in a town like Amsterdam with a model based on measurements; it is about $50\text{ }\mu\text{g}/\text{m}^3$ in the years 1990 and 1992. A large part of this quantity is of foreign origin, by the way (30 to $40\text{ }\mu\text{g}/\text{m}^3$). More than half of the fine dust concentration is formed by chemical conversions of acidifying gases. Say that 50% ($25\text{ }\mu\text{g}/\text{m}^3$) will be reduced due to abatement of acidifying emissions up to the sustainability standard. Then the goal would already be reached. Assuming a linear relation between the national emission and the remaining half of the average concentration in the representative big city, the emission has to be reduced by 20% to 25% if there is no reduction of the acidifying emissions. According to the CBS (1992), the emissions in 1990 and 1992 are respectively 77 and 70 million kg/year and the latter figure does not differ much from the data collected later in the "Emission Registration" (Berdowski *et al.*, 1993, 1994). The emission standard would then amount to 58 ± 5 million kg/year.

In the National Environment Policy Plan 2 (VROM, 1994) the goal for the year 2000 was set to 51 million kg/year (33% less than the emission of 1990), which is only a fraction stricter than our standard. This standard is under pressure of international discussion (Eerens, 1992); a concentration limit equal to $20\text{ }\mu\text{g}/\text{m}^3$, in accordance with European guidelines, and an emission standard equal to 20 million kg/year have been proposed. In this report, the latter standard is used despite the lacking of background information. Improved emission figures are applied in the present study as well, summing up to 44 million kg PM10 in 1990. The latter The necessary emission reduction in that year

would then amount to 24 million kg. It is recommended to improve the estimate for the standard in a later stage.

Neither of the concentration limits represents a threshold in the dose effect relationship. The World Health Organisation (1995) could not find any indication for such a threshold. If it would exist, it would have to be the concentration level beyond which the regeneration capacity of the relevant part of the environment (in this case, humans) vanishes, and the sustainability standard then should not exceed it. The sustainability standard must roughly approximate the emission in the optimal sustainable situation (Section 3.4.6). Such a level may very well exist without a threshold in the dose effect relationship.

4.7 Eutrophication

Many human activities burden ecosystems with natural substances that are essential for all organisms and are therefore called nutrients. Generally quickly growing algae and plants in an ecosystem profit most from this over-fertilisation or eutrophication (“over-feeding”), as well as the animals and other organisms that graze these plants and algae, the animals that prey upon them and so on. Less opportunistic species will become less abundant or even disappear from the system, so the ecosystem is changed. The greater the added nutrient flows are, the fewer species will remain. The nutrients that cause most of these problems are phosphate, ammonium, nitrite and nitrate, and organic substances from which these ions can be formed by organisms.

In order to arrive at harmonised standards for the emissions of nutrients, quantitative insight must exist in their effects on ecosystems via processes in air, soil and surface water nation-wide. Many eutrophication models have been developed and verified for separate ecosystems or structures of them, but we have not yet found a model covering all components of the environment in the Netherlands, though there may very well be one. We therefore chose to regard air, soil and water separately, giving attention to the mutual dependencies.

4.7.1 Air

Erisman *et al.* (1996) made calculations in which local emissions of ammonia, nitrite and nitrate (expressed as nitrogen) into air are maximised under the constraint that the critical deposition levels of nitrogen on the soils and surface waters of nature areas may not be exceeded. The critical loads were calculated with simple models, in which certain critical concentration levels might not be exceeded, in order to prevent eutrophication (De Vries, 1993 and 1995). A linear and static model was used for the transport of the mentioned nitrogen nutrients through the atmosphere. Allowed emissions and depositions were calculated per grid cell on a map of the Netherlands, for the (still projected) situation where the Ecological Main Structure is realised and must be protected (see Sections 3.5 and 4.2). Emission locations were allowed to be optimised; unrealistic emission densities were prevented. The total allowed nitrogen emissions thus found (the standard) amounts to 105 millions of kg nitrogen per year, with confidence limits of 65 to 145 millions of kg per year (see Table 4.2). The interval was calculated by increasing and decreasing all critical deposition levels with the same factor and by varying the constraint on the emission density.

It is assumed that the relative emission reduction for the total nitrogen emission into air is equal to the one required for the total phosphorus emission into air. This obviously incorrect assumption is acceptable to our opinion, because the phosphorus emission into air amounts to only one half percent of the total phosphorus emissions in water, soil and air and therefore does not influence the total of these emissions nor the total emission reduction costs much. See Table 4.2 for the results.

4.7.2 Soil

A simple model approximation was made for eutrophication of the Dutch agricultural area in the years 1986 – 1994. Infiltration of surface water as a source of nutrients was neglected compared to the main sources, the applications of manure, artificial fertilisers, sewage treatment sludge and compost. A simple model was constructed in which all agricultural soils together were represented by one compartment and the following in-site processes were taken into account: uptake of nutrients by the crop, die-of of a fraction of the crop, evaporation of gases like ammonia and seepage to the subsoil. The model was based on nutrient balances by the CBS (1989, 1992, and 1994) for unsaturated and saturated ground water in the Netherlands as a whole and approximates the average nutrient concentrations in the upper 10 meters of the ground water.

Sustainable fertilisation was originally approximated by “equilibrium fertilisation”, loosely defined as the set of nutrient doses that is just enough to alleviate the limitation of crop growth by nutrient shortage. On an annual basis, these nutrient quantities would then be equal to what the crop would need to fully develop during the growing season. The other growth factors like the crop characteristics, water table and sunlight would then determine the harvest. However, limitation of growth by one growth factor is not just switched off when the factor has been supplied sufficiently; growth limitation increases gradually as the factor increases, especially around such a critical level. Therefore, each reduction of the nutrient dosage in comparison with the original situation will lead to a certain reduction of the crop yield, as well as a reduction of nutrient losses to the subsoil. The nutrient dose may be called sustainable if the fraction of the dose that percolates to the ground water is minimal, but also if the crop loss by nutrient scarcity is minimal. These two ends are conflicting and an optimum can in principle only be established through macro-economic analysis, as part of the overall SNI calculation. This being way too much effort for the accuracy to be expected, sustainable fertilisation was defined slightly arbitrarily as the set of nutrient doses at which the crop yield is at least 85% of the yield in the original situation. A direct consequence of this criterion is that the considered nitrogen and phosphorus nutrients should occur in the optimal proportion for the average Dutch crop. This proportion, expressed as mass ratio of nitrogen (N) and phosphorus (P), is often posited to be 10. However, the model produced a better fit to the national N and P budgets and the national average N and P concentrations as well if that ratio was calibrated to 7,5.

Maintenance of a minimum crop yield and reduction of nutrient losses by leaching to the subsoil are not the most relevant considerations for sustainable fertilisation. More fundamental is the condition that life in the soil is not disturbed so much that unsustainable effects on terrestrial life including soil ecosystems occur, such as the disappearance of species on a global scale. It may be expected that equilibrium fertilisation results in a

sufficient reduction of nutrient loss for this goal. For security, the average nitrogen concentration in groundwater was limited to 5,6 mg N/litre, a value postulated in the 4th National Environmental Outlook as to protect soil life in the long run (RIVM, 1997); 11,5 mg N/l should be aimed at in the short run. An earlier estimate without any reference to time horizon was 9 mg N/l (RIVM, 1995). The model showed that the concentration limit of 5,6 mg N/l was practically reached at equilibrium fertilisation, defined above as leading to maximally 15% loss of crop yield.

Because of the simplicity of the model, the outcome could not be based on spatial variations of fertiliser dosage, soil type, water management type, other environmental conditions and crop type, which determine the local efficient fertiliser dose. It is expected, however, that the presented lumped model yields a sufficient first approximation of the sustainable nutrient *emissions*. The nutrient emissions are defined as the national annual total N and P contents of the doses of manure, artificial fertilisers, sewage sludge and compost applied in agriculture. The equivalent nutrient emission is the weighted sum of the N and P emissions, using the “natural occurrence” weights 1/10 and 1, respectively. These weights have a more general validity than the weights 1/7.5 and 1 following from the national agricultural model discussed above. The environmental pressure by these emissions is the difference of these emissions and the uptake of the nutrients by the crop. The nutrient emissions to the soil occurring in the nutrient balances used as input in the nutrient model do not correspond exactly with the emissions appearing in the NAMEA version used for the final SNI calculation for 1990. Therefore, the actual N and P emissions as input in the nutrient model are proportionally enlarged to match the total N and P emissions from the NAMEA, respectively. Their sustainable counterparts calculated with the nutrient model are enlarged with the same factors. The actual and sustainable emissions to the soil and the associated equivalent emission are given in Table 4.2. The equivalent sustainable emission amounts to 128 million kilograms of phosphorus (or eutrophication equivalents) per year. The uncertainties in the data and the experiences in calibrating the model lead us to expect a reliability interval of 100 to 150 million kg P-eq per year.

The environmental *pressure* is the emission minus the uptake by the crops. The sustainable pressure is approximately equal to the part of the sustainable emission that still leaches into the soil. This sustainable pressure amounts to about 60 million kilograms of nitrogen and a negligible amount of phosphorus, as soil adsorbs phosphates much better and therefore accumulates them far more than ammonia, nitrite and nitrate.

Nutrients coming from human activities arrive in terrestrial natural ecosystems mostly via deposition and infiltration. Many natural areas suffer far more from atmospheric deposition of nutrients than from nutrient supply by infiltration; we neglected the latter. Based on observations and simple simulations of processes influencing nutrient concentrations in soils, De Vries (1993, 1995) and Erisman *et al.* (1996) come to admissible levels of atmospheric deposition of nitrogen compounds on soils (so-called critical loads), caused by human activities, i.e. by emissions in air. The subject is discussed in Section 4.7.1, as the depositions are caused by emissions into air; evaporation of ammonia from organically fertilised soils is treated as such.

4.7.3 Surface water

CIW/CUWVO (1996) determined the national and annual average of the local total nitrogen concentrations and the national average of the annual 90 percentiles of the local total phosphorus concentrations and tests these statistics to (temporary) limit values and (ultimate) goal values. These data have been used instead of the 90-percentiles of the concentrations in (static) equilibrium. Moreover, the relation of these aggregates with, respectively, the total phosphorus load and the total nitrogen load on surface waters in the Netherlands is assumed linear. The emission standards are then found by dividing the emissions by the factor by which the above mentioned concentration statistics exceed the goal values. These rough simplifications are judged acceptable because the nutrient emissions to surface waters are smaller than the emissions to air and soil; see Table 4.2. The proportions between the limit values and the goal values of the concentrations have been applied to the sustainability standards for the nitrogen and phosphorus emissions to surface waters (table 4.2) to indicate rough uncertainty margins. It appears that the derived standards for emissions in surface water are at the lower end of the proposed range for the policy standard issued in the Second National Environmental Policy Plan, see VROM (1994). Limitations to atmospheric deposition of nutrients are taken care of in Section 4.7.1.

4.7.4 Total emissions and standards

The emissions to water, soil and air are totalled in Table 4.2. This may be done because transfers between these components of the environment are not incorporated in the emissions. Concrete: application of manure is counted as emissions of nitrogen and phosphorus to the soil. The resulting release of ammonia in the atmosphere is not counted as a part of the emission into air. This ammonia release and the emission of ammonia and nitrogen oxides into air are the main causes of the deposition of airborne nitrogen on soil. Again, this deposition is not counted as part of the emission of nitrogen in soil.

Table 4.2 Nutrient emissions and emission standards.

	Emission in 1990		Sustainability standard			Sustainable emission reduction in 1990		Standard NEPP-2
Total (million Eeq/year)	312	128	(100	- 150	)	184	(162 - 212)	
Nitrogen (million kg	1436	611	(490	- 700	)	825	(736 - 946)	
Air	420	90	(70	- 100	)	330	(320 - 350)	
Soil	956	500	(400	- 600	)	456	(356 - 556)	
Surface water	60	21	(10	- 30	)	39	(30 - 50)	25 - 75
Phosphorus (million kg	169	67	(51	- 80	)	102	(89 - 117)	
Air	0,6	0,1	(0,07	- 0,15)		0,5	(0 - 1)	
Soil	147	64	(49	- 76	)	83	(71 - 98)	
Surface water	21	3,0	(2,3	- 3,5	)	18	(18 - 19)	3 - 8

Margins due to uncertainties in the standards in parentheses; 1 Eeq = 1 eutrophication equivalent = 1 kg P = 0,1 kg N; NEPP-2 = National Environmental Policy Plan 2 (VROM, 1994).

4.8 Acidification

Emissions of various substances into air are acid or lead to reactions in the atmosphere or, after deposition, in soils, which have acid products. Deposition of acid substances causes chemical and biological changes in certain terrestrial and aquatic ecosystems. The most important “acidifying” substances emitted by human activities are sulphur dioxide (SO_2), nitrogen oxides (NO and NO_2) and ammonia (NH_3). Their reaction products are acids (H_2SO_4 , HNO_2 and HNO_3) and aerosols that may be converted into acids.

The consulted literature does not indicate whether biological species can actually disappear from a region, continent or the world as a result of acidification. Yet it is clear that soil chemistry has changed in many affected nature areas. One of the results is the increased leaching of aluminium to ground water. Poorly buffered ground and surface water is most vulnerable to acidification. Very soft water is therefore no longer found in the Netherlands (Bakema *et al.*, 1992). Many ‘soft’ lakes in Sweden have been severely acidified in the past decades, mainly due to emissions in Western Europe. It is also evident that species have disappeared from acidified ecosystems.

Several plants and trees suffer from damage to roots or leaves in acidified areas. Roughly one third of the heaths in the Netherlands had turned to grass lands by 1990, while another third was on its way (Bakema *et al.*, 1992); the process has been going on since. Rare species typical for heath vegetation have disappeared in these areas. It is not entirely clear whether these phenomena are effects of acidification, but this process cannot be cancelled out as a cause either. Limits to the acidity of soils have therefore been set that must prevent that the uptake of nutrients by plants is severely obstructed by damage to the roots, or that the soil is leached out (see e.g. De Vries, 1993 and 1995).

Isolated, oligotrophic and poorly buffered aquatic ecosystems are very vulnerable to acidification. Many meres and lakes previously falling under this description have changed in chemical and biological composition. Several species specific for oligotrophic, soft water have disappeared; in Sweden several lakes have completely died-off. Acidity limit values designed to protect the most vulnerable aquatic species were reviewed and assessed for Dutch surface waters by, among others, De Vries (1993 and 1995).

The critical acid levels for prevailing Dutch types of terrestrial and aquatic ecosystems were converted into critical depositions (or loads) by the use of chemical steady state models. De Vries (1993, 1995) shows that the critical depositions of nitrogen compounds in coniferous and deciduous woods on well drained sandy grounds for the limitation of acidification are 1.6 to 1.8 times less strict than the corresponding critical nitrogen depositions for the limitation of eutrophication. For surface waters, the critical nitrogen loads for acidification are 2.4 times stricter than the critical nitrogen loads for eutrophication. The critical loads for surface waters probably have a small influence on the total admissible emission. The national standard for acidifying emission in air is therefore chosen 1.5 to 1.7 times less strict than the national standard for the nitrogen emission in air for the prevention of eutrophication, as reported in Section 4.7. Expressed in moles of potentially available acid (H^+), called acidification equivalents (Aeq), the sustainability standard for the national emission of acidifying substances in air is 10 (6...15) billion Aeq/year. The emission of acidifying substances in air in the year 1990 is 38.4 billion

Aeq/year, respectively (CBS, 1999). The required emission reduction is therefore 28.4 (23...32) billion Aeq/year.

The estimate for the sustainability standard has to be improved in due time. The goal for the year 2010 issued in the second National Environment Policy Plan for the Netherlands is stricter: 4.3 ... 8.6 billion Aeq/year (VROM, 1994). The causes of this discrepancy have to be researched and, if necessary, be corrected.

4.9 Toxic substances in surface water

As mentioned in Section 3.5, a system of concentration limits for hazardous substances in soil and surface water has been developed in the Netherlands, directed towards the avoidance of risks for the existence of species and human health. The system consists of three basic concentration levels and two policy levels, the latter of which are not used by us. At the *maximum allowable risk level* of a substance (MAR), 95% of the still existing species *potentially* present in the Dutch ecosystems are protected against potential hazardous effects of the substance, in absence of other hazardous substances. The limit value is based on data on species that function at high trophic levels (further in the food chain), as these species are more vulnerable than other ones. The *negligible risk level* of a substance (NR) is intended to prevent risks that arise when the substance occurs together with other potentially dangerous substances (synergism). The NR limits for all potentially hazardous substances have to be respected simultaneously at all time in order to avoid the risk of these substances to ecosystems. Both the MAR and the NR of a substance must be greater than its average *natural background concentration*, the third basic level. The NR of a substance is simply determined such that its distance to the background level is one hundredth of the distance between the MAR and the background level. The NRs therefore are scientifically less well underpinned and less certain than the MARs.

It may be inferred that the NRs are designed to warrant that 95% of the species potentially present in a subsystem of the environment may maintain themselves in the subsystem if all NRs are respected in the subsystem. It would be safe to expect that all still existing species would be protected against extinction on a global scale if all NR limits were respected “everywhere in the world”. However, this goal could perhaps also be achieved if all NRs would be satisfied in a system of preferably linked areas that occupy only a part of the earth’s surface. Say that these areas are the oceans and a system of interlinked fresh water ecosystems such as brooks, rivers and wetlands and terrestrial ecosystems such as forests and smaller ‘nature’ areas. In the Netherlands, such a system is the Ecological Main Structure (EMS), which is adopted in Section 4.1 as the standard for sustainable land use. The application of the NRs to the ecosystems within this structure, including the oceans and the MARs to the other ecosystems could be sufficient for the prevention of the extinction of species on the global scale.

The system of NRs seems overly safe. We suspect the sustainability limits to the concentrations of hazardous substances in protected areas like the EMS to lie somewhere between the NRs and the MARs. For instance, many species seem to be protected sufficiently against the effects of heavy metals dosages if their concentrations approach the MARs instead of the NRs, because of a stimulating effect of the presence of (other) metals on the defence system of many species (Reijnders, personal communication). We

opt for the MARs for the concentrations of heavy metals in water and the NRs for the concentrations of other substances in water as sustainability limits within the structure of nature areas and, as said, for their MARs outside that structure. Sustainability moreover requires that these conditions be satisfied in equilibrium.

These conditions demand statistic information that can only be provided by fitting a spatial dynamic model for the considered substances in surface water and sediment to available data. The model's equilibrium solution belonging to a certain total emission of the substance must then be calculated. It is a pattern of equilibrium concentrations on different locations in the country, in this case in the national surface water system. Running the model with different total emissions of a substance while keeping the proportions between the local emissions equal should lead to the total national emission with which the locally valid limits to the concentrations are satisfied at all locations; this is the emission standard for the substance.

A model fit for the job is RIZA's model Horizon for a network of surface waters including their sediments. The readily available first version (De Boer en Van der Meijden, 1990) could not distinguish between the 'more natural' waters and the other ones in sufficient detail and was not fit to more recent data. It did provide a first insight in the spatial dispersion of the concentrations, however. In second instance, a simple box (or completely stirred reactor) type of model of all Dutch fresh waters was used. The condition that the MARs of the metals and the NRs of other compounds had to be complied with within 'nature area waters' could not be maintained. Instead, it was demanded that these limits were respected in the whole box, representing about 50% of all Dutch fresh waters.

The hazardous substances incorporated in the SNI calculation consists of eight heavy metals, a metalloid (arsenic) and eight polycyclic aromatic hydrocarbons (PAHs). These substances were chosen for a pragmatic reason: emission data and a joint cost effectiveness data were available, although the latter concern only the emissions through sewer systems and sewage water treatment systems. Aggregating the emissions with the aid of aquatic environmental toxicity potentials (AETPs) yielded a joint cost effectiveness curve that could be applied in the applied general equilibrium model. The data and the approach have been explored by Van der Woerd *et al.* (2000); see Section 6.5. The advantage of this procedure is that technical measures with effects on several substances are properly accounted for, i.e. with a single expenditure for each measure, but the risk of connecting substances to improper measures also exists.

After calibration of the box-type model to data for zinc in Dutch surface waters, it was applied using a maximum allowable risk concentration (MAR) equal to 7.9 µg/l and a background concentration of 2.8 µg/l. The model prescribed a sustainable zinc emission to Dutch surface waters of 190 tonnes per year, 62.2% lower than the emission in 1990, 502 tonnes. Standards for other heavy metals and PAHs were not yet calculated this way, mainly due to lack of time. Therefore, the relative reduction obtained for emissions of zinc in Dutch fresh waters was simply used for the equivalent emission of the whole group of considered heavy metals and PAHs in Dutch fresh waters, measuring up to 194.3 billion kg 1,4-dichlorobenzene in 1990. The standard is thus set to 73.5 billion kg 1,4-dichlorobenzene per year. Moreover, this standard was also supposed to warrant compliance with the relevant MARs and NRs (see above) in the oceans. Both assump-

tions are obviously wrong. In the final report on the basic data for this subject, the setting of standard will be described more realistically, so that the result can be used in future improved SNI calculations.

4.10 Dehydration

'Dehydration' and 'desiccation' are collective terms for 'all effects of the lowering of the groundwater table on forest, nature and the landscape, both as a result of a water shortage and changes in the effects of seepage and precipitation' (V&W, 1985). Causes are drainage of agricultural area, groundwater extraction for drinking and industrial water production and other activities, related to about 60%, 30% and 10% of the total affected nature area surface (RIVM, 1996). The process is going on in the Netherlands for more than a century, but especially since the 1950's. Main effects are the impoverishment of natural vegetation and its sequential effects, particularly on fauna. Many typical ecosystems such as moist grassland, moist heath, moist dune valleys, high moorlands, fens, natural forests, brook dales and deciduous forest are declining rapidly. Several specific species have disappeared from these systems (Pellenbarg and Beugelink, 1992).

Following the principles discussed in Sections 3.5 and 4.2, the sustainability standard would be that the species expected to occur in the Ecological Main Structure must be protected. However, the inventories of the effects and the measures needed to abate them are limited to the areas which the definition suggests, i.e. the existing nature areas (officially: the areas to which 'nature' has been assigned as main function or secondary function; in our reference system, these functions have to be understood as collective terms for the potential functions of these areas). As soon as urban nature areas are recognised as parts of the overall structure, for instance, the influence of urban and industrial drainage is expected to be greater than mentioned above. We conform ourselves to this data limitation, which should be removed in the second stage of the project.

Given this data limitation the standard must be adapted as recovery of the original groundwater table in 100% of the dried out nature areas, measured as surface. It is expected, however, that not all ecosystems involved will fully recover subsequently (RIZA, 1996). RIZA estimates that the total affected area has not changed much since 1985. This concerns 3050 km² dried-out area with main function 'nature' and 2550 km² dried-out area with side function 'nature'. In the Milieubalans 1996 these areas are estimated 2990 and 3250 km², based on a new inventory (RIVM, 1996).

The second National Environment Policy Plan (VROM, 1994) includes as a goal for the year 2010 a 40% reduction of the area with drought damage compared to 1985, by the way.

4.11 Soil contamination

In principle, the sustainability limit for concentrations of contaminants in soil can be assessed following the procedure described in Sections 3.5 and 4.9. These values would be the negligible risk levels (NRs) for these substances, which would have to be respected in 90 percent of all locations. In practice only information is available on concentrations in isolated measurement spots in several natural and agricultural areas and within a number of severely polluted locations. Considering even the large number of these polluted

locations, the total surface of these areas is definitely smaller than the 10% where we allow the concentration limits to be breached. It would however be cynical to include the problematic soil pollution locations in the 10% exception area of our procedure. As experts have not yet corroborated this percentage to some extent, it seems more practical to use concentration levels up to which the severely polluted locations have to be cleaned-up in order to reach a minimum safety level.

Choice of ‘multifunctional use’ as a goal for all locations would aim too high. In the first place, the SNI approach aims at minimal levels for the functions that the ecosystems somewhere in the region (ca. 100 km, see Section 3.5) can sustain forever, not for as many functions the location itself reasonably can get by cleaning it up. Secondly, it would in many cases be technically impossible to purify the soil up to the required concentration levels. Alternatives would be to dump the polluted or partially purified soil in controlled deposits, with doubtful advantages for the environment.

A less ambitious approach from an environmental point of view would be to let the concentration standards depend on the original functions of the area. Though this approach is closer to the SNI-approach than the multifunctional approach, it may still aim too high. This is because the original function levels may be (but do not need to be) higher than the minimally required function levels for sustainability, while moreover the latter need not be necessarily supplied at the polluted location.

In the second National Environment Policy Plan (VROM, 1994) a more modest approach is chosen. Lightly polluted locations are isolated and managed (“secured”), minimising the risk for people and the adjacent environment, at least on the middle long run. On the time scale of many future generations (sustainability) it is uncertain if the management can be maintained. Heavily polluted locations, which mostly form an urgent problem, are cleaning-up or “secured”; the extent of the local pollution determines the measures that are taken. This approach might be the closest to the SNI approach, except that the precautionary principle may be lost out of sight in some occasions.

Within this study, the multifunctional approach is therefore followed wherever possible. It entails that not only the location, but also the extracted soil must be purified up to the required level. Only in cases where this approach seems impossible, the approach advocated by VROM (1994) is followed. We are aware of the inconsistency of this combination; however, the subsequent cost estimation is just as rough, or worse.

4.12 Summary of standards

The next table shows the sustainability standards used in the SNI calculations reported in this study. The standards for the use of fossil fuels and the emissions of ozone layer depleting substances and fine dust have been incorporated in anticipation of their application in the second stage of the study, although the standard values might not be final for the purpose of calculating a sustainable national income.

Table 4.3 Sustainability standards for the Netherlands used in this study compared to the involved environmental pressure in the year 1990. The theme land use is not listed, as it is not quantified: the standard is to reserve land surface for extension of the nature areas up to the projected Ecological Main Structure, see Section 4.2.

Environmental theme	Standard	Pressure in 1990	Reduction in 1990	Unit
Fossil fuel depletion	1223	2265	1042	PJ/year
Enhanced greenhouse effect	53.3	251.0	197.7	billion kg CO ₂ -eq/year
Depletion of the ozone layer	0.6	10.4	9.8	million kg CFK11-eq/year
Smog formation	240	440	200	million kg NMVOS/year
Fine particles in air	20	44	24	million kg PM10/year
Eutrophication	128	312	184	million Eeq/year
Acidification	10.0	38.4	28.4	billion Aeq/year
Toxic substances in surface wa-	73.5	194.3	120.8	billion kg 1,4-DCB-
Dehydration	0	100	100	% affected area
Soil contamination	0	100	100	% polluted locations

P = peta = 10^{15} , billion = 10^9 , Aeq = acidification equivalent = 1 mole potential acid, as H⁺, Eeq = eutrophication equivalent = 1 kg P = 0,1 kg N, PM10 = fraction of fine particles with diameter less than 10 µm, NMVOS = non-methane volatile organic substances, 1,4-DCB = 1,4-dichlorobenzene

References

- Adriaanse, A. (1993). *Environmental policy indicators*. Sdu Uitgeverij, 's-Gravenhage.
- Beek, M. (1995). *De risico's van normen. Een overzicht van de methodiek en afgeleide (eco)toxicologische risicogrenzen ter onderbouwing van Streef-, Grens- en Interventiewaarden*. Rijkswaterstaat, Rijksinstituut voor Integraal Zoetwaterbeheer en Afvalwaterbehandeling, Lelystad, Werkdocument 95.097X.
- Berdowski, J.J.M., R.J.K. van der Auweraert, P.F.J. van der Most, R. Thomas and E.A. Zonneveld (1993). *Emissies in Nederland - 1992, Trends, thema's en doelgroepen, Ramingen 1993*. Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer, Centraal Bureau voor de Statistiek, Rijksinstituut voor Volksgezondheid en Milieuhygiëne, 's-Gravenhage, Publicatiereeks Emissieregistratie, nr. 20.
- Berdowski, J.J.M., R.J.K. van der Auweraert, P.F.J. van der Most, C.H.A. Quarles van Ufford, O. van de Velde and E.A. Zonneveld (1993). *Emissies in Nederland, Trends, thema's en doelgroepen, 1992 en ramingen 1993*. Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer, Ministerie van Verkeer en Waterstaat, Ministerie van Landbouw, Natuurbeheer en Visserij, Rijksinstituut voor Volksgezondheid en Milieuhygiëne, Centraal Bureau voor de Statistiek, 's-Gravenhage, Publicatiereeks Emissieregistratie, nr. 26.
- Bosch, P.R. (1995). *Energiedragers, bijdrage aan de rapportage van het Onderzoek Berekening Duurzaam Nationaal Inkomen*, Centraal Bureau voor de Statistiek, Voorburg.
- CBS (1996). *Rekeningen en indicatoren voor economie en milieu NAMEA 1986 – 1992*, Centraal Bureau voor de Statistiek, Voorburg.
- CBS (1997). *Milieustatistieken voor Nederland 1996*. Centraal Bureau voor de Statistiek, Voorburg.
- CBS (1999). *NAMEA 1990*. Elektronische publicatie.
- CIW-CUWVO (1996). *Voortgangsrapportage integraal waterbeheer en Noordzee-aangelegenheden 1996*. Commissie Integraal Waterbeheer.

- de Boer, B. (2000). *Aantasting van de ozonlaag. Basisrapport voor het project Berekening van het duurzaam nationaal inkomen*. Centraal Bureau voor de Statistiek (Statistics Netherlands), Voorburg, in preparation.
- de Boer, B. (2000). *Klimaatverandering. Basisrapport voor het project Berekening van het duurzaam nationaal inkomen*. Centraal Bureau voor de Statistiek (Statistics Netherlands), Voorburg, in preparation.
- de Boer, B. and A.M. van der Meijden (1990). *Prognose van de waterbodembodemkwaliteit*. DHV Raadgevend Ingenieursbureau BV, Amersfoort, in opdracht van Rijkswaterstaat, Dienst Binnenwateren/RIZA, Lelystad.
- de Leeuw, F.A.A.M. (1991). Ozon op leefniveau. In: RIVM, 1992. *National Environmental Outlook 1990-2010*. Rijksinstituut voor Volksgezondheid en Milieuhygiëne, Bilthoven, Samson H.D. Tjeenk Willink BV, Alphen aan den Rijn.
- de Leeuw, F.A.A.M. and H.J. van Rheineck Leyssius (1991). Calculation of long-term averaged and episodic oxidant concentrations for the Netherlands. *Atmospheric Environment*, 25A, pp. 1809-1818.
- de Vries, W. (1988). Critical deposition levels for nitrogen and sulphur on dutch forest ecosystems. *Water, Air and Soil Pollution*, 42, pp. 221-239.
- de Vries, W. (1993). Average critical loads for nitrogen and sulfur and its use in acidification abatement policy in the Netherlands. *Water, Air and Soil Pollution*, 68, pp. 399-434.
- de Vries, W. (1995). Kritische depositieniveaus voor totaal zuur en stikstof op bossen, appendix bij een stuk over *derde Actieprogramma Verzuring*, DLO Winand Staring Centrum, Wageningen. Eerens, H.C. (1992). Air pollution in towns. In: RIVM, 1992, *National Environmental Outlook 1990-2010*, Rijksinstituut voor Volksgezondheid en Milieuhygiëne, Bilthoven, Samson H.D. Tjeenk Willink BV, Alphen aan den Rijn.
- Erisman, J.W., A. Bleeker, P.S.C. Heuberger, A.H. Bakema, G.B. Makaske and A.F. Bouwman, *Ermissieplafonds voor ammoniak en maximale stikstofgiften per gemeente in Nederland, Een eerste orde benadering*. Rijksinstituut voor Volksgezondheid en Milieuhygiëne, Bilthoven, rapport nr. 722108019.
- Houghton, J.T., G.J. Jenkins and J.J. Ephraums (eds.) (1990). *The enhanced greenhouse effect: The IPCC Scientific Assessment*. Intergovernmental Panel on The enhanced greenhouse effect, Cambridge University Press, Cambridge. 365 pp.
- Houghton, J.D., B.A. Callander and S.K. Varney (eds.) (1992). *The enhanced greenhouse effect 1992. The supplementary reports to the IPCC Scientific Assessment*. Intergovernmental Panel on The enhanced greenhouse effect, Cambridge University Press, Cambridge.
- Hueting, R., P.R. Bosch and B. de Boer (1992). *Methodology for the calculation of sustainable national income*. Statistics Netherlands, Voorburg, Netherlands, Series Statistische Onderzoekingen no. M44; also World Wide Fund for Nature, Gland, Switzerland.
- Jäger, J. (1988). *Developing policies for responding to climatic change. A summary of the discussions and recommendations of the workshops held in Villach (28 September-2 October 1987) and Bellagio (9-13 November 1987) under the auspices of the Beijer Institute, Stockholm / World Meteorological Organization / UN Environment Programme, World Climate Programme Impact Studies*.
- Kindler, T.P., W.L. Chameides, P.H. Wine, D.M. Cunnold, F.N. Alyea and J.A. Franklin (1995). The fate of atmospheric phosgene and the stratospheric chlorine loadings of its parent compounds: CCl₄, C₂Cl₄, C₂HCl₃, CH₃CCl₃, and CHCl₃. *Journal of Geophysical Research*, 100, (1), pp. 1235-1252, paper no. 94JD02518.

- Nimitz, J.S., and R.S. Skaggs (1992). Estimating tropospheric lifetimes and ozone depletion potentials of one and two carbon hydrofluorocarbons and hydrochlorofluorocarbons. *Environmental Science and Technology*, 26, pp. 739-744.
- RIVM (1992). *National Environmental Outlook 1990-2010*. Rijksinstituut voor Volksgezondheid en Milieuhygiëne, Bilthoven, Samson H.D. Tjeenk Willink BV, Alphen aan den Rijn.
- RIVM (1993). *Nationale Milieuverkenning 3*. Rijksinstituut voor Volksgezondheid en Milieuhygiëne, Bilthoven, Samson H.D. Tjeenk Willink BV, Alphen aan den Rijn.
- RIVM (1994). *Milieurendement van het NMP-2: Bijlage E-H*. RIVM-rapport 251701013.
- RIVM (1995). *Achergronden bij: Milieubalans 95*. Rijksinstituut voor Volksgezondheid en Milieuhygiëne, Bilthoven, Samson H.D. Tjeenk Willink BV, Alphen aan den Rijn.
- RIVM (1996). *Milieubalans 1996*. Rijksinstituut voor Volksgezondheid en Milieuhygiëne, Bilthoven, Samson H.D. Tjeenk Willink BV, Alphen aan den Rijn.
- RIVM (1997). *Nationale Milieuverkenning 4 1997-2020*. Rijksinstituut voor Volksgezondheid en Milieuhygiëne, Bilthoven, Samson H.D. Tjeenk Willink BV, Alphen aan den Rijn.
- RIVM *et al.* (1997). *Natuurverkenning 97*. Rijksinstituut voor Volksgezondheid en Milieuhygiëne, Informatie- en KennisCentrum Natuurbeheer, DLO-Instituut voor Bos- en Natuuronderzoek, DLO-Staring centrum, Samson H.D. Tjeenk Willink BV, Alphen aan den Rijn.
- RIZA (1996). *WaterSysteemVerkenningen*, concept.
- Rotmans, J. (1990). Sea-level rise potentials. In: F.R. Rijsberman and R.J. Swart, 1990. *Targets and Indicators of Climatic Change*, The Stockholm Environment Institute.
- Rotmans, J. (1990). *IMAGE: an integrated model to assess the greenhouse effect*. Kluwer Academic Publishers, Dordrecht etc.
- Sprengers, S.A., L.K. Slager and H. Aiking (1994). *Biodiversity and the enhanced greenhouse effect. Part I: Establishment of ecological goals for the climate convention*. IVM- R94/09, Institute for Environmental Studies, Vrije Universiteit, Amsterdam.
- Takahashi, Y. (1966). Eine kurze Einführung in die Theorie des Zustandsraumes, Teil I. *Regelungstechnik*, 14, (10), pp. 449-455.
- Takahashi, Y. (1966). Eine kurze Einführung in die Theorie des Zustandsraumes, Teil II. *Regelungstechnik*, 14, (11), pp. 513-518.
- Teramura, A.H., M. Tevini, J.F. Bornman, M.M. Caldwell, G. Kulandaivelu and L.O. Björn (1991). Terrestrial plants In: *UNEP* (1991).
- Tevini, M., A.H. Teramura, G. Kulandaivelu, M.M. Caldwell and L.O. Björn (1989). Terrestrial plants. In: *UNEP* (1989).
- Tweede Kamer (1990). *Natuurbeleidsplan, Regeringsbeslissing*. Tweede Kamer der Staten-Generaal, 's-Gravenhage, vergaderjaar 1989-1990, 21 149, nrs. 2-3.
- UNEP (1989). *Environmental effects panel report, pursuant to article 6 of the Montreal Protocol on substances that deplete the ozone layer under the auspices of the United Nations Environment Programme (UNEP)*. Nairobi, Kenya.
- UNEP (1991). *Environmental effects of ozone depletion: 1991 update. Panel report pursuant to article 6 of the Montreal Protocol on substances that deplete the ozone layer under the auspices of the United Nations Environment Programme (UNEP)*. Nairobi, Kenya.
- van der Woerd, K.F., E.C.M. Ruijgrok and R.B. Dellink (2000). *Kosteneffectiviteit van Verspreiding naar water*. IVM-E00/01, Institute for Environmental Studies, Vrije Universiteit, Amsterdam.

- Vellinga, P. R.J. and Swart (1991). The greenhouse marathon: A proposal for a global strategy. *Climatic Change*, 18, pp. vii-xii.
- V&W (1993). *Evaluatienota water 1993*, 's-Gravenhage.
- V&W (1995). *Toetsing huidige en verwachte water(bodem)kwaliteit aan grenswaarden*, 's-Gravenhage.
- Versluys, C. (1996). RIVM / LBG. *Kosten duurzaamheid bodemsanering*, mimeo, en mondelinge mededeling.
- VROM (1994). *National Environmental Policy Plan 2*, 's-Gravenhage.
- WHO (1995). *Update and revision of the air quality guidelines for Europe*, World Health Organization, Meeting of the Working Group "Classical" Air Pollutants, Bilthoven, Netherlands, 11-14 October 1994, EUR/HFA target 21, EUR/ICP/EHAZ 9405/PB01.
- WMO (1999). *Scientific assessment of ozone depletion: 1998*. World Meteorological Organization, Geneva, Global Ozone Monitoring Project, Report no. 44.

5. An applied general equilibrium model to calculate a Sustainable National Income for the Netherlands

Reyer Gerlagh, Rob Dellink, Marjan Hofkes, Harmen Verbruggen

5.1 Introduction

5.1.1 Context and overview

This chapter presents in detail version 1.1 of the model²⁷ that is used to calculate different variants of a Sustainable National Income (SNI) according to Hueting. As described in Chapter 3, in order to calculate a sustainable national income, the costs needed to arrive at the chosen sustainability standard should be deducted from national income. Two ways of calculating these costs can be distinguished: the direct correction method and the integral correction method. The direct correction method only takes into account the direct costs to be made in order to prevent or restore the environmental functions. These costs can be due to either technical measures or to quantity measures, i.e. reduction in the volume of production. In this method, changes in relative prices and intersectoral reallocations are not taken into account. By contrast, the integral correction method does take account of all indirect effects.

The calculations of a sustainable National Income that will be presented in Chapter 7 are based on the integral correction method. The model used is a so-called Applied General Equilibrium (AGE) model. The main advantage of using a general equilibrium model is that such models allow for a comprehensive and consistent approach, while being able to take all indirect effects into account. The use of an AGE model allows us to appreciate our analysis standing in a rich tradition of environmental policy modelling. However, our motivation and interpretation of results differs in an important way from common model exercises. Most AGE models are used to calculate economy-wide consequences of specific policy instruments, for example energy taxes or carbon emission taxes, that aim at achieving certain environmental objectives, e.g. Jorgenson and Wilcoxon 1993a, 1993b, Boyd and Uri 1991. The model is used to test the feasibility of these policy instruments. Accordingly, a change in gross output of one or two per cent of GDP is considered substantial. We simulate an economy that switches towards a sustainability policy where resource use is substantially cut down, and we are not to be surprised if gross output decreases by ten per cent, twenty per cent, or even more. It is therefore clear that

²⁷ Version 1.0 was used for calculations up till August 2000. At that time Statistics Netherlands provided revised data and an update of the model was made. All results presented in this report are based on version 1.1. The formal model has undergone minor changes only. The most important revisions concern the number of sectors, which increased from 21 to 27, and the inclusion of new environmental themes, which increased from seven to nine.

we do not exercise a policy analysis, but instead, we use the model to calculate a measure of welfare, the Sustainable National Income according to Hueting.

In the next section of this chapter we will first describe the general principles of general equilibrium modelling. In Section 5.2, the general set-up of the SNI-AGE model will be described. Section 5.3 elaborates on the general set-up by providing all the details of the modelling exercise.

5.1.2 Applied General Equilibrium Modelling

Basically, a general equilibrium model consists of a set of ‘economic agents’, each of which demands and supplies commodities or ‘goods’. Agents are assumed to behave rationally. Each agent solves its own optimisation problem. The agents take the prices, which give information about the decision environment, as given. Equilibrium is defined as a state of the economy in which the actions of all agents are mutually consistent and can be executed simultaneously. Equilibrium is attained by adjusting the prices.

Generally there are two categories of agents: consumers and producers. Consumers maximise their utility under a budget constraint, for given prices and given initial endowments. Producers maximise profits under the restriction of their production technology, for given prices. Demand and supply, which result from the agents’ optimisation problems, meet each other on the markets. All commodities have prices associated. These prices adjust such that supply matches demand for every single commodity, or in other words, such that all markets are in equilibrium.

Before an applied general equilibrium model can be constructed several basic modelling questions should be answered (see Shoven and Whalley, 1984, Fullerton et al, 1984 and Cornielje, 1990). These basic modelling questions include, among others, the type of model (i.e. static or dynamic), the categories of goods and actors (e.g. level of aggregation) and functional forms of the agents’ behaviour. In the next section we will describe the how the environment is incorporated in the SNI-AGE model and list the main operational choices made with respect to these basic modelling questions.

5.2 General set up of the SNI-AGE model

5.2.1 A static comparative analysis

In our analysis, we follow Hueting and interpret sustainable income as reflecting the situation of the economy after an instantaneous change towards sustainable resource use. In this thought, transition dynamics do not matter, and the SNI calculations should not be burdened with transition costs. This contrasts with the usual policy analysis that aims at analysing the costs of environmental regulations, where one may also be interested in the costs of restructuring and reallocation of economic activities that has to take place. This involves a premature write-off of capital goods, and other transition or adaptation costs. For this reason, we conclude that where a dynamic analysis may provide useful information for a policy analysis, Hueting’s SNI is better calculated by a static model, which can be used to compare two distinct equilibrium states.

Another way of looking at the sustainable allocation to which the economy instantaneously changes, is by assuming that the sustainable allocation represents a sustainable economy that follows its own development path with lower resource use levels. In other words, environmental regulations required to hold the economy within the sustainability boundaries are announced a period in advance, long enough that economic agents are able to integrate this transition in the planning of their investment decisions. Transition costs are then minimised and can be neglected. By this way of reasoning, it is implicitly assumed that the early announcement enhances the substitution possibilities in the economy. This, in turn, should be expressed by applying medium to long-term substitution elasticities in the model calculations, instead of short-term elasticities, which are common in static modelling. However, long-term substitution elasticities for the sectoral breakdown as well as those pertaining to substitutions among economic and environmental variables are not readily available for the Dutch economy. As it presently stands, elasticities of a rather short to medium-term nature are applied.

Consistent with the static AGE modelling, calculations are based on the currently available technologies. This is of most importance for the estimated costs of applying to the sustainability standards; only known technological options are envisaged. Known technologies comprise options that are already on the market (but not yet implemented) as well as technological options that are indeed technically feasible, but still too expensive or not yet fully applicable and standardised, or both, to apply under present market conditions. These remote options will certainly be considered if more stringent environmental standards are enforced. By broadening the known technological options in this way, some justice is done to the early announcement assumption. For if this really would have been the case, the development of clean technology would probably have been accelerated. Hence, the cost of technical measures is based on the present state of technological knowledge, where present refers to 1990.²⁸

As no dynamics are modelled, the model does not allow for a detailed analysis of the build up of capital stocks. Capital is treated in a fairly uncomplicated manner. The model represents (1) depreciation costs, being a flow input in the production process that is proportional to the capital stock, (2) net investments, being a flow from consumers who want to supply an increased capital stock in the (not modelled) next period, and (3) the rate of return, being an income flow for the consumers that is proportional to the capital stock and thereby proportional to the capital depreciation flow. In a dynamic analysis a time path would have to be modelled with dynamic investments as well as time-dependent behaviour of the agents.

Despite the clear methodological choice for the static analysis, being confronted with the substantial shifts in the economy that are calculated in a later chapter, an obvious subject of interest is the transition dynamics that would be necessary if policy were to implement a sustainable allocation. Though such calculations would not provide information on the SNI itself, they may offer some insight in the real policy implications of a sustainability policy. A dynamic approach would allow for a phasing of environmental policies in time. In that case, not all environmental problems would have to be solved at once, but

²⁸ Note that on average, it takes about 2 decades for newly invented technical measures to become operational.

some optimal time schedule might be found. In contrast, the SNI-AGE model explicitly abstracts from a policy path, and assumes the total and immediate (although officially announced long before) implementation of sustainability criteria. It must also be noted that, although some of the sustainability standards as adopted in the model are actually based on underlying dynamic analyses, the static approach does not capture the full dynamic nature of the environmental system.

Yet, such a dynamic analysis is currently not possible, mainly because of the problem of data availability. A dynamic analysis would require data for a series of years, while the comparative-static approach requires data for a single historical year only. Time series for all relevant parameters and variables in the model are very hard to obtain, and if such time series exist, they are often not consistent.²⁹ Moreover, the actual building and calibration of a dynamic model would require much more effort than for the comparative static model. In view of the computations to be done with the SNI-AGE model, a dynamic analysis would require an operationalisation of the, mainly theoretical, literature on the driving forces behind innovations. Such an effort is far beyond the scope of the underlying study.

5.2.2 Counting SNI

Before describing the model, we discuss two features of Hueting's SNI that concern the interpretation of the numerical results, rather than the modelling itself. These two features are the use of prices from the current unsustainable economy, in contrast to the use of prices from the sustainable economy, and the correction of income for so-called double counting.

If the cost of measures to meet the sustainability standards are directly deducted from national income, it is conceivable to use the current market prices as a first approximation. If, however, SNI calculations are made with the help of an applied general equilibrium model, relative prices change, i.e. prices of environment-intensive products will generally increase compared to other products. The question now is in which set of prices SNI could best be expressed, such that a comparison with the original national income figure can be ascribed a meaningful interpretation. The two best-known income measures are named after Laspeyres and Paasche, using the initial prices and new prices to aggregate goods, respectively.

In the first alternative the set of relative prices of the base situation is used to weigh the volumes of the SNI. Intuitively, as the same price sets are used, this alternative would provide an adequate standard of comparison. However, two objections come to the fore. First, consistency between sustainable national income and sustainable national product is lost, because the volume shares of a SNI will differ from the original national income. Second, a SNI results in a new set of equilibrium prices and it is at odds with the sustainability concern not to use these prices reflecting the true scarcities. On the other hand, a major objection against the use of a new set of relative prices is the loss of a comparative standard. Since in equilibrium, only relative prices matter, the new equilib-

²⁹ For instance, the transition in the sectoral breakdown of production figures from the old SBI-74 categorisation to the new SBI-93 categories is not straightforward, though transition tables exist.

rium prices have to be scaled at the old price level to make this second alternative meaningful. Since there is no obvious preference for using ‘current’ or ‘new’ prices, both price sets will be used to calculate SNI variants, denoted by variants *a* and *b* for using the current and new prices, that is the Paasche and Laspeyres indexation, respectively.

In addition to correcting national income for the cost of meeting sustainability standards, national income should also be corrected for so-called double counting. Double counting refers to the expenditure on compensatory, restoratory and preventive measures to re-establish or maintain environmental functions, sometimes denoted as defensive measures. According to Hueting and many others, these expenditures wrongly enter national income as value added: loss of environmental functions is not written off, whereas restoration is written up. This line of reasoning can indeed be maintained in case defensive measures are taken in the sphere of consumption, not entering a production process as intermediate input. In our SNI calculations, the cost to reduce dehydration and the clean up of contaminated soils are double counting cases.

However, dehydration and contaminated soils are inherited from the past, and it makes no sense to attribute the total cleaning costs to the one year under consideration. Another procedure is therefore followed that is more in line with the overall approach of a comparative static equilibrium analysis. It is assumed that the total cost of soil clean up, amounting to 408 billion guilders, is born by the government. Furthermore, it is assumed that the soil clean up activities are spread over a 20-years period. Each year, 5% of the total amount is contracted out for soil clean up, which enters the SNI model as public consumption, but which is not included in the sustainable national income. The same applies to the reduction cost of dehydration, which amounts to 550 million guilders on a yearly basis. See Chapter 6, Section 6.5.3 for a further discussion.

5.2.3 The environment and the modelling of pollution abatement

The treatment of the environment is the most significant contribution of this model to existing AGE-models. The model considers nine environmental themes, for seven of which the environmental problem can be understood as an excessive emission of pollutants to the environment. The other two themes fall in the category defensive expenditures. A basic distinction is made between *abatable* and *unabatable* pollution. The definition of abatable pollution is that it can be removed (or cleaned, or prevented) by taking technical measures (also called abatement). Hence, the total amount of abatable pollution is determined by the technical abatement potential (with an upper bound of 100% of total pollution). All pollution that cannot be abated in this way is called unabatable.

The technical measures to reduce pollution are included through explicit abatement cost curves for various environmental themes. This approach displays the basic principles of Hueting’s methodology, where the correction of the traditional NI figures consists of the costs that have to be incurred to meet the sustainability standards. These costs consist of two parts. First, there are costs of technical measures which are investment costs (recalculated as annual costs) and operation & maintenance costs of changes in the production process. In economic terms, abatement is a substitute for a part of pollution that is labelled ‘abatable’. Second, the ‘unabatable’ part of pollution can only be reduced by volume measures, the cost of which consists of lost value added due to a reduction in the

production volume; see Hueting *et al*, 1992. Volume measures are accounted for by the endogenous restructuring of the economy in the AGE model. This section describes in general terms the modelling of technical measures. The formal modelling of both technical and volume measures is described in Section 5.3.3.

Abatement measures are included in the model through parameterised functions. Inclusion of explicit abatement measures would add substantial complexity to the model. The model version used for the calculations presented in this report attempts to maintain a relatively simple model structure, and for this purpose uses several assumptions that may be relaxed in following model versions. Even so, it should also be kept in mind that a more complete handling of abatement measures is currently impracticable because required data are not available. These assumptions concern the uniform shape of cost curves over all sectors (cost curves are different per environmental theme, but not per sector), the uniform expenditure effects of all reduction measures, the linkage of pollution and its reduction to output levels per sector, and the neglect of interaction between reduction measures realised for different environmental themes, that is the so-called secondary effects. We will now briefly discuss these assumptions.

Uniform cost curves and expenditure effects over all sectors

Cost curves that express the costs as a function of pollution reduction levels are available on an aggregate level only. There is no sector-specific data available, and thus, it is assumed that the same cost curve holds for all sectors³⁰. In particular, for all sectors, it is assumed that the same percentage of pollution is abatable through technical measures, while the remaining share can only be reduced through volume measures. Sectors that have relatively high pollution intensities are not assumed to have more opportunities to reduce their pollution. Thus, these sectors will mainly suffer from pollution reductions through volume measures. Relaxation of this assumption may substantially affect the sectoral distribution in the calculated sustainable economy.

There is also insufficient data for the expenditure effect of abatement measures. Abatement is modelled as the additional input of a certain mix of goods and capital. The additional demand for goods used for abatement is called the expenditure effect. In this case, the modelling structure is not only limited by data availability, but also the intractability of a model in which separate technical measures are specified with their own spending effects. From the data, we derive an average expenditure effect and this is imposed on all technical measures. This approach allows us to model a fictitious abatement sector that provides the abatement goods, and that has fixed input shares for capital, labour and various goods. Probably, the assumptions on a uniform spending effect over sectors does not substantially affect the calculated sustainable national income. Required reductions nearly exhaust the technical measures so that it is irrelevant whether certain expenditures apply to the first part or to a later part of a cost curve.

Linking pollution to output

Another assumption that may have serious consequences for the calculations is the linkage of pollution to output per sector, as opposed to linking pollution to inputs. In reality,

³⁰ Recently, data has become available on cost curves for groups of sectors, e.g. the aggregate of industries. This can be used to develop a model with sector-specific cost-curves.

abatement does not only increase expenditures, it also decreases the need for certain inputs. This is apparently clear for greenhouse gas emissions such as carbon dioxide. For a large part, reducing carbon dioxide emissions is equivalent to reducing the energy input. However, the model follows available data and associates pollution to the final users, without making an explicit linkage to the inputs. It is not clear what the consequences are for calculated overall costs of pollution reductions, but it is clear that the sectors contributing to energy production are less hurt in the calculated sustainable economy than they would have been if sustainability standards were implemented in practice. An exception is made for electricity. The model correctly attributes pollution associated to electricity production to the electricity producing sector, and not to the sector consuming electricity. A reduction in electricity consumption will therefore decrease pollution and only increase costs insofar other inputs need to be increased to substitute for the electricity reduction.

Secondary effects

Measures that aim at reducing emissions of one substance may lead to a change in the emission of another substance. For instance, improvement of energy efficiency to reduce CO₂ emissions may also lead to reduction of NO_x and SO₂ emissions. In line with the procedures of CBS and RIVM (VROM, 1994) that provided most data, a primary aim of the measure is then identified and the costs of the measure are totally attributed to that primary aim.

If the measure impacts two substances within the same theme (e.g., NO_x and SO₂), this procedure does not lead to double counting of the costs, but if one measure is included in two different themes (e.g., CO₂ and NO_x), the measure may well be defined as having a primary aim in both themes, and double counting of costs may occur. This criticism applies to the technical measures. For volume measures, secondary effects are fully captured in the model since a reduction of output volume will decrease pollution for all environmental themes proportionally.

Overall, the secondary effects will certainly lead to an overestimation of the costs of sustainability standards. See Chapter 6 for further discussion.

5.2.4 Additional operational choices

Now, we turn our attention to the other main operational choices that are required to specify the technical model details of our static AGE-model. These operational choices are presented as assumptions handling the employment level and wage rate, the capital stock and its rate of return, the recycling of environmental levies through a lowering of other taxes, the expenditures and savings of the government and private consumers, and international trade.

Employment effects

The already mentioned understanding that calculation of a SNI reflects an economy with a different development path has also implications for the choices on the modelling of employment. If executing a policy analysis, it can be argued that wages will not adjust downwards. Under these circumstances, a substantially decreasing output inevitably

leads to a decreasing employment level. On the contrary, the sustainable economy simulated by our calculations can be thought of as having followed a different path of development with an increasing output, be it at a lower level. According to Huetting, a sustainable economy will certainly not worsen the employment situation. In our calculations, we choose a straightforward approach and neglect influences from the labour market on SNI, be it positive or negative. The labour market is maintained very simple, whereby the available labour force is exogenously given by the employment level in the initial situation, and the labour market is cleared through an adjusting wage rate. The unemployment is supposed to be caused by other distortionary factors than wage rigidities.

The capital stock, investments, and the rate of return

The same arguments that decide the assumptions for the employment effects apply to the capital stock. In a policy analysis, in the short term, one takes the capital stock levels as given, and the rate of return adjusts in the new equilibrium. For the mid-term, if the rate of return decreases, investments decrease as well. In the long term, the capital stock adjusts and the rate of return slowly converges to its initial level. Our model abstracts from these transition dynamics, and assumes that the capital stock immediately adjusts; the rate of return is fixed at a rate determined by the accounting data for the initial economy. Investments consist of two parts, replacement of depreciated capital and net investments. Net investments are required to support economic growth, which is assumed to have the same rate in the sustainable economy and in the initial economy. Both replacement and net investments are assumed to constitute a fixed share of the capital stock. In other words, if the capital stock relative to total output increases by $x\%$, then required replacement increases by the same amount, as well as net investments, partly crowding out consumption.

In advance, it is ambiguous whether the capital-output rate will increase or decrease due to the sustainability measures. There are two opposing forces. On the one hand, capital intensive sectors tend to be environmental intensive as well. This implies that in a sustainable economy, production shifts to less capital-intensive sectors. On the other hand, end-of-pipe technical measures that reduce pollution tend to be capital intensive, so that abatement requires an increase in the relative capital stock. The overall effect cannot be predicted, but is a result of model calculations.

Recycling of environmental levies

The pollution reductions (the sustainability standards) are imposed on the economy by means of a regulating levy. Environmental use (pollution) is taxed to such an extent that the producers and consumers reduce their pollution to the allowable amount. The exact level of the environmental levy that is needed to ensure this is calculated endogenously within the model. In the model the equivalent format of pollution rights auctioned by the government will be used. We assume that the government owns the initial pollution rights as endowments, and then reduce the endowments to the sustainability levels. These will become scarce and receive a price, exactly in the same way as labour receives a price since it is a scarce production factor.

Revenues are recycled to the producers and consumers by a linearly homogeneous reduction of other existing taxes. There is no change in fiscal and income distributional

policies. If the revenues of the environmental levy more than suffice to satisfy the government budget, that is if they exceed the amount raised by existing taxes, additional revenues are redistributed to the private households by use of lump sum transfers.

Public consumption and savings

Public services are modelled as government consumption and are assumed to consist of a bundle of goods with fixed shares. The price elasticity of consumption is zero. The government budget as a share of total income remains constant. Public savings (or deficit) also remains constant as a share of income. As overall income decreases, consumption of all goods decreases in the same proportion.

Private consumption and savings

Private consumers are confronted with two effects: changing income because of changing wages and rents from capital, and changing prices because of comparative advantages of some sectors over other sectors. In the model calculations, the effects of lower income levels is approached by the use of good-specific income elasticities. Demand for agricultural products decreases less than proportional, demand for services decreases more than proportional, and demand for manufactured products as a share of total demand depends on the stage of economic development. In this way, consumption is thought of as consisting of necessary goods for subsistence and luxury goods. If income falls, the consumption of necessary goods will remain relatively stable, which is compensated by a more than proportional decrease in the consumption of luxury goods. Different from the public consumer, demand of the private consumers is supposed to have positive price elasticities. In general, the price of environment-intensive goods will increase and its consumption will decrease, whereas the price of environment-extensive goods will decrease and its consumption will increase. Environment-extensive goods will show an increase in relative consumption levels. In this way, consumption patterns will become more sustainable as a result of relative price changes. Similar to the government savings, private savings are constant relative to total income.

World-wide sustainability and international trade

For the small and open Dutch economy, adjustments in international trade will have substantial consequences. Again, sustainable national income turns out to be radically different from a standard policy analysis since it is one of the key assumptions of Hueting's sustainable national income that sustainability standards are applied all over the world, taking due account of local differences in environmental conditions. This may alter relative prices on the world market, and also, it may affect the size of the markets for Dutch exported goods.

We first discuss the latter, the export markets for Dutch goods, keeping in mind the standard macro-economic balance equations. The public and private savings surplus (or deficit) equals the trade balance surplus (or deficit). The savings surplus is assumed to constitute a constant share of national income and is set equal to that share in the base situation. This, in turn, determines the trade balance and the relative price level of the Netherlands *vis-à-vis* the rest of the world.

To understand the importance of taking into account the change in size of the export markets, it is helpful to imagine what happens if we abstract thereof and follow the common assumptions in general equilibrium modelling. In most applied general equilibrium models, it is assumed that foreign demand for export goods can only be increased by lowering export prices, and vice versa, will only decrease if export prices increase. Whereas the usual assumption fits the short term, it is less useful for the long term and for the analysis of sustainable national income. Assume that the Dutch economy under a sustainable regime has shrunk by factor two compared to the initial economy and that export markets are unaffected. This implies that for constant export prices, there is an enormous increase of the trade balance, since imports decrease proportionally with domestic income while exports do not decrease. To restore the trade balance, an appreciation of the Dutch currency would be required to increase imports and to decrease exports³¹. This is at odds with common sense, to have a model with an appreciation of the guilder because of a shrinking size of the Dutch economy.

Instead of the assumed fixed export market, we assume that the export market for Dutch goods is proportional to the domestic output level. This can be thought of as reflecting a long-term perspective with the following dynamic mechanism. Assume that the Dutch economy suddenly has shrunk by factor two, at period t , and that, in first instance, exports are unaffected. As total production decreases and exports remain constant, domestic supply decreases more than proportional, domestic prices increase, and henceforth, export prices increase. In the next period, the share of Dutch exports in world exports decreases and continues to fall as long as Dutch export prices exceed the world market prices. Domestic and export prices stabilise at their initial level when the Dutch export share has decreased by the same amount as the overall Dutch economy.³²

We now come to the second aspect of international trade, the relative prices of goods on the world market. A global implementation of sustainability standards will cause an international reallocation of relatively environment-intensive production activities because of local differences in environmental conditions. However, it is not feasible to estimate the resulting cost and changes in relative prices in other countries. So, additional assumptions have to be formulated with respect to relative price changes on the world market and the impact on import and export flows to and from the Netherlands.

First, with respect to relative prices, it can be assumed that relative prices on the world market do not change and are equal to the base situation. It is then assumed that there are no inherently environmentally intensive and environmentally extensive goods. For every good, the relative increase of its price in one country is compensated by a relative decrease in another country. As relative prices in the Netherlands do change, it becomes

³¹ Note that this argument abstracts from exchange rate agreements.

³² There is also another, more abstract, reasoning to explain the proportionality of exports relative to the size of the Dutch economy, namely, size neutrality of the model. Assume that the Dutch economy consists of two identical and equally sized sub-economies in a world that consists of many equal economies. Particularly, both sub-economies have imports and exports that constitute half of the total Dutch economy. If the size of the total Dutch economy decreases by factor two, for example because of the implementation of sustainability measures, the resulting economy would be equivalent to one of the initial sub-economies. This implies that both exports and imports are decreased by factor two (for constant export prices).

indeed feasible for the Netherlands to ‘export’ the costs of meeting the sustainability standards. Products that are relatively environment-intensive in the Dutch economy are confronted with increasing production costs and imports for these goods increase. Products that are relatively environment- extensive in the Dutch economy have decreasing production costs and exports for these goods increase. As a result, the production structure changes while the consumption structure can remain relatively unaltered.

Second, it can be assumed that world market prices change proportionally to Dutch domestic prices. In economic terms this boils down to the assumption that in reaction to worldwide sustainability policies, all production processes in foreign sectors go through a similar process of adjustment as in the Netherlands. In combination with an assumed fixed exchange rate, per sector the share of imports in total domestic demand, and the share of export in total domestic production, remains constant compared to the base situation.

It is thought that the second option comes closest to Hueting's methodology, but the members of the steering committee of the project under which the SNI-calculations were carried out were strongly divided about this issue, and proposed to calculate income measures using both options. Taking account of the choice for new or old prices, denoted in Section 5.2.1 by *a* and *b*, we have four variants that are calculated, namely:

Variant 1a: constant relative prices on the world market and SNI expressed in relative prices of the base situation (old prices)

Variant 1b: constant relative prices on the world market as in variant 1a, but SNI expressed in new equilibrium prices

Variant 2a: constant shares of imports and exports and SNI expressed in relative prices of the base situation (old prices)

Variant 2b: constant shares of exports and imports as in variant 2a, but SNI expressed in new equilibrium prices

This brings the general description of the model, its structure, and its assumptions to an end. The next section presents the detailed set up.

5.3 Detailed set up of the model, version 1.1

5.3.1 On agents and markets

The SNI-AGE model identifies domestically produced goods by the sector producing them. There is one non-produced non-environmental production factor, labour, and there is capital in the model. Besides these common elements, the model distinguishes environmental themes such as the greenhouse effect and acidification. To each of the environmental themes emission units are associated, e.g., greenhouse gas emissions in CO₂ equivalents. The term emission units as used in this Chapter is equivalent to the term pollution levels as used in other chapters. In the model, these emission units are treated as production factors comparable with labour, since a reduction in the use of emission units will decrease the output level. This is due to the fact that scarce means have to be allocated to abate pollution and cannot be used alternatively, i.e. as inputs for producers.

The agents in the model include the sectors (the producers), one private consumer, the government, and the Rest of the World (ROW). In addition to these standard agents, there are several auxiliary agents that are necessary to shape the model. These include the ‘investor’ who ‘consumes’ investment goods necessary for economic growth and the ‘capital sector’ who fabricates the composite capital good. The overview of the relationships in the model is presented in Figure 5.1. In the figure, black arrows represent commodity flows that are balanced by inverse income flows; grey arrows represent pure income transfers that are not balanced by commodity flows.

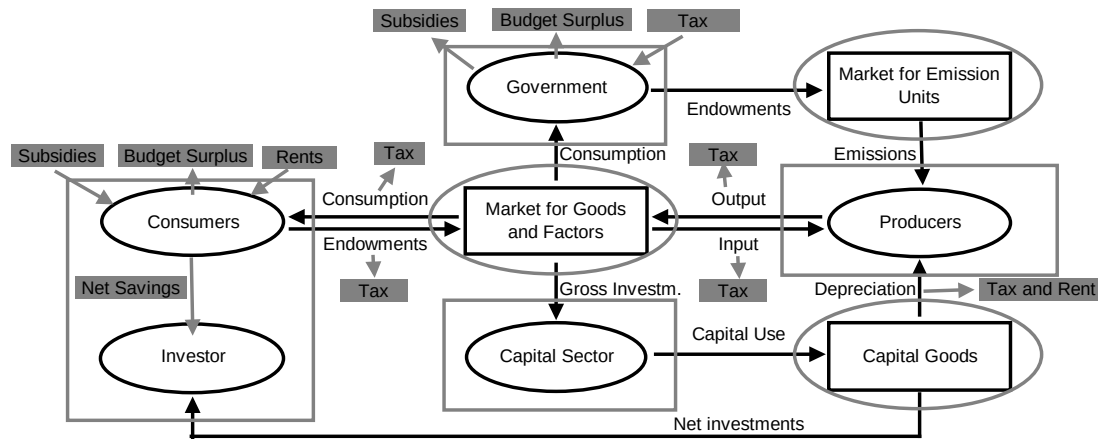


Figure 5.1 Overview of SNI-AGE model.

Demand and supply meet on the markets for goods and factors. The private consumers supply endowments (labour), which are used as inputs for the producers. The producers supply their output, which balances consumption by the private and public consumer and inputs for gross investments. Part of these investments balance with the depreciation of the capital stock, the remaining part, net investments, is used to sustain economic growth in the next period. The figure also shows the market for emission units, to which the government supplies her endowments, that is the amount she allows the economy to use, and where the producers demand the inputs of emission units they need for their production. Thus the government owns the environment as a public good and determines its use, based on the sustainability standards. Hence, the revenues from the sale of emission units enter the government budget.

The government levies taxes on the consumption (VAT), the supply of endowments (labour income tax), production and the capital use (profit tax). These public revenues are used, together with revenues from the sale of emission units, to balance the public expenditures that consist of public consumption, and lump sum subsidies for social security. The remainder is the public budget balance. Consumers use their income from the sale of endowments and lump sum subsidies to balance their consumption and net savings. Net savings are transferred lump sum to an auxiliary agent, the ‘investor’ who uses its income to pay for net investments.

Producers are assumed to have constant returns to scale technologies, which implies that profits, apart from a rate of return on capital, are zero, and hence, that the value of inputs

is equal to the value of outputs. In Figure 5.1, this can be visualised by placing a grey box around the agents, over which the net income and expenditure flows sum to zero. The same applies to clearing markets, where (the value of) total supply matches total demand. This is visualised by a grey ellipse.

If we draw a grey box around the entire domestic economy, we find that the budgets close, except for the budget balances of the private and public consumers. However, we have omitted international trade from the figure. Overall, the budget surplus is equal to the surplus on the trade balance, represented through the well-known identity:

$$Y = C + I + (X-M), \quad (1)$$

where $Y-C-I$ is the income surplus of the consumers compared to the expenditures on consumption and investments, and $(X-M)$ is the surplus export compared to the imports. Of course, in case of a budget deficit the opposite holds

In the following sections, we single out specific elements of the broad figure, and elaborate upon them in more detail. First, Section 5.3.2 presents our notation, the use of indexes and nested CES functions to give details of individual behaviour. Following, Section 5.3.3 discusses producers, Section 5.3.4 international trade, and Section 5.3.5 consumers. At the end in Section 5.3.6, we define equilibrium and present all budgets, zero profit conditions, the trade balance, and commodity balances in one unifying framework, the Social Accounting Matrix (SAM).

5.3.2 Individual behaviour; the use of nested CES structures and indexes

In order to be able to derive demand and supply, production and utility functions have to be specified. We assume that these functions are of the so-called nested Constant Elasticity of Substitution (nested CES) type (see Sato, 1967 and Keller, 1980 for more details). A CES function is a function for which the elasticity of substitution is constant. The elasticity of substitution is the relative change in the ratio of two inputs, say a and b , if the (exogenous) price ratio between b and a rises by 1%. So, for example, if the constant elasticity of substitution between a and b is 0.5, this means that the relative input ratio a/b rises with 0.5% if the relative price ratio p_b/p_a rises with 1%.

A nested CES production function is a production function where output is defined as a CES function of (aggregates of) inputs, which are in turn defined as CES-functions of (aggregates of) inputs at a lower level (Figure 5.2). At the highest level there is only one component, which coincides with total production/output. At the lowest level the components correspond with the inputs. Each knot can have its own elasticity of substitution. As already mentioned in the previous section producers are assumed to have constant returns to scale technologies, which implies that profits, apart from a rate of return on capital, equal zero.

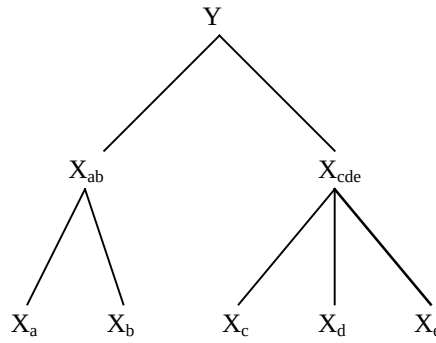


Figure 5.2 An example of a nested CES structure.

The same principle can be applied to the utility function. The concept of a nested CES utility function rests upon the assumption that utility is built up as a utility tree, which consists of a number of levels. At each level several knots are distinguished representing utility components. Each knot aggregates two or more utility components of a lower level into a utility component at a higher level of aggregation. At the highest level there is only one component corresponding with overall utility, while at the lowest level the utility components correspond with the goods in the economy. Using nested CES utility functions allows for the use of different elasticities of substitution at each utility component that is distinguished.

Suppose a producer produces one output (Y) using 4 inputs (X_1 , X_2 , X_3 and X_4), where X_3 and X_4 are first combined into a composite good X_{34} with substitution elasticity ϕ , and the composite good (X_{34}) is combined with X_1 and X_2 (with substitution elasticity σ) to obtain the output Y . The general nested CES production function can then be written as:

$$Y = (a_1 X_1^\rho + a_2 X_2^\rho + a_{34} X_{34}^\rho)^{1/\rho}, \text{ and} \quad (2)$$

$$X_{34} = (a_3 X_3^\psi + a_4 X_4^\psi)^{1/\psi}, \quad (3)$$

for some parameters a_1 , a_2 , a_{34} , a_3 , a_4 , where $\rho = (\sigma - 1)/\sigma$ and $\psi = (\phi - 1)/\phi$. A convenient notation is:

$$Y = \text{CES}(X_1, X_2, X_{34}; \sigma); \text{ and} \quad (4)$$

$$X_{34} = \text{CES}(X_3, X_4; \psi). \quad (5)$$

For zero elasticities, e.g. $\sigma = 0$, the production function reduces to a so called Leontieff or input/output structure:

$$Y = \min\{a_1 X_1, a_2 X_2, a_{34} X_{34}\} \quad (6)$$

For large numbers of inputs in the function, the notation $Y = \text{CES}(X_{1-2}, X_{34}; \sigma)$ can be used, or alternatively, if we have a set $\mathbf{I} = \{1, 2\}$ (sets are written in bold), we may write $Y = \text{CES}(X_{\mathbf{I}}, X_{34}; \sigma)$. In Figure 5.3, the nested CES function is drawn as follows:

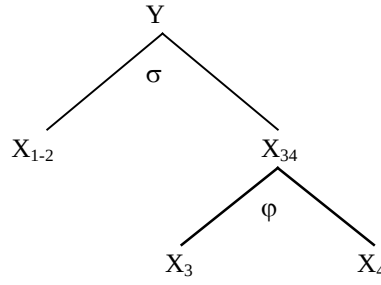


Figure 5.3 Representation of nested CES functions.

Throughout this paper, we will mostly use notation as in formulas (4) and (5). We also use the set-index to condense summation over indexes. Let the set of firms be denoted by J , and let the output of firm j be denoted by Y_j , its value is pY_j , now, if we sum the value over all firms, we use the notation: $pY_J \equiv \sum_{j \in J} pY_j$.

5.3.3 Producers

There are 27 private goods domestically produced, each good by a separate producer, denoted by $j \in J_G$. The index $j \in J$ is used to denote all producers in the model, including auxiliary producers such as the ‘Trade Margin’, the ‘Abatement’ sector, and the ‘Capital’ sector, described at the end of this section. The subscript ‘G’ distinguishes the produced private goods that are used for consumption from the other producers in the model.

Another group of auxiliary producers are the producers of ‘emission services’, which are necessary to model the reduction of pollution through increased abatement. Emission units are treated as production factors, since a reduction decreases output. There is so called unabatable pollution that is proportional to output. These enter the CES tree at the first level directly below output, and are part of a branch with elasticity zero. The remaining part of pollution is ‘abatable’, that is, they can be decreased if one increases the input of abatement goods. This is modelled through the use of a fictitious composite good, ‘emission services’ that uses pollution and abatement goods as substitutable inputs. The distinction between abatable and unabatable pollution would imply that emission units enter the CES production tree at two different branches. This is incompatible with the MPSGE language in which the model is written (Rutherford, 1997). Therefore, we also introduce ‘emission services’ as an auxiliary producer, which output is used by the other firms, and which input consists of emission units and abatement goods.

Private goods producers

Output is denoted by Y_j^{out} . The output is determined by an aggregate materials input, denoted as *intermediates* ($INTM$) (aggregates are in capital), an aggregate factors input, denoted as *primaries* ($PRIM$), non-competitive imports (ncm) (labels are in italics), trade margins (tm), unabatable emission units (EU), and emission services (ES). The latter aggregate inputs have fixed shares, in other words, elasticity zero, which is represented as follows:

$$Y_j^{out} = \text{CES}(\text{OUTP}_j, F_{ncm,j}, F_{tm,j}, EU_{E,j}, ES_{E,j}; 0) \quad (7)$$

where

$$OUTP_j = CES(INTM_j, PRIM_j; \sigma_j) \quad (8)$$

$$INTM_j = CES(F_{J_G, j}; \sigma_j^{Intm}) \quad (9)$$

$$PRIM_j = CES(K_j, L_j; \sigma_j^{Prim}) \quad (10)$$

where $F_{J, j}$ denotes the vector of inputs from the other sectors in the j -th sector, K_j denotes the inputs of capital goods that are necessary to balance depreciation, L_j denotes the labour use, and E denotes the environmental themes. Since K_j denotes an input flow of goods produced by an auxiliary ‘capital sector’, it is also denoted by $K_j \equiv F_{cap, j}$. Non-competitive imports $F_{ncm, j}$ are those imports that have no domestic substitute. Furthermore, note that as indicated by the subscripts, the substitution elasticities may differ between the sectors.

Outputs and inputs do not operate on the same market, since there is international trade between them, discussed in Section 5.3.4. The market for domestic outputs is denoted by ‘Y’, the market for domestic inputs by ‘D’. Since the production structure has constant returns to scale, profit maximisation gives zero profits:

$$p_j^Y Y_j^{out} = p_j^D F_{J, j} + q_E EU_{E, j} + s_{E, j} ES_{E, j} + p_{lab}^D L_j + T_j + R_j \quad (11)$$

where paid taxes T_j are given by

$$T_j = \tau_j^Y p_j^Y Y_j^{out} + \tau_{cap}^D p_{cap}^D K_j + \tau_{lab}^D p_{lab}^D L_j, \quad (12)$$

and the where the value of rents is given by

$$R_j^D = r \cdot p_{cap}^D K_j. \quad (13)$$

The vector τ_j^Y contains the sector specific taxes and subsidies (if $\tau_j^Y < 0$) which are assumed to be proportional to output, τ_{cap}^D is the tax rate on profits from capital, r is the rate of return the consumers want for their capital relative to the depreciation costs (if depreciation is 10% per year, and the rate of return is 5% per year, then $r=0.5$), τ_{lab}^D is the tax rate on income from labour, prices for emission services are denoted by s , and prices for emission units are denoted by q . Multiplication by index-sets is written according to $q_{E, j} EU_{E, j} = \sum_{e \in E} q_{e, j} EU_{e, j}$ and the same applies for the use of the index J in

$p_j^D F_{J, j}$. Note that the inproduct $p_j^D F_{J, j}$ in (11) includes costs of non-competitive imports, trade margins, and capital replacement.

As stated in Section 5.2.4, it is assumed that the capital stock adjusts in order to ensure a constant rate of return, that is, r is constant over all alternative calculations.

Trade margins

Trade margins do not represent a real produced good, but are fictitious to account for payments between sectors for the distribution and transport of goods. These payments

are assumed to be a fixed part of the production costs. Hence, trade margins are not subject to taxes and are made of a bundle of produced goods in fixed proportions. Its supply is represented through an auxiliary separate producer, which production function is given by:

$$Y_{tm}^{out} = CES(F_{J,tm}; 0) . \quad (14)$$

The zero profit condition gives:

$$p_{tm}^Y Y_{tm}^{out} = p_J^D F_{J,tm} \quad (15)$$

for the firm $j = 'tm'$.

This producer has a different production function than the other producers: there are no substitution possibilities between the various goods ($\sigma=0$), and there is no demand for primary production factors, pollution or abatement, associated with this special producer. Since the output of the trade margin producer enters the production function of the other producers at the top level, with elasticity zero, it is assured that the trade margins are fixed relative to the aggregate production levels of the producers.

Emission services producer

For each polluting agent (either producers $j \in J$ or consumers $h \in H$) and each environmental theme $e \in E$, a fictitious production sector is modelled, called 'emission services'³³.

This producer explicitly represents the trade-off between paying for pollution and investing in abatement activities.

$$ES_{e,j}^{out} = CES(EA_{e,j}, F_{abat,e,j}; \sigma_{e,j}^{ES}), \quad (16)$$

and the zero profit condition gives:

$$s_{e,j} ES_{e,j}^{out} = q_e EA_{e,j} + p_{abat}^D F_{abat,e,j} \quad (17)$$

where $EA_{e,j}$ denotes the volume of abatable pollution, $F_{abat,e,j}$ denotes the inputs of the abatement sector, $s_{e,j}$ denotes the price for emission services, and q_e denotes the price for emission units. For consumer-related abatable pollution, we substitute h for j . The iso-output curve has the following typical shape:

³³ Though this producer is labelled emission services, it is actually formulated for all kinds of pollution.

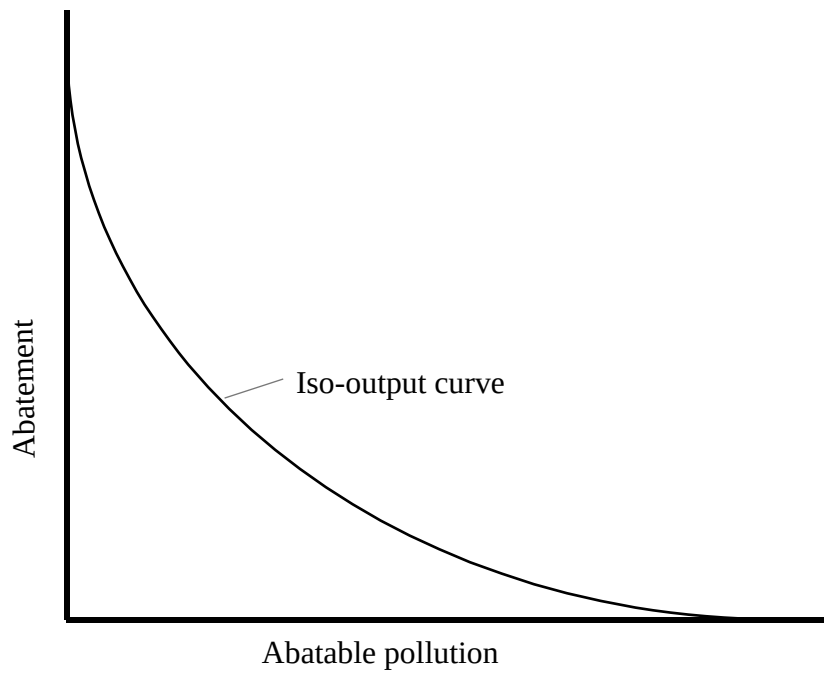


Figure 5.4 Iso-output curve for environmental service sector.

The cost-effective abatement curve is, by pollution definition, the mirror image of the iso-output curve: abatement costs increase if the level has to decrease. The substitution elasticities $\sigma_{E,j}^{ES}$ and $\sigma_{E,h}^{ES}$ (which exceed unity so that the iso-output curve touches the axes) determine the possibilities to substitute between pollution and abatement; for $\sigma=\infty$, the curve becomes a straight line, i.e., marginal costs do not increase as the abatement proceeds. The values for these elasticities are taken from cost-abatement-curves (see Chapter 6), and typically lie between 2 and 10, and represent the technical options open to the agents to reduce their pollution levels.

Abatement producer

Abatement activities are modelled through the specification of an abatement producer which produces a good that is used to reduce pollution in the ‘emission services’ sector. Indirectly, this specification ensures that firms and households can choose between paying some price for pollution and investing in abatement activities.

The inputs into the production function of the abatement sector represent the so-called spending effects of implementing technical measures: if a new filter is installed to reduce pollution, then this filter has to be bought (and produced) somewhere, leading to an increased demand for filters. It is assumed that there is one abatement sector the output of which is used to reduce pollution for all environmental themes. This implies a homogeneous spending effect over all themes.

The production function of the abatement sector is similar to that of the trade margins.

$$Y_{abat}^{out} = CES(F_{J,abat}; 0). \quad (18)$$

The zero profit condition gives:

$$p_{abat}^Y Y_{abat}^{out} = p_J^D F_{J,abat} \quad (19)$$

Production of the capital good

All sectors require capital (K_j) as production factor. Their demand for capital goods consists of replacement costs. Furthermore, the ‘investor’ demands the capital good to increase the capital stock for the next (not modelled) period. For this purpose, we model an auxiliary capital sector. The output of this sector is a stream of capital goods that enters the production functions of the firms as a counterbalance to capital depreciation, and it enters the utility functions of consumers as net investments. This modelling approach implies that the capital stock is not fixed, but is endogenously determined in the model. Its volume is determined by a desired rate of return. This is explained in Section 5.3.6. This capital good is composed of an aggregate material input consisting of the private goods and ‘trade margins’, with fixed shares. The production function is given by:

$$Y_{cap}^{out} = CES(F_{J_G, cap}, F_{tm, cap}; 0), \quad (20)$$

and the zero profit condition gives:

$$p_{cap}^Y Y_{cap}^{out} = p_{J_G}^D F_{J_G, cap} + p_{tm}^D F_{tm, cap} \quad (21)$$

for $j = \text{‘cap’}$, the capital sector.

5.3.4 International trade

Foreign trade has two components, imports and exports. To arrive at the amount of goods that can be used for inputs in the production functions and for consumption, first add imports to domestic production, and then subtract exports.

Furthermore, we follow the common assumption that imports are imperfect substitutes for similar domestic commodities, known as the Armington approach. Thus, the market for goods is more complex than Figure 5.1 suggests, because of international trade. In the model, there are three markets, one for domestically supplied goods, labelled ‘Y’, one for domestic demand, labelled ‘D’. These two markets were already introduced in the previous section. The modelling of trade requires one additionally auxiliary market, labelled ‘S’, and a world market on which a single good is traded, labelled ‘T’. In terms of the model, domestic supply by producers (from market ‘Y’) together with imports of a single world market good (from market ‘T’) are used to produce an auxiliary good (for market ‘S’) that, in its turn, is used to produce exports (for market ‘T’) and goods for the domestic demand market (for market ‘D’). Figure 5.5 gives an overview. The box with a grey boundary singles out the central market box of Figure 5.1.

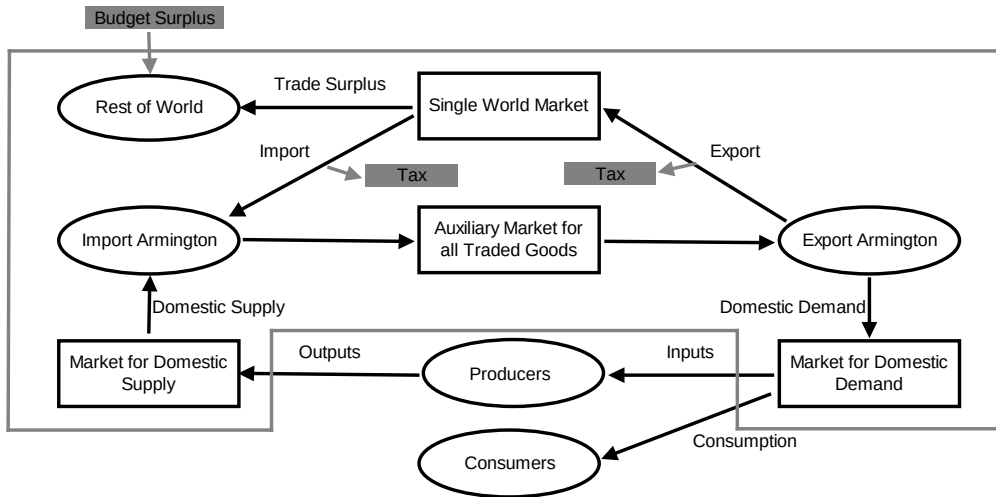


Figure 5.5 Overview of trade flows.

The trade surplus, that is the value of exports minus imports, is by identity equal to the total budget surplus of the consumers in Figure 5.1. Now, we will work out the details of this figure.

Imports

The domestically produced goods and the corresponding competitive import are combined into a separate good ‘S’:

$$Y_j^{Arm,S,out} = CES(Y_j^{Arm,Y,in}, M_j; \sigma_{imp}^{Arm}) \quad (22)$$

and the zero profit condition gives:

$$p_j^S Y_j^{Arm,S,out} = p_j^Y Y_j^{Arm,Y,in} + (1 + \tau_j^M) p^T M_j \quad (23)$$

where τ_j^M is the import tax rate. Revenues from import taxes are denoted by

$$T_j^M = \tau_j^M p^T M_j \quad (24)$$

The Armington specification allows for a difference in prices between domestically produced goods and their imported substitutes. More precisely, this framework assumes that domestically produced goods and the corresponding competitive imports are imperfect substitutes. Hence a change in domestic prices leads to a shift in demand towards the competitive imports, but only to a limited extent.

Typically, for a small open economy as the Netherlands, the elasticity has a value of approximately $\sigma_{imp}^{Arm} = 4$. Alternatively, we can assume that imports comprise a fixed proportion of the goods available on the domestic markets, variant 2 described at the end of Section 5.2.4, which is formally represented by an assuming that the elasticity is zero:

$$\sigma_{imp}^{Arm} = 0.$$

The general specification also applies to commodities that are not domestically produced, such as the non-competitive imports, j =‘NCM’, in which case the Armington specification degenerates into:

$$Y_j^{Arm,S,out} = M_j. \quad (25)$$

For commodities that are not traded, such as the auxiliary goods produced by the ‘trade margins sector’, the ‘abatement sector’, and the ‘capital sector’, the Armington specification degenerates into:

$$Y_j^{Arm,S,out} = Y_j^{Arm,Y,in}. \quad (26)$$

Thus, if convenient, we can use the general CES specification to allow for convenient aggregation over traded and non-traded sectors.

Exports

It is common in general equilibrium modelling to assume that foreign demand for export goods can only be increased by lowering export prices, and vice versa, can only be decreased by increasing export prices. Whereas this assumption fits short term policy analyses, it is less useful for the SNI-calculations. As explained in Section 5.2.4, we assume that export markets increase or decrease proportionally to domestic production.

We now proceed with the model equations. Total supply on the auxiliary market ‘S’ (either domestically produced or imported) is split into exports and domestic supply.

$$CET(Y_j^{Arm,D,out}, X_j; \sigma_{exp}^{Arm}) = Y_j^{Arm,S,in} \quad (27)$$

and the zero profit condition gives:

$$p_j^D Y_j^{Arm,D,out} + (1 - \tau_j^X) p^T X_j = p_j^S Y_j^{Arm,S,in} \quad (28)$$

where τ_j^X is the export tax rate. Revenues from export taxes are denoted by

$$T_j^X = \tau_j^X p^T X_j \quad (29)$$

Note the CET-function is on the left-hand side of the equation, which indicates that from one input, two outputs are produced, domestic supply ($Y_j^{Arm,D,out}$) and exports (X) (see Breuss and Tesche 1993, Eq. 9 for a similar functional form). The elasticity is not a substitution elasticity as in the other equations, but a transformation elasticity. The transformation elasticity gives the rate at which the production of one of the outputs can be substituted by the production of another output. A low transformation elasticity indicates that few such possibilities exist, and that production of one output almost automatically means that the other output is also produced. Similar to the imports, for a small open economy as the Netherlands, the elasticity has a value of approximately $\sigma_{exp}^{Arm} = 4$, and if we assume that exports comprise a fixed proportion of the goods available on the domestic markets, variant 2 of Section 5.2.4, this is captured by assuming that the elasticity is zero: $\sigma_{exp}^{Arm} = 0$.

Again, for non-traded commodities, the Armington specification degenerates into

$$Y_j^{Arm,D,out} = Y_j^{Arm,S,in}. \quad (30)$$

Since for these goods, there are no imports as well, substitution of (26) gives:

$$Y_j^{Arm,D,out} = Y_j^{Arm,Y,in}, \quad (31)$$

and consequently,

$$p_j^D = p_j^Y. \quad (32)$$

5.3.5 Consumers

The model distinguishes four consumers, a public consumer, a private consumer, a subsistence consumer, and an investor. The latter two represent specific consumption patterns, and are, so to say, part of the private consumer. For each consumer, the model assumes that there is a fictitious 'utility producer' that transforms all goods and services into a fictitious good 'utility' that is specific for the consumer, which in turn is demanded by the associated consumers. The main advantage of the introduction of this fictitious sector is that the total 'utility level' of the consumers can directly be read from the activity level of this fictitious producer. Secondly, it enables maximal flexibility through the use of (lump sum) transfers between the consumers, e.g. the subsistence level remains constant, independent of the overall income level, and net investments are a fixed rate of the capital stock, which implies that the economy grows at a fixed rate.

Subsistence consumption

As regards the subsistence consumption, the following figure may be helpful to illustrate the principle.

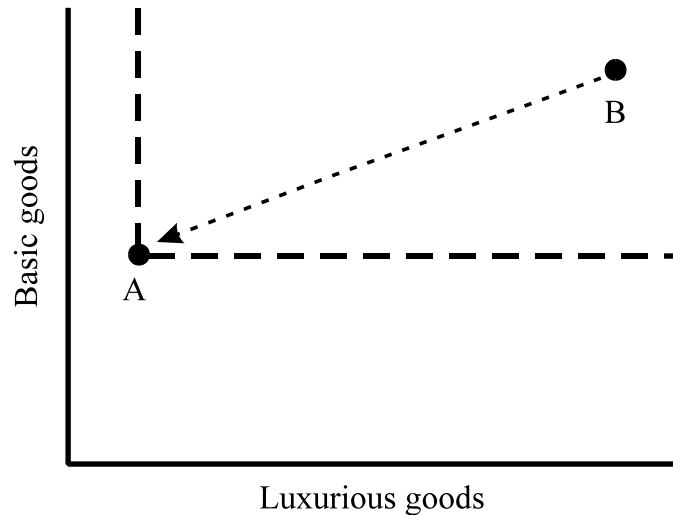


Figure 5.6 Consumption change by income decrease.

The nested CES-functions are linearly homogeneous, that is, the relative preferences are independent of the aggregate income/consumption level. Therefore, they imply that consumption is linear in income. To take account of income elasticities unequal to unity, we follow the literature on linear expenditure systems (Samuelson 1948, Stone 1954) and

specify a subsistence consumption level, the consumption basket given by point A in Figure 5.6. Now, if income decreases, the subsistence consumption remains constant, so that excess consumption shifts linearly from B to A, instead from shifting linearly from B to the origin. In this way, an increase in the consumption of the private households will lead to a more than proportionate increase of total consumption of luxury goods, and a less than proportionate increase in the total consumption of basic goods.

The model equation for the utility production of the subsistence consumer is marked by the substitution elasticity equal to zero: for the subsistence consumer, there are no possibilities to shift consumption from one good to another:

$$W_h^{out} = CES(C_{J,h}, EU_{E,h}, ES_{E,h}; 0) \quad (33)$$

for h the subsistence consumer.

The equation states that households obtain utility from the consumption of goods (C), including consumption of non-competitive imports ($j='ncm'$) and 'needs to pollute' to be able to consume. This is similar to the producers: the pollution stemming from consumption by the households can be re-interpreted as a 'necessary input' in the utility function. As with the producers, the pollution is split into that part of the pollution that can be decreased by investing in abatement (represented by the composite input emission services $ES_{E,h}$) and the 'unabatable'³⁴ pollution ($EU_{E,h}$).

The subsistence consumer is auxiliary and has no own income from labour or capital. Instead, expenditures are paid out of a lump sum transfer from the 'private household'. The budget constraint therefore reads:

$$LS_{subs} = (1 + \tau_{J,h}^C) p_J^D C_{J,h} + q_E EU_{E,h} + s_{E,h} ES_{E,h} \quad (34)$$

where LS_{subs} is the lump sum transfer, which level is precisely sufficient to maintain the initial consumption level. Total taxes paid for subsistence consumption consist of

$$T_{subs} = \tau_{J,h}^C p_J^D C_{J,h} \quad (35)$$

The requirement that subsistence consumption is maintained, irrespective of a decrease in income of the private households can formally be represented through the following complementarity condition:

$$LS_{subs} \geq 0 \perp W_h^{out} \geq \bar{W}_h^{out} \quad (36)$$

where the bar denotes the initial benchmark level. However, the equation is incompatible with a situation in which the consumer's income decreases so much that it becomes insufficient to pay for subsistence expenditures. To take account of that case, we specify the subsistence deficit, WD_{subs} , change (36) into:

$$LS_{subs} \geq 0 \perp W_{subs}^{out} + WD_{subs} \geq \bar{W}_{subs}^{out} \quad (37)$$

and add

³⁴ Again, it should be noted that the term 'unabatable' does not mean that this pollution cannot be removed at all, but rather that this is not possible by implementing technical measures. The 'unabatable' pollution can be reduced by reducing the consumption level.

$$WD_{subs} \geq 0 \quad \perp \quad W_{priv}^{out} / \bar{W}_{priv}^{out} \geq a W_{subs}^{out} / \bar{W}_{subs}^{out}, \quad (38)$$

for some $0 < a < 1$. The last equation states that the subsistence deficit is zero unless welfare of the private consumer decreases below the fraction a of the initial level. From then on, both private welfare and subsistence welfare decrease proportionally.

For completeness, we notice that as regards emission units, the government owns the initial pollution rights which implies that the government receives their value as income. Therefore, it is unnecessary to specify an incremental tax that increases the price.

Investor

Gross investments are partly required to offset the decline of the capital stock due to depreciation, and the other part is used to increase the capital stock. Firms require capital goods as inputs to balance depreciation, whereas consumers are assumed to demand for net investments. This is modelled through the use of a fictitious consumer, the ‘investor’, whose consumption is consequently the engine of economic growth. After all, an increasing capital stock permits an increasing flow of capital services that can be used for production. The utility production function for this consumer $h = \text{‘investor’}$ only consists of the capital good:

$$W_h^{out} = CES(C_{cap,h}; 0) \quad (39)$$

and the budget constraint is:

$$LS_{invs} = p_{cap}^D C_{cap,h} \quad (40)$$

Now, in this case, the net investments are determined such that they are a fixed proportion of gross investments. In other words, net investments increase or decrease relative to the benchmark situation with the same amount as the gross investments:

$$LS_{invs} \geq 0 \quad \perp \quad W_h^{out} / \bar{W}_h^{out} \geq Y_{cap}^{out} / \bar{Y}_{cap}^{out}, \quad (41)$$

where Y_{cap}^{out} are the scenario gross investments, and $\bar{Y}_{cap}^{out}$ are the benchmark gross investments.

Private households

The excess utility production sector for the private household is modelled as follows:

$$W_h^{out} = CES(Food_h, Trans_h, Serv_h, Other_h, NCM_h, EU_{E,h}, ES_{E,h}; \sigma_h^{top}) \quad (42)$$

where

$$Food_h = CES(C_{1,h}, C_{4,h}; \sigma_h^{food}) \quad (43)$$

$$Trans_h = CES(C_{2,h}, C_{8,h}, C_{18,h}; \sigma_h^{trans}) \quad (44)$$

$$Serv_h = CES(C_{19,h}, C_{20,h}, C_{21,h}; \sigma_h^{serv}) \quad (45)$$

$$Other_h = CES(C_{3,h}, C_{5-7,h}, C_{9-17,h}; \sigma_h^{other}) \quad (46)$$

for h = private excess consumption³⁵.

This utility function thus allows for direct substitution between the food-related goods (agricultural products and food products) and then at the higher level for substitution of the composite Food with other products. Similarly the transport-related goods and services (including for instance the use of petrol) are combined, the services are combined and the other goods are combined. This set up of the utility function is based to a large extent on the TaxInc model of Statistics Netherlands (see Keller, 1980 and Statistics Netherlands, 1990).

The private households receive income from selling their endowments, labour, from the rate of return on capital which they own, and they receive a lump sum transfer from the government for, say, social security. The budget thus becomes:

$$\begin{aligned} p_{labr}^D \bar{L}_h + r p_{cap}^D K_h + LS_{gov} + p_h^w BD_h = \\ p_J^D C_{J,h} + p_{ncm}^D C_{ncm,h} + q_E EU_{E,h} + s_{E,h} ES_{E,h} + LS_{subs} + LS_{invs} + T_h \end{aligned} \quad (47)$$

for h the private consumer, where $\bar{L}_h$ is the labour supply which is fixed at the benchmark level, and where BD_h is the budget deficit expressed in utility units that have a price p_h^w . Taxes paid by consumers amount to

$$T_h = \tau_{J,h}^C p_J^D C_{J,h} + \tau_{J,ncm}^C p_{ncm}^D C_{ncm,h} \quad (48)$$

The budget deficit is supposed to be a constant fraction of total income, which, because of its units of measurement is formally represented by:

$$BD_h / \bar{BD}_h = W_h^{out} / \bar{W}_h^{out} \quad (49)$$

The government lump sum transfer has its initial level as a lower bound, but can increase if relative private income decreases compared to public income otherwise. In formal terms, its level is chosen to ensure that the aggregate private welfare levels increase or decrease proportionally to the public welfare level:

$$LS_{gov} \geq \bar{LS}_{gov} \quad \perp \quad \frac{W_{subs}^{out} + W_{invs}^{out} + W_{priv}^{out}}{\bar{W}_{subs}^{out} + \bar{W}_{invs}^{out} + \bar{W}_{priv}^{out}} \geq \frac{W_{govn}^{out}}{\bar{W}_{govn}^{out}}. \quad (50)$$

It is assumed that employment remains constant, which is formally represented by the fixed labour supply together with the assumption of perfect markets. However, for computational reasons, the model contains the possibility to put a lower bound on real wages. This extension is mainly justified to improve performance of the algorithm for the computation of the equilibrium. In the scenarios, it is never used. For completeness, we give a brief description. If the real wage (price level of labour divided by the aggregate price level) decreases below x% of the original real wage, then the assumption of full employment is replaced by a surplus of labour supply, or in other words, involuntary unem-

³⁵ Please note that if all substitution elasticities are zero, the nested CES structure collapses into a single level CES function with elasticity zero. Hence, the utility production function for the subsistence consumer may be written in a multi-level structure, analogue to the utility production function for the private households.

ployment is introduced. In the current version of the model, x is chosen to be 10%, so a fall in real wages of 90% is allowed before the clearing labour market assumption is removed. In the model, an active lower bound on the real wages in effect reduces the income of the private households.

The government consumer

The government consumer has a similar set up as the private households. The utility function as stated above for the private households can also be used for the government consumer. However, the commodity shares and associated pollution pattern of the government is different from the private households, as the government is responsible for the provision of public goods. Moreover, while the private households receive their income from the possession of the primary production factors labour and capital, the government receives income from selling emission units, and earns a tax income to pay for its expenses. The emission units are modelled as endowments, E_E , which level depends on the sustainability criteria that the government wishes to implement, e.g., a seventy per cent reduction is straightforwardly achieved by a proportional reduction of E_E . The budget is given by:

$$p_E^D E_E + p_h^w B D_h + T = p_J^D C_{J,h} + p_{ncm}^D C_{ncm,h} + q_E E U_{E,h} + s_{E,h} E S_{E,h} + L S_{gov} \quad (51)$$

where the tax revenues T are given by:

$$T = T_J + T_M + T_X + T_H, \quad (52)$$

where the taxes for producers, imports, exports, and consumers are given by (12), imports (24), exports (29), consumers (35), and (48), respectively. Revenues from the sale of emission units are returned to the consumers by a linearly homogeneous reduction of tax rates:

$$\tau_{<>} = a \bar{\tau}_{<>} \quad (53)$$

where we use points in brackets '<.>' to indicate the various indexes, and where the uniform tax scaling parameter a is determined by

$$a \geq 0 \perp \frac{W_{govn}^{out}}{\bar{W}_{govn}^{out}} \geq (1 - \varepsilon) \frac{W_{subs}^{out} + W_{invs}^{out} + W_{priv}^{out}}{\bar{W}_{subs}^{out} + \bar{W}_{invs}^{out} + \bar{W}_{priv}^{out}}. \quad (54)$$

where $\varepsilon > 0$ is a small but necessary positive number to prevent indeterminacy between a and the lump sum transfers in equations (50) and (54). Together, the complementarity constraints ensure that taxes are uniformly lowered if the sale of emission units generate sufficient income, and if the tax system is entirely 'green', that is if taxes are fully re-

place by revenues from selling emission units, then the surplus of government income is lump sum redistributed to the private households.³⁶

We notice that, because the emission units have no production costs, considering them as public endowments is equivalent to levying a tax, since in both cases, the users costs are entirely paid to the government. An alternative reduction scheme, in which firms are confronted with emission intensity standards is much more difficult to implement, since the total emission levels will simultaneously depend on the standards and the activity levels of the firms, which implies that the former has to be specified endogenously. The use of pollution rights enables a straightforward implementation where the limited supply sets the emission upper bounds.

The Rest of the World

As noted in Equation (1) and Section 5.3.4, the surplus on the international trade balance should match the budget surplus of the private and public consumers,

$$p^T M_J = p^T X_J + p_H^w BD_H . \quad (55)$$

In the model, this is represented through an auxiliary consumer, the ‘rest of world’ (h =‘row’) that consumes the single good traded on the world market,

$$W_h^{out} = C_h^T , \quad (56)$$

and receives the budget surpluses of the private and public consumer, $-p_H^w BD_H$, as income. To ensure that the fictitious ROW-consumer has positive income, it is given an initial amount of endowments of the international traded good, equal to the benchmark import volume $\bar{M}_J$. The budget thus becomes:

$$p^T C_{row}^T = p^T \bar{M}_J - p_H^w BD_H . \quad (57)$$

In equilibrium, the commodity balance for the internationally traded good ensures that imports plus consumption by the ROW-consumer equals exports plus the ‘endowments’ of the ROW-consumer:

$$M_J + C_{row}^T \leq X_J + \bar{M}_J \quad \perp \quad p^T \geq 0 . \quad (58)$$

Substitution of the budget (57) in (58) gives (55), so that, indeed, the trade balance mirrors the budget balances for the domestic consumers.

³⁶ If $\varepsilon=0$, the taxes can be increased by increasing a while lump sum transfers are increased at the same moment. Thus, there is an indeterminacy. If $\varepsilon>0$, there are three regimes. First, $a>0$ so that the RHS of (54) is binding, which implies that (50) is unbinding, and therefore that $LS_{gov}=1$. Secondly, if $LS_{gov}>1$, which implies that the RHS of (50) is binding, and this implies that the RHS of (54) is unbinding so that $a=0$. Thirdly, in the situation in between, both the RHS of (50) and (54) are unbinding, which implies that $a=0$ and $LS_{gov}=1$.

5.3.6 Market equilibrium

Commodity balances

In this set up of the model, market equilibrium is fully characterised by profit maximisation of the firms, utility maximisation of the consumers, and commodity balances for all goods which are considered in this section. For every market, supply matches demand unless prices are zero, in which case the good has no value and supply can exceed demand³⁷. For the market of domestically produced private goods ('Y'), this amounts to:

$$Y_j^{Arm,Y,in} \leq Y_j^{out} \perp p_j^Y \geq 0, \quad (59)$$

Similarly, the auxiliary market labelled 'S', satisfies:

$$Y_j^{Arm,S,in} \leq Y_j^{Arm,S,out} \perp p_j^S \geq 0, \quad (60)$$

and the market for domestic demand satisfies:

$$F_{j,J} + C_{j,H} \leq Y_j^{Arm,D,out} \perp p_j^D \geq 0 \quad (61)$$

for all goods produced by firms $j \in J$. The commodity balances (59), (60), (61) do not only apply for consumer goods, but for the non-traded trade margins and capital as well. We specifically write:

$$F_{tm,J} \leq Y_{tm}^{out} \perp p_{tm}^D = p_{tm}^S = p_{tm}^Y \geq 0, \quad (62)$$

for trade margins, and for capital:

$$F_{cap,J} + C_{cap,inv} \leq Y_{cap}^{out} \perp p_{cap}^D = p_{cap}^S = p_{cap}^Y \geq 0. \quad (63)$$

Both last two equations are not in contrast with (59)-(61), but merely a special case. For non-competitive imports, which are not produced domestically, we specifically have:

$$F_{ncm,J} + C_{ncm,H} \leq Y_{ncm}^{Arm,D,out} = M_{ncm} \perp p_{ncm}^D = p_{ncm}^S = (1 + \tau_{ncm}^M) p^T \geq 0. \quad (64)$$

The market for the abatement good, however, is different, since it is used by the producers of emission services, so that (59), (60), (61) is replaced by:

$$F_{abat,E,J} + F_{abat,E,H} \leq Y_{abat}^{out} \perp p_{abat}^D = p_{abat}^S = p_{abat}^Y \geq 0. \quad (65)$$

For emission services, we have:

$$ES_{e,j}^{in} \leq ES_{e,j}^{out} \perp s_{e,j} \geq 0. \quad (66)$$

and

$$ES_{e,h}^{in} \leq ES_{e,h}^{out} \perp s_{e,h} \geq 0. \quad (67)$$

³⁷ Notice that we do not use the excess demand format where one solves for equilibrium prices only, and where excess demand is strictly positive for zero prices. In our set up, we do not exclude the possibility of goods that have no value, and hence have excess supply and a zero price.

So far, we have given the commodity balances for produced goods. Similar balances apply for the factors. For emission units, we have:

$$EU_{e,J} + EA_{e,J} + EU_{e,H} + EA_{e,H} \leq \bar{E}_{e,govt} \perp q_e^D \geq 0. \quad (68)$$

For labour we have:

$$L_J^{in} \leq \bar{L}_H \perp p_{lab}^D \geq 0. \quad (69)$$

Finally, at the world market, commodity balance (58) applies.

Equilibrium

We have now specified all equations of the model, and we can define equilibrium. In equilibrium, producers maximise profits as represented through the zero profit conditions, (11) that applies for the producers J_G , and the producer of the abatement goods $j='abat'$, (15) for the 'trade margins', (17) for the producer of 'emission services', (21) for the producer of 'capital goods', (23) for the Armington import specification, and (28) for the Armington export specification. Furthermore, consumers maximise utility subject to the budget balances, (34) for the 'subsistence consumer', (40) for the 'investor', (47) for the 'private consumer', (51) for the government, and (57) for the 'rest of world'.

Also, in equilibrium the commodity balances hold for all goods, (59) for the domestically produced goods 'Y', (60) for the auxiliary goods 'S', (61) for the goods that satisfy domestic demand 'D', (58) for the world market good 'T', (64) for the non-competitive imports 'ncm', (62) for the trade margins 'tm', (65) for the 'abatement goods', (66) for the 'emission services'. Equivalently, commodity balances hold for factors, (68) for 'emission units', and (69) for 'labour'.

Finally, transfers are specified on the basis of specific assumptions. Consumers require a fixed rate of return r on capital, which defines the rents (13). Government taxes producers (12), imports (24), exports (29), and consumers (35), (48) based on a uniform tax rate (53) which level is given by (54). The expenditures on subsistence and net investments are defined by (36) and (41), respectively. The private consumer's budget deficit is defined by (49), the lump sum transfer from the government to the private consumers by (50).

Social accounting matrix

The commodity balances, zero profit conditions, and budget constraints listed above that represent an equilibrium are summarised in the Social Accounting Matrix (SAM). Table 5.2 gives the complete SAM for the model. On the axes, the SAM first lists the different types of goods, 'Y', 'S', 'D', indexed by j , non-competitive imports 'ncm', trade margins 'tm', abatement goods, and emission services indexed by (e,j) . Factors follow, 'emission units' indexed by e , and labour. The list of commodities ends with the world market good 'T'. For these goods and factors, columns sum to total supply and rows sum to total demand, representing the commodity balances (equations are indicated in the column headings). Next, the SAM lists the producers J_G of consumer goods, the producer of the abatement goods $j='abat'$, the producer of 'trade margins', the producer of 'emission services', the producer of 'capital goods', the Armington import specification, and the

Armington export specification. For these production technologies, columns sum to expenditures and rows sum to revenues, representing the zero profit conditions. Next, the SAM lists the 'subsistence consumer', the 'investor', the 'private consumer', and the government. Columns sum to expenditures, whereas rows sum to income, representing the budget constraints. Finally, the SAM lists the 'foreign sector', or 'rest of world'. Both the column and row sum to total import value representing the trade balance. A schematic SAM is given in Table 5.1.

Table 5.1 Schematic Social Accounting Matrix.

	Goods	Factors	Producers	Consumers	ROW	Total
Goods			<i>Inputs</i>	<i>Consumption</i>	<i>Exports</i>	Demand
Factors			<i>Input</i>			Demand
Producers	<i>Outputs</i>					Revenues
Consumers		<i>Endowments</i>	<i>Transfers</i>	<i>Transfers</i>	<i>Budget Deficit</i>	Income
ROW	<i>Imports</i>					Import Value
Total	Supply	Supply	Expenditures	Expenditures	Import Value	

Table 5.2 Full SAM (Social Accounting Matrix) for SNI-AGE model¹

	Goods ('Y',j) (59)	Goods ('S',j) (60)	Goods ('D',j) (61)	ncm (64)	tm (62)	cap (63)	Abat (65)	ES (66,67)	EU (68)	Labour (69)	Good ('T') (58)	Prod (11)	Arm Imp (23)	Arm Exp (28)	tm (15)	Capital sector (21)	Abatement (19)	Em Serv (17)	Govern ment (51)	Subs. cons. (34)	priv. Cons. (47)	Investor (40)	ROW (57)
Goods ('Y',j)												$Y_j^{Arm,S,in}$											
Goods ('S',j)												F_{j,i,j_2}				F_{j,i,j_2}			$C_{j,h}$				
Goods ('D',j)												F_{j,i,j_2}				F_{j,i,j_2}			$C_{j,h}$				
Non-competitive imports												F_{j,i,j_2}				F_{j,i,j_2}			$C_{j,h}$				
Trade margins												F_{j,i,j_2}				F_{j,i,j_2}			$C_{j,h}$				
Capital												F_{j,i,j_2}				F_{j,i,j_2}			$C_{j,h}$				
Abatement																		F_{j,i,j_2}					
Emis. Serv (e_j), (e, h)												$ES_{e,j}$							$ES_{e,h}$	$ES_{e,h}$	$ES_{e,h}$		
Em units (e)												$EU_{e,j}$							$EU_{e,h}$	$EU_{e,h}$	$EU_{e,h}$		
Labour												L_j											C_{row}^T
Good ('T')													M_j										
Producers (j)	Y_j^{out}																						
Armington imp (j)		$Y_j^{Arm,S,out}$																					
Armington exp (j , 'ncm')			$Y_j^{Arm,D,out}$	$Y_{ncm}^{Arm,D,out}$							X_j												
Trade margins																							
Capital sector																							
Abatement sector																							
Emission Serv (e_j)								$ES_{e,j}^{out}$															
Government									$\bar{E}_{e,gov}$			T_j	T_j^M	T_j^X					T_{subs}	T_{priv}			BD_{gov}
Subsistence consumer																							
Private consumer										$\bar{L}_h$		R_j							LS_{priv}	LS_{subs}			BD_{priv}
Investor																							
ROW											$\bar{M}_j$												

¹ The light grey columns and rows denote elements of the SNI-AGE model directly linked to the inclusion of the environment, extending the usual static AGE model.

References

- Boyd, R. and N.D. Uri (1991). An assessment of the impacts of energy taxes. *Resource and Energy*, 13, pp. 349-379.
- Breuss, F. and J. Tesche (1993). Hungary in transition: a computable general equilibrium model comparison with Austria. *Journal of Policy Modeling*, 15, pp. 581-623.
- Cornielje, O.J.C. *Rationing and capital mobility in applied general equilibrium models*. VU University Press, Amsterdam.
- Dellink, R.B. and K.F. van der Woerd (1997). *Kosteneffectiviteit van milieuthema's*. IVM-R97/10, Institute for Environmental Studies, Vrije Universiteit, Amsterdam.
- Hueting, R. P.R. Bosch and B de Boer (1992). Methodology for the calculation of sustainable national income, *Statistics Netherlands Report M44*, SDU Publishers, The Hague.
- Jorgenson, D.W. and P.J. Wilcoxon (1993a). Reducing US carbon emissions: an econometric general equilibrium assessment. *Resource and Energy Economics*, 15, pp. 7-25.
- Jorgenson, D.W. and P.J. Wilcoxon (1993b). Reducing US carbon dioxide emissions: an assessment of different instruments. *Journal of Policy Modeling*, 15, pp. 491-520.
- Keller, W.J. (1980). *Tax incidence*. North-Holland, Amsterdam.
- Keuning, S.J. (1993). An information system for environmental indicators in relation to the national accounts. In: W.F.M. de Vries (ed.), *The value added of national accounting*, Statistics Netherlands, SDU Publishers, The Hague.
- Mishan, E.J. (1981). *Introduction to normative economics*. Oxford University Press, New York.
- Rutherford, T.F. (1997). Applied general equilibrium modeling with MPSGE as a GAMS subsystem: an overview of the modeling framework and syntax, *mimeo*, University of Colorado.
- Samuelson, P.A. (1948). Some implications of linearity. *Review of Economic Studies*, 15, pp. 88-90.
- Sato (1967). A two-level constant-elasticity-of-substitution production function. *Review of Economic Studies*, 34, pp. 201-218.
- Shoven, J.B and J. Whalley (1992). *Applying general equilibrium*. Cambridge University Press, Cambridge.
- Statistics Netherlands (1990). Tax incidence in the Netherlands: accounting and simulations. *Statistics Netherlands report M42*, SDU Publishers, The Hague.
- Statistics Netherlands (1994). *National Accounts*. SDU Publishers, The Hague.
- Stone, R. (1954). Linear expenditure systems and demand analysis: an application to the pattern of British demand. *The Economic Journal*, 64, pp. 522-527.
- VROM (1994). *Methodiek Milieukosten*. Publicatiereeks Milieubeheer 1994/1.

Appendix 5.I List of indexes and symbols

Consumers

Label (<i>h</i>)	Description
<i>priv</i>	Private households
<i>subs</i>	Subsistence consumer
<i>govn</i>	Government consumer
<i>Inv</i>	Investment consumer

Production sectors

Label (<i>j</i>)	Description
1	Agriculture and fisheries
2	Extraction of oil and gas
3	Other mining and quarrying
4	Food- and food products
5	Textiles, clothing and leather industries
6	Paper and –board industry
7	Printing industry
8	Oil refineries
9	Chemical industry
10	Rubber and plastics industry
11	Basic metals industry
12	Metal products industry
13	Machine industry
14	Electrotechnical industry
15	Transport equipment industry
16	Other industries
17	Energy supply
18	Water supply
19	Construction
20	Trade and related services
21	Transport by land
22	Transport by water
23	Transport by air
24	Transport services
25	Commercial services
26	Non-commercial services incl. government
27	Other goods and services
<i>ncm</i>	non-competitive imports
<i>tm</i>	trade margins
<i>cap</i>	capital goods

Symbol	Description
Y_j^{out}	Domestically produced supply of good j ($j=1,\dots,21$, 'tm', 'cap')
$Y_j^{Arm,Y,in}$	Input of domestically produced good j in Armington specification
$Y_j^{Arm,S,out}$	Available volume of good j for export and domestic demand ($j=1,\dots,21$, 'ncm', 'tm', 'cap')
$Y_j^{Arm,S,in}$	Used volume of good j for export and domestic demand
$Y_j^{Arm,D,out}$	Supply of goods and services to the domestic market (total supply minus exports)
F_{j_1,j_2}	Demand for good j_1 by sector j_2
$EU_{e,j}$ ($EU_{e,h}$)	'Unabatable' pollution of theme e by sector j (consumer h)
$ES_{e,j}$ ($ES_{e,h}$)	Demand for emission services of theme e by sector j (consumer h)
$ES_{e,j}^{out}$	Supply of emission services of theme e by sector j (consumer h)
$EA_{e,j}$ ($EA_{e,h}$)	'Abatable' pollution of theme e by sector j (consumer h)
L_j	Demand for labour by sector j
$\bar{L}$	Total supply of labour
M_j	Competitive import of good j
X_j	Export of good j
a_{ij}	Intermediate demand for good i by sector j per unit of production
$C_{j,h}$	Demand for good j by consumer h
W_h	'Utility level' of consumer h
LS_h	Lumpsum transfer income of consumer h
BD_h	Budget deficit of consumer h
σ_j	Substitution elasticity at the top level of the production function for sector j
σ_j^{intm}	Substitution elasticity between intermediate goods in production function for sector j
σ_j^{prim}	Substitution elasticity between primary factors in production function for sector j
$\sigma_{e,j}^{ES}$ ($\sigma_{e,h}^{ES}$)	Substitution elasticity between (abatable) pollution and abatement
σ_{imp}^{Arm}	Substitution elasticity between domestically produced goods and competitive imports
σ_{exp}^{Arm}	Substitution elasticity between exports and domestically supplied goods
σ_h^{top}	Substitution elasticity at the top level of the utility function for consumer h
σ_h^{food}	Substitution elasticity between food related products in the utility function for consumer h
σ_h^{trans}	Substitution elasticity between transport related products in the utility function for consumer h
σ_h^{serv}	Substitution elasticity between services in the utility function for consumer h
σ_h^{other}	Substitution elasticity other products in the utility function for consumer h
p_j^Y	Supply price of (domestically produced) good j
p_j^S	Price of good j on auxiliary market 'S'

Symbol	Description
p_j^D	Demand price of good j on domestic market
$p_{labr'}^D$	Price of labour
p^T	Price of foreign exchange
q_e	Price of pollution of theme e
$s_{e,j} \quad (s_{e,h})$	Price of emission services of theme e for sector j (consumer h)
p_h^W	Price of utility for consumer h
τ_j^Y	Tax on output of good j
$\tau_{labr',j}^D$	Tax on demand for labour by sector j
$\tau_{cap',j}^D$	Tax on demand for capital by sector j
τ_j^M	Tax on import of good j
τ_j^X	Tax on export of good j
$\tau_{j,h}^C$	Tax on consumption of good j by consumer h
a	Endogenous reduction in tax rates as means of redistribution of regulating environmental levies (expressed as fraction)

6. Calibration of an applied general equilibrium model for the Netherlands in 1990

Rob Dellink, Reyer Gerlagh, Marjan Hofkes and Luke Brander

6.1 Introduction

The model as described in the previous chapter is used to calculate consequences of a sustainability policy in the Netherlands. The parameters of the model are calibrated to represent empirical data for the Netherlands in 1990. In general, the data needed to calibrate an applied general equilibrium model are twofold. First, data is needed that describes the initial situation; these base year data are used to specify the initial accounting matrix and can be used to calculate the historical national income. Second, the reactions of the agents to a given impulse are determined by the substitution and income elasticities and the abatement cost curves. Besides these two types of calibration data, a so-called impulse has to be specified, which represents the shock that is given to the system. In this case, the impulse equals the sustainability standards for the environmental themes. Together with the structure of the model as laid down in the model equations (see Chapter 5), these three types of inputs determine the value of the sustainable national income, which can then be compared to the initial level of national income.

The data used to calibrate the initial accounting matrix is described in Section 6.2. Section 6.3 briefly discusses how the policy impulse is interpreted in the context of the sustainability analysis. Section 6.4 deals with the values of the elasticities used in the model; the values for the elasticities themselves are represented in Appendix I. Section 6.5 contains the description of the abatement cost curves used. In this section, the methodology is explained and the empirical cost curves for each theme are presented.

6.2 Data for the initial SAM

6.2.1 Introduction

In a comparative-static model, the data for the initial situation consist of data for one historical base year. In our case, the base year data are taken from historical data for 1990 for the Netherlands, provided by Statistics Netherlands (2000) and are based on the National Accounts and environmental statistics for 1990. The data table for the initial situation is omitted because of its size, but will be described in the sections below.

The data for the initial Social Accounting Matrix (SAM) are custom-made for the AGE-SNI model by Statistics Netherlands (2000). The fact that a custom dataset had to be prepared shows that national accounts with environmental satellite accounts are not well-established yet. One reason for this is that the categorisation of production sectors often differs between economic and environmental accounts. Some production sectors are

economically highly relevant and hence require a sufficiently disaggregated set-up (like the services sub-sectors) in the economic accounts, while their environmental impact is relatively unimportant (and hence their representation in environmental accounts is often at a higher level of aggregation). Similarly, there are also sectors that are highly significant from an environmental perspective, but are less relevant in the economic accounts (*e.g.* chemical sub-sectors). Moreover, for some sub-sectors Statistics Netherlands may be prohibited to provide disaggregated data for reasons of privacy (if there is one dominant producer in the sub-sector).

There is a series of statistics made by Statistics Netherlands that does capture both the economic and environmental accounts at a reasonable level of disaggregation called NAMEA (see for example Keuning, 1993). This set of statistics is readily available for more recent years and will in the future become available for earlier years also. Unfortunately, at the time the data for this project had to be compiled, NAMEA data for 1990 could not be used. This does not mean that the data in both sources are radically different: the underlying data are mostly based on the same rough data as compiled by Statistics Netherlands. However, there may be differences in definitions (mainly in the environmental accounts) and in representation (including aggregation).

The economic and environmental data that are used in the initial SAM are described in more detail below.

6.2.2 Economic data

On the production side, 27 private goods producers are identified; this allows for a moderate degree of detail on the side of economic and environmental diversity. A more disaggregated set-up was not feasible due to data limitations. The list of production sectors is given in Appendix I.

On the household side the level of disaggregation is much less. There are essentially just two household groups: private households and the government, where consumption of the former is split into subsistence consumption and excess consumption. Furthermore, as mentioned in the previous chapter, there is an 'investor' to describe net investments necessary for economic growth.

In the accounting matrix, capital income, denoted in the national accounts as 'other income', is split into separate rows for depreciation and profits.

In most accounting matrices, competitive imports are given in a single row (often together with non-competitive imports), representing the value of imports *by importing sector*. Hence, in such a set-up, the element in the column for Agriculture and row for competitive imports gives the total imports of goods and services by the Agricultural sector. Similarly, the column for Private households contain the total consumption of imported goods in the imports-row.

However, in the AGE-SNI model, imports are specified *by imported good or service* see Chapter 5). This can be represented in the accounting matrix by taking the competitive imports as a column. Then, each row of this column describes how much of the good is imported. Given the Armington assumption on international trade, these imports then rival with domestically produced goods and services. The non-competitive imports are still given by a single row.

To construct the imports by imported good or service in the ‘imports-column’, a full matrix of competitive imports is provided by Statistics Netherlands. Summing all rows in this matrix gives the imports-row (imports by importing sector), and summing all columns provides the required data for the imports-column (imports by imported good or service). These data are transposed to the column through a simple procedure where the import matrix is first aggregated with the matrix of (domestic) intermediate deliveries (which is commonly known as the A-matrix) and then the imports column is disaggregated from this ‘total intermediate deliveries’ matrix. The economic interpretation of the resulting accounting matrix is that each domestic producer imports the competing import goods and services and then sells this to clients together with its own domestic production.

The data for tax categories could unfortunately not be custom-made for this project. The categories in the model follow the categorisation in the National Accounts, and lack sufficient detail for the AGE model. For instance, sectoral data on taxes paid for the use of capital by firms is not distinguished from output-related firm taxes and import taxes are only available by the importing sector, while the AGE model requires import taxes by imported good. However, the significance of (the misspecification in) the tax categories in the SNI analysis may be limited, as the assumption is made that all existing tax rates are reduced proportionately when government collects revenues from the sale of the pollution permits (see Chapter 5). Nonetheless, it is strongly suggested that the treatment of taxes is improved in later versions of the accounting data (and model).

Two entries in the accounting matrix cannot be handled by the economic model: taxes on exports and stock changes of non-competitive imports. These entries are excluded from the matrix.

Some characteristics of the production in the Netherlands in 1990 are given in Table 6.1 below. First, total production value is given, and then the value added (including taxes). The column for total consumption includes both consumption by private households and government consumption. The net trade column is calculated as the difference between the export and import values of the good (note that these are imports by good, not by importing sector).

Table 6.1 Sectoral economic data for the Netherlands, 1990 (in millions Dutch guilders at 1990 prices).

Good	Production value	Value added	Total consumption value	Net trade value
Agriculture and fisheries	42661	21015	1884	2492
Extraction of oil and gas	17970	14309	0	-8669
Other mining and quarrying	1295	885	6	-1260
Food- and food products	76594	16367	20827	14978
Textiles, cloth. and leather ind.	9158	3075	1391	-9850
Paper and -board industry	9159	3238	263	-2480
Printing industry	20215	8341	4051	-1458
Oil refineries	25591	7719	4981	8614
Chemical industry	46742	14635	1481	9655
Rubber and plastics industry	9009	3240	189	-3548
Basic metals industry	10127	3754	17	-3306
Metal products industry	19611	7260	227	-1136
Machine industry	17833	6901	74	-7499
Electrotechnical industry	22739	10775	594	-20911
Transport equipment industry	18614	4836	476	-8971
Other industries	20039	7765	1598	-8055
Energy supply	19752	7224	7471	-384
Water supply	2128	1478	1347	0
Construction	78081	27963	1807	2237
Trade and related services	124187	76498	19508	-161
Transport by land	17251	11052	3028	3829
Transport by water	7303	2546	251	4437
Transport by air	7597	2905	1559	4236
Transport services	10240	6301	1359	1872
Commercial services	231232	153825	116402	-11486
Non-commercial services	81753	55572	73562	-1974
Other goods and services	1782	79	0	-472

Note: goods are represented by their production sector.

From the production column of Table 6.1 it can be seen that the Commercial services sector is the largest sector in terms of production value; it comprises almost one quarter of total production in the economy. The economic importance of this sector is even larger in terms of value added: almost one third. The second largest sector is the Trade sector, followed by the Non-commercial services (including government). Looking at total consumption the picture is slightly different: the Commercial services remain the largest sector (constituting 44% of total consumption value), but Trade is no longer second largest. This indicates that the Trade sector is to a large extent involved in inter-sectoral trade (as could be expected).

6.2.3 Environmental data

The environmental data for the historical year encompass the following environmental themes: the enhanced greenhouse effect, depletion of the ozone layer, acidification, eutrophication, dispersion of toxic substances to water, smog formation, dispersion of fine particles to air, dehydration and soil contamination. Those latter two are conceptually different from the other environmental themes, and are not specified on a sectoral basis. Hence, they are not discussed here.

Another part of the environmental data are related to the technical measures to reduce the environmental pressure. These data are taken from Statistics Netherlands (De Boer, 2000a,b) and Dellink and Van der Woerd (1997), and based on figures by Utrecht University (Blok et al, 1991) and RIVM (RIVM, 1998), respectively. These are discussed in more detail in Section 6.5.3 below.

Table 6.2 presents the sectors in the economy that have a large or small share in total pollution levels. Not surprisingly, Agriculture, Chemical industry, Commercial services and Consumers are among the largest polluters for at least three environmental themes. These sectors could be expected as large polluters, as they are either very large economic sectors (Commercial services accounts for almost one quarter of total production in the economy) or known for their environmental impact. The two sectors that are listed most as small polluters are Other mining and Water supply, both very small sectors in economic terms (0.1% and 0.2% share in total production respectively).

Table 6.2 Large and small polluting sectors in **absolute** terms.

Environmental theme	Large polluting sectors (share* in brackets)	Small polluting sectors (share* in brackets)
Greenhouse effect	Energy supply (15.9%) Consumers (13.7%) Agriculture (13.5%)	Water supply (0.0%) Printing industry (0.1%) Other mining (0.1%)
Ozone depletion	Rubber and plastics industry (51.1%) Non-commercial services (11.3%) Commercial services (5.9%)	Other mining (0.0%) Water supply (0.0%) Transport by water (0.0%)
Acidification	Agriculture (42.4%) Transport by water (9.1%) Consumers (8.9%)	Transport by air (0.0%) Water supply (0.0%) Rubber and plastics industry (0.0%)
Eutrophication	Agriculture (73.1%) Consumers (7.7%) Commercial services (5.4%)	Other mining (0.0%) Rubber and plastics industry (0.0%) Other goods and services (0.0%)
Smog formation	Consumers (42.3%) Oil and gas extraction (16.1%) Chemical industry (7.3%)	Other mining (0.0%) Other goods and services (0.0%) Transport services (0.1%)
Fine particles	Basic metals industry (15.0%) Consumers (13.6%) Chemical industry (9.5%)	Oil and gas extraction (0.0%) Other mining (0.0%) Printing industry (0.0%)
Dispers. to water	Commercial services (49.3%) Chemical industry (19.3%) Non-commercial services (18.3%)	Transport by air (0.0%) Oil and gas extraction (0.0%) Water supply (0.0%)

* Factor calculated as pollution by sector divided by total pollution in economy (per theme).

Some environmental themes are much more concentrated in a few sectors than the others. Even though this cannot be directly read from Table 6.2, the shares of the largest 3 polluting sectors gives some insight into this issue. For the Enhanced greenhouse effect, the shares of the largest 3 polluters is relatively small (some 43% of total pollution), indicating a more or less even spread of pollution across the economy. This is in line with the intuition that energy use is widespread across all sectors. Another relatively even spread environmental theme is Dispersion of fine particles to air. Other environmental themes are much more concentrated. For example, Eutrophication is concentrated to al-

most three-quarters in the Agricultural sector; Depletion of the ozone layer is concentrated to some extent in the Rubber and plastics industry, but other sectors contribute to this environmental problem as well; Dispersion of toxic substances to water is concentrated in the three sectors listed in Table 6.2.

Regardless of whether the pollution is concentrated in some sectors or not, there are always some sectors that hardly contribute to the environmental problem (see the last column in Table 6.2), either because they are very small sectors or because they have a low pollution intensity for that environmental theme.

In Table 6.3 the high and low polluting sectors in relative terms are represented. This table gives insight in the pollution intensity of the various sectors. For producers, this intensity is calculated as the pollution in the sector divided by the production quantity; for consumers, the intensity equals pollution divided by total consumption. After the sector name, the table gives pollution factors, which are defined as the pollution intensity of the sector compared to the average pollution intensity of the economy. A factor above unity gives high pollution intensities, a factor below unity means a low pollution intensity. If the factor equals unity, the sector pollutes just as much as could be expected according to its share in total production. So, Table 6.3 shows for example that the production sector with the highest CO₂-equivalent emissions is Energy supply, which has an intensity 5.6 times the average climate intensity.

*Table 6.3 High and low polluting sectors in **relative** terms.*

Environmental theme	High polluting sectors (factor* in brackets)	Low polluting sectors (factor* in brackets)
Greenhouse effect	Energy supply (5.6) Transport by air (2.9) Rubber and plastics industry (2.7)	Consumers (0.0) Printing industry (0.0) Water supply (0.0)
Ozone depletion	Rubber and plastics industry (20.2) Other goods and services (3.2) Other industries (0.6)	Other mining (0.0) Water supply (0.0) Transport by water (0.0)
Acidification	Transport by water (8.4) Agriculture (6.7) Transport by land (2.9)	Transport by air (0.0) Consumers (0.0) Rubber and plastics industry (0.0)
Eutrophication	Agriculture (22.0) Water supply (0.7) Food and -products industry (0.6)	Other mining (0.0) Rubber and plastics industry (0.0) Consumers (0.0)
Smog formation	Oil and gas extraction (9.0) Transport by land (2.6) Rubber and plastics industry (1.8)	Other mining (0.0) Consumers (0.0) Other goods and services (0.0)
Fine particles	Basic metals industry (7.4) Transport by air (6.2) Transport by water (4.7)	Printing industry (0.0) Oil and gas extraction (0.0) Consumers (0.0)
Dispers. to water	Chemical industry (8.2) Basic metals industry (4.7) Non-commercial services (4.5)	Transport by air (0.0) Consumers (0.0) Oil and gas extraction (0.0)

* Factor calculated as pollution intensity of sector divided by average pollution intensity in economy (per theme).

The most striking difference between Table 6.2 and Table 6.3 is the role that consumers play in pollution: in absolute terms, the consumers rank among the largest polluters for 5

of the 7 environmental themes. In relative terms, this does not mean that consumption is very polluting per unit (guilder) of consumption; on the contrary, for 6 of the 7 themes, the pollution intensity of consumption is among the lowest of the economy. Note that this observation is dependent on the way pollution is attributed to the sectors: the tables above report direct pollution emitted by the sector, not all pollution *caused* by the sector. Evidently, if pollution were attributed according to cause³⁸, the environmental intensity of consumption would be much higher.

In general, the large polluting sectors (Table 6.2) also have a relatively high pollution intensity (Table 6.3). Examples include both the Commercial and Non-commercial services. This correlation between absolute and relative pollution does not hold for sectors with low absolute pollution levels. There, some sectors are very small in economic terms (*e.g.* Other mining, Water supply and Other good and services), so that even high pollution intensities make them among the least polluting sectors in absolute terms.

One technical problem that had to be dealt with was the fact that the waste handling facilities (part of the non-commercial services) have substantially negative pollution coefficients for eutrophication (mainly household greens and manure that are incinerated or dumped), combined with positive CO₂-emissions. This negative pollution is larger than the positive eutrophying pollution in the other parts of the Non-commercial services, and consequently the total sector Non-commercial services has a negative pollution coefficient for eutrophication. This can lead to technical problems in the model if a system of pollution permits is introduced; therefore these eutrophication ‘sinks’ are re-attributed to the sectors in which these emissions have originated (like the agricultural sector and the households).

6.3 The impulse

As the goal of the model is to calculate a sustainable national income, the impulse can be described as the sustainability standards that need to be satisfied. These sustainability standards are described in a separate chapter, as they are a central part of the methodology (see Chapter 4). The sustainability standards enter the model as a reduction in the public endowments of pollution rights.

Table 6.4 summarises the sustainability standards for the various environmental themes taken into consideration.

³⁸ Which pollution is ‘caused’ by what economic activity can be viewed from different angles. For example, one could attribute all pollution during the production of goods and services that are meant for consumption as being ‘caused’ by consumption. This is the perspective used in the text. Another view could be that pollution is ‘caused’ by the components of the good or service and then be traced back to its inputs. In this view, the pollution from burning petroleum can be attributed to the oil refineries and eventually to the extraction of oil. This perspective is elaborated upon in the Appendix to Chapter 7.

Table 6.4 Sustainability standards for the environmental themes, 1990.

Environmental theme	Units	Base 1990	Sustainability standard	Required reduction (%)
Greenhouse effect	billion kg. CO ₂ equivalents	251.0	53.3	197.7 (78.8%)
Ozone depletion	million kg. CFC11 equivalents	10.4	0.6	9.8 (94.2%)
Acidification	billion acid equivalents	38.4	10.0	28.4 (74.0%)
Eutrophication	million P-equivalents	312.0	128.0	184.0 (59.1%)
Smog formation	million kilograms	440.0	240.0	200.0 (45.5%)
Fine particles	million kilograms	44.0	20.0	24.0 (54.6%)
Dispers. to water	billion AETP-equivalents	194.3	73.5	120.9 (62.2%)

6.4 Values of elasticities

The reactions of the agents are given by the elasticities in the model in Appendix I. For the producers, the elasticities comprise substitution elasticities that govern the possibilities to change the production processes by using less of one input and more of another input. For household, the elasticities comprise substitution elasticities to identify the rate at which different consumption goods are interchangeable in the satisfaction of needs, the income elasticities to identify the change of the consumption pattern when income decreases, and the trade elasticities to identify the change in trade patterns when domestic prices change. The values for the elasticities are based on the *TaxInc* model (Keller 1980, Statistics Netherlands, 1990).

The calibration of the substitution elasticity between pollution and abatement is based on the abatement cost curves for the various environmental themes. The abatement cost curves are discussed below; the procedure to calibrate the substitution elasticity is explained in Appendix 2 to this Chapter.

6.5 Abatement cost curves for various environmental themes

6.5.1 Introduction

According to Hueting's methodology, the correction of the traditional national income figures consists of the costs that have to be incurred to meet the sustainability standards. However, costs of pollution reduction consist of costs of technical measures and costs of volume measures. The costs of technical measures are investment costs (recalculated as annual costs) and operation & maintenance costs of changes in the production process. The costs of volume measures are lost value added, due to a reduction in the production volume. In this section only the costs of technical measures are treated. These costs are called the costs of reduction of 'abatable' pollution. Costs of reduction of 'unabatable' pollution, i.e. of volume measures, are not dealt with here³⁹.

A rational polluter, if faced with the necessity to reduce pollution, will first take the cheapest measures and then, if necessary, turn to the more costly measures. The marginal - and thus also the total - cost curve will therefore be monotonously non-decreasing. As a

³⁹ See Chapter 5 for a discussion on this distinction.

rule, not all pollution can be prevented by technical measures. Therefore, the cost curve approaches a vertical asymptote, where marginal (and total) costs approach infinity.

A marginal cost curve of reduction will then take the shape of a step function where, from the origin, each time the next cheapest measure is introduced until the last, most expensive measure is reached and no further reduction is possible with technical means. The integral of the marginal cost function yields the function of total reduction costs with respect to the total (cumulative) pollution reduction. The total cost functions are fitted to a CES function, as schematically pictured in Figure 6.1.

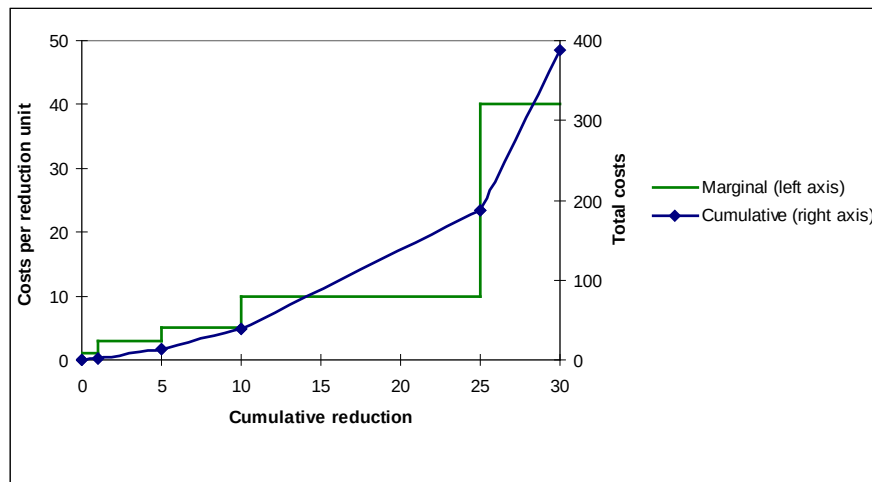


Figure 6.1 Marginal and cumulative costs of pollution reduction.

For most environmental themes (apart from the climate related themes), the main data source was RIVM's RIM⁺ model⁴⁰. The measures, as well as their costs and reduction effects, reflect as much as possible the technological state of the art of the early 1990s.

The last two themes, dehydration and soil contamination are special cases, in the sense that they are inheritances from the past, not caused by annual (1990) pollution. The reduction costs are not costs of pollution reduction but total costs of cleaning up and restoration. The costs consist totally of 'abatable' costs, for volume measures are not applicable. For these themes, an abatement cost curve is not relevant; in the model just an estimate of the annual costs involved are included into the analysis.

6.5.2 Methodology

All abatement cost curves used in this study follow the same methodology. The main issues involved in setting up abatement costs curves are discussed below.

⁴⁰ RIM⁺ is the improved version of RIM, a Dutch acronym for Computation and Information system for the Environment; this system contains emission coefficients and emission factors for various economic sectors, as well as technical reduction measures with their costs and their effects on emissions. This model has recently been abandoned by RIVM, without a economy-wide replacement model being available.

Definition of environmental costs and the discount rate used

The methodology for calculating costs and resulting reduction of pollution technical measures is in line with the methodology that is used by CBS and RIVM, and described in detail in *Methodiek Milieukosten* (VROM, 1994).

The costs are calculated as seen by the target groups. This implies that they include taxes (VAT, for households) and excises (on fuels). The excises play a role in particular, when a measure leads to fuel saving that can be deducted from the reduction costs.

The total environmental costs consist of capital costs (including investment and interest costs), operational costs (including additional labour and energy costs) and operational revenues (including *e.g.* sale of new by-products). Investments are converted to annual depreciation and interest costs using the annuity method. The discount rate is calibrated to the real capital market interest rate, which is defined as the real interest on government bonds. This interest rate has in recent years fluctuated between 4% and 5%. For practical reasons, a stable discount rate of 5% is used in calculations by RIVM.

In 1998 the official methodology for calculating environmental costs has been revised (VROM, 1998). One important change is that the interest rate should be chosen differentially: the capital market interest rate should be raised with an excess percentage depending on the economic sector that implements the abatement measure. RIVM has chosen not to follow this change in the official methodology, for practical reasons (Hanemaaijer, 2000). The figures that are used to calculate the abatement cost curves for the SNI are based on the (old) RIVM methodology and consequently, a discount rate of 5% is used for all abatement measures.

The cost figures do not include any transaction (*e.g.*, implementation, enforcement or monitoring) costs. The cost curves are superimposed on the 1990 situation with respect to levels of production and consumption of the various sector and with respect to the technological state of the art (plus costs and effects) of pollution reduction.

Negative abatement costs

Near the origin of the cost curve, the calculated costs of reduction may be negative; *i.e.* reduction can be achieved with net savings. This is not in line with theory and implies that certain assumptions are violated, be it assumptions on rational behaviour of the target groups, on equilibrium in the economy, on used prices and discount rates, *et cetera*. A good entry into the literature on the reasons why firms do not implement cost-effective measures is Velthuisen (1995), who focuses on energy-saving measures.

Keeping the negative abatement costs is clearly inconsistent with the assumptions behind the applied general equilibrium model: as all agents are assumed to behave rationally, these measures would immediately be implemented, regardless of the environmental policy level (in other words: these measures should have been implemented in the baseline already).

However, correcting for these negative costs is not straightforward. One could assume that the negative costs implicitly reflect hidden costs and thus the total costs of the measure should be raised with the hidden cost (leading to zero net costs). However, it is arbitrary to set the hidden costs exactly equal to the negative net costs: any hidden cost larger than the negative net cost will also ensure compliance with the model assumptions.

Moreover, if the measures with negative net costs should be corrected for hidden costs, the costs of all measures should be corrected for hidden costs. Again, the size of the correction cannot be determined objectively.

Another option to deal with the negative net costs is to exclude these measures from the abatement cost curve. The reasoning behind this could be that these measures will automatically be implemented if a (restrictive) environmental policy is installed. However, this assumption is in contrast with the historical fact that a restrictive environmental policy was already active in 1990 in the Netherlands. Furthermore, removing these measures from the analysis would also mean removing the associated potential for pollution reduction. Given the fact that the estimation of these pollution reduction potentials is important for the calculation of the SNI, removing the negative net cost measures is undesirable.

As a practical (ad-hoc) solution, the negative net costs of abatement measures are set equal to zero, which is equivalent to assuming them to be equal to the hidden cost. The model thus calculates zero costs for the emission reductions associated with these measures. This assumption has no major influence on the calculated sustainable national income, since this is based on stringent emission reductions where the cost curves show unambiguously significant positive costs and since the reduction potential is calibrated correctly.

Attribution of pollution and abatement measures to specific sectors

One problem that occurs in more environmental themes is that the economic sector that can abate the pollution may differ from the economic sector to which the emissions are attributed. This is especially prominent in the cases of depletion of the ozone layer (mainly emissions of CFCs) and dispersion of toxic substances to water.

In the case of CFCs, this problem is dealt with by correcting the pollution data to reflect where the abatement measures can be taken. For example, the CFCs that are present in refrigerators are attributed to the industry that produces the refrigerators, even though the actual emissions will not occur until the refrigerator is made waste after consumption.

In the current version of the AGE-SNI model, the sectoral component of the abatement measures is not fully developed (see Chapter 5), and consequently, the problem of attributing to sectors is neglected. However, this issue is treated in the sensitivity analysis in Chapter 7.

Interaction of measures

Reduction measures may interact in a number of ways. The description below of how was dealt with interactions, is based on Dellink and Van der Woerd (1997) and does not necessarily apply for the theme of the enhanced greenhouse effect, which is based on a separate study (de Boer and Bosch, 1995). The possible ways of interactions are exclusiveness; sequentially; interaction between themes and substances; and interaction between measures.

Exclusiveness of measures

Introduction of one measure may make certain other measures inapplicable. For instance, a fuel switch from coal to gas excludes the measure of coal gasification. The following method was used. The cost-effectiveness of the mutually excluding measures was calculated and the most efficient measure was then introduced in the curve. A drawback of this procedure is that a situation may occur where the total effect of the less efficient measure is higher than that of the chosen measure and that therefore the total reduction potential of abatable emissions may be underestimated.

Sequentiality of measures

Sometimes, a measure cannot be taken before another one is introduced. For instance, a third phase water purification cannot be realised before a second phase purification. This may lead to a situation where a less efficient measure is taken before a more efficient one. This problem was solved by combining measures into packages. Suppose that we have measure a that reduces pollution from 100 to 50 units, and measure b, that must follow measure a, reducing further from 50 to 35 units; moreover, we have a separate measure c, that reduces pollution from 100 to 40 units. The measures are then redefined as: a; (a + b); and c.

Interaction between themes and substances

Reduction of pollution of one substance may lead to a change in the pollution of another substance. For instance, improvement of energy efficiency may lead to reduction of CO₂, NO_x and SO₂ emissions. In line with the procedures in RIM⁺, a primary aim of the measure is then identified and the costs of the measure are totally attributed to that primary aim.

If the measure impacts two substances within the same theme (e.g., NO_x and SO₂), this procedure does not lead to double counting of the costs, but if one measure is included in two different themes (e.g., CO₂ and NO_x), the measure may well be defined as having a primary aim in both themes, and double counting of costs may well occur.

Interaction between measures

The combined effect of two measures can be lower than the sum of the effects of the two separate measures. For instance, a fuel switch to low sulphur fuel and flue gas desulphurisation have, if combined, a lower effect than the sum of the effects of each measure if applied without the other.

This could also be solved by combining the measures in packages. However, if many measures interact, the number of packages grows rapidly to unmanageable amounts. The used procedure is that, if measures a and b interact, and if in combination they have the effect of measure c ($= a + b$), then the measure with the lowest efficiency, say measure b, is redefined as having the effect $c - a$.

6.5.3 The cost curves of the environmental themes

The enhanced greenhouse effect

The greenhouse gases (GHG) that cause the enhanced greenhouse effect are mainly: CO₂; methane; nitrous oxide; and CFCs and halons. The effects of these substances on the enhanced greenhouse effect, as well as the duration of their effects, vary. The way in which these GHGs can be aggregated into CO₂ equivalents is not unambiguous, but depending on the mix of emissions (and emission reductions). The coefficients that were chosen to aggregate the GHGs into CO₂ equivalents are described in Statistics Netherlands (2000); they are based on the long-term Global Warming Potentials of the substances. The construction of the abatement cost curve for the enhanced greenhouse effect is discussed in detail in De Boer (2000a).

Technical measures and costs to reduce fossil fuel use, and thus CO₂ emissions, were taken largely from the ICARUS database (Blok, 1991; Blok et al., 1991) which comprises about 300 measures ranging from more efficient energy use and co-generation to local solar power systems, and from ECN's MARKAL model (Okken, 1991; Okken et al., 1992).

Measures to reduce methane emissions were collected from various sources (see De Boer, 2000a) and comprise changes in the composition of animal fodder; more efficient use of manure; measures in the production and distribution of natural gas; and measures at waste dumps. The measures of changing animal fodder and of more efficient management of manure are also effective for reduction of nitrous oxide. The measures to reduce CFCs and halons consist of replacing them by HCFCs (with much lower warming potential) or by other substances. The resulting cost curve is depicted in Figure 6.2.

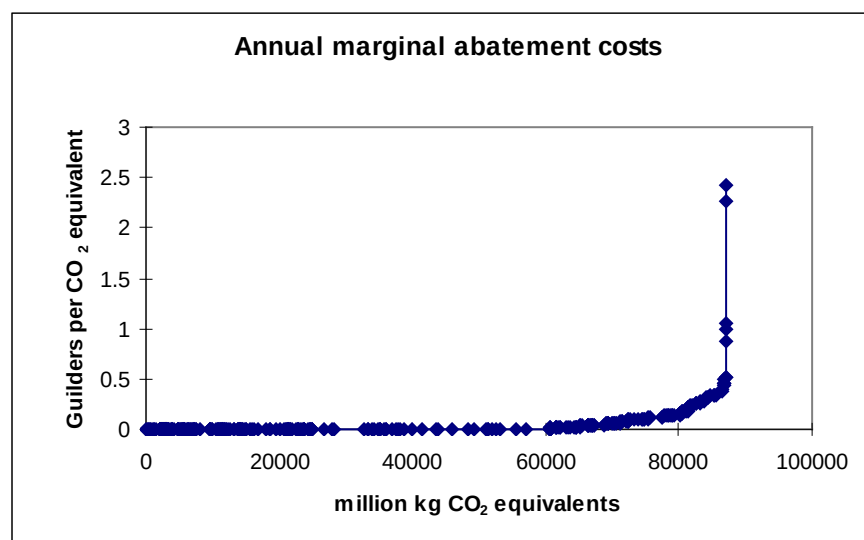


Figure 6.2 Marginal costs of reduction of greenhouse gases.

Many measures have negative net costs (corrected to zero costs, see Section 6.5.2). The reason for negative cost figures lie in considerable energy savings. Negative-costs op-

tions include a number of measures in the energy intensive greenhouse agriculture; energy efficiency measures in households and transport; energy saving by intensifying aluminium recycling; introduction of co-generation in the chemical industry, the foodproducts industry and other industries; plus a large variety of smaller energy savings in all industrial sectors, in households and in office buildings.

Measures with small, but positive net costs are situated in the middle of the curve. Apart from additional energy saving measures, they consist of CFC reduction and reduction of methane and nitrous oxide.

Marginal costs are gradually rising to NLG. 0.40/kg CO₂-eq per year with measures such as replacement of CFCs and HCFCs in cooling installations; reuse of waste warmth in the ferro metal industry; double glazing and roof insulation in houses; the use of wind and hydro in electricity generation.

Measures with marginal costs between NLG. 0.40-0.80/kg CO₂-eq per year include building of energy efficient houses; wall and floor insulation; and use of biogas from manure.

At the right hand side of the curve, with marginal costs rising steeply from NLG. 0.80/kg CO₂-eq per year onwards, one finds solar energy in houses and the use of reverse osmosis in food industry for saving fossil fuels. The effectiveness of these most expensive options is rather small.

The curve of total costs is depicted in Figure 6.3, together with the approximation by a CES curve.

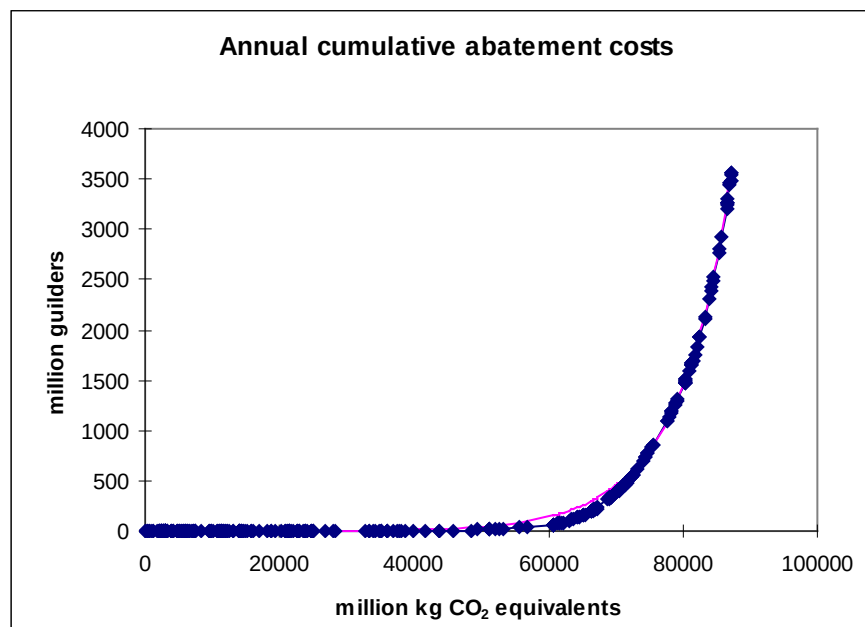


Figure 6.3 Total costs of reduction of greenhouse gases.

Depletion of the ozone layer

The depletion of the ozone layer is primarily caused by emissions of CFCs and halons. Just like the enhanced greenhouse effect, this is a climate problem. The inventory of the reduction measures for this environmental theme is laid down in De Boer (2000b). All 15 measures entail the replacement of the polluting gas with other substances. Note that in many cases the replacement gas is a HCFC or HFC. As these gases did not pose an environmental problem in 1990, they are not included in the analysis. However, in reality it has turned out that these replacement gases are also polluting.

The costs of the CFC-replacement measures varies from zero (for replacement of sterilisation gas sprayers) to just over 300 guilders per kilogram of CFC11-equivalent emissions (for replacement in commercial and industrial cooling systems). Most measures have a cost-effectiveness of around 9 guilders per kilo CFC11-equivalent. All measures together can reduce historical CFC11-equivalent emissions with 95% and have an associated cost of a little more than 150 million guilders (half of which is contributed by the single most expensive measure).

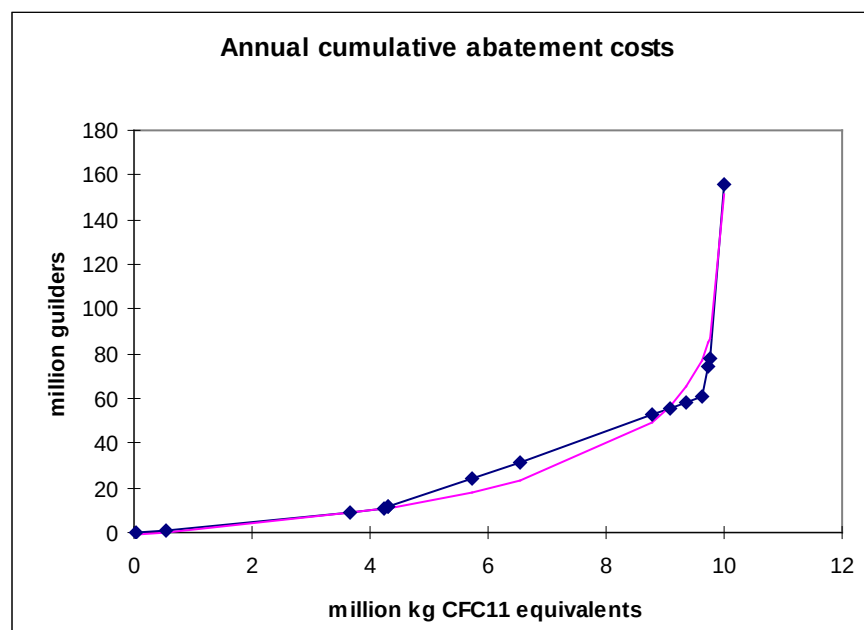


Figure 6.4 Total costs of reduction of ozone depleting emissions.

Acidification

The substances that cause acidification are NO_x , SO_2 and ammonia (NH_3). The first two are mainly related to the combustion of fossil fuels, the last one to agriculture. Emissions of the three substances can be aggregated into acidification equivalents as follows: 1 kg NO_x = 22 acid equivalents; 1 kg SO_2 = 31 acid equivalents; and 1 kg NH_3 = 59 acid equivalents. The measures to reduce acidification were taken from the RIM⁺ database and comprise about 170 options. The cost curve for reduction of acidification and the approximation with a CES function are given in Figure 6.5.

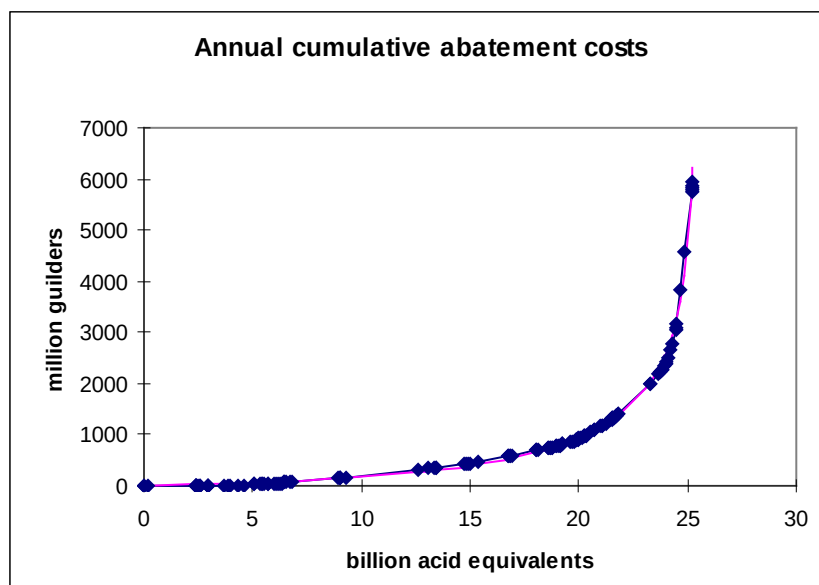


Figure 6.5 Total costs of reduction of acidifying emissions.

At the left hand side of the curve, there are two measures with negative net reduction costs (corrected to zero costs), related to the restriction of maximum speed in traffic. Their effect on acidification is small. The next cost-effective measure is injecting manure in agricultural land, with a very substantial effect of 2.2 billion acid equivalents reduction at zero costs. Then, after a number of rather insignificant measures with respect to both costs and effects, the next sizeable measures are leanburn and flue gas circulation in gas driven engines. Thereafter follow a number of measures in refineries; their costs are actually underestimated as the operation and maintenance costs are unknown and therefore not included. The next sizeable measures relate to emission standards for river-crafts, trucks, diesel busses and tractors. An effective, but more costly measure, with a reduction in SO_2 of 3.3 billion acid equivalents, is the introduction of coal gasification/STAG for electricity generation, costing NLG. 143 million. Measures relating to flue gas desulphurisation in power plants and the reduction of process emissions of SO_2 in industry are effective, but costly.

Measures that reduce emissions even further than a 25 billion acid equivalents reduction include emission standards for petrol fuelled cars, reduction of maximum speed of vans and (very high costs and low effects) Low NO_x burners for combi-installations for electricity, and measures to reduce fuel evaporation in LPG and petrol fuelled cars.

With exclusion of the measures with the highest cost/effect ratio, 25.5 billion acid equivalents can be prevented at a total cost of NLG. 5,100 million.

Eutrophication

The substances that cause eutrophication are phosphorus (P) and nitrogen (N). They mainly stem from agricultural use of fertiliser and manure in agriculture, but emissions of NH_3 and NO_x contribute as well. The substances can be aggregated into phosphor

equivalents as follows: 1 kg P= 1 P equivalent; 1 kg N= 0,1 P equivalent. The measures to reduce eutrophication, as well as their costs, are taken from RIM⁺, and amount to a number of 145 options, of which 125 are also present in the cost curve of reduction of acidification. The curve, together with the CES approximation, is given in Figure 6.6.

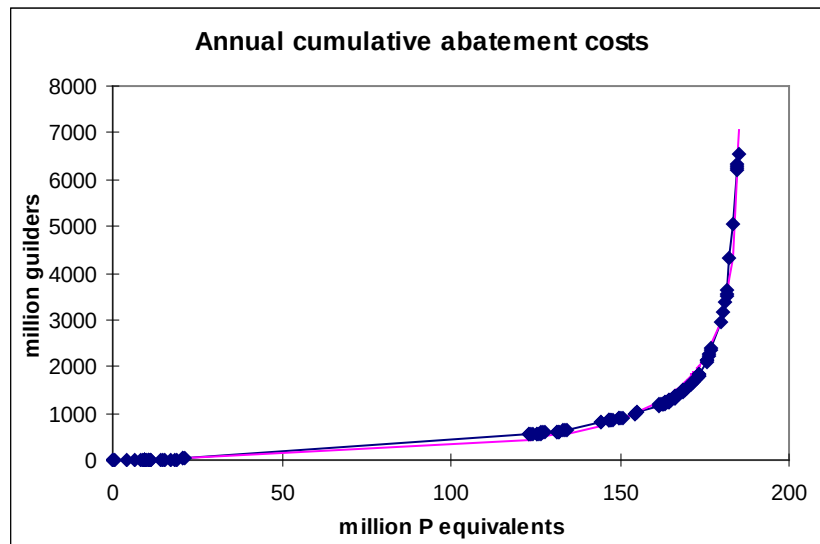


Figure 6.6 Total costs of reduction of eutrophying emissions.

When the measures for reduction of emissions to air (NO_x , NH_3) are omitted, the total reduction of eutrophication in the sectors agriculture, industry and sewerage that can be achieved amounts to about 130 million P equivalents, as compared to a total maximal reduction of abatable emissions of 185 million P equivalents. The most important measure consists of elimination of excess manure, which reduces over 100 million P equivalents at a yearly cost of about NLG. 500 million. Due to lack of data this measure could not be subdivided into its components, which include also dephosphating and denitrifying of wastewater from industry and households. Further steps in the reduction relate to additional measures in sewerage and water purification, and the least cost-effective measure at the very end of the curve is relocation of farms: a reduction of 0.02 million P equivalents at the fabulous cost of NLG. 200 million yearly.

Dispersion to air: smog formation

For the cost curve of smog formation (VOC: Volatile Organic Components, in particular hydrocarbons), 39 measures were identified, of which 8 were deleted because they were excluded by other measures, while twice two measures had to be combined due to sequentiality. This results in 29 points on the curve. The measures with the best cost-effectiveness at the left hand side of the curve are mainly identified in VROM's KWS-2000 programme and relate to households, the construction sectors, industry, services and the energy sector. About 150 million kilograms can be reduced at relatively low costs of about NLG. 500 million yearly. The measures at the right hand side are mainly within the target group of traffic and transportation, and are mostly not primarily aimed

at VOC reduction. They include emission standards for river crafts, locomotives and LPG vans and measures to prevent fuel evaporation. The total reduction potential amounts to somewhat less than 200 million kilograms at total costs of about NLG. 3,500 million. The cost curve and its approximation by a CES curve are given in Figure 6.7.

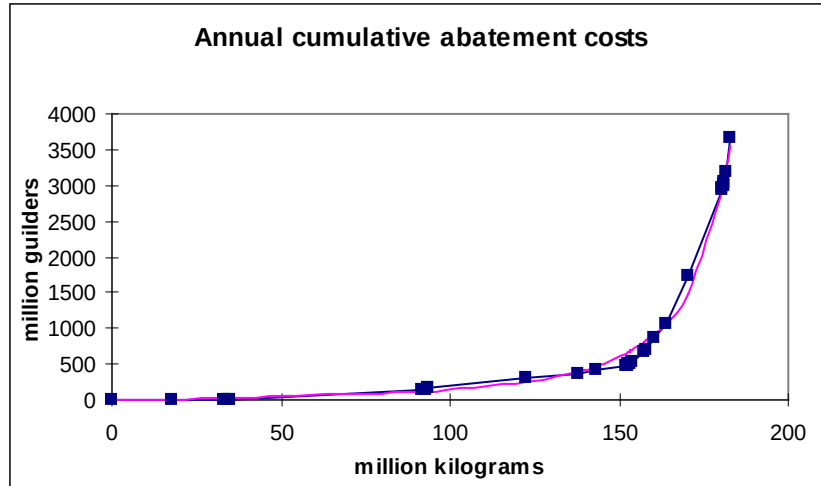


Figure 6.7 Total costs of reduction of VOC emissions.

Dispersion to air: fine particles

Another important source for dispersion to air are the emissions of fine particles (PM10) to air. Together with VOCs, they contribute to local air pollution.

In their 1997-study, Dellink and Van der Woerd constructed an abatement cost curve for fine particles. The curve contains 36 measures, starting with 3 measures that are relatively cheap and are specifically aimed at reducing PM10-pollution, and furthermore containing measures that are primarily aimed at reducing NOx, but also reduce pollution of fine particles. In total, the curve can reduce almost 44 million kilograms of PM10 at a cost of around 2.5 billion guilders annually.

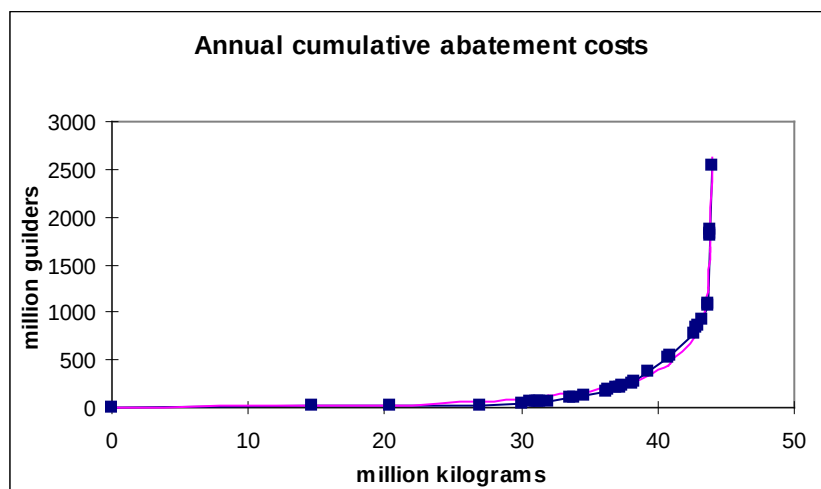


Figure 6.8 Total costs of reduction of fine particles to air.

Dispersion of toxic substances to water

Originally, Zinc was chosen as an example for water pollution with heavy metals (see Dellink and Van der Woerd, 1997). However, the number of measures to reduce zinc is limited, only 13, of which 1 had to be omitted as it was excluded by another measure. Of the resulting 12 measures, the costs of 5 are zero, or assumed zero for lack of data. These are various measures such as adaptation of roof gutters and pipes and of crash barriers (zero costs) and a ban on emissions of phosphorous gypsum (costs unknown). The first measure with positive costs is the use of coatings in the construction sector. Other effective measures are adaptation of greenhouses and a fourth phase in water purification. A separate problem is that the attribution of abatement measures and pollution to specific sectors is problematic (for example, consumers can hardly influence the choice of using zinc in the rain gutters to their houses; nonetheless, the emissions of zinc take place slowly over the time of 'consumption' of the house and are normally attributed to the consumers).

All in all, the zinc abatement cost curve thus constructed turned out not to be useful for the SNI calculations⁴¹. Therefore, an alternative source of data for this environmental theme is used: data for dispersion of toxic substances to surface water (based on Wagemaker *et al.*, 1999 and Van der Woerd *et al.*, 2000). The data consist of 8 heavy metals (including zinc) and 9 polycyclic aromatic hydrocarbons (PAHs).

The data still do not cover the whole field of dispersion to water. Not all toxic substances are taken into account (Wagemaker *et al.*, 1999, consider around 200 relevant substances; however, the most important substances are taken into account), and not all sources of pollution are included in the analysis. Only measures aimed at reduction of indirect draining to surface water are included, measures aimed at direct draining to surface water and measures aimed at diffuse draining are not considered. Moreover, both the pollution data, abatement measures and the sustainability standard are confined to surface water; groundwater and the effect of the toxics on the oceans (which is the most important aspect of this environmental problem in the long run) are not taken into consideration.

As another problem, only data for 1995 are available. These data are extrapolated to 1990 using a simple but crude procedure. The costs of the measures are only corrected for inflation between 1990 and 1995 (using a general inflation index), but without correcting for technological developments over time (no measures that are present in the 1995 database are excluded for 1990, no 'new' measures added for 1990, no correction is made for decreasing costs over time, *et cetera*). This procedure does have one problematic side-effect: when an SNI for 1995 is calculated and compared to 1990, the abatement data for this environmental theme will be based on the same information, thereby rendering a comparison less valuable for this environmental theme. Furthermore, the estimated operational costs of the measures could only be crudely included in the analysis due to a lack of reliable data (the operational costs of the measures are estimated as 3 percent of capital costs).

⁴¹ One complication in this respect was that preliminary calculations showed that the model is extremely sensitive to the specification of the Zinc-data.

One specific choice to be taken when composing the abatement cost curve for such diverse toxic substances is the choice of the equivalence factors. For other environmental themes, the choice of equivalence factors can be based on scientific insights (*e.g.* the enhanced greenhouse effect or acidification), but for dispersion of toxic substances there are many different options for the equivalence factors. Fortunately, the study by Van der Woerd *et al.* (2000) shows that the resulting abatement cost curve is quite insensitive to this choice. Basically, both the shape of the abatement cost curve and the order of the measures within the curve remain virtually unchanged when switching to other equivalence factors. Therefore, one of the most common physical alternatives is used to construct the abatement cost curve for this environmental theme: the “aquatic ecotoxicity-potentials” (AETP; see Huijbregts, 1999)⁴². The AETP of a particular substance is determined by the ratio of the predicted effect concentration and the predicted no-effect concentration, compared to the same ratio for a reference substance. The AETP values are taken directly from Van der Woerd *et al.* (2000), without recalculating these factors for the changes in circumstances caused by the shift towards a sustainable situation. Consequently, the AETP values are independent of the actual calculations in the SNI-model (a condition for the equivalence factor to be useful, see Van der Woerd *et al.*, 2000).

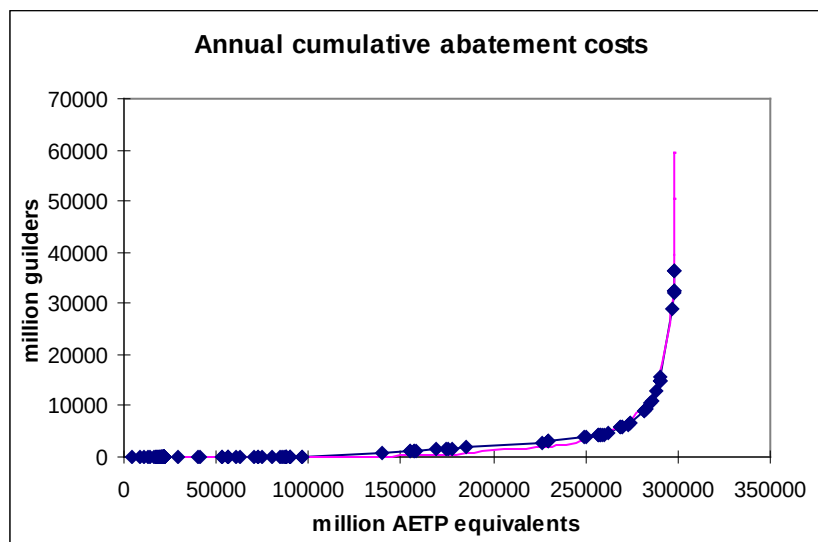


Figure 6.9 Total costs of reduction of dispersion of toxic substances to water.

Dispersion to soil

For dispersion of heavy metals to the soil, no measures could be found. Clearly, this does not reflect the true state of technology with respect to for example abatement of soil contamination with heavy metals. It merely indicates that in 1990, this environmental theme had no importance in environmental policy. As a consequence of the absence of an

⁴² There are some theoretical drawbacks to this alternative. Huijbregts (2000) presents superior equivalence factors for sustainability analysis; however, these were not available in time to be included in the analysis.

abatement cost curve, this environmental theme cannot be captured in the SNI calculations. As direct pollution of heavy metals to the soil is limited (most pollution is emitted to surface water), and as soil contamination is taken into account, the effects of this omission on the sustainability calculations are also presumed to be of minor importance.

Dehydration

For the estimation of costs to reduce the arid/dehydrated area, use was made of a study of policy scenarios for the Water Systems Explorations (WaterSysteemVerkenningen, RIZA 1996). The scenarios are each composed of a variety of measures, but due to data shortage it was not possible to carry out the analysis on a measure by measure basis. Measures of the scenarios include a variety of local small scale projects such as: adaptation of the water system, depoldering, extraction of drinking water, extraction of industrial water, and reduction of irrigation water use.

The scenarios used for the cost curve are: Present Policy 2000 (Huidig Beleid 2000; HB 00); Present Policy 2015 (HB15); System 2015 (S15); and Reversing the Trend 2045 (Trendbreuk 2045; TB45). The time horizons of the scenarios differ, which leads to smoothing out the cost differences. Table 6.5 depicts the annual costs of full and sustained rehydration.

In Dellink and Van der Woerd (1997), a concept version of the RIZA data were used. Some of the costs of the measures have been revised in the final version; consequently, the total costs for this environmental theme have been changed from 860 million guilders per year to 550 million (RIZA, 1996).

Note that all abatement costs for the environmental theme dehydration are assumed to be public costs. In reality, some of the costs will be borne by private sectors. However, this is a relatively small portion of all costs (especially in 1990, it has become increasingly important in later years).

Table 6.5 Costs for dehydration and soil contamination.

	Total costs	Annual costs
	(Billion NLG)	(Million NLG/yr)
Dehydration		550
Soil contamination	408	20400

Soil contamination

Estimation of the cost curve of cleaning up of contaminated soil from the past is a heroic, if not absurd, effort. Data is weak or lacking and the estimation should be interpreted, at most, as an indication of the order of magnitude.

The first and possibly largest problem is that no complete inventory of contaminated locations is available. Although after the first cleaning up operation (at Lekkerkerk in 1980) a policy was formulated to clean up all contaminated locations within only one generation, a more realistic policy target would be to complete within one generation the inventory of all contaminated locations. In recent years, the number of suspect locations grew with a factor 200 from about 3 thousand to 600 thousand. The 600 thousand loca-

tions were, admittedly and necessarily roughly, categorised in three classes: not severely contaminated, not urgent severely contaminated, and urgent severely contaminated.

The bodies involved in cleaning up soil contamination are various, but for estimation of the costs a restriction was made to locations under the responsibility of provinces, with some additional information on private cleaning costs. Not only are the types of contamination different, also the cleaning techniques and their extent of effectiveness differ. Apart from isolation (which is not really cleaning up) one can distinguish, among others, bioremediation; air ventilation; steamstripping, thermal cleaning <400°C; thermal cleaning >400°C; floatation; land farming; bio-reactors; and extraction plus biological cleaning of silt. The range of costs shows a factor 30 or more between the cheaper and the most expensive techniques. The estimation of costs for total sustainability is in the range of NLG. 230 - 450 billion (total, not yearly costs; see Table 6.1).

Waste disposal

Waste represents an enormous quantity of resources both in the form of materials and energy. Waste generation in the EU is increasing, and amounted to roughly 3.5 tonnes of solid waste per person in 1995 (excluding agricultural waste). The main sources of waste are household consumption, manufacturing, construction and demolition, and mining. Solid waste is also increasingly produced through processes attempting to reduce other environmental problems, for example sewerage sludge from water treatment and residues from cleaning of flue gases.

The quantity of waste produced is observed to be positively related to economic activity. Christiansen and Fischer (1999) show a strong relationship between the generation of municipal, construction and hazardous waste and per capita national income in the EU. This relationship still holds despite large sectoral changes in Western Europe (moving away from heavy industry and towards the service sector) and the adoption of cleaner technologies in production. Recent work in waste management has focused on de-linking economic growth and waste generation. The fact that Austria and the U.S. share similar levels of GDP per capita but that Austria generates half the quantity of waste per capita shows that the relation between income and waste is not fixed.

The main waste management processes are landfill, incineration, and recycling/ recovery. In the EU an increasing proportion of the resources contained in waste is recovered as materials through recycling or as energy through incineration and biogas processing. More than 50%, however, is deposited in landfills. The Netherlands has a different waste processing profile from the EU norm, with 16% landfill, 11% incineration, and 74% recycled⁴³.

Waste management has a number of associated environmental impacts including:

- Leaching of nutrients, heavy metals, and toxic compounds from landfills;
- Use of land for landfills (including loss of natural areas);
- Emission of greenhouse gases from landfill and incineration;
- Air pollution and toxic by-products from incinerators;
- Increased transport of recyclable material;
- Air and water pollution and secondary waste streams from recycling plants;

⁴³ 1996 figures, EEA 1998, Statistical compendium for the Second Assessment.

- Risk of extreme pollution damage from hazardous waste.

The environmental theme of waste disposal is relevant to Hueting's methodology for the calculation of sustainable national income in that it impacts on several environmental functions in such a way as to endanger their availability over time. Waste, potentially, has impacts on land use, climate change, and air and water quality. Except for land use, these environmental themes and their associated functions and sustainability standards have already been considered and are included in the SNI-AGE model (see above and Chapter 4). The measures available for achieving a sustainability standard for waste disposal would, to a large extent, duplicate the measures undertaken to reach the standards for climate change and air and water quality. For example, limiting the quantity of land-fill is a potential measure for reducing methane emissions under the sustainability standard for the enhanced greenhouse effect, and also for meeting a sustainability standard for waste. The inclusion of the cost of achieving a waste standard could, therefore, result in double counting of expenditure on technical measures.

A category of waste for which a sustainability standard might be usefully applied is hazardous waste. The environmental impact of waste generation is a function of the degree of hazard associated with it as well as the quantity produced. Dangerous substances in waste, e.g. radioactive material or heavy metals, even in small quantities, can have large negative impacts on the environment. The generation of hazardous waste necessitates different waste processes and may have different treatment lifetimes. This form of waste has the potential to damage human health and biodiversity directly, and so a sustainability standard would not be additional to those already set.

Following the practical conditions for sustainability set out in Section 3.5, a sustainability standard for hazardous waste would correspond to a total quantity and storage system of such waste which has an associated risk to human health that is 'acceptable'. Hueting suggests that under the precautionary principle the generation of hazardous waste should be zero. To meet this standard only the volume measure of ceasing all processes that generate hazardous waste is applicable. For the Netherlands this would require the closure of its nuclear power stations, as well as many other economic activities which produce hazardous material.

Some expenditures on waste processing may be defined as defensive expenditure. For example, the decontamination of land is restorative expenditure to maintain an environmental function. This accounting issue is dealt with in Section 5.2.2. In brief, such expenditures should be treated in the same way as the cost of technical and volume measures, and be subtracted from national income.

Land use

Land can be defined as the complex of soils, waters and climate upon which life occurs (Jurgens 1992). Land, as an element in our bio-physical surroundings, provides a range of environmental functions. Land-uses include agriculture, natural habitat, forestry, transport networks, and residential and industrial areas. The quality as well as the quantity of land is important in supporting these land uses.

Hueting recognises spatial competition as one of three distinct types of competition between environmental functions, the others being quantitative and qualitative competition.

Spatial competition exists when the amount or space is deficient with respect to the existing and future needs for it. The use of land for a certain function may exclude its use for other functions (see Hueting, 1992b).

The sustainability standard for a particular land use is an objectively determined level at which the environmental function of that land use is maintained over time. Land use is, with varying degrees of ease and cost, a reversible process. Generally any type of land use can be converted into another. The environmental function supported by a particular land use may, however, not be so easily recreated. In the approach taken by Hueting (see Section 3.5) any change in land use which negatively affects the rate of extinction of biological species is deemed unsustainable. Indeed, the importance of including land use in the calculation of sustainable national income is that one of the key causes of species extinction is change in land use in terms of natural habitat loss. Hueting also classifies changes in land use as unsustainable if travelling distances to environmental functions, which provide benefit through observation of them (e.g. national parks), become unreasonable.

Section 4.2 sets out a land use sustainability standard for the Netherlands based on the existing policy objective of an Ecological Main Structure. In brief, the EMS is a system of interconnected natural areas which allows species of both fauna and flora to maintain population levels. The technical and volume measures required to achieve this sustainability standard would impact on a number of sectors in the economy. Transport networks, which segment natural areas and species populations, could be partially dismantled or adapted to increase the environmental function of species preservation. Agricultural practices such as enlargement of field sizes and removal of hedgerows would possibly be reversed. Other possible measures might include the further restriction of the enlargement of urban areas and the limitations on water level control. The cost of such measures, as are necessary to meet the sustainability standard, needs to be subtracted from national income. It appears in general that such measures are not duplicated through the achievement of other sustainability standards, and so the inclusion of a land use sustainability standard would further reduce the sustainable national income measure relative to conventional national income.

Depletion of non-renewable resources

Non-renewable resources are those that have a finite or extremely slow forming stock, e.g. fossil fuels and copper. The relevance of non-renewable resources, and fossil fuels in particular, to the calculation of sustainable national income and the sustainability standard for fossil fuels is defined in Section 3.5 and Section 4.1. In brief, the sustainability standard for the use of fossil fuels is the rate of extraction and use which maintains the availability of the environmental function of the resource over time. This sustainable extraction rate is equal to the combined rate of efficiency improvements and substitution of fossil fuel use.

In this respect Hueting does not draw a strong distinction between renewable and non-renewable resources (Hueting and Reijnders, 1998). The functions of renewable resources remain available as long as their regenerative capacity remains intact. The functions of non-renewable resources remain available through the development of efficiency

improvements and substitutes. The rate of this substitution should be such that the same provision of the function is available.

The technical and volume measures which are available to meet the fossil fuel sustainability standard are largely a duplication of those used to achieve the greenhouse effect sustainability standard i.e. the substitution of renewable for non-renewable energy sources and the reduction of activities which use fossil fuels. To include the cost of meeting both standards in the calculation of SNI would result in significant double counting. The extent to which these two sustainability standards overlap can be examined by comparing the initial estimates of the necessary reductions in fossil fuel use under each standard. The fossil fuel sustainability standard is estimated to require a reduction in fossil fuel use to 64% of its 1990 levels, whereas the greenhouse effect standard requires a reduction to a little less than 25% of 1990 levels⁴⁴. This suggests that including the fossil fuel sustainability standard in the model will not greatly alter the current results.

The inclusion of a sustainability standard for non-renewable resources in the SNI-AGE model is also complicated by the methodological problem of constructing an abatement cost curve. In contrast to the other environmental themes, which concern pollution damage, the sustainable use of non-renewable resources is concerned with reducing the rate of resource depletion. An abatement cost curve will consist of substitution and efficiency options which are currently not implemented, and to a relatively large extent of volume measures. There is, however, very little data available covering the cost of volume measures for reducing the use of non-renewable resources.

6.5.4 Possibilities for constructing abatement cost curves for 1995

This section studies the feasibility of constructing abatement cost curves with 1995 as base-year by making an inventory of the available information at the National Institute of Public Health and the Environment (RIVM) and by researching the possibilities for improving the existing data-matrix where 1990 is the base-year.

For the environmental themes enhanced greenhouse effect and depletion of the ozone layer the construction of abatement cost curves with base-year 1995 appears feasible, since all required information is available. However, the information is not available from one source and requires a standardisation for greenhouse gases other than carbon-dioxide and the gasses which have been substituted to avoid depletion of the ozone layer, which have a relative high warming potential. Thereupon, the number of measures within these two global environmental themes is vast and it may require up to 40 labour days to construct reliable abatement cost curves.

Abatement cost curves with 1995 as base-year for the theme acidification can easily be derived. These preliminary curves are available and can be compared with the earlier abatement cost curves with 1990 as base-year. This comparison shows that the technical possibilities to reduce acidic emission within the sectors traffic and transport and the sec-

⁴⁴ The requirement for the enhanced greenhouse effect sustainability standard is actually a reduction in greenhouse gas emissions, but for the sake of argument this is assumed to roughly correspond to a reduction in fossil fuel use.

tor energy have increased. The overall curve shows a lower reduction capacity (14 instead of 25 billion acid equivalents). The most important cause for this is that in the meanwhile a number of measures have already been taken.

For the theme eutrophication no new information about changes in measures has become available. An update to base-year 1995 requires up to 20 labour days.

Data about smog formation and dispersion of fine particles to air are relatively easy to collect. Most of these measures fit into the sector traffic and transport, and 2 to 3 labour days are required to put all the relevant information together.

Data for the theme dispersion of toxic substances to water are readily available for base-year 1995 and do not need to be updated. The theme could however be broadened to include all important toxic substances and all pollution sources. Within the theme “dispersion to water”, the data-matrix of 1990 as used in an earlier version of the AGE-SNI model only considered the emissions of Zinc to water, and is extended by jointly treating to the emissions of 8 heavy metals and 9 poly-cyclic aromatic hydrocarbons (PAHs) to water. For a good overview of the emission of heavy metals and PAHs, it is important to make an inventory of point and diffuse emissions. This is expected to be a time consuming task, but it might be possible by consulting the Institute for Inland Water Management and Waste Water Treatment (RIZA).

The themes dehydration and soil contamination are mainly based on policy-measure-packages, which can be updated in a few days.

The following table 6.6 presents the results of this feasibility study, which is an estimate of the required labour days –including coordination time– for making an update to 1995 without any methodological changes.

Table 6.6 Labour time required for an update of existing abatement cost curves to base year 1995.

Environmental theme:	Rough estimate
Greenhouse effect	10-30
Depletion of ozone layer	5-10
Acidification	3-5
Eutrophication	5-20
Smog formation	2-3
Dispersion of fine particles to air	2-3
Dispersion of toxic substances to water	0-0
Dehydration	0-1
Soil contamination	1-3
Coordination	30-40
Total	58-115

6.5.5 Final remarks

The cost curves presented in this chapter are estimates with weaknesses. They are an approximation to which various improvements can be made.

First, the data bases that were used are not complete. In particular, the pollution reduction measures of RIM⁺ model are acknowledged by RIVM itself to need further completion and updating, be it within the structure of RIM⁺ or within some other new structure.

It seems that the reduction measures that were used for the enhanced greenhouse effect are more comprehensive. Apart from the completeness of the data, the accuracy is unknown.

Secondly, the costs of some measures were double-counted. There is an overlap in measures with respect to the enhanced greenhouse effect and to acidification (in particular energy saving measures) and with respect to acidification and eutrophication (measures on nitrogen). A measure can be seen as the primary aim for the perspective of one theme, but the same measure may also be a primary aim in another theme. In the used methodology, the costs of that measure are then double counted. It is yet unclear how this flaw in the analysis could be corrected in the stylised modelling structure.

Thirdly, excises and (for households) VAT are included in the prices. From a macro economic viewpoint one might argue that factor prices should be used. However, the sectors in the model react on prices as perceived by them, so including excises and VAT is correct. Moreover, to the extent that revenues of emission charges replace taxes, excises and VAT should diminish. But as excises and VAT are an integral part of the cost curves, they are built into of the cost curves and cannot be discarded as such. This leads to price distortions that are difficult to justify.

The incompleteness and the double-counting are influences that result in an overestimation of the costs of reduction. Whether the inconsistency in the discount rate and the inclusion of excises and VAT lead to a structural bias is unclear, but all four points mentioned above lead to inaccuracy. Although the estimated cost curves are based on the best available information, an improvement of the estimates can be achieved by further research. And how to deal correctly with the double counting requires, in addition, an analytical effort.

References

- Blok, K. (1991). *On the reduction of carbon dioxide emissions*. Thesis, Rijksuniversiteit Utrecht, ISBN 90-73958-01-6.
- Blok, K., E. Worrell, R.A.W. Albers and R.F.A. Culenaere (1991). *Data on energy conservation techniques for the Netherlands*, Report W-90008, Utrecht University.
- Christiansen, K.M. and C. Fischer (1999). *Baseline projections of selected waste streams: development of a methodology*. EEA technical report.
- de Boer, B. (2000a). The greenhouse effect. *Mimeo*, Statistics Netherlands, Voorburg.
- de Boer, B. (2000b). Depletion of the ozone layer. *Mimeo*, Statistics Netherlands, Voorburg.
- de Boer, B. and P. Bosch (1995). *The greenhouse effect: an example of the prevention cost approach*. Paper prepared for the second meeting of the London group on national accounts and the environment, Washington, March 15-17.
- de Boer, B. and R. Hueting (1998). Supply and demand curves for environmental themes. *Statistics Netherlands Report*, forthcoming.
- Dellink, R.B. and K.F. van der Woerd (1997). *Kosteneffectiviteit van milieuthema's*. IVM-R97/10, Institute for Environmental Studies, Vrije Universiteit, Amsterdam.
- EEA (1999). *Environment in the European Union at the turn of the century*, Chapter 3.7, Waste generation and management.
- Hanemaaijer, A. (2000). *unpublished*, RIVM, Bilthoven.

- Hueting, R. (1992a). Correcting national income for environmental losses: a practical solution for a theoretical dilemma. In: Krabbe, J.J., and W.J.M. Heijman (eds.), *National Income and Nature: Externalities, Growth and Steady State*.
- Hueting, R. (1992b). The Economic Functions of the Environment. In: P. Ekins (ed.), *Real-life Economics*.
- Hueting, R., P. Bosch and B de Boer (1992). *Methodology for the calculation of sustainable national income*. Statistics Netherlands.
- Hueting, R., Bosch, P., B de Boer (1995). The calculation of sustainable national income, *Occasional Papers and Reprints*, IDPAD 1995-2.
- Hueting, R. and L. Reijnders (1998). Sustainability is an objective concept. *Ecological Economics*, 27, pp. 139-147.
- Hueting, R., L. Reijnders, B de Boer, J. Lambooy and H. Jansen (1998). The concept of environmental function and its valuation, *Ecological Economics*, 25.
- Huijbregts, M.A.J. (1999). *Priority assessment of toxic substances in the frame of LCA; development and application of the multi-media fate, exposure and effect model USES-LCA*. University of Amsterdam.
- Huijbregts, M.A.J. (2000). Priority assessment of toxic substances in life cycle assessment. *Chemosphere*, 14, pp. 541-573.
- Jurgens, C.R. (1992). *Tools for the spatial analysis of land and for the planning of infrastructures in multiple-land use situations*. Doctoral thesis.
- Keller, W.J. (1980). *Tax incidence*. North-Holland, Amsterdam.
- Keuning, S.J. (1993). An information system for environmental indicators in relation to the national accounts. In: W.F.M. de Vries (ed.), *The value added of national accounting*, Statistics Netherlands, SDU Publishers, The Hague.
- Okken, P.A. (1991). *CO₂ reduction consensus? A conceptual framework for global CO₂ reduction targets, the importance of energy technology development*. Report nr. ECN-RX-91-093ECN, Petten.
- Okken, P.A., P. Lako, D. Gerbers, T. Kram and J. Ybema (1992). CO₂ removal in competition with other options for reducing CO₂ remissions. *Energy Conversion and Management*, 33, pp. 6-10.
- RIVM (1991). *Nationale Milieuverkenning 2*. Bilthoven.
- RIVM (1996). *Milieubalans 1996*. Bilthoven.
- RIVM (1998). Data for the AGE-SNI model, *unpublished*.
- RIZA (1996). *Watersysteem Verkenningen*, Lelystad.
- Statistics Netherlands (1990). *Tax incidence in the Netherlands: accounting and simulations*. Statistics Netherlands report M42, SDU Publishers, The Hague.
- Statistics Netherlands (1994). *National Accounts*. SDU Publishers, The Hague.
- Statistics Netherlands (2000). Data for the AGE-SNI model 1990, *unpublished*.
- van der Woerd, K.F., E.C.M. Ruijgrok and R.B. Dellink (2000). *Kosteneffectiviteit van verspreiding naar water*. IVM-E00/01, Institute for Environmental Studies, Vrije Universiteit, Amsterdam.
- Velthuisen, J.W. (1995). *Determinants of investment in energy conservation*. SEO-report 357, Amsterdam, 349 pp.
- VROM (1994). *Methodiek Milieukosten*. Publicatiereeks Milieubeheer 1994/1.
- VROM (1998). *Kosten en baten in het milieubeleid, definities en berekeningsmethoden*. Publicatiereeks Milieustrategie 1998/6.

Wagemaker, F.H., W. van Starckenburg, J. Bouma, A.P.A. van Ewijk, I.G.W.M. Kuppen and J.C. van den Roovaart (1999). *Waternverkenningen: een strategie voor de aanpak van microverontreinigingen in communaal afvalwater*. RIZA nota 99.027, RIZA, Lelystad.

Appendix 6.I. Elasticity data

The current version of the model (version 1.1, available at September 2000), uses the following elasticities, based on the TaxInc model (Keller, 1980, Statistics Netherlands, 1990).

Table A6.I.1 Producer substitution elasticities.

Sector Name		Top level (σ_j)	Intermediates (σ_j^{intm})	Value added (σ_j^{prim})
Y1	Agriculture and fisheries	0.4	0.1	0.3
Y2	Extraction of oil and gas	0.9	0.5	0.5
Y3	Other mining and quarrying	2	1.3	0.8
Y4	Food- and food products industry	0.4	0.2	0.2
Y5	Textiles, clothing and leather industry	0.4	0.2	0.2
Y6	Paper and –board industry	0.5	0.2	0.3
Y7	Printing industry	1.4	0.6	0.9
Y8	Oil refineries	0.9	0.5	0.5
Y9	Chemical industry	0.3	0.2	0.1
Y10	Rubber and plastics industry	0.3	0.2	0.1
Y11	Basic metals industry	0	0	0
Y12	Metal products industry	0.7	0.2	0.4
Y13	Machine industry	0.7	0.2	0.4
Y14	Electrotechnical industry	0.6	0.6	0
Y15	Transport equipment industry	0.3	0	0.3
Y16	Other industries	1.2	0.6	0.6
Y17	Energy supply	0.1	0.1	0
Y18	Water supply	0.1	0.1	0
Y19	Construction	1	0.3	0.7
Y20	Trade and related services	1.8	0.7	1.1
Y21	Transport by land	0.7	0.3	0.4
Y22	Transport by water	0.7	0.3	0.4
Y23	Transport by air	0.7	0.3	0.4
Y24	Transport services	0.7	0.3	0.4
Y25	Commercial services	1.5	0.7	0.9
Y26	Non-commercial services	0	0	0
Y27	Other goods and services	0	0	0

Table A6.I.2 Consumer income elasticities.

Sector Name	Consumer income elasticities
Y1 Agriculture and fisheries	0.48
Y2 Extraction of oil and gas	0.38
Y3 Other mining and quarrying	0.38
Y4 Food- and food products industry	0.44
Y5 Textiles, clothing and leather industry	0.88
Y6 Paper and –board industry	0.38
Y7 Printing industry	0.70
Y8 Oil refineries	1.33
Y9 Chemical industry	0.88
Y10 Rubber and plastics industry	1.00
Y11 Basic metals industry	0.59
Y12 Metal products industry	1.10
Y13 Machine industry	1.01
Y14 Electrotechnical industry	1.01
Y15 Transport equipment industry	1.41
Y16 Other industries	1.11
Y17 Energy supply	0.27
Y18 Water supply	0.20
Y19 Construction	1.25
Y20 Trade and related services	1.40
Y21 Transport by land	0.39
Y22 Transport by water	0.39
Y23 Transport by air	0.39
Y24 Transport services	0.39
Y25 Commercial services	0.79
Y26 Non-commercial services	0.76
Y27 Other goods and services	0.00

Table A6.I.3 Consumer substitution elasticities.

	Demand (σ_h^{top})	Food (σ_h^{food})	Transport (σ_h^{trans})	Services (σ_h^{serv})	Other (σ_h^{other})
Private households	0.5	0.8	0.5	0.9	0.5
Government consumer	0	0	0	0	0

Table A6.I.4 Trade elasticities.

Imports & domestic production (σ_{imp}^{Arm})	4
Exports & domestic demand (σ_{exp}^{Arm})	4

Appendix 6.II. The incorporation of abatement data

Introduction

This appendix describes in which way technical information on abatement techniques is included in the environmental-economic AGE-SNI model. The AGE-SNI model is presented in detail in Chapter 5; the model is specified in the MPSGE sub-routine of the GAMS program (see Rutherford, 1997). The methodology proposed here is more general of character; it can be used in a wider range of environmental economic models.

First, the methodology is discussed in detail; then, the methodology is compared to the treatment of abatement in other empirical environmental-economic models and some final remarks are made.

Details of the methodology

The specification of the abatement information in the economic model can be broken down into several steps. First, data derived from so-called bottom-up empirical studies is aggregated into so-called abatement cost curves, which describe the marginal abatement costs for increasing levels of pollution reduction. Second, these abatement cost curves also provide the information on the total (technical) potential of pollution reduction. Third, as investing in abatement involves the purchase of economic goods, a production function for the Abatement producer has to be specified. Fourth, the abatement cost curves are approximated by means of a so-called ‘iso-output curve’ that reflects the trade-off between pollution and abatement at a constant level of production and consumption. The trade off is parameterised through the use of CES functions. Fifth and finally, the calculated parameters are included in the economic model. Each step will be elaborated upon below.

Construction of the abatement cost curves

As a first step, abatement cost curves have to be constructed for each environmental theme from the raw technical data. This step involves ranking the measures by cost-effectiveness and solving some methodological and practical problems (including how to deal with measures that exclude each other and measures that have to be taken in a fixed order). For details on this first step see Dellink and Van der Woerd (1997) and De Boer (2000a,b).

Calculation of the technical potential for emission reduction

In the model, a basic distinction is made between abatable and unabatable pollution. The main point in this distinction is that unabatable pollution can only be reduced by reducing the volume of production (hence, reduction measures for unabatable pollution are often called volume-measures; see for example Hueting et al, 1992), while abatable pollution can be reduced by investing in abatement measures. The definition of abatable pollution is that it can be removed (cleaned, prevented) by taking technical measures for pollution reduction (i.e. by investing in abatement goods).

From the abatement cost curves the maximum amount of pollution that can be reduced by investing in the technical measures is derived. This technical potential of pollution reduction determines the total amount of abatable pollution; all pollution that cannot be abated in this way is called unabatable. Note that if the technical potential is higher than (or equal to) the actual pollution levels, all pollution is labelled abatable⁴⁵ and if there are no technical measures at all, all pollution is labelled unabatable.

This separation of pollution into an abatable and unabatable portion deviates from the 'standard' assumption that all costs of pollution reduction can be captured through the abatement cost curve (see below).

Calibration of the production function for the Abatement producer

In the economic model, it is assumed that a special production sector exists, the Abatement producer, that supplies 'abatement goods' to the polluters (production sectors and households). For the Abatement producer, a production function has to be specified. The information for this production function can be taken from the cost components upon which the total costs data in the abatement cost curves are based: for each individual technical measures, the data describe not only the total annual costs of the measure, but also the components that make up these costs. These components include costs for produced goods, energy costs, labour costs, capital costs, *et cetera*.

The interpretation of this production function is that investing in abatement involves the purchase of additional produced goods (like filters), energy, labour and capital. The inputs into the production function of the abatement sector represent the so-called spending effects of implementing technical measures: if a new filter is installed to reduce emissions, then this filter has to be bought (and produced) somewhere, leading to an increased demand for filters.

The form of the production function for the Abatement producer is assumed analogous to the other production sectors: a nested-CES function is used, where producers maximise profits under constant returns to scale and perfect competition.

In the current project, it is assumed that the share of different inputs in the technical measures are constant throughout and across the abatement cost curves. In other words, no difference is assumed in labour- and capital intensity between low-cost and high-cost measures or greenhouse effect and acidification measures. This assumption implies a homogeneous spending effect over all themes. Though this denies the variety that underlies the technical measures that make up the abatement cost curves, the empirical data do not allow for a more detailed description of the cost components. As a consequence of this assumption, there is no need for separate Abatement producers for each environmental theme.

⁴⁵ Though at first glance it may seem implausible, it is certainly not impossible that the technical potential to reduce pollution is larger than the actual pollution level. The reason is that the data for all technical measures are based on a common historical level of pollution and are, at least in design, not specified in an additive way. Naturally, pollution can never become negative.

Specification of the functional form of the iso-output curves

Iso-output curves are used to reflect the trade-off between polluting and investing in abatement. This trade-off exists for any given level of production (and for consumers for any given level of consumption).

The following function describes the iso-output curve in the two-dimensional plane with cumulative abatement expenditures $\hat{A}$ on one axis, and abatable pollution $\hat{E}_{ab}$ on the other axis:

$$\left(\frac{\hat{A}}{A^*}\right)^\rho + \left(\frac{\hat{E}_{ab}}{E_{ab}^*}\right)^\rho = 1 \quad (\text{A.1})$$

where A^* is the maximum level for cumulative abatement expenditures (that is the expenditures when all technical measures are fully implemented so that abatable pollution is zero), E_{ab}^* is the maximum abatable pollution level, ρ is the CES elasticity parameter and, finally, 1 is the (normalised) level of production (or consumption). Both the abatement expenditures and abatable pollution are scaled as a fraction of their respective maximum amounts.

We can rewrite cumulative abatement as a function of abatable pollution, $\hat{E}_{ab}$, where A^* , E_{ab}^* and ρ are considered parameters:

$$\hat{A}(\hat{E}_{ab}; A^*, E_{ab}^*, \rho) = A^* \cdot \left\{ 1 - \left(\frac{\hat{E}_{ab}}{E_{ab}^*} \right)^\rho \right\}^{1/\rho} \quad (\text{A.2})$$

and compare the modelled abatement levels (2) with the data-set of pairs of abatable pollution and cumulative abatement costs, $(E_{ab,j}, A_j)$, for all individual technical measures, denoted by subscript j . However, some technical measures are already implemented in the historical year⁴⁶. This is also reflected in the accounting matrix used: the production sector Abatement has positive inputs and output in the base year. To account for this, we add an unknown initial pollution reduction level, $E_{ab,0} \geq 0$ to all pollution reduction levels of the data set $E_{ab,j}$, and we add an unknown initial abatement cost-level A_0 to the abatement costs $A_j \geq 0$. The data set of pairs of abatable pollution and cumulative abatement costs with which the model is compared becomes $(E_{ab,j} + E_{ab,0}, A_j + A_0)$.

Then, the squared vertical distance between the empirical abatement cost curve and the modelled iso-output curve is minimised. The difference between estimated and actual abatement expenditures is weighed with the pollution reduction achieved by the technical measure to ensure that large measures, that reduce a lot of pollution, are given sufficient weight in the procedure. In formula:

⁴⁶ The technical measures that are already implemented in the base situation are not part of the abatement cost curves. Some measures are partially implemented in the base year; then, the remaining potential is included in the abatement cost curves.

$$\text{Min } \sum_j \left\{ \left(\hat{A}(E_{ab,j} + E_{ab,0}; E_{ab}^*, A^*, \rho) - A_j - A_0 \right)^2 \cdot ER_j \right\} \quad (\text{A.3})$$

adjusting the parameters $E_{ab,0}, A_0, E_{ab}^*, A^*, \rho$, where j denote the individual technical measures, $\hat{A}_j$ and A_j represent the modelled and actual abatement expenditures and ER_j is the pollution reduction associated with measure j .

Estimation of the parameters of the iso-output curves

The value of ρ estimated for each iso-output curve can be translated into a substitution elasticity, σ , which is given by $\sigma = \frac{1}{(1-\rho)}$. By the procedure described in the previous section, for each environmental theme the substitution elasticity between pollution and abatement is calculated and included in the model.

The modelled abatement expenditures in the initial situation are given by $\hat{A}(E_{ab,0}; E_{ab}^*, A^*, \rho)$. This ‘starting value’ represents the abatement expenditures already taken in earlier years which led to the pollution level in the base year.

From duality theory (see Diewert, 1974) it is known that equilibrium prices can be associated with the equilibrium levels, and so the associated price for abatable pollution, and hence the price for pollution rights, can be derived from the calculated parameters:

$$p = \left(\frac{A^*}{E_{ab}^*} \right) \cdot \left\{ \left[\frac{E - E_{unab}^*}{E_{ab}^*} \right]^{\rho-1} \cdot \left[1 - \left(\frac{E - E_{unab}^*}{E_{ab}^*} \right)^{\rho} \right]^{\rho/\rho-1} \right\} \quad (\text{A.4})$$

If the estimated initial abatement expenditures are zero, then the calibrated initial price of pollution rights is zero as well. This provides a technical problem in the model, as in that case prices provide no information on the iso-output curve. Hence, if the calibrated initial abatement expenditures are zero, one (arbitrary) other point on the iso-output curve is taken to provide the model with the necessary information..

Incorporation of the abatement data in the economic model

The abatement data is incorporated in the economic model at two places:

- (i) through the specification of the Abatement producer,
- (ii) through the specification of the composite good ‘environmental services’.

The specification of the Abatement producer is discussed above. The output of the Abatement producer can be called ‘abatement goods’. For each environmental theme and each polluting sector the abatable pollution and abatement goods are combined into environmental services. These environmental services reflect the substitutability between pollution and abatement in the production and consumption processes. The substitution elasticities between both inputs are given by the iso-output curves (where they are estimated).

A problem is the benchmarking of the pollution services: in the historical data, there are no expenditures on pollution (rights), nor are the abatement expenditures explicitly reflected in the accounting matrix. The model has to be augmented to include both items.

As discussed above, the fictitious ‘virtual current price of pollution rights’ (per environmental theme) is calculated from the iso-output curves using duality theory (see above). This price is used to benchmark the pollution data in the pollution services: the total value of pollution services equals the abatement expenditures plus abatable pollution times the price of pollution rights (per unit of pollution). In order to regain the original balance between costs of production and value of output (and for consumers the original balance between income and value of consumption), polluters are awarded an fictitious additional output (income source) with a value exactly matching the calibrated current expenditures on pollution rights. One could interpret this approach as a system where the polluters own the pollution rights. In the policy simulation, the ownership of the pollution rights moves to the government.

The (virtual) current abatement expenditures as calibrated from the iso-output curves are separated from their counterparts in the accounting matrix and the Abatement producer is included as a separate row in the accounting matrix (remember that the column of the Abatement producer can also be separated as the inputs for the Abatement producer are determined by its production function). Notice that although there is only one abatement good, the marginal abatement costs can differ between polluters and between environmental themes, as the environmental services are different for each combination. Moreover, the total amount of pollution that can be reduced through technical measures is sector- and theme-specific.

If the current set-up, abatement is modelled purely as a flow. This approach is taken as the costs and effects in the abatement cost curves are determined as annual costs and effects. The methodology can easily be extended to include abatement activities as a stock decision, analogue to the way capital is captured as production factor in the production function. This distinction between the stock and flow of abatement is however not very relevant given the comparative-static nature of the model.

References

- de Boer, B. (2000a). The greenhouse effect. *Mimeo*, Statistics Netherlands, Voorburg.
- de Boer, B. (2000b). Depletion of the ozone layer. *Mimeo*, Statistics Netherlands, Voorburg.
- Dellink, R.B. and K.F. van der Woerd (1997). *Kosteneffectiviteit van milieuthema's*. IVM-R97/10, Institute for Environmental Studies, Vrije Universiteit, Amsterdam.
- Diewert, W. E. (1974). Applications of duality theory. In: M.D. Intriligator and D.A. Kendrick (Eds.), *Frontiers of quantitative economics*, North-Holland Publishing Company, Amsterdam. pp. 106-206.
- Huetting, R. P.R. Bosch and B. de Boer (1992). Methodology for the calculation of sustainable national income. *Statistics Netherlands Report M44*, SDU Publishers, The Hague.

7. Calculations of a sustainable national income: four variants

Harmen Verbruggen, Rob Dellink, Reyer Gerlagh and Marjan Hofkes

7.1 Introduction

It is well understood that national income is an inadequate indicator of social welfare. Dependent on the perspective, national income is either incomplete, misleading, or both. Many attempts have been made to improve and/or supplement this central statistic of national accounts. One of these attempts is extensively dealt with in this report, namely the correction of national income for environmental losses. To be more precise, the aim of this report is to investigate the feasibility of calculating a national income for the Netherlands that takes the environment as a welfare generating economic good into account, according to the methodology so strongly advocated by Hueting. This methodology would result in a so-called Sustainable National Income (SNI). Chapter 3 of this report gives a thorough explanation of Hueting's SNI methodology. Here, Hueting's SNI methodology is briefly summarised, but not discussed.

In operationalising this methodology, an empirical and integrated environment-economy model has to be used. This intermediate step certainly makes the operationalisation not a simple exercise. A number of choices has to be made and additional assumptions have to be formulated to make the model run and come up with credible results. Of course, these choices and additional assumptions can be questioned. For that very reason, a number of alternative calculations has been performed to gather insight into the impact of different choices and assumptions, both with respect to the order of magnitude of the corrections and from an analytical perspective. All this will be dealt with in Section 7.2. Section 7.3 presents and briefly discusses the so-called abatement cost curves per environmental theme. These curves are needed to translate the costs of meeting the sustainability standards, through model calculations, into corrections of national income. The results of the alternative SNI calculations will be presented and discussed in Sections 7.4. Some final remarks are made in Section 7.5. In the appendix to this chapter some additional exercises are presented.

It should be pointed out that this report presents still incomplete alternative calculations of a SNI. These results should therefore be interpreted with care. Still a great many improvements and refinements are needed (see also Chapters 5 and 6 and the appendix to this chapter for further discussion).

7.2 Operational choices and additional assumptions

According to Hueting, the objective to construct a SNI boils down to a correction of national income for environmental losses. With environmental losses is meant the forgone

use of the environment due to competition between the different functions the environment performs to sustain economic activities and human life. As national income is recorded in market prices, the correction for environmental losses should be in comparable terms. Hence, ideally, shadow prices have to be found on the basis of demand and supply curves for environmental functions. Then, environmental losses can be expressed in market prices and deducted from national income to arrive at a SNI.

However, two major problems are encountered. First, supply and demand functions for environmental functions have to be constructed. In principle, it is feasible to discover a supply curve, because the maintenance of environmental functions involves costs. Hence, the supply curve is made up of costs to restore and maintain environmental functions. The sustainability level corresponds with a point on this curve. Hueting denotes this curve as elimination cost curve, here referred to as the abatement cost curve⁴⁷. The construction of the abatement cost curves is further dealt with in the next section. By contrast, the construction of a complete demand curve is mostly impossible for various (theoretical) reasons. Hueting's practical solution for this theoretical dilemma is to assume that people have a preference to use vital environmental functions sustainable, since the Dutch and many other governments in the world have officially embraced the concept of sustainable development. Consequently, the officially stated pursuit of sustainable development is interpreted as sustainable use of environmental functions and approximated by sustainability standards. With this interpretation, it is assumed that individual preferences for the sustainable use of the environment are absolute and independent of costs. That is why Hueting's correction of national income is denoted as a *sustainable* national income. Other assumptions about individual and social environmental preferences would result in different green national incomes, not in a SNI. Hueting's methodology distinguishes itself from other approaches in that it pursues a correction of national income on the basis of assumed preferences for sustainability, i.e. the sustainability standards, instead of stated preferences for the conservation of the environment through, for instance, the use of a contingent valuation method, or revealed preferences for environmental quality through, for instance, hedonic pricing and production factor methods⁴⁸ (Hueting, 1992). According to Hueting and Reijnders (1998), these standards guarantee the indefinite availability of environmental functions and are in this sense objective (cf. Den Butter and Verbruggen, 1994). Then, it is indeed possible to come up with an imputed value for an environmental loss, i.e. the costs to meet the sustainability standards. The costs comprise technical measures as well as a shift to less burdening economic activities. All these costs are to be incurred by industry, government and households, and are considered to be intermediate expenditures and should therefore not count as income, or alternatively, should be deducted from national income.

⁴⁷ To be precise, the term 'elimination cost curve' denotes the total costs to restore and maintain environmental functions, including both technical and volume measures, while the term 'abatement cost curve' denotes only the costs related to technical measures. Since the costs of production and consumption changes are endogenous to the economic model, the abatement cost curves are input to the model.

⁴⁸ Hueting argues that environmental preferences can only partially be revealed by expenditures to compensate or restore the loss of functions, whereas methods such as contingent valuation cannot yield reliable data (see Chapters 2 and 3).

Then we run into the second difficulty. The environmental losses estimated in this way cannot simply be deducted from national income. For that, the magnitudes of these losses are too substantial. An entirely other economy and hence SNI would have resulted if these environmental losses would have been prevented or restored. We then envisage a hypothetical sustainable economy with a hypothetical SNI. This can only be approached through model calculations. For that purpose, an applied general equilibrium (AGE) model for the Dutch economy has been constructed, inclusive of environmental variables (see Chapters 5 and 6).

However, the operationalisation of this approach, i.e. the conversion in a model, is definitely not straightforward. This conversion has two levels. The first level is of a more general nature and translates methodological assumptions into general model characteristics. This general conversion will be discussed in this section, because various possibilities arise and operational choices have to be made. At the second level, the general model characteristics have to be translated into technical model specifications, and additional specifications have to be decided upon.

The following methodological assumptions of Hueting's approach need further explanation:

- an instantaneous realisation of the sustainability standards;
- this instantaneous realisation, however, involves no transition cost;
- the sustainability standards are applied all over the world in order to prevent a reallocation of environmental pressure among countries. This, of course, affects international trade relations;
- the sustainability standards are to be realised at the present state of technological knowledge;
- in addition to technical measures to meet the sustainability standards, reductions in the level of particular economic activities in favour of environment-extensive activities, so-called volume measures, are envisaged;
- national income should also be corrected for double counting;
- there ought to be no effects on the level of employment, at least not negative;
- the SNI should preferably be measured in new, i.e. sustainable, relative prices;
- consumption patterns will change;
- the role of the government is not supposed to change in a sustainable economy.

Instantaneous realisation

Correcting national income for environmental losses is a strictly static approach. This is not undone by using an AGE model to simulate a sustainable economy that matches with a SNI, because this sustainable economy is brought about instantaneously. Hence, the SNI is a hypothetical construct that results from a comparative static model exercise.

No transition cost

The SNI calculations should not be burdened with other cost than environment-related loss of functions. In addition to technical and volume measures to meet the sustainability standards, other costs are very well thinkable. To arrive at a sustainable economy, a drastic restructuring and reallocation of economic activities has to take place. And this inevitably involves a premature write-off of capital goods, and transition or adaptation costs.

As these non-environment-related costs should not enter a SNI, it has to be assumed that the (instantaneous) change to a sustainable economy has officially been announced a period in advance, long enough that economic agents are able to integrate this transition in the planning of their investment decisions. Transition costs are then minimised and can be neglected. By this way of reasoning, it is implicitly assumed that the early announcement enhances the substitution possibilities in the economy. This, in turn, should be expressed by applying medium to long-term substitution elasticities in the model calculations, instead of short-term elasticities, which are common in static modelling. However, long-term substitution elasticities for the sectoral breakdown as well as those pertaining to substitutions among economic and environmental variables are not readily available for the Dutch economy. As it presently stands, elasticities of a rather short to medium-term nature are applied.

World-wide sustainability and international trade

To calculate a SNI for a particular country, assumptions have to be made with respect to policies in the rest of the world. This is especially relevant for a small and open economy such as the Netherlands, as a unilateral sustainability policy could cause an international reallocation of relatively environment-intensive production activities. To do away with that unwanted effect, it has to be assumed that similar sustainability standards are applied all over the world, taking due account of local differences in environmental conditions. However, it is not feasible to estimate the resulting cost and changes in relative prices in other countries. So, additional assumptions have to be formulated with respect to relative price changes on the world market and the impact on import and export flows to and from the Netherlands.

Two alternative assumptions come to the fore. But before these alternatives are explained, it should be realised that the SNI model calculations have to stick to the standard macro-economic balance equations. Thus, public and private savings surplus (or deficit) equals trade balance surplus (or deficit). The savings surplus is assumed to constitute a constant share of national income and is set equal to that share in the base situation. This, in turn, determines the relative price level of the Netherlands *vis-à-vis* the rest of the world and the trade balance.

In the first alternative, it is assumed that relative prices on the world market do not change. In the event that the domestic system of relative prices also stays the same, Dutch exports will change in proportion to the level of domestic production per sector. Thus, in the first instance, world market outlet for Dutch exports moves along with sectoral production levels. However, if domestic relative prices do change in response to sustainability standards, exports of goods and services which become more expensive relative to the world market will decrease more than proportionally and *vice versa*. As regards imports, the standard procedure in AGE modelling is followed, whereby imports are proportionally linked to the level of domestic demand. If an import product becomes cheaper relative to a domestic substitute, imports will decrease less than proportionally and *vice versa*. In this alternative, it is assumed that sustainability policies all over the world do not influence relative prices on the world market, but are specified through shrinking export and import markets. In addition, as relative prices in the Netherlands do change, it becomes indeed feasible for the Netherlands to partly realise its sustainability standards by importing relatively environment-intensive products, of which the cost of

production increase in the Netherlands, and exporting relatively environment-extensive products, of which the cost of production will decrease in the Netherlands. This is only partly possible, as the sizes of export and import markets move along with domestic sectoral production and demand levels.

Second, it can be assumed that per sector the share of imports in total domestic demand, and the share of export in total domestic production, remain constant compared to the base situation. In economic terms this boils down to the assumption that in reaction to world-wide sustainability policies, all production processes in foreign sectors go through a similar process of adjustment as in the Netherlands. Or again in other words, it is then implicitly assumed that changes in relative prices in other countries and in the Netherlands are equal.

The SNI will be calculated for both foreign-trade assumptions. It will be clear that the latter assumption of constant import and export shares comes closest to Hueting's methodology. For the sake of clarity, no attention is paid to environmental pressure emanating from transport of internationally traded goods.

Present state of technology

In estimating the cost of technical measures to meet the sustainability standards, only known technological options can be envisaged. Known technologies comprise options that are already on the market as well as technological options that are indeed technically feasible, but still too expensive or not yet fully applicable and standardised, or both, to apply under present market conditions. These remote options will certainly be considered if more stringent environmental standards are enforced. By broadening the known technological options in this way, some justice is done to the early announcement assumption. For if this really would have been the case, the development of clean technology would have been accelerated. Hence, the cost of technical measures is based on the present state of technological knowledge, and refers to the 1990s.

Volume measures

In Hueting's methodology, in addition to technical measures to meet the sustainability standards, also a shift from environment-intensive to environment-extensive production activities and consumptive expenditures is envisaged. Instead of going on holiday by air to far remote and exotic destinations, Dutch consumers in a sustainable economy rather prefer a biking holiday or go to France by train. In the SNI model calculations, these so-called volume measures are included through inter- and intra-sectoral substitution mechanisms. The inter-sectoral substitution takes place through the well-known mechanism of price adjustment. Environmentally intensive goods show an increase in their price if sustainability standards are imposed on the economy, and their consumption and use by other sectors will decrease. On the other hand, goods that are produced by a relatively environmentally friendly process become cheaper, and consequently demand and use will increase. The intra-sectoral substitution is more difficult to grasp. Within the aggregation level of one sector, producers can switch towards other processes that are less polluting. Also, producers can make another good, though this will not show up in the model if the initial and new goods fall within the same category of aggregate goods. No matter which adjustment occurs, the shift in production goes at the cost of the value of out-

put. Meeting the sustainability standards imposes an additional constraint that decreases the opportunities of producers to make profit. If the level of economic activities is measured in terms of value added, sustainability implies a decrease in activity. However, expressed in terms of labour, the activity level will not necessarily have to decrease.

Most importantly, the model endogenously weighs against each other the cost of technical measures, derived from the abatement cost curve, and the cost of reducing sectoral production, approached by loss of value added. It is in this trade-off very well possible that volume measures are taken before all technical possibilities to reduce emissions are exhausted, namely as soon as the marginal cost of technical measures exceed the marginal cost of volume measures.

Double counting

In addition to correcting national income for the cost of technical and volume measures to meet the sustainability standards, national income should also be corrected for so-called double counting. Double counting refers to the expenditure on compensatory, restoratory and preventive measures to re-establish or maintain environmental functions, sometimes denoted as defensive measures or asymmetric entering. According to Hueting and many others, these expenditures wrongly enter national income as value added: loss of environmental functions is not written off in the year of origin, whereas restoration is entered afterwards. This line of reasoning can indeed be maintained in case defensive measures are taken in the sphere of consumption, not entering a production process as intermediate input. In our SNI calculations, the cost to reduce dehydration and the clean up of contaminated soils are double counting cases in point.

However, it is unfeasible to revise the national income accounts for these specific double countings in a once-only correction. Another procedure is therefore followed that is more in line with the overall approach of a comparative static equilibrium analysis. It is assumed that the estimated total cost of soil clean up amounting to 408 billion guilders (see Chapter 6) is borne by the government. It is assumed that the soil clean up activities are spread over a 20-years period. So, each year 5% of the total amount is contracted out for soil clean up, which will then be entered in the SNI calculations as a yearly deduction. The reduction cost of dehydration is also assumed to be financed out of, and likewise deducted from, the government budget and amounts to 550 million guilders on a yearly basis (see Chapter 6).

Labour market and capital market

The already mentioned understanding that in the calculation of a SNI only environmental losses have to be considered as relevant corrections and, hence, should not become infected too much by related side-problems, also means the neglect of influences from the labour market on SNI, be it positive or negative. According to Hueting, a sustainable economy will certainly not worsen the employment situation, simply because environmental care in satisfying a particular need will require more labour. Consequently, the labour market can be very simply modelled, whereby the labour force is exogenously given and the labour market is cleared through an adjusting wage rate. In the present calculations, the supply of labour is equated with the level of employment in 1990 and wages are endogenously adjusted such that demand for labour equals supply. It will be

clear that SNI will result in downward adjusted wage rates and concomitant productivity levels. The alternative would be labour time shortening at higher productivity levels. This, however, is not in line with Hueting's SNI methodology that envisages a different, sustainable path of economic development.

The arguments that led to the assumptions with respect to the modelling of the labour market also apply to the capital market, which is very simply modelled: there is a fixed rate of return on capital and the capital stock immediately adjusts. This fixed rate of capital return equals 5% in the present calculations, which approaches the average long-term interest rate in 1990. At the demand side of the capital market, both replacement and net investments are assumed to constitute a fixed share of the capital stock. At the supply side, public and private savings make up a constant share of total income. As already indicated, an equilibrium on the capital market is obtained by accommodating a savings surplus or deficit through a compensating surplus or deficit on the balance-of-payments.

Old and new prices

It has already been indicated that the correction of national income has to be expressed in directly comparable (shadow) market prices. This is conceivable if as a first approximation the costs of measures to meet the sustainability standards are directly deducted from national income. If, however, SNI calculations are made with the help of an AGE model relative prices change, i.e. prices of environment-intensive products will generally increase compared to other products. The question now is in which set of prices SNI could best be expressed, such that a comparison with the original national income figure can be ascribed a meaningful interpretation. The two best-known income measures are named after Laspeyres and Paasche, using initial prices and new prices to aggregate goods, respectively.

In the first alternative, the set of relative prices of the base situation is used to weigh the volumes of the SNI. Intuitively, as the same price sets are used, this alternative would provide an adequate standard of comparison. However, at least two objections can be raised. First, consistency between national income and national product is lost, because the volume shares of a SNI will differ from the original national income. Second, a SNI results in a new set of equilibrium prices and it remains strange to use the old price set. A major objection against the use of a new set of relative prices is the loss of a comparative standard. At least, the new equilibrium prices have to be scaled at the old price level to make this second alternative meaningful. Hence, two price sets will be used to calculate SNI variants.

Private consumption

Additional assumptions have to be made as to the economic behaviour of consumers in calculating a SNI. More precisely, how would consumers have reacted in case of (substantially) lower income levels of an SNI path of economic development. In Hueting's methodology, it is assumed that a twofold adjustment of consumption patterns have to be envisaged. First, real spendable income will be lower as production factors are employed to keep up environmental functions. In the model calculations, the effects of lower income levels is approached by the use of income elasticities which specify a demand for

necessary products (like agricultural products and energy and water supply) that decreases less than proportional and a demand for luxuries (*e.g.* commercial services and metal products) that decreases more than proportional with the stage of economic development. In this way, consumption is thought of as consisting of necessary goods for subsistence and luxury goods. If income falls in the model calculations, the consumption of necessary goods will remain relatively stable, which is compensated by a more than proportional decrease in the consumption of luxury goods. Second, consumption patterns will become more sustainable as a result of relative price changes. Thus, in addition to income substitution effects, the model includes the concept of price elasticities. In general, the consumption of environment-intensive goods and services will decrease, whereas environment-extensive goods and services will show an increase in relative consumption levels. It is assumed that private consumers have more substitution possibilities than the public consumer (the government), whose demand is determined by public services that have to be supplied.

Government

In line with the neglect of transition cost and labour market effects, the government is not supposed to have a disturbing impact on the calculation of a SNI. Thus, there is no change in fiscal and income distributional policies. This neutral role of the government implies that environmental functions are owned by the government and that the use of these functions should be paid for. Pollution to the environment is then considered as a public endowment, and as this pollution is constrained by sustainability standards, the value that is imputed in the context of the modelling exercise entirely accrues to the government. Put differently, the government sells pollution rights of which the price is endogenously determined in the model. To guarantee budget neutrality, the revenues from the sale of the pollution rights have to be returned to the producers and consumers by a linearly homogeneous reduction of taxes. In case revenues from pollution rights exceed the government budget, the surplus will be redistributed to private households through a lump sum.

Technical model specification

In addition to the operational choices, decisions had to be reached on a number of technical model specifications. These are dealt with in more detail in the technical model description (Chapter 5). Specifications related to abatement of pollution are worth briefly mentioning here. In the model calculations, there is one abatement sector in operation that delivers pollution reductions to all other sectors. As yet, there is no diversification among sectors in expenditure effect of abatement investment. And, for the time being, pollution is linked to the volumes of production and consumption.

Four variants

Because no decisive preference can be given to one of the two assumption on foreign trade as well as on the use of old or equilibrium prices, 4 SNI variants will be calculated. Of the following variants, variant 2b is most in line with Hueting's methodology.

Variant 1a: constant relative prices on the world market and SNI expressed in relative prices of the base situation (old prices)

Variant 1b: constant relative prices on the world market as in variant 1a, but SNI expressed in new equilibrium prices

Variant 2a: constant shares of imports and exports and SNI expressed in relative prices of the base situation (old prices)

Variant 2b: constant shares of exports and imports as in variant 2a, but SNI expressed in new equilibrium prices

7.3 Abatement cost curves for various environmental themes

7.3.1 Introduction

According to Hueting's methodology, the correction of the traditional national income figures consists of the costs that have to be incurred to meet the sustainability standards. However, costs of pollution reduction consist of costs of technical measures and costs of volume measures (see above). The costs of technical measures are investment costs (re-calculated as annual costs) and operation & maintenance costs of changes in the production process. In this section only the costs of technical measures are treated. These costs are called the costs of reduction of 'abatable' pollution. Costs of reduction of 'unabatable' pollution, i.e. of volume measures, are not dealt with here⁴⁹.

A rational polluter, if faced with the necessity to reduce pollution, will first take the cheapest measures and then, if necessary, turn to the more costly measures. The marginal, and thus also the total cost curve will therefore be monotonously non-decreasing. As a rule, not all pollution can be prevented by technical measures. Therefore, the cost curve approaches a vertical asymptote, where marginal (and total) costs approach infinity.

A marginal cost curve of reduction will then take the shape of a step function where, from the origin, each time the next cheapest measure is introduced until the last, most expensive measure is reached and no further reduction is possible by technical means. The integral of the marginal cost function yields total reduction costs as a function of cumulative pollution reduction. The total cost functions are fitted to a CES function, as schematically pictured in Figure 7.1.

The environmental themes that are included in the SNI calculations are the following: the enhanced greenhouse effect, depletion of the ozone layer, acidification, eutrophication, smog (tropospheric ozone) formation, dispersion of fine particles to air, dispersion of toxic substances to water, dehydration and soil contamination. For a detailed description of the abatement cost curves for these environmental themes is referred to Chapter 6. This section continues with general methodological issues.

⁴⁹ Please note that the model set-up ensures that 'abatable' pollution will be reduced by means of changes in production and/or consumption patterns if that is cheaper than investing in the technical measure. On the other hand, unabatable pollution can only be reduced through production and/or consumption changes, not by technical measures.

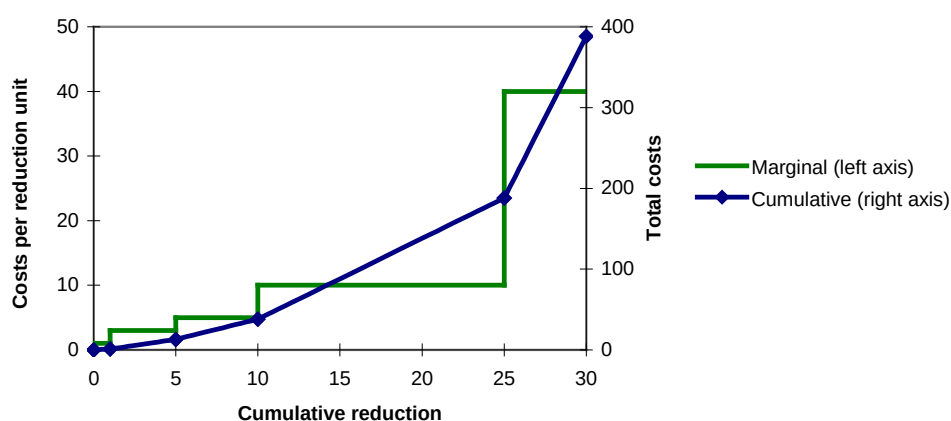


Figure 7.1 Marginal and cumulative costs of pollution reduction.

7.3.2 Methodology

The methodology for calculating costs of technical measures and resulting reduction of pollution is in line with the methodology that is used by the Netherlands Bureau of Statistics (CBS) and the National Institute for Public Health and the Environment (RIVM), and described in detail in VROM (1994).

The costs are calculated as seen by the *target groups*. This implies that they include taxes (VAT, for households) and excises (on fuels). The excises play a role in particular, when a measure leads to fuel saving that can be deducted from the reduction costs.

The total environmental costs consist of capital costs (including investment and interest costs), operational costs (including additional labour and energy costs) and operational revenues (including *e.g.* sale of new by-products). Investments are converted to annual depreciation and interest costs using the annuity method. The discount rate is calibrated to the real capital market interest rate, which is defined as the real interest on government bonds. This interest rate has in recent years fluctuated between 4% and 5%. For practical reasons, a stable discount rate of 5% is used in calculations by RIVM.

Near the origin of the cost curve, the calculated costs of reduction may be negative, meaning that reduction can be achieved with net savings. This is at odds with theory and implies that certain assumptions are violated, be it assumptions on rational behaviour of the target groups, on equilibrium in the economy, on used prices and discount rates, or whatever. As a practical (ad-hoc) solution, the negative net costs of abatement measures are set equal to zero, which is equivalent to assuming them to be equal to the hidden cost. The model thus calculates zero costs for the emission reductions associated with these measures.

The cost curves are superimposed on the 1990 situation with respect to levels of production and consumption of the various sectors and with respect to the technological state of the art (plus costs and effects) of pollution reduction.

Reduction measures may interact in a number of ways. The possible ways of interactions are exclusiveness, sequentiality, interaction between themes and substances, and interaction between measures. Chapter 6, Section 6.5.2, gives a detailed description of the ways these interactions have been dealt with.

7.4 Results

7.4.1 Mechanisms

Table 7.1 presents the sustainability standards for the various environmental themes which function in combination with the corresponding abatement cost curves as a reference for the alternative SNI calculations.

Table 7.1 Sustainability standards for the Netherlands, 1990.

Environmental theme	Units	Base 1990	Sustainability standard	Required reduction (%)	
Greenhouse effect	Billion kg. CO ₂ equivalents	251.0	53.2	197.7	(78.8%)
Ozone depletion	Million kg. CFC11 equivalents	10.4	0.5	9.8	(94.2%)
Acidification	Billion acid equivalents	38.4	10.0	28.4	(74.0%)
Eutrophication	Million P-equivalents	312.0	128.0	184.0	(59.1%)
Smog formation	Million kilograms	440.0	240.0	200.0	(45.5%)
Fine particles	Million kilograms	44.0	20.0	24.0	(54.6%)
Dispers. to water	Billion AETP equivalents	194.3	73.5	120.9	(62.2%)

To gather an understanding of the mechanisms at work in the transition from the ordinary national income to a SNI, Figures 7.2A – 7.4B present diagrams for the break up of national income per expenditure category, per sector and per production factor, respectively. The A-diagrams show changes on the way to a SNI in steps of one-tenth of compliance with the sustainability standards, and only refer to variant 1b. The B-diagrams compare the distribution over different expenditure categories for SNI variants 1b and 2b. To simplify the comparison, only the results in new equilibrium prices are shown here. The complete results for all SNI variants are presented in the next section.

The most noticeable feature that can be learned from the A-diagrams is that the SNI substantially drops only after about 70% of the sustainability standards are met. In other words, and not unexpectedly, the last 30% of the sustainability standards involves the highest cost and causes the major part of reduction in SNI. The last 10% of the sustainability standards is responsible for about one-third of total costs. At this intensity of environmental policy, pollution can only be reduced at very high economic costs.

The B-diagrams where SNI variants 1b and 2b can be compared with national income of the base situation, clearly show a substantially lower SNI value for variant 2b than for variant 1b. Apparently, as the specification of imports and exports as constant shares in total domestic demand and production leaves no room for an environmentally-extensive specialisation of the Dutch economy, the restructuring of the economy has to be more drastic and, hence, SNI is substantially lower.

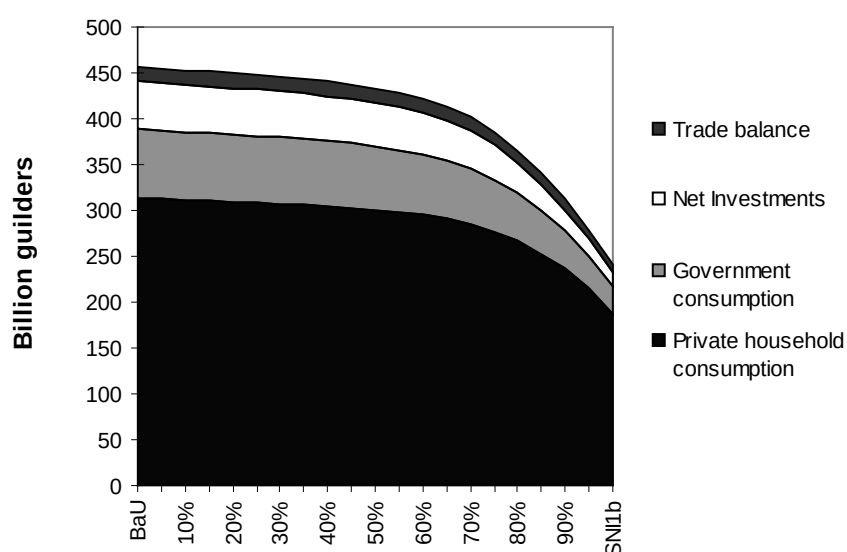


Figure 7.2A Break-up of National Income per expenditure category: from base to SNI (variant 1b).

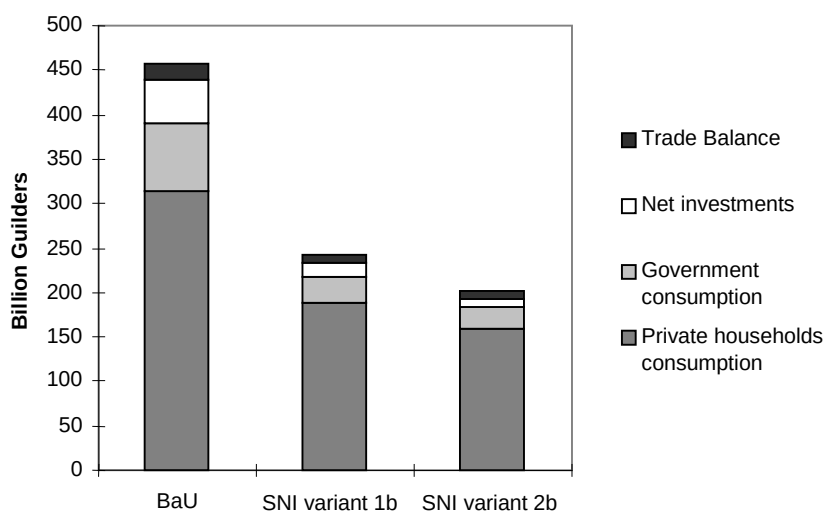


Figure 7.2B Break-up of National Income per expenditure category: distribution over categories (variants 1b and 2b).

Of the distinguished expenditure categories presented in Figure 7.2A, net investments, i.e. investments in addition to replacement investments, decrease most sharply. In the base situation, net investments constitute 11.2% of national income, whereas in SNI variant 1b their contribution is reduced to 5.9%. This can be explained by a reallocation of production from relatively environment-intensive sectors, which are on average also relatively capital-intensive, to cleaner and more labour-intensive sectors, such as services. The lower net investment share in SNI implies that the upward pressure on capital demand stemming from increased abatement activities is more than offset by a fall in

capital demand due to this reallocation. This results in a decreasing capital stock. The positive trade balance decreases in proportion, which is due to the general assumption that the trade balance equals a constant share of the savings surplus in national income. The consumption of the private households is most severely affected in a SNI in absolute terms, but the share of private consumption in SNI variant 1b increases from 69% to 78%. This is the combined effect of a proportional decrease in spendable income levels and the increase in relative prices of the goods consumed by the private household. In contrast, government consumption as share of SNI decreases. This can only mean that the so-called Non-commercial services (including governmental services), of which the government is by far the largest client, experience a relative price decrease, as the substitution elasticities for these services are close to zero. Relevant examples include infrastructural projects (such as roads), education and health care. In addition, account has also to be taken of the fact that part of the government expenditure is spent on the reduction of dehydration and soil contamination. These double countings are not yet corrected for in this figure.

Figure 7.2B facilitates a comparison of the levels of the SNI variants 1b and 2b with national income in the base situation. SNI variants 1b and 2b are 47% and 56% lower than the original national income figure, respectively. Net investments in SNI variant 2b further decrease to 5.4% of SNI, and private consumption now has an even larger share in national income.

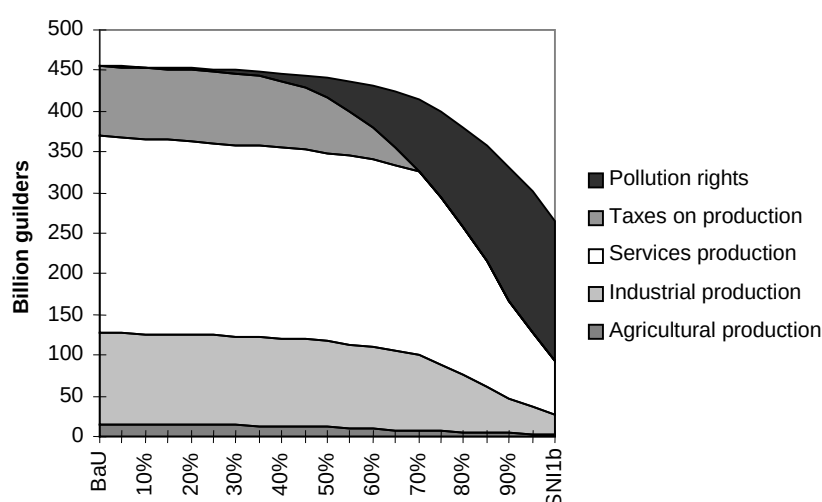


Figure 7.3A Break-up of National Product per sector: from base to SNI (variant 1b).

The changes in the volumes of total tax income as well as value added in agriculture, manufacturing and services are presented in Figure 7.3A. It has to be recalled that expenditures on so-called defensive measures are not counted as part of SNI (see also Section 7.2 where this issue is dealt with in more detail). This implies that the sum of the components as given in Figure 7.3A exceeds the SNI, the difference being the amount of double counting.

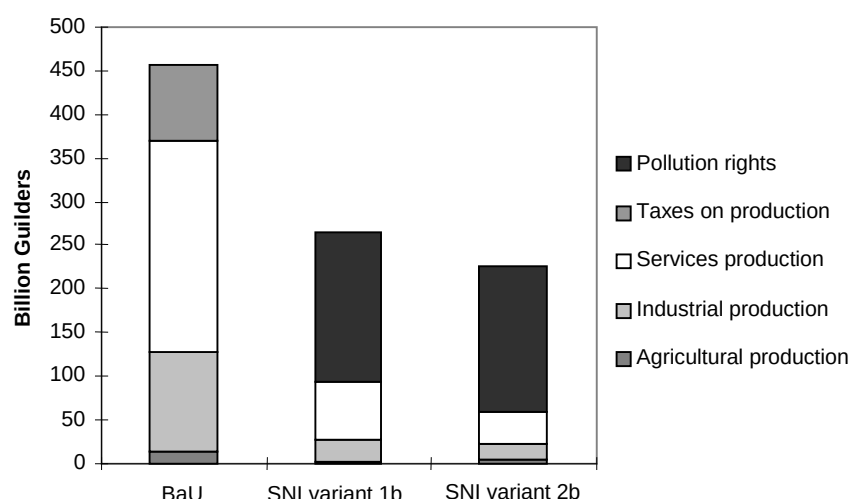


Figure 7.3B Breakup of National Product per sector: distribution over categories (variants 1b and 2b).

From Figure 7.3A it can be seen that agricultural production is hit hardest. Its share⁵⁰ drops from 3.2% in the base situation to 0.9% in SNI variant 1b. Part of this decline is due to increased imports of agricultural products, which is facilitated in this variant. Apparently, in this SNI variant there is hardly any room for agricultural production. The shares of manufacturing and services also decline in SNI, services more than manufacturing. This is particularly due to the more necessary character of manufacturing production, expressed in lower income elasticities, compared to services. Put differently, the lower share of services is in line with the lower income level of the SNI. Moreover, in the SNI variants at new equilibrium prices, no compensation takes place in the form of higher prices, as services are generally relatively clean.

The most striking result of the SNI variants in new equilibrium prices is the more than complete greening of the tax system. The government revenues of the sale of pollution rights appear to become higher than government expenditure when about 70% of the sustainability standards are met. At that point, revenues from the sale of pollution rights replace all existing taxes. The excess revenues that arise in case of full compliance to the sustainability standards are redistributed to private households as lump-sum payments. In SNI variant 1b, more than 64% of the total SNI value is made up by the value of these pollution rights. There are two main mechanisms at work here that govern the greening of the tax system. First, the total value of national income decreases significantly. This implies that the total size of the government sector also decreases. Hence, less taxes can be collected. In other words, there are less existing tax revenues to be replaced by the revenues from the sale of the pollution rights. Second, since the required reductions in pollution levels are very high, the demand for pollution rights exceeds the supply several times. Like any economic (scarce) good, this puts an upward pressure on the price of the pollution rights. Consequently, high prices for the pollution rights also mean high reve-

⁵⁰ In order to have shares summing to 100%, shares presented are calculated relative to the sum of the components without correcting for double counting.

nues from the sale of these rights by the government. This mechanism is explored in more detail in the discussion on the environmental results below.

Figure 7.3B shows that the different way of treating imports and exports has a clear impact on the structure of production. Due to the fixed trade shares in SNI variant 2b, the possibilities for changing the structure of production are much smaller. Thus, agriculture can keep up a share in SNI variant 2b of 1.6% as opposed 0.9% in variant 1b, whereas manufacturing and services come out at substantially lower shares. The latter also has to do with the much higher prices for pollution rights in SNI variant 2b than in variant 1b, due to the limited reallocation possibilities of production in variant 2b. Consequently, the share of pollution rights is about 64% and 73% in SNI variants 1b and 2b, respectively.

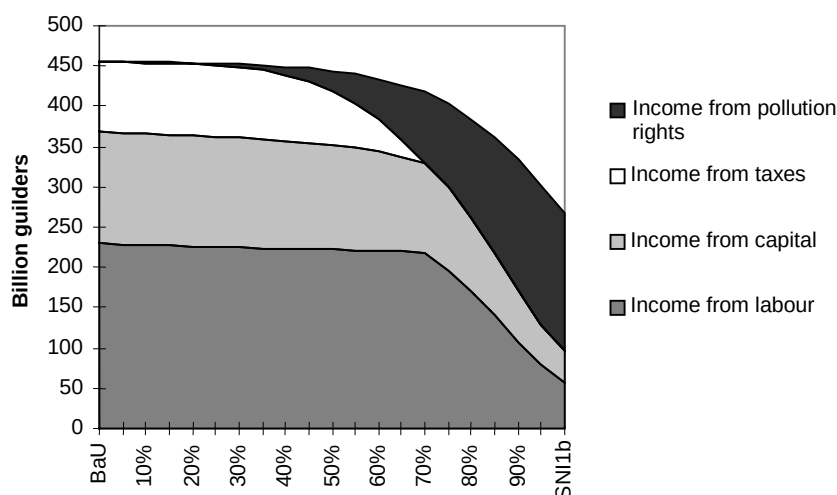


Figure 7.4A Breakup of National Income per production factor: from base to SNI (variant 1b).

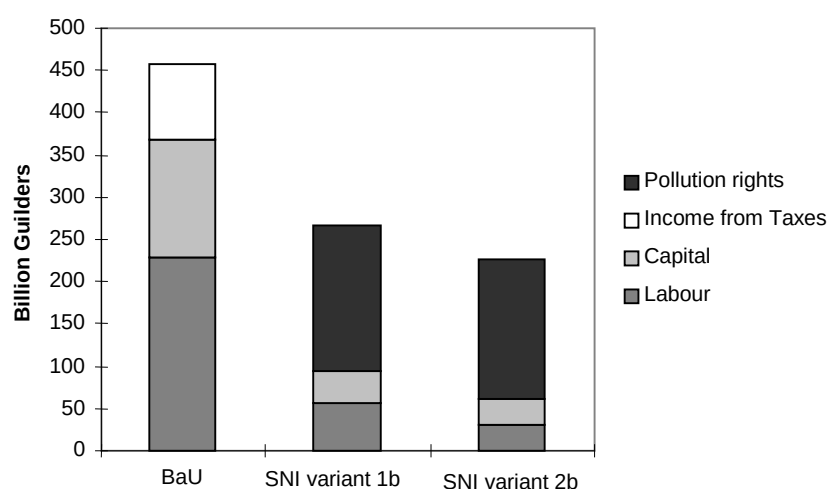


Figure 7.4B Breakup of National Income per production factor: distribution over categories (variants 1b and 2b).

Figure 7.4A gives the development of the various income categories in SNI variant 1b. Income from the production factors capital and labour follow the general trend: a substantial reduction is observed after about 70% of the required pollution reduction is achieved. In the SNI equilibrium of variant 1b, the capital income share accounts for about 14% and the labour income share accounts for about 21%. As indicated before, existing taxes are more than completely replaced by the revenues from pollution rights after about 70% of the sustainability standards are realised. Finally, it can be seen from Figure 7.4B that the share of labour income in SNI variant 2b drops further. Both income sources now account for about 13% each.

To sum up the preliminary results of this section, two findings stand out. First, SNI calculations are very sensitive to the way international trade is specified. Second, the expression in new equilibrium prices has a major impact on the composition of SNI, per expenditure category, the sectoral break down, as well as per source of income. More insight will be gained by discussing the results of the various SNI calculations in old and new prices in detail in the next section.

7.4.2 Macro-economic results

Tables 7.2 to 7.5 present the macro-economic results of the four SNI variants. In comparing these tables it becomes clear that SNI variants 1a and 1b with constant relative world market prices are about 47–49% lower than national income in the base situation, whereas SNI variants 2a and 2b with constant shares of imports and exports are about 56–58% lower. The extent to which SNI drops is thus significantly determined by the specification of international trade. The use of alternative sets of prices is of minor importance for the macro-economic results. This is not surprising if the scaling of new equilibrium prices on the level of old prices, as discussed above, is taken into account.

By contrast, the use of old or new equilibrium prices has a major impact on the composition of SNI. Hence, the composition of the SNI variants 1a and 2a in old prices changes roughly proportionally. SNI variants 1b and 2b in new equilibrium prices show drastic compositional changes. This is particularly due to the imputed prices for pollution rights. In the base situation at old prices these rights have a negligible value. At new equilibrium prices, however, the value of pollution rights outweighs all other SNI categories. It is also noteworthy that if an old set of prices is used to weigh the different components of SNI, national income and national product diverge.

Table 7.2 Macro-economic results in billions of guilders: SNI variant 1a.

	Base	SNI	Change (%)
National Income	456.71	233.87	-49%
Private households consumption	313.96	164.18	-48%
Government consumption	75.07	37.92	-49%
Net investments	51.45	20.34	-60%
Trade Balance	16.22	11.44	-29%
Exports	229.36	81.32	-65%
Imports	-213.14	-69.88	-67%
National Product	456.71	237.34	-48%
Agricultural production	14.76	2.94	-80%
Industrial production	112.65	59.19	-47%
Services production	241.60	179.41	-26%
Taxes on production	87.66	0.00	-100%
Pollution rights	0.00	7.52	
Double counting	0.00	-20.95	

Note: constant world market prices; variables based on old prices

Table 7.3 Macro-economic results in billions of guilders: SNI variant 2a.

	Base	SNI	Change (%)
National Income	456.71	193.65	-58%
Private households consumption	313.96	139.11	-56%
Government consumption	75.07	31.76	-58%
Net investments	51.45	16.15	-69%
Trade Balance	16.22	6.62	-59%
Exports	229.36	69.27	-70%
Imports	-213.14	-62.65	-71%
National Product	456.71	186.01	-59%
Agricultural production	14.76	4.57	-69%
Industrial production	112.65	50.39	-55%
Services production	241.60	136.25	-44%
Taxes on production	87.66	0.00	-100%
Pollution rights	0.00	7.36	
Double counting	0.00	-20.95	

Note: constant trade shares; variables based on old prices

Table 7.4 Macro-economic results in billions of guilders: SNI variant 1b.

	Base	SNI	Change (%)
National Income	456.69	241.37	-47%
Private households consumption	313.95	187.88	-40%
Government consumption	75.07	30.24	-60%
Net investments	51.45	14.20	-72%
Trade Balance	16.22	9.04	-44%
Exports	229.36	64.24	-72%
Imports	-213.13	-55.20	-74%
National Product	456.69	241.37	-47%
Agricultural production	14.76	2.37	-84%
Industrial production	112.65	25.61	-77%
Services production	241.59	66.15	-73%
Taxes on production	87.66	0.00	-100%
Pollution rights	0.00	170.74	
Double counting	0.00	-24.79	

Note: constant world market prices; new equilibrium prices

Table 7.5 Macro-economic results in billions of guilders: SNI variant 2b.

	Base	SNI	Change (%)
National Income	456.69	201.43	-56%
Private households consumption	313.95	159.39	-49%
Government consumption	75.07	23.48	-69%
Net investments	51.45	10.90	-79%
Trade Balance	16.22	7.66	-53%
Exports	229.36	80.13	-65%
Imports	-213.13	-72.47	-66%
National Product	456.69	201.43	-56%
Agricultural production	14.76	3.56	-76%
Industrial production	112.65	19.47	-83%
Services production	241.59	37.22	-85%
Taxes on production	87.66	0.00	-100%
Pollution rights	0.00	165.35	
Double counting	0.00	-24.18	

Note: constant trade shares; new equilibrium prices

7.4.3 Sectoral results

Figure 7.5 shows the changes in the structure of production. These changes are expressed as relative changes in the volume of output per sector. So prices do not enter these figures and there is no distinction between variants a and b (old and new prices). Therefore, variants 1a and 1b and variants 2a and 2b are presented in one figure as variant 1 and variant 2, respectively. From Figure 7.5 it can be seen that the changes in the structure of production are much more pronounced in SNI variant 1 as compared to SNI variant 2. In SNI variant 1 some sectors shrink considerably in the Netherlands. These include a range of environment-intensive sectors like the Chemical industry, Rubber- and plastics industry and Basic metal industry. The small Other goods and services sector decreases more than proportionally (in all variants). Another small sector, Transport by water is also severely hurt in variant 1. It is remarkable that the Printing industry is reduced by a very small percentage, while Transport services are even increasing in variant 1. These sectors clearly benefit most from trade.

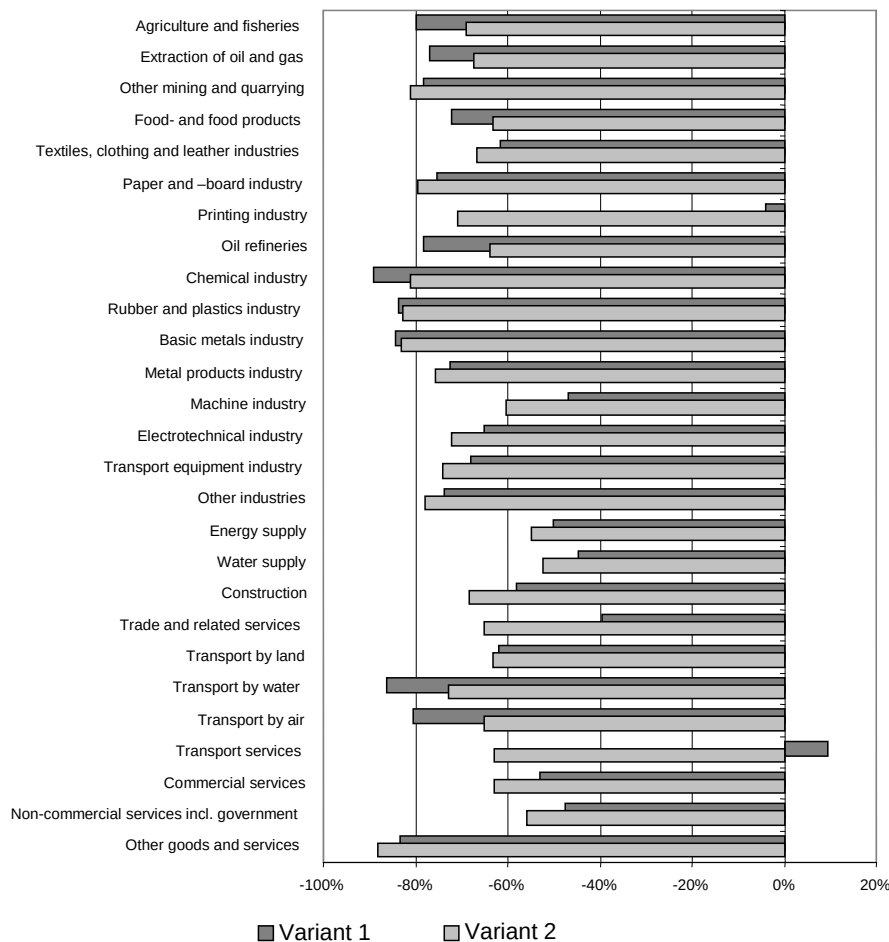


Figure 7.5 Changes in the structure of production in SNI variants, in percentages.

In SNI variant 2, the impact of the sustainability standards range for all sectors between a 50% and 90% reduction. Production of Other goods and services decreases most by 88%⁵¹. The Energy supply, Water Supply and Non-commercial services are relatively well off with a decrease of 55%, 52% and 56%, respectively. Some sectors are among the most severely hit in all SNI variants, such as Chemical industry, Rubber- and plastics industry, Basic metal industry and Other goods and services, whereas there are no sectors with a systematically small impact. In variant 2 there are no possibilities to replace domestically produced goods by imports of the same goods. Domestic demand for the domestically produced goods is therefore relatively less affected than in variant 1. On the other hand, the (potential) positive impact of increased exports on domestic production is also absent. Given that substitution among the different goods by the consumers is limited, this means that the sectoral differentiation of production losses is less prominent than when these trade effects are included in the analysis.

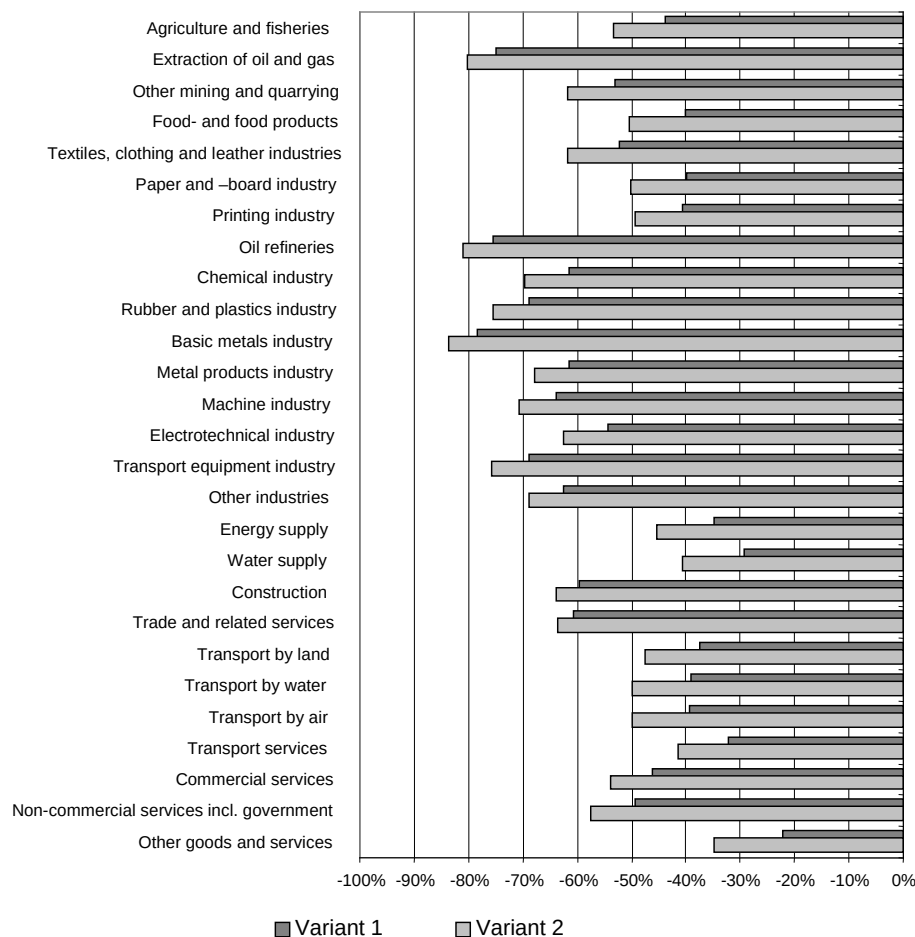


Figure 7.6 Changes in the composition of consumption in SNI variants, in percentages.

⁵¹ This is not as surprising as it may seem at first glance. This sector, which comprises many different small firms, is modelled with zero substitution elasticities in the production function. This indicates that the sector's flexibility to shift towards more environmentally friendly production techniques is assumed to be absent.

The changes in consumption patterns as depicted in Figure 7.6 are less substantial than the changes in production structure, especially for SNI variant 1. Furthermore, the differences between the SNI variants are not that large, given the larger decrease in national income in variant 2. The specification of international trade has little impact on the consumption pattern, but especially affects the overall decrease in consumption levels.

Another difference between production and consumption effects is that the increase in production levels that some sectors observe is not reflected in the consumption levels: in all variants the consumption levels of all goods and services decrease. The conclusion that can be drawn from this is that the small production decrease of the Printing industry and the production increase of the Transport services sector in variant 1 are much more related to export effects than to consumption effects.

There are some noteworthy differences between the sectors. These arise from different pollution intensities, substitution possibilities and income elasticities of the various goods and services. The consumption of Extraction of oil and gas, Basic metal industry and Oil refineries is reduced more than average, whereas the consumption of Energy supply, Water supply, Transport services and Other goods and services decrease less than average. The latter goods and services all have small income elasticities.

7.4.4 Environmental results

This section presents the results for the environmental themes. First, the abatement expenditures are specified per SNI variant. Then the expenditures on pollution rights and corresponding prices and volumes are presented.

Table 7.6 Abatement expenditures in SNI variants in billions of guilders.

Environmental theme	Variant 1a	Variant 1b	Variant 2a	Variant 2b
Greenhouse effect	3.89	4.60	4.02	4.64
Ozone depletion	0.02	0.03	0.02	0.02
Acidification	0.02	0.03	0.05	0.06
Eutrophication	0.00	0.00	0.01	0.01
Smog formation	0.00	0.00	0.00	0.00
Fine particles	0.00	0.00	0.01	0.01
Dispersion to water	0.00	0.00	0.00	0.00
Dehydration	0.55	0.55	0.55	0.55
Soil contamination	20.40	20.40	20.40	20.40
<i>Total abatement expenditures</i>	<i>24.89</i>	<i>25.61</i>	<i>25.06</i>	<i>25.69</i>

It is clear from Table 7.6 that the abatement costs measured in new equilibrium prices (variants 1b and 2b) are slightly higher than measured in old prices (variants 1a and 2a). An outstanding result is that in all variants, the largest abatement expenditures are paid for reduction of greenhouse gas emissions. These greenhouse effect measures account for over 98% of all abatement expenditures. By contrast, the costs of measures against eutrophication, smog formation, fine particles and dispersion to water are negligible. The major explanation of this result is that, as a side effect of the stringent greenhouse gas standard, the sustainability standards for the remaining environmental themes can easily be met or are not even binding, see also Table 7.7.

Table 7.7 Pollution in the base year and in different SNI variants.

Environmental theme	Units	Base 1990	Standards	Variant 1b	Variant 2b
Greenhouse effect	Billion kg. CO ₂ eq.	251.0	53.2	53.2	53.2
Ozone depletion	Million kg. CFC11 eq.	10.4	0.5	0.5	0.5
Acidification	Billion acid equivalents	38.4	10.0	10.0	10.0
Eutrophication	Million P-equivalents	312.0	128.0	103.7	118.5
Smog formation	Million kilograms	440.0	240.0	177.4	161.3
Fine particles	Million kilograms	44.0	20.0	8.7	8.0
Dispersion to water	Billion AETP equivalents	194.3	73.5	73.5	64.2

The results found for abatement costs carry over to the prices of and expenditures on pollution rights. Table 7.8 shows the prices of the environmental themes in guilders per unit of pollution. Prices are given for the initial reference situation ('base 1990'), and for the two variants 1b and 2b. Recall that variants 1a and 2a use the same prices as the base case. As the units are non-comparable between themes, the price differences between the various themes are not analysed. The differences between the old prices and the new equilibrium prices demonstrate the impact on relative prices of complying with sustainability standards. For example, in SNI variant 1b, a greenhouse gas pollution right for one kilogram CO₂-equivalents amounts to 3,203 guilders. This is well above any figure found in the literature (mostly in the range of US\$ 10 to 50 per ton carbon-equivalents, or about 80 to 400 guilders per thousand kilogram CO₂ equivalents).

Table 7.8 Price of pollution rights in SNI variants in guilders per theme unit.

Environmental theme	Units (guilders per)	Base 1990	Variant 1b	Variant 2b
Greenhouse effect	Thousand kg. CO ₂ equivalents	0.00	3,203.20	3,098.82
Ozone depletion	Kg CFC11 equivalents	2.05	23.56	19.36
Acidification	Thousand acid equivalents	8.45	14.62	27.04
Eutrophication	P-equivalents	0.93	0.32	0.46
Smog formation	Kilograms	0.36	0.22	0.33
Fine particles	Kilograms	0.46	2.24	3.26
Dispersion to water	Thousand AETP-eq.	0.00	0.55	0.74

The prices presented for the reference situation in 1990 are based on the slope of the abatement cost curves, in the reference situation, representing the marginal costs of pollution reductions (see Appendix 6.II). In Table 7.9, these prices are multiplied by the actual pollution levels, and one can see that, for acidification and eutrophication, in the base year, expenditures amount to about 300 million guilders, each. It should be emphasised that these expenditures are calculated as part of the calibration procedure, and do not appear in the data.

In SNI variants 1b and 2b, most expenditures on pollution rights go to the greenhouse effect. The huge costs of the greenhouse gas emission rights can be explained by the very strict sustainability standard, especially in comparison with the amount of pollution that can be avoided through technical measures: 78.8% of greenhouse gas emissions have to be reduced, while only about 50% can be reduced by means of technical measures. Consequently, costly volume measures (economic restructuring) have to be taken to reduce greenhouse gas emissions. Expenditures on pollution rights for all other themes are negligible, similar to the results found for the abatement costs.

Table 7.9 Expenditures on pollution rights in the SNI variants in billions of guilders.

Environmental theme	Base 1990	Variant 1b	Variant 2b
Greenhouse effect	0.00	170.45	164.89
Ozone depletion	0.02	0.01	0.01
Acidification	0.32	0.15	0.27
Eutrophication	0.29	0.03	0.05
Smog formation	0.16	0.04	0.05
Fine particles	0.02	0.02	0.03
Dispersion to water	0.00	0.04	0.05
<i>Total expenditures on pollution rights</i>	0.00	170.74	165.35

Total expenditures on pollution rights are equal to the total revenues from pollution rights as collected by the government. This can be checked by comparing the last row in Table 7.9 with the rows for pollution rights in Tables 7.4 through 7.5. In SNI variants 1a and 2a, expenditures on pollution rights are quite small, as old prices are used for valuation⁵².

7.5 Final remarks

The main emphasis of the research was on the construction of an applied general equilibrium model that is good enough to give reasonably credible results. Although this target seems to be met, many improvements, refinements and sophistications can still be made. Many of these are already indicated in the text. Without being exhaustive, the following points deserve special attention.

1. The coverage of relevant environmental functions (themes) is not complete. Especially land use and waste disposal ask for inclusion.

⁵² To be precise, the prices used here to calculate the expenditures on pollution rights in the base year are based on imputed prices for pollution rights, using the actual pollution levels in the base year as the total volume of rights that are distributed.

2. The modelling of international trade needs further elaboration.
3. The information on technical options of abatement and their costs, on which the presently used cost curves are based, is not entirely up to date. New material on applicable technologies and costs needs to be incorporated.
4. In the present model, pollution is linked to outputs. It has correctly been argued that part of the pollution could better be linked to certain types of inputs, for instance: CO₂ emissions to fuel inputs. Modelling pollution through links with (fuel) inputs will allow a better reflection of substitution possibilities (see the appendix to this chapter).
5. Per theme, reduction of pollution through technical measures is now modelled through an abatement sector which 'delivers reduction' to the other sectors. This implies that, per theme, the shape of the abatement cost curve is the same for all sectors. It is necessary to differentiate the abatement cost curves between sectors and to differentiate the expenditure effects of technical abatement.
6. A whole gamut of sensitivity analyses can be done by changing and modifying assumptions that underlie the SNI calculations. Among the variables and assumptions that can be modified are: base year, elasticities, assumptions on foreign trade, cost curves, and old versus new prices.

Finally, attractive and understandable ways of communication must be found to inform the public and politicians, as well as the scientific community, on the reached results, their meaning and their limitations.

References

- Blok, K. (1991). *On the reduction of carbon dioxide emissions*. Thesis, Utrecht University, Utrecht.
- Blok, K., E. Worrell, R.A.W. Albers and R.F.A. Cuelenaere (1991). *Data on energy conservation techniques for the Netherlands*, report W. 90008, Department of Science, Technology and Society, Utrecht University.
- de Boer, B. and P. Bosch (1995). *The Greenhouse effect: an example of the prevention cost approach*. Paper prepared for the second meeting of the London group on national accounts and the environment, Washington, March 15-17.
- Dellink, R.B. and K.F. van der Woerd (1997). *Kosteneffectiviteit van milieuthema's*. IVM-R97/10, Institute for Environmental Studies, Vrije Universiteit, Amsterdam.
- den Butter, F.A.G. and H. Verbruggen (1994). Measuring the Trade-Off Between Economic Growth and a Clean Environment. *Environmental and Resource Economics*, 4, pp. 187-208.
- Hueting, R. (1992). Correcting National Income for Environmental Losses: a Practical Solution for a Theoretical Dilemma, in: J.J. Krabbe and W.J.M. Heijman (eds), *National Income and Nature: Externalities, Growth and Steady State*, Kluwer Academic Publishers, Dordrecht/Boston/London.
- Hueting, R. and L. Reijnders (1998). Sustainability is an Objective Concept. *Ecological Economics*, 27, pp. 139-147.
- Okken, P.A. (1991). *CO₂ reduction consensus? A conceptual framework for global CO₂ reduction targets, the importance of energy technology development*. Report nr. ECN-RX-91-093ECN, Petten.

- Okken, P.A., P. Lako, D. Gerbers, T. Kram and J. Ybema (1992). CO₂ removal in competition with other options for reducing CO₂ remissions. *Energy Conversion and Management*, 33, pp. 6-10.
- RIVM (1991). *Nationale Milieuverkenning 2*. Bilthoven.
- RIVM (1996). *Milieubalans 1996*. Bilthoven.
- RIZA (1996). *Watersysteem Verkenningen*, mimeo.
- VROM (1994). *Methodiek Milieukosten*, Publicatiereeks Milieubeheer 1994/1, The Hague.
- VROM (1998). *Kosten en baten in het milieubeleid, definities en berekeningsmethoden*, Publicatiereeks Milieustrategie 1998/6, The Hague.

Appendix 7.I Some additional exercises with the AGE-SNI model

A7.I.1 Introduction

In Chapter 7, we present the results for the Sustainable National Income (SNI) for the Netherlands, for four variants 1a, 1b, 2a, and 2b, which differ with respect to assumptions on international trade and assumptions on prices used to express the SNI. Though variant 2b seems to come closest to Hueting's intentions, the four variants stand for our hesitation to pinpoint one set of assumptions as the unambiguous choice that represents Hueting's methodology. The four variants are not meant to be exhaustive. There are many other assumptions in the model for which we could think of a reasonable alternative, and for some of them, we are interested to see how the numerical results presented in Chapter 7 change if we employ the alternative.

The committee that guided the project has decided to present the four variants of Chapter 7 as the main results, and has asked the researchers to carry out two additional exercises to give an impression of the possible changes in the calculated SNI if other assumptions are followed. The first exercise, presented in Section A7.I.2, sketches the changes we expect to come about when pollution would be linked to the inputs of intermediates and the specific consumption patterns, instead of being linked to the output of a sector and the aggregate consumption level. A qualitative discussion on the sensitivity of the model results to this assumption has been given in Section 5.2.3. Here, we add a numerical exercise to the discussion. The second exercise, presented in Section A7.I.3, sketches the changes in the SNI that may come about when using different sustainability standards. For some environmental themes such as the enhanced greenhouse effect, it is still uncertain, from a natural scientist's point of view, which current level of emissions can be considered sustainable. Since the SNI is (by definition) dependent on the sustainability standards for emissions, it is thought to be crucial for the user of the SNI figures to have a basic understanding of the sensitivity of results regarding possible different choices in standards.

In Section A7.I.4, after the two exercises that calculate different values for the SNI, we turn to a more general examination of our model. In Section 5.1.1, we remarked that, commonly, applied general equilibrium (AGE) models are used to calculate economy-wide consequences of specific environmental policies, for example energy taxes or carbon emission taxes. In this report, we apply our AGE model for a different purpose, calculating the SNI, which does not reflect an environmental policy, but is a green income measure. Nonetheless, the model has a general structure comparable with other AGE models and should be capable of calculating the costs of specific environmental policies. We find it constructive to examine the model's behavior when using it for that purpose, and we compare our results with results in the literature. We choose to calculate the costs, measured in loss of income, of a greenhouse gas emission tax that aims at reducing greenhouse gas emissions by 50%.

Finally, Section A7.I.5 concludes.

A7.1.2 Reallocating pollution; simulating a link of pollution to inputs

A7.1.2.1 Introduction

To begin with, let us motivate the need for a reallocation of pollution in the SNI-AGE model. In the current set-up of the model, pollution is linked to the output per sector and to aggregate consumption levels. Pollution caused by the activities in a sector is assumed to be proportional to the output. To reduce pollution in that particular sector, two options are open. First, there are technical pollution reduction measures; abatement activities can substitute for part of the pollution. Second, total output can be reduced; the sector shrinks. As noted in Section 5.2.3 of this report (linking pollution to output), in practice, there is a third option available. Large part of pollution is linked to intermediate deliveries (inputs). If we substitute the polluting inputs by other inputs causing lower pollution levels, this will reduce pollution without the need for decreasing output. For example, a large part of carbon dioxide emissions are associated with the combustion of fossil fuels, or in terms of the model, with the input of intermediates from the sector Oil refineries. Cutting the inputs from the Oil refineries sector, and substituting for this by increasing inputs from other sectors will decrease greenhouse gas emissions, while maintaining total output. To capture the third pollution reduction option in the model, substitution of inputs, it seems necessary to link part of pollution to inputs, rather than to outputs alone.

However, the current SNI-AGE model and the input data for the model do not facilitate this insight. Linking pollution to intermediate deliveries would substantially increase the complexity of the model, and it is unfeasible to realise that aim within the current project. Moreover, currently, pollution data are available per sector only; the data do not specify to which intermediate deliveries pollution can be attributed. As it stands, in the current version of the model, using the current data, it seems likely that sectors contributing to pollution through their intermediate deliveries are less hurt in the calculated sustainable economy than they would have been if sustainability standards were implemented in practice.

Nonetheless, we think it is possible, more or less, to get around the problem. We use an approach based on the current version of the model that may approximate the results that would be reached if we would jointly link emissions to intermediate deliveries and output. In our approach, we adjust the input data for pollution, and show how the current version of the model can be used to make a first estimate of (differences in) results – such as for income and sectoral effects – that can be expected once we would link pollution jointly to intermediate inputs and output. Most importantly, we check whether linking part of emissions to intermediate deliveries will increase or decrease the calculated SNI level.

The roundabout approach is best explained by the following numerical exposition for greenhouse gas emissions. In 1990, greenhouse gas emissions account to 251 MtC equivalents, implying an intensity for the Dutch economy of 0.550 kgC/NLG. In absolute terms, the Energy supply contribute most, emitting 39.9 MtC. Per value added, the Energy supply also ranks highest with emissions of 7.1 kgC/NLG, more than ten times the average intensity. Remarkably, the direct contribution of Oil refineries only amounts to 10.4 MtC, and per value added, emissions amount to 3.7 kgC/NLG. This figure is however flattered. To see this, we first look at the sector Energy supply. This sector in-

cludes electricity production. When consumers and other sectors use electricity, emissions caused by electricity production are attributed to the Energy supply sector. To conclude, when it comes to electricity, emissions are effectively linked to the consumption pattern and intermediate deliveries. On the other hand, the sector Oil refineries produces energy carriers such as petrol and when these are used by consumers and other sectors, emissions caused by combustion are attributed to the final users. Thus, when it comes to energy carriers, our data do not link emissions to the consumption pattern nor to the intermediate deliveries. The sector Energy supply and Oil refineries are treated differently. Further on in this appendix, we present results from calculations where we make an attempt to attribute emissions to intermediate deliveries and consumption goods, and in turn, attribute the emissions to the sector producing the intermediate deliveries and consumption goods. We find that under this procedure, total emissions attributed to the Oil refineries sector increase from 10.4 MtC to 49.8 MtC. Per value added, total emissions of the Oil refineries rise to 17.8 kgC/NLG, surpassing the Energy supply by far. The reallocated emissions seem to better reflect the direct and indirect contribution of sectors. Calculations for the SNI based on the reallocated emissions may then be used as an approximation of calculations that would be possible with a model linking part of emissions to intermediate deliveries and consumption patterns.

In the next section, we will describe the technical details of the procedure we followed to reattribute pollution. The subsequent section presents the results in more detail, comparing our findings with those presented in Chapter 7.

A7.1.2.2 Technical description of the procedure

For a technical description of the reallocating pollution from the output per sector to the input, we use the following variables:

- pollution per sector and consumer, $E_{e,j}$ and $E_{e,h}$,
- output per sector, Y_j ,
- consumption per consumer type, $C_{j,h}$, and
- intermediate deliveries from sector j_1 to sector j_2 , denoted by F_{j_1,j_2} .

where e denotes the environmental theme, j the sector and h the consumer.

The current version of the model assumes that, if no abatement activities take place, pollution $E_{e,j}$ and $E_{e,h}$ are proportionally linked to output, Y_j , and consumption, C_h . Formally, we can write

$$E_{e,j} = \alpha_{e,j} Y_j, \quad (\text{A.1})$$

$$E_{e,h} = \alpha_{e,h} C_h, \quad (\text{A.2})$$

where α denotes the pollution intensity of the sectoral output and of aggregate consumption, respectively. In an extended version of the model, we could link pollution to both output and input, or to both aggregate and sectoral consumption, writing:

$$E_{e,j} = \hat{\alpha}_{e,j} Y_j + \sum_{j_1 \in J} \hat{\beta}_{e,j_1,j} F_{j_1,j}, \quad (\text{A.3})$$

$$E_{e,h} = \hat{\alpha}_{e,h} C_h + \sum_{j_1 \in J} \hat{\beta}_{e,j_1,h} C_{j_1,h}, \quad (\text{A.4})$$

where $\beta_{e,j_1,j}$ denotes the pollution intensity of the intermediate deliveries, and $\beta_{e,j_1,h}$ of consumer goods. That is, the second term represents the pollution attributed to the use of intermediates and consumption per good. However, the current data does not provide sufficient information to calculate parameters β . We thus reduce the dimension of the parameters β , and assume that all users of an intermediate good j have the same pollution associated to the input of the good j , which in turn, is equal to the pollution associated to the consumption of the good.

$$\beta_{e,j_1,j} = \beta_{e,j_1,h} = \beta_{e,j_1}. \quad (\text{A.5})$$

This results in

$$E_{e,j} = \hat{\alpha}_{e,j} Y_j + \sum_{j_1 \in J} \hat{\beta}_{e,j_1} F_{j_1,j}, \quad (\text{A.6})$$

$$E_{e,h} = \hat{\alpha}_{e,h} C_h + \sum_{j_1 \in J} \hat{\beta}_{e,j_1} C_{j_1,h}. \quad (\text{A.7})$$

The parameters $\hat{\alpha}_{e,j}$ and $\hat{\beta}_{e,j_1}$ that satisfy the equations (6) and (7) are not necessarily unique, but the degree of freedom is sufficiently reduced to determine reliable values for them.

However, the current model version is incapable of associating pollution to intermediate deliveries, so that we need another assumption to make the analysis operational. Because pollution can also be reduced through abatement measures, we have to assume that these carry over from the sector using the intermediate deliveries to the sector producing the intermediate deliveries; the same applies for consumer goods. Thus, we assume that abatement measures to cut pollution associated to intermediate deliveries and consumption do only depend on the intermediate or consumption good, and do not depend on the sector or consumer using the good. This assumption allows us to reallocate pollution to the sector that produces the intermediate good:

$$\tilde{\alpha}_{e,j} Y_j = \tilde{E}_{e,j} = \hat{\alpha}_{e,j} Y_j + \hat{\beta}_{e,j} \left(\sum_{j_1} F_{j,j_1} + \sum_h C_{j,h} \right), \quad (\text{A.8})$$

where the tilde ($\sim$) denotes the parameters that enter the model to produce an alternative calculation of sustainable income when pollution is attributed to goods that indirectly cause pollution rather than to the sector that directly pollutes when using the good.

Our objective is to maximise the quantity of pollution that is attributed to the intermediate deliveries and consumption patterns, $\sum_{j_1} \hat{\beta}_{e,j_1} \left(\sum_j F_{j,j_1} + \sum_h C_{j_1,h} \right)$. Dividing the quantity by total pollution, we calculate the ratio R_e and solve

$$\text{Max : } R_e = \frac{\sum_{j_i} \hat{\beta}_{e,j_i} \left(\sum_j F_{j_i,j} + \sum_h C_{j_i,h} \right)}{\sum_j E_j + \sum_h E_h}, \quad (\text{A.9})$$

for $\hat{\alpha} \geq 0$ and $\hat{\beta} \geq 0$, subject to (6) and (7), given pollution data $E_{e,j}$ and $E_{e,h}$, output Y_j , intermediate deliveries $F_{j,j}$, and consumption C_h .

We carried out the analysis for all environmental themes, and found for greenhouse gases the most substantial reallocation of pollution. Just over one third of greenhouse gas emissions could be explained by the use of intermediate deliveries and consumption patterns; solving (A.9) gave $R_e=0.38$. For ozone, eutrophication, and dispersion of heavy metals, we were not able to reallocate pollution, that is, we found $R_e=0$. For acidification, smog, and fine particles, we found lower levels of pollution attributed to intermediate deliveries, $R_e=0.16$, $R_e=0.14$, $R_e=0.25$, respectively. In our discussion of results, we therefore most often refer to the change in greenhouse gas emissions.

A7.1.2.3 Numerical results

Table A7.I.1 shows for four environmental themes the reallocation of pollution. From this table we can see, for instance, that greenhouse gas emissions attributed to Oil refineries increases most, and that emissions that first were attributed to the Chemical industry and to Energy supply are decreased, since they can be attributed to the intermediate deliveries from the Oil refineries. We emphasise the need to be cautious in interpreting the results, as the reallocation of pollution is based on a simple econometric approach and it does not explain pollution. To be useful for (future) policy analysis, the approach will require to be worked out more carefully. Yet, the main result of Table A7.I.1, that is the vast increase in greenhouse gas emissions attributed to the Oil refineries, seems to make sense.

Table A7.I.1. Absolute changes in the sectoral allocation of pollution when pollution is attributed to intermediate deliveries and consumption patterns.

	Greenhouse effect	Acidification	Smog Formation	Fine particles
Units	MtC equivalents	10E9 acid equivalents	kt	kt
Agriculture	-4.4	-0.1	-0.1	2.3
Oil and gas extraction	8.7	1.9	-2.9	-0.0
Other mining	0.2	1.5	0.0	1.5
Food-related industry	14.1	0.4	-0.4	-0.5
Textile- and leather industry	2.2	0.2	0.9	1.6
Paper and –board industry	-0.2	-0.1	-0.1	-0.1
Printing industry	-0.2	-0.0	-0.9	-0.0
Oil refineries	38.4	-1.0	-0.4	-0.0
Chemical industry	-14.4	-0.5	-0.8	-0.3
Rubber and plastics industry	-0.1	-0.0	-0.1	-0.0
Basic metals industry	0.8	0.1	-0.1	0.6
Metal products industry	-0.7	-0.1	-0.4	-0.3
Machine industry	-0.4	-0.0	-0.4	-0.1
Electrotechnical industry	-0.5	-0.1	-0.6	-0.1
Transport equipment industry	0.1	-0.0	4.6	0.4
Other industries	-0.8	-0.4	-0.3	-0.5
Energy supply	-1.1	-0.6	-0.0	-0.0
Water supply	-0.1	-0.0	-0.0	0.2
Construction	-2.2	-0.5	-1.2	-0.6
Trade and related	-2.9	-0.2	-3.3	-0.5
Transport by land	-2.2	-0.0	32.9	-0.0
Transport by water	0.9	-0.0	-0.4	-0.0
Transport by air	-1.4	-0.0	12.1	-0.1
Transport services	1.1	-0.0	-0.4	0.3
Commercial services	-2.7	-0.3	-2.9	-0.2
Non-commercial services	-2.1	0.9	-2.7	-0.2
Other goods and services	-0.3	-0.0	-0.0	-0.0
Ratio of reallocated pollution (R_e)	0.38	0.16	0.14	0.25

Note: There are no significant changes in pollution for depletion of the ozone layer, eutrophication and dispersion to water.

After having reallocated part of pollution, we are able to recalculate the SNI values for the four variants presented in Chapter 7. Since the SNI values found under variant 1a and 1b, and 2a and 2b, respectively, did not differ very much, we limit our exercise to the SNI presented in new prices, that is we demonstrate only the alternative calculations for variants 1b and 2b. Results are presented in Table A7.I.2.

Table A7.I.2 Changes in SNI due to reallocation of pollution.

	Income in billions of guilders		Income, per cent decrease relative to BAU	
	variant 1b	variant2b	variant 1b	variant 2b
BAU	456.7		0.0%	
Results of Chapter 7	241.4	201.4	47.1%	55.9%
Results after reallocating pollution	275.7	208.3	39.6%	54.4%

The effects of the reallocation of emissions are substantial. Under variant 1b, with constant relative prices on the world market, the reallocated pollution increases income by 33.7 billion guilders. Compared to the reference ‘business as usual’, income moves from a 47.1% decline to a 39.6% decline. Under variant 2b, with constant shares of exports and imports, the effect is smaller. Now, reallocated pollution increases income by 6.9 billion guilders; compared to the reference ‘business as usual’, income moves from a 55.9% decline to a 54.4% decline.

There is no simple explanation for the increase in income that is reached by reallocating pollution. We may say that linking emissions to intermediate deliveries and consumption goods adds some flexibility to the model: the third reduction option mentioned in Section A7.I.2.1. However, we simulated the linking of emissions to intermediate deliveries while using the same model as for the calculations in Chapter 7. Thus, from the modelling point of view, the third option is not present in our exercise. Nonetheless, we think the basic idea of the argument, an increased flexibility of the economy to cope with sustainability standards, carries over. An analysis of the distribution of emissions over the economy shows that the distribution becomes more skewed (uneven) after the reallocation of emissions. Pollution is reallocated towards the sectors that were already pollution intensive, and away from sectors that were already pollution extensive. As a result, the shrink of the economy that is necessary to meet the sustainability standards is more selective. This argument also explains why the increase in sustainable income is more pronounced under variant 1b than under variant 2b. In Chapter 7, we have already seen that under variant 2, the economy has fewer opportunities to direct the economic shrink towards the polluting sectors, and thus, a more skewed distribution of pollution has not so much impact.

We also look at the sectoral effects. Since the impact of the pollution reallocation is the highest for variant 1b, we focus on the sectoral changes within this variant. Figure A7.I.1 pictures the changes in sectoral output levels that are caused by the reallocation of pollution. For the sectoral output levels under the initial emission levels, we refer to Figure 7.5 of Chapter 7.

We can see from Figure A7.I.1 that the reallocation of pollution leads to a small decrease in the output of the Oil refineries (sector 8): nearly 2 per cent point, where we denote by ‘per cent points’ that amounts are expressed as percentages of the BAU output level. Intuitively, we would expect a larger impact for this sector, which now has the highest greenhouse gas emission intensity. However, most sectoral output levels increase, total income increases by about 7.5 per cent point, and relative to this, the output of the Oil refineries decrease by nearly 10 per cent point. Another result that raises attention is the reduction of Transport services by 69% as compared to the reference case presented in Chapter 7. The main explanation for this outlier is the surprising sectoral distribution of the reference case itself in Chapter 7, in which the Transport services sector could expand its production by 9%, whereas other sectors had to decrease output by about 50%. Under reallocated pollution, the output of Transport services decreases by about 60%, reaching the same level found for many other sectors.

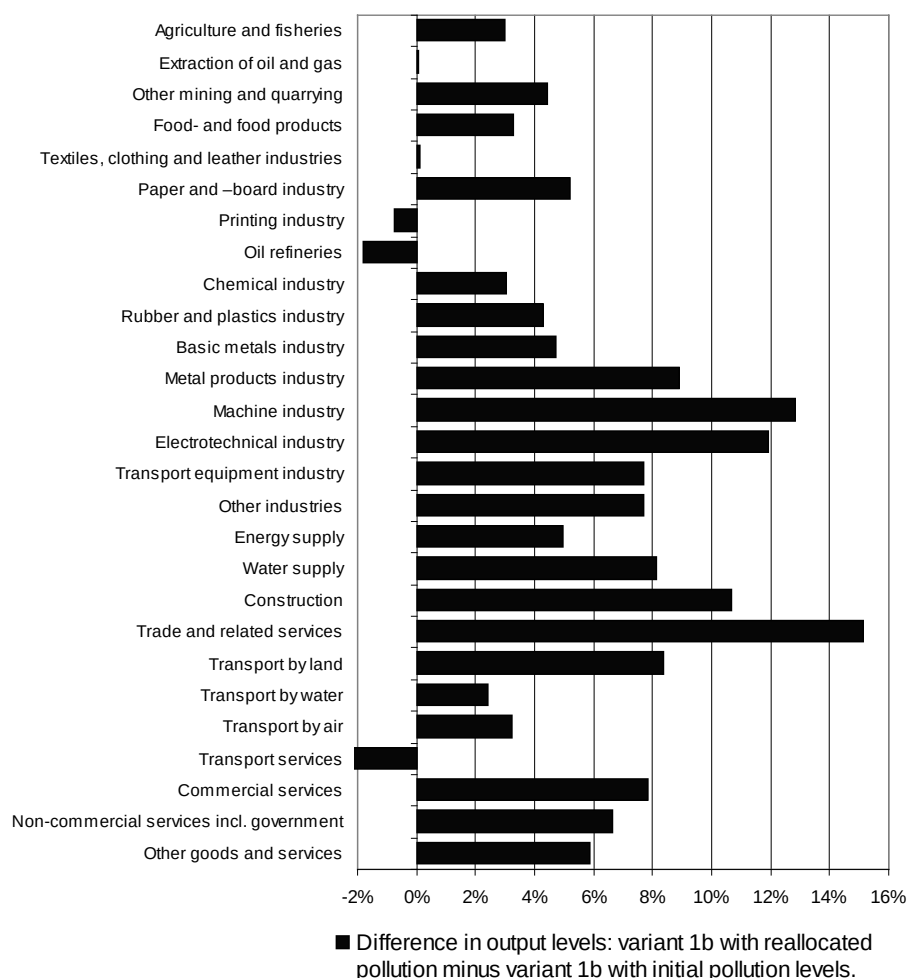


Figure A7.I.1 Difference in sectoral output between variant 1b of Chapter 7 and variant 1b with reallocated pollution, presented as per cent points (percentages of BAU levels).⁵³

A7.I.3 Assessing the impacts of different sustainability standards

The second exercise, presented in this section, is meant to give an idea of the dependence of the SNI on the sustainability standards. For some environmental themes such as the enhanced greenhouse effect, it is still uncertain, from a natural scientist's point of view, which current level of emissions can be considered sustainable. To have a basic understanding of the implications of this uncertainty, we have calculated the SNI levels for different sustainability standards that were weaker and stronger than the standards used in Chapter 7, respectively. In Table A7.I.3, similar to the analysis for the reallocated emissions, we present the results for variants 1b and 2b:

⁵³ For transport services, the bar reaches the value of –69%.

Table A7.I.3 Changes in SNI due to small changes in the sustainability standards.

	Income in billions of guilders		Income, per cent decrease relative to BAU	
	variant 1b	variant2b	variant 1b	variant 2b
BAU		456.5		0.0%
Results of Chapter 7	241.4	201.4	47.1%	55.9%
Allowed pollution +10%	261.5	220.4	42.7%	51.7%
Allowed pollution -10%	220.0	181.7	51.8%	60.2%

From Table A7.I.3, we see that, under variant 1b, the SNI increases by 20.1 billion guilders, or 4.4 per cent points, if the quantity of allowed pollution units is increased by 10%. Relative to its own level, the SNI increases by nearly 8%. The SNI-level seems to be almost proportional to the level of pollution allowed under the sustainability standards. This almost linear relation also applies to the decrease of allowed pollution units, and it even better applies to the changes calculated for variant 2b. The reason we think this proportionality holds is that, at the sustainable state, the economy has used most of its flexible options to achieve the required emission reductions. The major option left to further reduce emissions is by a uniform reduction of all economic production activities.

A7.I.4 An additional exercise: reducing GHG emissions by 50%

This section is used for a more general examination of the model. AGE models have often been used to calculate economy-wide consequences of specific environmental policies, for example energy taxes or carbon emission taxes. Here, we examine the behavior of the model when using it for that purpose. Furthermore, we compare our results with typical results in the literature. We choose to calculate the costs, measured in loss of income, of a greenhouse gas emission tax that aims at reducing greenhouse gas emissions by 50%. Though this aim represents a rather stringent environmental policy, comparable calculations have been carried out in the literature, because of the understood urgency of the enhanced greenhouse effect.

Similar to the calculations for the SNI, we have two basic variants, one with world market prices unchanged, and the other with world market prices changing proportionally to price changes in the Dutch economy. Table A7.I.4 presents the results. For these exercises, we find that results presented in new prices do not differ much from results presented in old prices, and we only present results in new equilibrium prices (variant 1b and 2b).

Table A7.I.4 Income effects of a 50% GHG emission reduction, under different assumptions.

	Income (billion NLG/yr)		Income decrease (%)	
	variant 1b	variant2b	variant 1b	variant 2b
BAU		456.5		0.0%
50% GHG emission reduction	434.5	441.2	4.9%	3.2%
Same as above, reallocated emissions	437.4	447.5	4.2%	2.0%

Remarkably, the calculated costs of a 50% GHG emission reduction differ substantially between the various assumptions. Using the basic emission data, costs amount to 4.9% or 3.2%, dependent on whether world market prices remain unchanged, or change proportionally with prices in the domestic market, respectively. If emissions are reallocated as described in Table A7.I.1, costs decrease to 4.2% and 2.0%, respectively. Our range of costs, from 2.0% to 4.9% falls within the range found in the literature. Boero *et al.* (1991a, 1991b) give an overview of AGE models that are used for this purpose, and find a decrease of income ranging from 1 to 4.5%.

We can also use this scenario exercise to study the sectoral effects of a greenhouse gas policy, and to get a basic feeling of the prospects of the basic emission data and the reallocated emission data. Figure A7.I.2 gives the sectoral effects, for variant 1b, that is when world market prices are unaffected. Sectoral changes are diverse. Some sectors show a decrease of output of about 60%, notably Transport by water and air. For other sectors, a stringent GHG emission reduction policy proves to be an opportunity allowing production growth. Comparing the calculated effects based on the initial emission data and the reallocated emission data, the figure adds to the credibility of the reallocation procedure. Without reallocating emissions, the output of the Oil refineries sector decreases by less than 10%, while many other sectors show a much sharper decrease. Having emissions reallocated, the Oil refineries sector is hit most sharply, showing a cut in output by over 50%. We think the latter result is more probable.

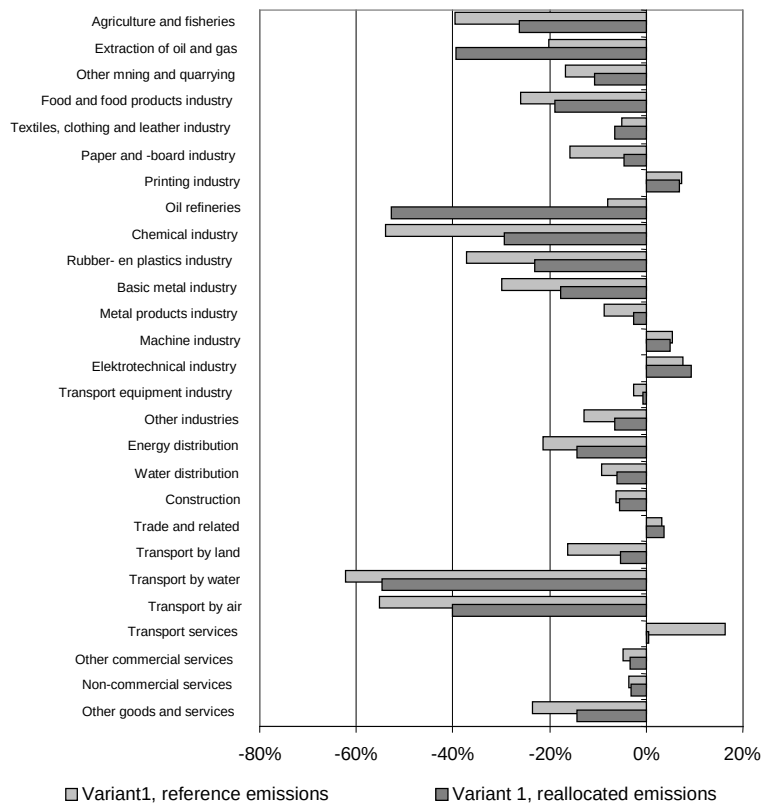


Figure A7.I.2 Sectoral effects on output under a 50% GHG emission reduction; comparison between reference emission data and reallocated emissions data.

A7.1.5 Conclusions

The main conclusion of this appendix is that the reallocation of pollution to intermediate deliveries may lead to a substantially higher sustainable national income level. We simulated the linking of emissions to inputs by reallocating emissions. Under variant 1b, where world market prices are unaffected, the income reduction (as compared to the BAU allocation) changes from 47% to 40%. Under variant 2b, where world market prices change proportionally to domestic prices, the income reduction changes from 56% to 54%. We are to be careful in interpreting the numerical results, for at least two reasons. First, the reallocation of pollution is based on an econometric approximation that does not explain the pollution. Second, the results are driven by the enhanced greenhouse effect being the critical theme in the calculations of the SNI. When another environmental theme would be critical, we could expect a different result, because for other themes we found a lower share of pollution that could be attributed to the intermediate deliveries.

As for the relation between sustainability standards and the calculated SNI-level, we found an almost linear relation between allowed emissions and the SNI-level. It seems that the major option left to further reduce pollution consists of a nearly uniform reduction of all economic production activities. The other way around, we can also say that any allowed increase of emissions will lead to an almost uniform increase in economic activities. Uncertainty as regards the sustainable level of emissions, based on the natural scientific analysis of the processes at play, thereby directly translate in an almost proportional uncertainty regarding the sustainable income level.

Finally, we have also used the model for a more standard policy analysis, as opposed to the SNI-calculations presented in Chapter 7. Though we have not gone into the details, we note that the results of this exercise are in line with the results found in the literature.

References

- Boero G., R. Clarke, and L.A. Winters (1991a). *The macroeconomic consequences of controlling greenhouse gases: a survey*. HMSO, dep. of the env., London.
- Boero G., R. Clarke, and L.A. Winters (1991b). *Controlling Greenhouse Gases: A survey of global macroeconomic studies*. Discussion papers 91-25, University of Birmingham, Birmingham.