8.1 Introduction

In this thesis an ECCO-type model is presented as a planning tool to gain insights in the physical relationships between economic activity and the natural environment and to assess the physical development potential of an economy given various sets of pre-conditions. The development of the Netherlands ECCO model emerges from the notion that the physical linkage between economic activity and the natural environment is an important aspect of sustainable development and that current and future human needs and wants can only be fulfilled within biophysical constraints.

Besides some general concluding remarks on the concept of sustainable development and the related issue of economy-environment interrelationships made in section 8.2 and section 8.3, this concluding chapter presents the main conclusions of this thesis by formulating answers to the research questions posed in the first chapter. Furthermore, in section 8.5 the role of the ECCO methodology in the sustainable development debate is discussed by focusing on three issues that are relevant within the framework of this study. The first issue is the role of system approaches when studying sustainable development. The second issue goes into the role of ECCO when viewing sustainable development from the WCED perspective. Finally, the third issue is the long-term effects of efficiency improving technology as implemented in the Netherlands ECCO model. In the WCED perspective sustainable development is a process of interaction between three interrelated subsystems: the ecological subsystem, the economic subsystem and the socio-cultural subsystem.

Some suggestions for future research activities based on this ECCO study were made in the preceding chapter. In the final section the work carried out in this ECCO study is placed in a broader perspective by relating it to other relevant research programs currently carried out at IVEM. In addition, prospects of future research lines are discussed in more detail.
8.2 Sustainable Development as a guiding principle

The primary motivation for writing this thesis is the recognition that the impact of human activity on the environment is leading to a continuous degradation of the natural environment and that the rate at which we settle our affairs cannot be sustained in the long-term without reducing the carrying capacity of the surrounding natural environment.

The (social, cultural or economic) development of human societies is made possible because of (bio)physical inputs derived from the natural environment. It is generally recognised that present day life-styles (both in developed and developing countries) are not environmentally sustainable (the herewith interrelated notion that present day life-styles are thus not economically sustainable has not become widely accepted yet).

The concept of sustainable development has been generally accepted as a yardstick in development planning and environmental management. Despite the general support given to the concept of sustainable development there is not much consensus about the implementation of sustainable development because of differences in stakes and interpretations. Different interpretations of sustainable development are related to different world-views or images as discussed in chapter 1. These images determine the questions posed and the tools adopted when designing long-term strategies aiming at sustainable development.

Taking the Brundtland definition of sustainable development as a starting point, sustainability issues are associated with the full range of human activities carried out to fulfil basic and less basic human needs and to improve the quality of life, herewith emphatically including social structures within the societies, as well as the physical environment. Therefore sustainable development issues call for interdisciplinary research approaches.

In order to assess whether development is sustainable, conditions for achieving it have to be determined. Since it is impossible to take into account the complete economy-environment interface the notion that the (bio)physical features of the natural environment are of great importance in the sustainability debate has been addressed in this study. Herewith the concept of sustainable development is related to the throughput of matter and energy through the economic subsystem. Therefore the (bio)physical interrelationships between economics and the natural
environment form an important subject in this study. Rather than regarding the economic system as isolated from the surrounding environment, the economic system is viewed as a subsystem dependent on natural services of the overall ecosphere (see figure 1.2).

8.3 Economy-Environment interrelationships

An economic system is most often thought of as 'a set of institutions and activities designed to efficiently allocate scarce resources among things that provide benefits, thereby satisfying human needs and wants' (Turner et al., 1994). In mainstream economics the economy is regarded as a closed circular system (see figure 1.1) isolated from the natural environment. As a result, (bio)physical constraints to economic processes are only considered to a limited extent in conventional economic analyses. From a physical viewpoint this model is regarded as impossible as various natural services are essential for economic production and consumption processes. At present it is realized more and more that the sustainability of the economy-environment interface depends on whether biophysical constraints are recognized by the economic system. In this study it is argued that the production of goods and services feeds on a continuous inflow of resources and energy from the environment to the society. This results in the generation of waste flows out of the society to the environment. In general terms, natural services are essential to the economic system. The broad range of natural services are often comprised in the phrase 'natural capital', consisting of three components (i.e. non-renewable resources, renewable resources and life supporting environmental services such as waste assimilation, maintenance of atmospheric quality and the maintenance of bio-diversity). In this respect Barbier and Markandya (1993) argue that natural capital has the potential to contribute to economic productivity and welfare.

To what extent the natural capital stock can be depleted for increasing human welfare is the key question in the debate on weak and strong sustainability (see also section 2.6). Weak sustainability is based on the assumption that natural capital and human made capital are close substitutes whereas within the strong sustainability paradigm it is assumed that it is not acceptable to run down environmental assets. Turner and Pearce (1993) distinguish four main reasons for
protecting natural capital. The first reason concerns the uncertainty about the consequences for human well-being of running down natural capital. The irreversibility of some of the consequences of human actions is regarded as a second reason. This is closely related to the life-support functions of the natural capital stock, which is mentioned as a third reason. Removing ecological assets that serve life-support functions might result in possible major harm for humankind. Finally loss aversion is a fourth reason for protecting natural capital. The authors argue that people are highly averse to environmental losses.

To relate economic development with the 'physical reality', Natural Capital Accounting has been adopted as a method in this thesis. This methodology aims at obtaining physical data on flow and stock resources from the natural environment additional to conventional economic information. Natural Capital can be accounted for in many different types ranging from detailed information on the use of a single resource stock or flow to aggregated monetary estimates of resource inputs. In this thesis economy-environment links are expressed in physical terms. No direct attention is given to complex life support systems nor to biological diversity as part of the natural capital stock. This restriction on the implementation of the economy-environment interface is addressed further in subsection 8.5.2.

In this study the economy is portrayed via a physical model that represents the economy as a system that converts raw materials by means of energy into goods and services, taking into account the laws of thermodynamics.

Both the description of metabolic flows of matter and energy related to the production of goods and services and the environmental impacts of these flows are within the domain of research of the 'environmental physiologist' as put forward by Moll (1993). Without making a priori choices with respect to a particular worldview, this perspective portrays the physical flows within and between the economy and the environment, distinguishing between societal metabolism and environmental metabolism.

The concept of metabolism is rooted in biology. In ecological science metabolism refers to the resource cycles and flows of energy that determine the organism-environment interaction. The main purpose of metabolism in an ecological sense is 'survival of the individual'. With the concept 'societal metabolism' an analogy is drawn between resource cycles and energy flows within
an ecosystem and the use of resources and energy related to economic activity in order to study the long-term environmental impact of economic production and consumption processes. In contrast to the metabolism concept as applied in ecological science, metabolism related to economic activity not only refers to maintenance of life (‘survival’) but also to less basic needs (i.e. ‘life enjoyment’).

This study starts from the notion that energy provides an important means of characterizing the physical activities within an economy. The incorporation of energy as a unit of account is considered as a central means for clarifying the interrelationship between societal metabolism and environmental metabolism. Therefore the throughput of matter and energy through an economy is measured in terms of the amount of primary energy expended in the subsequent stages of production. This method was made operational by designing an ECCO-type model for the Netherlands. The following section evaluates the process of developing the Netherlands ECCO model and the application of this model within the sustainable development framework in outline.

8.4 Designing NLECCO as a tool for exploring sustainable development paths

ECCO-type models have been designed for a number of (developing and developed) countries and regions since 1984 when the first pilot studies were carried out on an experimental basis to test the ECCO paradigm. Various reasons justify the design of an ECCO-type model for the Netherlands (these reasons can be found in section 1.8). The main justification for developing another national ECCO model is that the use of physical resources and the structure of an economic system are mutually related and that they are largely determined at a national scale. For the Netherlands the availability of large natural gas reserves and the presence of a large oil refining capacity appeared to be key elements in past economic developments and are also considered to be of significant importance in determining future economic developments.

The key activities of this study are related to the development of the Netherlands ECCO model plus the application of this model in terms of the exploration of relevant scenarios within the sustainable development framework. These activities are reflected in the research questions presented in section 1.8. In the rest of this section the main conclusions of this study are presented by
formulating answers to the three research questions posed in section 1.8.

**Research question 1:**

*Given the inadequacies of present approaches, is it possible to construct an ECCO-type model in such a detail that it can be applied to explore the long term physical consequences of diverse strategies as well as of alternative, more sustainable, strategies?*

In this study an ECCO-type model was constructed based on the general structure of ECCO as shown in figure 3.4. In order to construct the model an initial data set was developed using various methods. In its current state the model represents the most important man-influenced metabolic flows through the Netherlands economy in energy terms. The embodied energy concept turns out to be a valuable means to trace the flows of primary energy through an economic system.

With respect to the level of required (or desired) detail it can be stated that the level of aggregation is a function of the research questions posed. The ECCO model presented in this study consists only of a limited number of economic sectors. This high level of aggregation appeared to be sufficient to explore the long-term physical development potential of the Netherlands economy in broad outlines. However, theoretically there are no lower limits to the level of aggregation. In subsequent stages of model development every sector of interest can be desaggregated to the desired level of detail.

**Research question 2**

*Is it possible to sufficiently quantify the stocks of embodied energy and the flows of embodied energy as well as direct energy flows within the Netherlands’ economy?*

This question has been addressed in chapter 5 and chapter 6. The direct energy flows were determined using various energy statistics. Input-output energy analysis (IOEA) was applied to calculate the cumulative energy intensities of the 59 production sectors distinguished in the input-output table. The calculated energy
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intensities were applied to draw up an energy input-output table of 1985, consisting of the ECCO sectors distinguished in NLECCO (see table 5.4), and to determine the flows of embodied energy through the economy. Flow diagrams of the direct and indirect energy flows through the Dutch economy in the year 1985 are given in figure 5.2 and, in more detail, in figure 5.3. For the year 1985 it appeared that in contrast to the direct energy import-export balance, which was more or less in an equilibrium, the export of primary energy embodied in goods and services (2035 PJ) grossly exceeded the embodied energy in imports (1574 PJ).

In order to estimate the past primary energy expenditures required to build up the stock of capital goods as present in 1985, the results of IOEA were used as a starting point. Taking into account the past trends in primary energy requirements of investments the primary energy embodied in the fixed capital stocks of the ECCO sectors was estimated. Where possible, different methods were used to calculate the capital energy of a sector. Comparison of these results showed a satisfactory level of similarity. However, due to various uncertainties the results should be interpreted only at a high level of aggregation. Nonetheless the level of aggregation appeared to be sufficient for constructing the Netherlands ECCO model in its present state.

Research question 3

What are, under different pre-conditions, the possible strategies (related to the various world-images) to achieve a transition towards a sustainable society with relation to the throughput of matter and energy and the emission of fossil fuel related gases?

This question has been addressed in chapter 7 in which several scenarios were presented aiming at reducing the throughput of fossil fuels. From a physical perspective, reducing the throughput of matter and primary energy seems an obvious strategy to follow when aiming at sustainable development. A multitude of options, both demand-side oriented and supply-side oriented, are available for reducing the throughput. Rather than investigating the impact of many of these options in more detail, the long-term impact of two policies, namely investments
in energy conservation programs and the large-scale introduction of solar energy were evaluated in broad outlines. The emission of CO₂ was taken to determine the effects of changes in fossil fuel use on the emission of fossil fuel related gases. General conclusions to be drawn from these scenarios are:

- both energy conservation policies and the large-scale introduction of solar energy supply systems appear to be technically feasible options to reduce the throughput of primary energy. Moreover it should be noted that in contrast to the implementation of energy conservation measures the large-scale introduction of solar energy supply systems is surrounded with many difficulties and uncertainties and sets high demands for human skills as adaptiveness and inventiveness.

- from an energy point of view, the energy return of investment (EROI) of energy conservation measures indicates a large energy conservation potential.

- the long-term impact of energy conservation measures strongly depends on the assumptions made with respect to the (post 2015) technological innovations. To maintain the current level of energy efficiency, technological innovation should at least equal the increasing effort to extract and refine fuels from sources of decreasing quality.

- energy conservation measures lead to a reduction of the depletion rate of indigenous natural gas reserves, herewith extending the available transition time. Elongating the time period available to perform the transition towards a sustainable end state is important since such a transition needs to be accompanied with drastical changes in the social structures of a society. The implementation of such a ‘social transition’ calls for a sufficiently long transition period.

- measures aimed at increasing the efficiency of production processes (i.e. reducing the fossil fuel requirements per unit of output) initiate an accelerated growth of economic production. This trend interferes with the reduction of the throughput of fossil fuels as a primary condition for sustainable development. In order to avoid this ’flywheel effect’ structural changes in the organisation of the economy are required, having a profound impact on all aspects of society. It is the role of ECCO to assess the physical consequences of these qualitative changes of the economic system. Therefore it is necessary to develop a new generation of ECCO-type models with changeable allocation.
of energy investments. Thus within the NLECCO paradigm environmental policies aiming at increasing the efficiency of fossil fuel use induce economic growth measured in quantitative terms (volume growth). This phenomenon is conflicts with ’standard economic theory’ that takes economic growth as a basic condition for generating financial access space for investments in environmental policies. This contrast will be discussed further in section 8.5.3.

DISCUSSION

8.5 Introduction

The concept of sustainable development has played an eminent role in this thesis, both at a conceptual level and at an operational level. Throughout this study several aspects of the sustainability concept that are relevant within the scope of this study have been discussed.

ECCO is presented as a tool to assess the physical development potential of an economy taking into account sustainability conditions related to resource utilisation and environmental quality (see section 7.2). Below some essential aspects of sustainable development as discussed in this study are related to the ECCO approach in order to determine the role of ECCO in the sustainable development debate. Two (interlinking) issues that require additional discussion at the end of this study are addressed in the upcoming subsections. Subsection 8.5.1 discusses the need to study sustainable development from a system approach whereas subsection 8.5.2 goes into the role of ECCO when viewing sustainability from a holistic perspective. Finally, in subsection 8.5.3 some supplementary comments are made on the flywheel effect of efficiency-increasing technological changes as implemented in NLECCO.

8.5.1. ECCO and sustainable development from a system approach

Sustainable development can be applied to at least three interrelated subsystems e.g. the global ecosystem, the socio-cultural system and the economic system. Sustainable development implies that these three systems should be balanced simultaneously. The notion that these subsystems interact in a complex way and
that feedbacks within and between these dynamic systems might lead to emerging properties at different levels of complexity fuelled the realisation that opposite to the classical reductional approach, the wider systems perspective offers the possibility to understand more about the complex ‘real world’.

A central idea in the system approach is that the whole of the system is more than the sum of its parts. In this respect Peet (1992) argues that ‘the central idea is of a set of elements connected and related in order to form a whole, whose properties are not those of the components but are properties of the whole itself’. The three systems mentioned here can be specified as open systems. Open refers to the inflow of energy or information. The behaviour of open complex systems such as social systems or natural systems can be characterized as non-linear dynamic: cause and effect are distant in time and space. This makes it very difficult to recognize and implement the short-term and long-term effects of events occurring at present day.

The notion that human systems such as economic systems do not tend to an equilibrium state but are in a metastable state (also known as dynamic instability), depending on inflows of matter, energy and/or information to maintain this state is among the basic principles underlying ECCO.

Policies aimed at sustainable development are about actions to be taken in order that future development of the society is in harmony with ‘sustainability goals’. In the ECCO perspective it is recognized that to identify sets of policies more insights are required in the functioning of complex open systems such as an economy. Furthermore it is recognized that, since sustainable development deals with the future, the potential for change of the system under study needs to be identified at a time scale relevant within the sustainable development framework. Taking the ECCO approach as a point of departure it is studied whether or how the evolving economic system can physically sustain the goals that have been set, whether these goals are economic, social or environmental.

8.5.2. ECCO and the sustainability of subsystems
In the preceding subsection it is suggested that sustainable development can be applied to three interrelated subsystems. From this viewpoint sustainable development is concerned with simultaneously balanced sustainable economic, socio-cultural, and ecological development. Sustainable development implies that
developments in the economic subsystem should all be in harmony with developments in the socio-cultural and ecological subsystem. This distinction between different 'kinds of sustainability' raises the question whether a hierarchy exists in the distinguished types of sustainability. In this respect Baines (1989) argues that ecological sustainability is an underlying principle for sustainable resource use and waste management, which is, in turn, the basis for a sustainable society. According to Peet (1992) a sustainable society 'involves accepting the physics of ecological sustainability, sustainable resource use, and waste management. It also requires elimination of material poverty, integration of ecological, social, and economic considerations into resource management policies and decision making, and development of ecological and integrative sciences'.

The concept of sustainable development offers a means to explore the interrelationships between the natural environment, economic activity and ethics. Herewith sustainable development can be characterized as an ethical guiding principle (see also de Vries, 1989). Within the ECCO paradigm it is recognized that sustainability addresses to the global system in its widest sense rather than being restricted to economic issues alone and that social and cultural attributes of a society play their role too. Three primary conditions that should be simultaneously met when aiming at sustainable development are mentioned in section 7.2. These conditions are derived from the underlying notion that the natural capital stock acts as the physical basis of economic activity and that therefore a physical analysis should preamble the economic analysis and the social, cultural and political acceptability of the preferable direction of economic development. Taking the physical resource base as a starting point when considering economy-environment interrelationships, the natural environment is simultaneously regarded as a source of natural capital, providing life-sustaining materials and energy, and as a sink of waste residuals. The natural capital accounting approach adopted in this study aims at identifying the extent to which physical factors constrain a societies’ development potential.

Within the ECCO paradigm energy is applied as a numeraire as energy enables the production of goods and services to be accounted for in terms of one important characteristic. The use of the energy numeraire also underlines the notion that fossil energy cannot be substituted for by human made capital and that efficiency improvements (e.g. reducing the input of fossil fuels per unit of output)
are restricted by the second law of thermodynamics.

In this study ‘sustainable development’ refers to the physical basis of economic development. This restriction excludes ecological issues such as biodiversity conservation although it is obvious that the extraction of physical resources and energy are directly and indirectly related to a broad range of ecological factors that affect the quality of the natural environment. Since development is restricted here to economic development, socio-cultural aspects of development are not directly considered in the ECCO approach. This relates to the idea that, although it is recognized that the organisation of an economy is based on socio-cultural structures, the underlying production and consumption processes are physical.

Summarizing this subsection it can be stated that sustainable development refers to the complex economy-environment interface, explicitly taking into account ethical, moral and normative questions. Taking this notion as a starting point it becomes clear that there is no single criterion for sustainable development. In this thesis it is argued that energy provides an important means to describe the physical nature of economic activity although it is recognized that an energy based tool as ECCO only provides a part of the knowledge required to explore transition paths towards a more sustainable future. A multi-disciplinary approach is needed to gain the necessary information and knowledge and to develop sustainable development indicators that can be applied to guide policy makers who, to a significant extent, fill in our common future.

### 8.5.3 Energy efficiency improvements economic growth in NLECCO

One of the conclusions that was drawn from the scenario studies presented in chapter 7 concerned the notion that efficiency improvements in terms of reduced fossil fuel inputs per unit of output initiated an accelerated growth of economic output. This indirect effect of measures to be taken when aiming at sustainable development appears to interfere with a primary condition for sustainable development: reducing the throughput of fossil fuels. At first sight this might be seen as a disappointing outcome of the energy conservation scenarios. However, this result can also be interpreted as encouraging for energy conservation policies.

The notion that investments in energy conservation programs lead to an accelerated growth of economic production in the long term seems to be at
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variance with the standard economic argument that economic growth is a primary condition to set up a financial basis for policies aiming at preventing and reducing environmental losses and degradation. Two important reasons that underlie the current, mainstream economy theory based, initiatives to help alleviate our environmental problems through market-based incentives are mentioned here.

Firstly, within the mainstream economic perspective (short-term) economic success is considered to be equivalent to growth in economic production, mostly measured in terms of GDP. Since investments in energy conservation measures increase the short-term production costs, and do not directly contribute to an increasing production this type of investments is often regarded as inefficient. Secondly, within the mainstream economic perspective natural resources are regarded as an entity separated from the economy. This is demonstrated by the fact that market prices of natural resources often do not reflect the full costs involved in their use. More strongly, many natural resources have no price attached to their use at all. It might be clear that both reasons mentioned here are interrelated. Full cost pricing of natural resources would make energy conservation measures much more attractive.

The continuing economic growth in industrialized economies has been made possible by, among other things, increasing labour productivity through substitution of labour by capital and the increasing efficiency of production processes. The labour-capital substitution that marked the path of industrialization has been encouraged by the fact that, compared to capital and labour inputs, the costs of natural capital input has been low. By focusing on capital and labour as the central factors of production and not taking into account the full costs of environmental assets, the (external) costs of environmental loss and degradation have been imposed upon the society as a whole. Thus in standard economic theory, conclusions about an efficient allocation of factors of production are premised on the absence of natural capital as an essential means of production. From this it can be concluded that, when redirecting economic production and consumption towards a sustainable future, economic theory should emphatically include natural capital when dealing with allocation questions.

The scenario studies presented in chapter 7 showed that efficiency-increasing technological changes alone are not sufficient to reduce the throughput of fossil fuels through the economy. Policies aimed at sustainable development should be
guided by measures such that efficiency-increasing technological progress should dominate throughput-increasing technology. Furthermore, the direction of capital investments should be guided such that the scale of economic activity remains within the carrying capacity of the physical environment (see also Turner et al., 1994). Such a qualitative change of the structure of the economy and production and consumption activities is also within the scope of the WCED: ‘In essence, sustainable development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations.’

Within the framework of the metabolic modelling methodology of the environmental physiologist, ECCO-type models can be fruitfully applied to assess the ’hard’ physical constraints imposed upon the changes as indicated the WCED definition of sustainable development. Within this context, the amount of time available to perform a transition from the present unsustainable state towards a sustainable future is suggested here as an appropriate indicator for sustainable development.

8.6 Related research lines and prospects

8.6.1 Related research lines at IVEM

Before discussing in more depth some future research lines that build upon the work presented in this study, it is useful to relate the ECCO research project to some other relevant interrelated research lines carried out in the same time period at IVEM and other research groups1 in order to place the work done in this ECCO study in a broader perspective.

The complementary IVEM research projects are all linked through related research questions, and the exchange of concepts, methodological elements, tools, and research output.

At IVEM the concepts sustainability and quality as well as the transition towards a more sustainable future function as an interrelated set of guidelines for

1 The NLECCO research project is closely related to research carried out by the Edinburgh modelling group led by professor M. Slessor.
formulating frameworks for new research programs. The choice for these guiding concepts is based on the notion that the rate at which humanity settles its affairs cannot be sustained in the long-term future without reducing the carrying capacity of the natural environment. At IVEM the interface between societal metabolism and environmental metabolism and the related metabolic flows are studied at various levels from the viewpoint of material use and energy consumption in various research projects. In this area of research formal models are applied to link empirical, theoretical and normative criteria.

In NLECCO the physical basis of the long-term economic development potential is studied at the national level. Taking the global resource base as a starting point, in a complementary study carried out simultaneously with this ECCO study the concept of global sustainable development is implemented in terms of physical constraints that might limit a transition towards a sustainable global society in which the energy supply system is entirely based on renewables. The study takes into account the concepts of liveability and intra- and intergenerational equity (Mulder, 1995). The approach adopted in that study is noted as a backcasting approach; a sustainable, liveable and equitable global society at some future moment is taken as a point of departure.

In another study economic activity is regarded from an energy perspective by calculating and evaluating the cumulative primary energy requirements of all sectors comprised in the Dutch input-output table applying input-output energy analysis (Wilting, 1993). The knowledge gained in this project has been used to calculate an initial data set for the Dutch ECCO model. As a follow up of the calculation of the cumulative energy intensities, this type of research has been continued by evaluating the changes in the cumulative energy requirements of the production sectors over a twenty years time period and analyses of the energy intensity of household consumption items (Wilting, 1994). The results of this research line produce a much more detailed picture of the total level of services rendered than is possible at the present level of aggregation of NLECCO. Substitution issues at the end-use level can fruitfully be studied (and compared) by using both approaches.

Besides energy consumption, material use as well as the environmental impacts relevant within the context of energy consumption and material use can be regarded when studying societal and environmental metabolism. At IVEM a
dynamic lifecycle modelling methodology has been developed parallel to the cluster of energy studies. This line of research is addressed in Moll (1993).

8.6.2 Prospects
Various factors determine the direction of future research. Not seldom, throughout the different stages of a research project new questions arise the demand for additional research. Furthermore, additional research should fit within the overall framework of research projects already being performed. These two considerations are at the base of the suggestions for future research as previously presented in subsection 7.15.3. I conclude this study by describing three challenging lines of research that are relevant both within the scope of this ECCO study and within the framework of types of research I summarized in the previous subsection.

From the Netherlands ECCO study it emerged that various import-export conditions might significantly increase or reduce the physical potential of growth at the national level. To further investigate the implication of the role of incoming and outgoing physical flows it seems necessary to broaden the physical analysis from the national level to the international level. Such a research line also comes to meet the increasing integration and interdependency between national economies and economic sectors of different economies. These considerations are at the base of a Ph.D. project aimed at the development and application of an ECCO model of OECD-Europe. This project has been initiated at the beginning of 1995.

A second interesting research line that is closely related to the ECCO OECD-Europe project links the use of materials and the consumption of energy to study societal and environmental metabolism. In the Netherlands ECCO model the emphasis was on energy consumption for reasons already explained. Analogous to reducing the throughput of fossil fuels through an economy, reducing the rates at which materials are used has important consequences for the economy-environment interface in terms of physical resource depletion, energy consumption and the emission of waste residuals to the natural environment. The throughput of raw materials can be reduced by, among other things, technological innovations or materials recycling. To inquire into metabolic flows of materials, flows of (selected) materials need to be evaluated on a quantitative basis first. Subsequently the long-term impact of policy measures aimed at reducing the throughput of
materials should be evaluated. This type of research lies within the framework of the metabolic modelling methodology of the environmental physiologist. A way to implement this line of research is to extend the ECCO models with a satellite set of accounts of material use. The development of an ECCO model for OECD-Europe offers the opportunity to combine these research questions that are both relevant within the context of studying societal and environmental metabolism. Also at the beginning of 1995, at IVEM a Ph.D. project has been initiated that, among other things, addresses to the questions formulated above.

In addition to several ways to broaden the level of aggregation from the national to the international level, the final line of research mentioned here emphasizes the need for studies into the level of household consumption, herewith extending the level of aggregation from meso to micro level. In the Netherlands ECCO study the emphasis was on the production structure of the economy although it has been realized that a main objective of producing of goods and services is to satisfy human needs and wants and that consumer activities are also of significant importance when studying the physical aspects of economic activity. Therefore studying societal and environmental metabolism at the level of households appears to be an interesting field of research complementary to this ECCO study. The notion that a large variety of goods and services is consumed by households and that the consumption of this complex mix of goods and services is changing over time is at the base of the interdisciplinary and interuniversity environmental research program HOMES in which I am currently involved. This program in which several disciplines participate (i.e. environmental sciences, economics, spatial sciences, household sciences, behavioral and social sciences and political and administrative sciences) studies complex environmental problems by focusing on household metabolism in the broadest sense.

Such interdisciplinary research programs are important ingredients in the process of designing physically feasible, socially acceptable and effective policy instruments for reducing societal metabolism rates to levels that are acceptable under environmental quality constraints. In this context ECCO-type studies can make important contributions.