Modelling a Socially and Environmentally Sustainable European Union

A Decision-Support Tool

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„The SuE Model“

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1 Annex *Table of Content Technical Report*

1 Summary

SuE is the first system dynamics model of the EU 15 economy not based on financial, but on energy and material flows. That defines its weaknesses (no regional disaggregation, no direct modelling of fiscal measures) as well as its strengths (giving directly accessible information on the physical and thus the environmental effects, as well as on the economic and labour impacts of policy measures). It is not intended to provide predictions, but to compare policies and technologies regarding their impacts on economic, social and environmental sustainability.

The scenarios run with the model so far (and all users are invited to develop scenarios of their own) make clear that the current trends in the EU 15 are far from being sustainable: continued, they would increase unemployment, CO_2 emissions and material flows.

The scenarios also demonstrate that the traditional strategy of reducing unemployment by strengthening economic growth is not really an option: this would result in economically and environmentally unsustainable situations.

However, the model does not only deny acceptance of policy measures: simulations reveal that a carefully designed combination of policy measures, e.g. of shorter working weeks, earlier retirement, dematerialisation of the economy, energy saving, eco-efficient services and (in particular for the non-market services sector) slowed rationalisation (e.g. by low wage support schemes) can contribute to a development that brings us from the current path bound for catastrophe onto the road towards sustainable development.

For details of scenario results the busy reader may skip chapters 3 and 4 - containing background information on the model and the modelling process - and jump from the introduction straight to *Scenario Results* and the *Outlook* (chapter 5 and 6).

Although much more work on and with the model is needed before its potential to improve the information base of policy making has been exploited to the full, its usefulness is already obvious: be it a warning against too simple solutions.

2 Introduction

The project „Modelling Sustainable Europe“ was designed to supplement existing European initiatives towards forecasting economic and employment trends with a broadened and deepened intellectual framework in order to put short term economic developments in perspective with the long term goal of sustainable development.

Based on an extended and modified version of the existing system dynamics ECCO models, simulations have been done on the European scale in order to illustrate the short- and medium-term economic and employment impacts of sustainability policies. This should be generating a.o. insights on the future development of employment opportunities and on the policies needed to foster sustainable economic developments.

The output of the simulations has been analysed with a special emphasis on the structural change under way and the employment effects involved. Comparison of different scenarios provides us with some information about the employment effects of different forms of eco-efficiency policies.

Consequently, this study gives at least some helpful hints for the future prioritising of politics on the European level regarding environmental sustainability and the implicit employment effects.

The core purpose of the study described here is to develop and to apply a tool to improve the information basis for decision makers, enabling them to take the kinds of side effects and rebound mechanisms into account that are not obvious in policy planning so far. Results give at least hints at the most socially conscious policy towards sustainable economic development.

The bulk of our work was dedicated to the development of a model suitable for the purpose of policy decision support. Whereas this task has been successfully completed (although improvements are - as always - still possible), we have not exhausted the variety of policy strategies that might be tested. The reader is invited to identify, develop and test scenarios of his/her own.

2.1 Main objectives and core questions

2.1.1 Objectives

The implementation of sustainability suffers - amongst other things - from the lack of support from the business community and parts of political class. The opposing forces consist mainly of interest groups which see their interest violated if this particular version of structural change would come or at least come accelerated by politics. Instead of looking for the opportunities, they focus on the risks and go for avoidance or at least delay of sustainability policies.

Our model is designed as a tool to help identifying opportunities on the macro level, identify winning sectors and win-win-strategies and can be used to try convince at least some of the sustainability laggards of the chances this development has to offer.

The model does not instruct users what to do, but it is a helpful "mistake detector" identifying the unintended side effects certain policy measure might have. It does not (and is not intended to) substitute for political decision making, but tries to make the knowledge basis for these decision a bit more reliable.

In order to provide useful information about and possible scenarios for an economically, socially and environmentally sustainable development for Europe the project has addressed a number of key issues, based on different runs of the model. This includes efforts to

- develop a better understanding of the economic dynamics and their physical base, as well as of cost-relevant resource-based economic feed-back mechanisms and rebound effects,
- assess the impacts of implementing different strategies towards sustainable resource consumption upon consumption, investment and economic growth potentials,
- assess the related labour effects of different policy scenarios, based on economic developments
- analyse strategies towards sustainable economies, by offering the opportunity to compare policy strategies as refers to their respective impact on growth and employment,
- develop strategies to enhance the move towards sustainable production and consumption patterns while taking care in particular of the employment effects,

2.1.2 Core questions

The objectives outlined above have been the guideline steering the work throughout the project. However, to become operational they had to be translated into work packages tackling tasks formulated in the „language“ of the model system (and thus maybe sounding less ambitious).

Since policy decision support by the model is delivered through different scenarios and their comparison, we have formulated our core questions in terms of the kind of scenarios to be developed and linked these to the questions to be dealt with. So we defined the following sets of scenarios to be developed:

(1) to generate two different **reference scenarios** (with a reference period from 1995 to 2020) against which to compare all policies tested (for details see Technical Report Chapter 2)

- a business-as-usual-scenario, where trends observed for the validation period (1985-1995) have been extrapolated into the future. This scenario can furthermore serve as an assessment of the (un-)sustainability of current trends in Europe.
- a status-quo-scenario, where 1995-values have been maintained until 2020.

(2) In order to identify the changes that need to be introduced into the direction the EU-15 economy develops if negative consequences on the above mentioned variables are to be avoided for socio-economic and other reasons, **policy scenarios** are needed, which integrate a number of the above mentioned intervention scenarios and analyse their synergistic and/or antagonistic effects.

The basic question which all policy scenarios were linked to was: How much would - ceteris paribus - an x-fold reduction of the overall material flows (including energy, compared to current flows) over the next y years reduce the growth potential of the EU 15 economy? What are the implications on socio-economic variables/indicators such as employment, technology, well-being in terms of material standard of living etc.?

2.2 Assessing Sustainability

Sustainability today is considered a compound policy target with environmental, economic, social and institutional dimension. Due to the complexity of the task, so far little operational concepts for policies towards sustainable development exist - the curing of symptoms of unsustainability still prevails. Thus for a decision support tool like SuE, it is crucial not only to focus on these symptoms but look for the causes behind, the driving forces that must be changed to bring our societies and economies on the road towards sustainability.

Quite obviously, employment and income redistribution are two core driving forces in the social field, and both of them play an important role in the model presented here (as they have in previous models). Probably the key economic criterion on the micro level is the generation of enough surplus to maintain and modernise the capital stocks, e.g. enough profits for reinvestment (this should set a limit to the share of profits not reinvested, i.e. handed out to the shareholders). On the macro level this translates into the growth potentials the SuE model is analysing. Therefore investment of Human Made Capital HMC (see p. 52) is the key driving force in the model. The institutional dimension, however, is out of reach of a physical model. It comprises participation, social consensus and changing preferences, which are an exogenous variable to the model.

Whereas the interaction of economic and social sustainability has been a prominent research topic in economics and sociology for a long time (although usually not under the label of

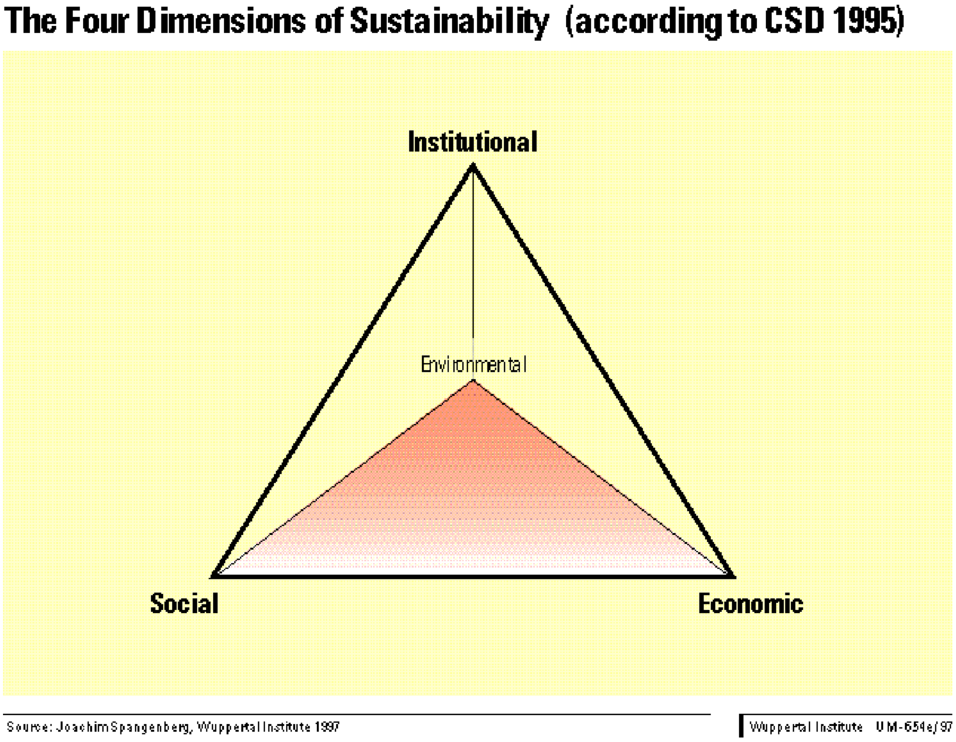

Figure 1: The Four Dimensions of Sustainability (according to CSD 1995)

sustainability), the link of both disciplines to the physical basis of our economies and societies has long been ignored. This is the gap SuE is helping to bridge. This is also the reason why we give some room here to provide the reader with background information on the physical dimension of sustainability and how to quantify it. We will come back to the economic considerations in chapter 4.5, 4.6 and 5, and to the social dimension in the scenarios (chapter 6).

2.2.1 The Physical Dimension of Sustainability

The innovative element in SuE, as compared to other economic models, is the physical basis of the model, rooted in energy and material flow analysis. This is all the more important, since energy and material consumption are at the core of the physical (un-) sustainability, which is thus directly assessable with the SuE model.

The project brought together a physically based model (the energy flow based ECCO model and the deep knowledge of the energy sector from Edinburgh) and the material flow analysis (concept developed and data gathered by the Wuppertal Institute). Going from the assumption that sustainable development is a development that does not exceed the carrying capacity of Nature, we used both energy and material flow analysis to assess the carrying capacity of nature - a concept based on hard science, not easy to quantify, but also not open to negotiations and compromising at will like many social and economic policy targets.

The concept as used here differs to some degree from the approaches familiar to policy makers: we try to derive targets from the assessment of the carrying capacity, quantify them in input terms (1) and try to identify the policy strategies suitable to reach them. Together these

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[1] Outputs like SO_2 and CO_2 are calculated on the basis of the inputs used. The model gives the information on these outputs, e.g. CO_2 reduction scenarios (see chapter 6) can be tested.

elements haven proven a satisfactory basis to assess the physical as well as the economic sustainability potentials of the EU 15 economy.

In order to get back to the broader picture of sustainability, the biological aspect has to be included to get a comprehensive view of the environmental dimension. This has been achieved by including a „biological module“ in the model, representing agriculture, forestry and fisheries and by including e.g. concerns about biodiversity in the scenarios (for this, the experience of the Tampere team was instrumental).

The purpose of an economic model, however, is not only in the environmental dimension, but in the better understanding of the interlinkages between the physical and the economic, social and institutional dimension. To this behalf, the model must be based on sound economic thinking (a task for the economists from Madrid and Wuppertal) as well as on reliable data (gathered by all teams).

2.2.2 Environmental vs. Economic Sustainability

The *physical* dimension of sustainability refers to leaving intact - for an infinite length of time - the stability of the internal evolutionary processes of the ecosphere, a dynamic and self-organising structure. The ecosphere, as well as the anthroposphere, is part of a larger system, and open to flows of either materials or energy, or both. Thus, the anthroposphere is an open, thermodynamic subsystem of the earth with respect to materials and energy. And the earth is - for all practical purposes - closed to flows of external matter but open to energy inputs, consisting mainly of solar radiation. It is primarily this window to energy inputs from space which provides room for a sustainable use of natural resources for humankind.

An economic system is environmentally-sustainable only as long as it is physically in a (dynamic) steady-state, i.e. the amount of resources utilised to generate welfare is permanently restricted to a size and a quality that does not overexploit the sources, or overburden the sinks, provided by the ecosphere. Without this:

- human economies would have to continue to draw on the *stock* of natural resources (e.g. high grade ore, crude oil, fertile soil) or, from an energy viewpoint, they would continue to use up low-entropy resources which sooner or later (i.e. sometime in the 3rd millennium) would be exhausted ([2]);
- the immense (and rapidly increasing) *flows* of resources through the global economies would continue to lead to an increase in entropy, resulting in a variety of unpredictable and irreversible environmental impacts. These will include slow, long-term changes such as global warming, as well as short-term irregularities such as storms, stronger hurricanes and flooding rivers, resulting from the destabilisation of ecological systems. This is equivalent to threatening the life-support system of humankind.

Whereas the size of stocks and their accessibility is an economic issue (and one of crucial importance for the long term economic sustainability), ecology worries about resource flows, since these are what contributes to environmental impacts ([3]). Thus, the *environmental* condition of sustainability is a physical steady-state system, with the smallest-feasible flows of

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[2] This could only be avoided if the resouce productivity would grow at a sufficiently high rate and without any limit, as the formal models in the neoclassical tradition show - if not even predict; unfortunately, this is against both common sense and the laws of thermodynamics.

[3] Hinterberger, F. et al., Material Flows vs. Natural Capital: What Makes an Economy Grow? (accepted for publication in Ecological Economics 1998).

resources at the (functionally, not geographically defined) input and output boundaries between the technosphere and the ecosphere.

2.2.3 The Concepts of Sustainability, Carrying-capacity and Critical Loads

As current experience with climate change, ozone depletion, acidification, eutrophication, forest decline, falling water tables, desertification, erosion and loss of biodiversity (to name a few) indicates, we are already at or even beyond the limits of carrying-capacity ([4]). Due to the technical skills of humankind, its innovative drive and the material growth of the anthroposphere, an infinite number of - ever-changing - disruptive interactions can occur at the boundaries to the ecosphere. Moreover, these impacts are characterised by non-linear relationships between stresses and responses. An unknown quantity of these effects can neither be detected within human time horizons, nor - were they found and measured - could they be attributed to distinct causes ([5]). This precludes the observation or theoretical calculation - and thus quantification - of the totality of concrete consequences of human (economic) activities on ecosystems ([6]).

Since neither the carrying-capacity nor the critical load can ever be precisely determined, the political application of these natural science-based concepts must necessarily take into account the precautionary principle. This means that decision-makers must steer the economy not by scratching the guard-rails, but by staying clear of them, keeping the economy in the middle of the road towards sustainability.

There are several options to describe the environmental impacts of humankind, all of which may be helpful for specific purposes. From our point of view, the chosen option needs to identify those characteristics that permit easy translation into policy action, in a directionally-safe manner.

- Using descriptions of the *state of the environment* (e.g. forest dieback or number of endangered species) can help illustrate the need for immediate action and guide curative measures. Due to the complex character of environmental systems, however, and in particular to the widely unknown rebound effects ([7]) it is hardly ever possible to clearly identify underlying causes, and thus not possible to design appropriate policy responses to the driving forces of environmental degradation.
- Taking the state of the *stocks of environmental resources* (existing biodiversity, reserves of fossil fuels and minerals etc.) as a measure may indeed be the basics of resource economy ([8]), but this provides hardly any information about the environmental situation and trends: Coal in the ground does not cause environmental harm, unless it is mined and burnt.

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[4] The maximum continually-supportable rate of output has been called the *critical load,* and the maximum continually-supportable rate of flow, the *carrying-capacity*.

[5] Hinterberger, F., Biological, Cultural and Economic Evolution and the Ecology-Economy-Relationship, in: Van den Bergh, J.C.J.M. et al. (Eds.), Towards Sustainable Development, Concepts, Methods and Policy, Washington 1994; Hinterberger, F., On the Evolution of Open Socio-Economic Sytems, in: Mishra, R.K. et al. (Eds.), On Self-Organisation, Berlin/Heidelberg 1995; Spangenberg, J.H., Evolution und Trägheit, in: Kaiser, G. (Ed), Kultur und Technik im 21. Jahrhundert, Frankfurt 1993.

[6] Schmidt-Bleek, F., Wieviel Umwelt braucht der Mensch, Berlin/Basel 1993.

[7] Rebound effects are here understood to include all effects that overcompensate efficiency gains by additional growth, at least partly due to the reinvestment of the additional income from the efficiency gains.

[8] This is no easy approach since the stocks, as well referred to as natural capital, are hard to quantify. Financial valuations based on current market prices are only applicable to marketable goods, and "willingness to pay" anlyses give information about cultural values of the people interviewed but contain no information about the ecological value of the stocks concerned.

Resource stock assessment is therefore an inappropriate measure for the use of environmental space.

Unlike stocks, however, *resource flows* are of key importance for environmental deterioration, providing good estimates about the use of environmental space. The throughput of resources, however, must be measured at a well-defined point to permit the reproduction of data and international harmonisation. The most appropriate choice for this point of measurement is obviously the border between the ecosphere and anthroposphere (or human sphere, as W. Rees calls it). Since there are functionally two of these borders, on the input as well as on the output side, we now have to compare the usefulness of choosing one of these options.

2.2.4 Input vs. Output Measurement

Traditional environmental politics has focused on regulating the output side of the economy. Pollution abatement equipment, BAT (best available technology) for emissions reduction, critical loads assessment, all these measures are different ways of reaching the same goal: influencing the quality and quantity of the outputs our economy releases into the ecosphere (only relatively recently has the insight grown that products are the main emissions of industrial societies, and product regulations are just beginning to be included in environmental regulation). Output-related regulations usually aim at qualitative product characteristics, relying on command and control mechanisms.

Environmental research as well has focused on the interaction of anthropogenic outputs with the ecosphere, with great effort invested and limited - albeit important and helpful - results.

On the other hand, input-related regulations have long been known, in the form of fleet efficiency regulations and licences for mining (relative-input limitations) and logging or ground water extraction (absolute-input limitations). Output-related regulations are focused on quantities to be reduced, rather than on qualities to be forbidden; they are therefore the prime choice for the application of financial incentives and other market-based instruments.

For operationalising sustainability, then, which approach is more suitable ?

- Whereas the number of materials entering our economic systems is limited to 50 - 100 abiotic substances including energy carriers (9), output control has to handle about 100,000 substances from the chemical industry alone, each of which interacts in various ways with the ecosphere and the other substances emitted.
- Whereas the number of points of entry into the anthroposphere is limited to some 20,000 (10), the exits are beyond any control: every smokestack, every exhaust pipe, every waste dump, every drainpipe is such an exit (Figures based on estimates for the German economy).

In designing appropriate policy measures, focusing on the inputs can provide higher regulatory efficiency with much less effort in control. This becomes particularly important when the introduction of market-based financial instruments is considered: regulating outputs with financial instruments will either need a new control bureaucracy or generate the risk of massive free-rider effects.

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[9] Here e.g. limestone, crude oil or hard coal are counted as one substance each. Substances without economic value are excluded.

[10] Extraction points of minerals, energy carriers and water, where they enter the antroposphere, but excluding air. An oil field e.g. is considered one entry point.

2.2.5 Subjects of Measurement

The next step is to define which inputs need to be analysed to provide a comprehensive and directionally-safe, but simple, assessment ([11]). Every use of environmental resources needs:

- a realm where it can take place,
- materials as the physical basis of the agents and their instruments, and
- energy to provide the work (in the physical sense) involved in the use.

Thus, we propose energy, materials and land to be the core categories of our analysis. Each of them can - if necessary - be split up into environmentally-relevant subcategories such as e.g. air, water, soil, biotics and minerals for materials, fossil, renewable and nuclear for energy or build-up, pasture and agricultural for land use.

Consequently, we have chosen to define the flows to be controlled in order to approach sustainability, in terms of the physical inputs of materials, energy and land-used into our economic system.

2.2.5.1 Land Use

For land use, the need for a sustainable pattern is evident from the threats to biodiversity and soil fertility loss, in Europe particularly due to erosion and the leaching of micro nutrients. However, so far no broadly accepted measure for biodiversity exists, and probably none can be developed to quantitatively cover the ecosystem, species and genetic level of biodiversity, not least because of the lack of data. Similarly, no international agreement has been reached on a standard classification methodology for measuring soil quality losses, although some work is under way on behalf of UN-CSD. Consequently, the criteria to be proposed here for strategies towards a more sustainable land use have to be more qualitative than quantitative in nature ([12]) at least for the time being.

2.2.5.2 Energy

The relevance of energy flows is beyond any (serious) doubt even in the political arena, as illustrated by the Kyoto negotiations. This not due to expected shortages of supply like in the 1970s, but based on the predicted and partly visible effects of fossil fuel use, in particular on climate change.

This focus on the sink instead on the source problem is appropriate, since the sinks seem to offer the more restrictive bottleneck, but that does not mean that the resource issue could be simply forgotten. Already today it becomes obvious (as predicted by Meadows 1992 ([13]) and confirmed by material flow data from the Wuppertal Institute) that market prices do not reflect the increasing of low entropy resources, physically expressed by the ever increasing efforts needed to explore, win and refine them.

Consequently, from an economic as well as an environmental point of view, increasing resource productivity (getting more out of less) is the solution to be headed for. Whereas the reduction of consumption is targeted at the causes of the current problems, most other

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[11] Simplicity is not only an important precondition for administration and decision makers to use the concept for policy guidance, but as well to communicate the goals set and the results achieved in a transparent and reliable way to a broader public. This is the key task for indicator development, see e.g. Spangenberg, J.H., Environmental Space based Indicators: A Compass on the Road towards Sustsianability, in: SCOPE (Ed.), Sustainability Indicators, London 1997.

[12] For more details see Lehmann, H., Reetz, T., Sustainable Land Use, Wuppertal Paper 26, 1994.

[13] Meadows, D., New Limits to Growth,

approaches are focused on moderating the symptoms - helpful as they can be, these efforts will only succeed in combating the problems if the underlying trends are reversed.

2.2.5.3 Material Flows

Each use of a natural resources, be it water for drinking or cooling, minerals for industrial production or construction, land for agriculture or air for breathing inevitably uses materials and increases the entropy of the overall system. We consider the total material flow an appropriate measure of disturbance, and we regard the reduction of material flows a necessary (although not in all cases sufficient) means of reducing the pressure of humankind on the global environment in a directionally-safe manner. The goal of reducing material flows is proactive, in that it does not refer to individual symptoms of environmental damage, but to the overall impact on the system, thereby trying to prevent future damages as well as reduce the current potential for disturbance. Although a *direct* link of material flows to environmental stresses is evident only in a minority of cases (as was the case with total energy consumption until the threat of global warming from CO_2 emissions was taken seriously), many of the well-known symptoms of environmental degradation, from declining fish stocks to reduced fertility due to e.g. persistent chemicals accumulation, can undoubtedly be traced to intense material flows as the indirect cause.

The present levels of consumption and investment in the rich countries (with 20% of the world's population) are responsible for ca. 80% of the world's natural resource use, whereas the picture is reversed for poor countries. Moreover, existing investigations of long-term trends in the *intensities of use (IU) of materials* ([14]) *and energy* ([15]) suggest that these tend to grow rather than decrease in the early stages of development - as a consequence of both structural and technological changes through time. Thus, equity concerns as well as feasibility considerations demand that resource efficiency increases dramatically in industrialised countries to allow for fair shares of the common heritage of mankind to be available to all world citizens ([16]) without significant reductions of the quality life in the North. Consequently, we consider dematerialisation as an operationalisation of key aspects of the normative concept of sustainable development.

2.3 The Project Development Process

The starting point of our work was to get familiar with our tools: the ECCO model (see chapter 3.2), the sustainability targets derived from the environmental space calculations (see chapter 3.4) and the methodology of material flow accounting (see chapter 3.3). This, together with some more economic considerations (see chapter 3.5) and the input provided by the advisory boards of the project (see chapter 3.6) led us to define our targets in terms of desirable model characteristics and modifications, extensions and adjustments as compared to existing models.

However, we also faced a number of restrictions when comparing the desirable and the possible. They partly resulted from the significant, but limited resources in time, money and

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[14] Basic references are: Malenbaum, W., Law of Demand for Materials, in: Proceedings, Council of Economic, AIME Annual Meeting, New York, 1975; Fortis, M. Stadi della Crescita e Consumi di Materialio Industriali, Dip. di Economia dell'Università di Ancona, Studi sullo Sviluppo n. 4, 1993; Considine, T., Economic and Technological Determinants of the Material Intensity of Use, Land Economics, 67(1), pp. 99-115, Feb. 1991; Jaenicke, M. et al., Umweltentlastung durch industriellen Strukturwandel?, Berlin, 1992.

[15] See for example Proops, J.,, Energy intensities, I-O analysis and economic development, in Ciaschini, M. (Ed.) Input-Output Analysis, Current Developments, Chapman and Hall, London 1988.

[16] Carley, M., Spapens, Ph., Sharing the World, London 1998.

manpower available to the project, to the tasks as described in the contract and finally the inherent limitations that any approach necessarily has.

Throughout this handbook we have noted those ideas that could lead to future improvements, if resources to implement them were available. Here a brief overview is given on what has or what has not been achieved.

2.3.1 Developing an EU-15 data base

An essential step in preparing SuE was an input-output table in both economic and material flow terms for the entire EU-15 (see chapter 3.3.4). 1985 was chosen as the year of model initiation, so as to provide a ten year time-series for validation. Fortunately, an economic EU 12 input-output table existed, which was amplified to EU 15 from OECD data.

The material input-output table is based on the 1990 German physical input output table (PIOT)[17]. In a major effort the extension to the European scale (EU 15) has been done using a variety of data sources (described in detail in the Appendix of the Technical Report). In its current state, it can be considered a good first approximation of a European physical input output table (EU-PIOT).

2.3.2 Integrating Material Flows

One important extension of the ECCO-methodology with respect to its focus on physical resources is the integration of material flows. The implementation is based on the concept of the *Physical* Input Output Table((18)), thus not only accounting for product flows of traditional input output tables *in physical terms (tons)* but also for material flows between the natural environment and the econonmy. It especially focusses on the input side of material flows (in three categories - abiotics, water, air) where two main aspects have been taken into account. On the one hand, - as a measure for the environmental impact caused by the EU economy - the total material input into the European economy is determined which consists of domestic raw material inputs and imported raw materials(19). On the other hand, it is traced back how much material input is activated - directly and indirectly - by each sector’s deliveries to final demand to be interpreted at the highly aggregate level of sectors as MIPS-values (Material Input per Service Unit)((20)). The latter are determined by means of Input Output Analysis making use of the dynamic version of the intermediate transaction matrix driven by corresponding quantities at "embodied energy level".

2.3.3 Economics

For a number of reasons, not least to accommodate the priorities of material flow accounting, but also rooted in economic analysis, model sectors have been defined (see chapter ´4.2.4). In particular, as compared to earlier ECCO models, the manufacturing sector was split up to give room for a separate construction sector, and market services got a sub-sector reflecting eco-efficient services.

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[17] Stahmer, C., Kuhn, M., Braun, N., Physical Input-Output Tables - German Experiences, London Group Meeting on Environmental Accounting, Proceedings Volume, Stockholm 1996; see also chapter 3.3.4.

[18] see chapter 3.3.4

[19] In contrast to the Total Material Requirement (TMR) (chapter 3.3.3) - which recently has been accepted by the UNCSD as official ecological indicator to be determined for all national economies - the indicator TMI as calculated by the SuE model does not comprise "rucksacks" (i.e. materials not used) of imported raw materials. (For a discussion of orders of magnitude see section 3.3.4.) Due to limited time resources a complete analysis of rucksacks of EU imports could not be done in the frame of this project. However, it could be subject of a forthcoming study.

[20] Schmidt-Bleek, F., Wieviel Umwelt braucht der Mensch?, op. cit.

To satisfy the requests (e.g. from the advisory boards, see chapter 3.6) to stronger reflect demand side of the economic mechanism, a simple structure has been integrated, offering an optional consumption driven modus of investment. Furthermore, load factors have been introduced to permit users to model the situation where demand is not sufficient to utilize the full production capacity (for details see the technical handbook).

2.3.4 Deliverables

2.3.4.1 Software: Model and Front End

SuE is a simulation model with a non-linear feed-back structure. The time frame is the period 1995 - 2020, though this can be extended. Each team had the responsibility for developing parts of the model, which were combined into a whole, inserting them in a modular way. A large amount of time-variant data is generated, all of which represent criteria of performance, that is, indicators, referring to the objectives and core questions already outlined.

However, the task of defining strategies and the interpretation of results lies with the user: the model points out consequences of parameter changes reflecting policy measures, but does not optimise for an externally set goal.

Beyond the tasks defined by the contract, we identified the need and have accepted the challenge to develop a user-friendly front-end, which provides a layer of accessibility on top of the underlying equations. It is a Windows-like program, which leads the user through the process of exploring policy options, and allows the user to change coefficients and view the effect. In a broader sense it guides the user around issues which form the background of the project.

2.3.4.2 Developing the Scenarios

The scenarios developed have their roots in the ”Towards Sustainable Europe” study (see chapter 4.4 ([21])). That study, which was essentially normative, indicated that to achieve sustainability would require reductions in material, energy and land inputs, for two reasons. Firstly to reduce the pressure on the limited environmental space available in the European Union countries. Secondly to reduce resource consumption to such a degree that a global equality in resource availability can be reached, also in the so-called less-developed countries of the world as they struggle to develop their economies.

These concerns have been reflected in scenarios focusing on dematerialisation, eco-efficient services, energy saving etc. In a second step, elements of these scenarios were brought together to develop a variety of more integrated sustainability scenarios. For scenario descriptions and their results see chapter 4.

2.3.4.3 Conclusion

SuE is both more and less than a national ECCO model (see chapter 4.2). It is necessarily less, because the EU 15 is a large, highly varied territory and - at least in some respects - without the consistent statistical data base to be found in many national statistics.

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[21] Spangenberg, J.H. (Ed.), Towards Sustainable Europe, A Study from the Wuppertal Institute for Friends of the Earth Europe, Luton et al. 1995.

On the other hand it is more of a model because the research on material flow analysis see chapter 4.3) and the materials/economy interaction has been incorporated ([22]).

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[22] Schmidt-Bleek, F., Wieviel Umwelt braucht der Mensch, op. cit.; Adriaanse et al., Resource Flows: The Material Basis of Industrial Economies, A Joint Study of the World Resources Institute, Wuppertal Institute, the Netherlands Ministery of Housing, and the Japanese National Institute for Environmental Planning Washington 1997; Hinterberger, F., Luks, F., Stewen, M., Ökologische Wirtschaftspolitik, Basel et al. 1996 (forthcoming in English as: *Ecological Economic Policy, 1997)*; Spangenberg, J.H. et al., Material Flow Based Indicators in Environmental Reporting, op. cit.

3 Method description

In developing the SuE model, we have based our efforts on existing experience, as described above (chapter 2.3). Therefore we here present those background experiences to provide the reader with full insight into the philosophy as well as the methodology in and behind the SuE model. This includes a brief introduction into modelling in general and into system dynamics in particular, as well as some basic information about the Sustainable Europe concept and ECCO models, which have been the basis of developing SuE.

3.1 Possibilities and limits of modelling and system dynamics

Before going to propose any concrete approach to our SuE model, it is necessary to be clear about the purposes and limitations of the modelling process, as well as of any particular model. Further, it is important to understand the basic patterns of behaviour of a model (i.e. how it arrives at it's results). This chapter does not go into the detail of the mathematics underlying the systems dynamics simulation, but rather to consider in a qualitative way the behaviour patterns typical of a non-linear model such as SuE.

3.1.1 Purpose of Models

A model is a description of elements of the behaviour and an assumption about the structure of a system of some sort, usually a part of the real world. The selection of elements and behavioural patterns to be reproduced by the model depends on the questions to be asked and the modeller’s assessment of the characteristics regarded important.

Models - like indicators and other policy instruments - are tools to reduce the complexity of the real world to a limited number of factors considered important for a specific purpose. This simplification is necessary in order to be better able to analyse these factors, their effects and their interactions. In this sense, models can be built as tools for exploring the behaviour of systems, without having to interfere with the real system. Testing the potentially disastrous effects of an economic policy on a model is far kinder than trying it out untested on the real world!

Further, models may be understood as an attempt to understand the workings of a system better, although, naturally, some understanding of the system is required before the model can be built. Here it is often useful to further simplify the description of the system being studied, i.e. to simplify the model structure, so that it's behaviour is simpler, and easier to interpret. When building a model, typically one will begin with a very simple structure, and refine the structure, adding more complex, realistic behaviour, once the simple structure has proven itself satisfactory on the basic level it represents.

This raises an important point about any modelling process: models can only partly reflect the real world system they intend to represent. When modelling a system as complex as a national economy, the degree of simplification is very great, and hence the results obtained from the model will be approximations to the behaviour of the real economy. No matter how complex the model structure, there will always be some unpredictable factors operating in the real world which may affect the real economy in a way that the model is unable to predict.

In economics, models are technical realisations of economic theories, reproducing futures theory predicts (e.g. general equilibrium models). On this basis, modelling is used to assess the future of an economic system under different external conditions. This does not necessarily mean that the model is being used to make supposedly accurate predictions about what will happen. The results of models are always limited in a double sense: by the structure, which may not properly reflect all factors relevant to theory, and by theory itself. Theory as such is a simplification of reality, so some more or less influential factors from the real world will inevitably be left out.

Opposed to that stand model like SuE not explicitly guided by a specific theory ([23]). In these cases, the art of model making and of assessing model results lies largely in an ability to capture the key driving factors for the problem being studied, in as simple a fashion as possible. Key factors in this sense are those most strongly influencing the system behaviour - a fact that makes a close link to experience an evident necessity in order to bring the model close enough to reality. Once this effort has proven successful, a given model can be considered to be an early warning system, in that it can indicate the effects of existing behaviour patterns or alternative options when extended through to their logical conclusions.

3.1.2 What is a Model?

All complex models consist of elements or components, their modes of interaction (structure), and - last but not least - data. The anatomy of a model is defined by the way the components relate to one another. Components are subsystems or subunits, fed by input data or data from other subunits, processing them according to their own structure (fixed in algorithms), and delivering them to other subunits or as system output.

3.1.2.1 Structure

The structure of a model is a description of the way in which the components of the real world under analysis are believed to interact. The algorithms of the model, an expression of the structure, transform the model input into output.

3.1.2.2 Data

A model has two types of data. Input data is fed into the model before it is used, specifying any initial conditions and values. Input data refer to empirical findings and must be researched or otherwise acquired by the model user. Output data are the results produced by the model, as a result of the input data and model algorithms.

In an ideal world, the input required by the model is dictated by the model structure. In reality, unfortunately this is not always the case, since the availability of data in a suitable form often limits the type of structure that the model may use.

It is also worth mentioning quality of data here. The more reliable the information one feeds to the model, the more reliable the results may be (provided that the structure is adequate).

Thus a model can be seen to exist on two levels: as a series of mathematical statements relating numerical data, and as a series of relationships between system features. The mathematical structure and the algorithms of the model should arise from an examination of the system to be studied, and a subsequent formulation of the way in which the system operates regarding the topic under study.

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[23] Even these models are obviously not theory-free. They have to make certain assumptions about the functioning of the economy (equivalent to an investment function, a production function etc.), which are the basis of some core structural elements of the model.

3.1.3 System Dynamics Modelling

A number of families of mathematical structures exist. The one used by the SuE model is system dynamics, or deterministic linear dynamics. Without going into great mathematical detail, the basic features of this family of models, and what these features bring to the modelling process in terms of realism and complexity of behaviour will be discussed.

3.1.3.1 System Dynamics Models

In simple terms, a model - and more generally, any set of equations - is termed deterministic if it behaves in a precisely predictable fashion, such that, given a well-defined set of starting conditions (input data), the output data of the model follow a pre-determined pattern. Further, with knowledge of the set of equations, it is possible to calculate the output for any future time without having to work out the output values for all preceding times. This means that for every $n > 0$ the output of t_n can be calculated using only the information about the algorithms and the data of t_0 (a property known as determinism), without any information needed about the situation at t_i with $0 < i < n$.

The need for this information, however, is exactly what characterises a stochastic model: output at each t_n can only be calculated based on information about the state of the system at t_{n-1}. Consequently, the state at t_n in such stochastic systems is unpredictable at t_0, as long as not *all* t_i $(i = 1,...,n)$ have been calculated.

In addition, there exist *non-linear* models, and the behaviour they produce is quite complex, even if the model as such is relatively simple. This approach to modelling has its merits in (re-)producing complex and chaotic behaviour, however, it also has its flaws. Unless the time steps calculated are infinitely small (impossible in practice), an error will occur during the calculation. And, the smaller the model's timestep is, the longer it will take to run. So, when running a non-linear model, one must reach a compromise between speed and accuracy.

The type of model that is used in SuE is basicly linear and deterministic, however some table functions introduce some non-linearity in the model.

3.1.3.2 Storages

In a linear model, each variable is set, directly or indirectly, as a function of time, and only of time. In system dynamics, a variable of this type is referred to as a storage, or level variable. Aspects of past states of the system are stored in these variables, and brought forward to bear on current system behaviour. For example, in a population level variable, the gross birth rate increases the level of the population, and the gross death rate decreases it. The overall effect on the level depends on the relative sizes of these rate variables. Most level variables will tend to be in a dynamic situation of this sort, with different rate variables increasing and lowering them simultaneously.

Storages/levels occur frequently in real-world systems. In addition to the case of populations already mentioned, consider the number of hospitals or schools in a city, the amount of pollution in a lake or river, or the amount of fuel in the tank of a car.

3.1.3.3 Delays

Delays are another feature of real-world systems, through which information on past states are transferred into the present. Delays may be of two types, material or information.

Material delays occur due to the fact that transformation of material from one state to another cannot always be effected instantly. Consider the raw materials required to make a complex piece of machinery, say a mining vehicle. In constructing a model of a mining economy, a level variable to represent the stock of mining machinery would need to be created. This variable would control the rate at which it was possible to extract metal ore from the ground. In wishing to increase the stock of machinery, and hence the mines' output, raw materials and energy would need to be diverted towards building more machinery. The materials and energy could be diverted quickly if desired, but realistically it would not be expected that the machine would be fully operational as part of the operational stock of equipment until some time later. Thus, the rate of increase of the stock of mining equipment would depend not on how much material and energy we diverted towards building it up now, but rather on how much was diverted this time ago. Again, the past behaviour of the system determines its present state.

In an informational delay, the delay is caused by the rate at which information is able to reach the bodies responsible for reacting to the information. This type of delay is a necessary feature of most planning activities, and of policy making. This will only be a serious problem, of course, if the system is able to change significantly over the same or an even shorter time scale as the delay length.

Delays of both types (material and informative) occur frequently throughout the real world, and have a great impact on the behaviour of both human and natural forces.

Well-known examples include the debates on the role of time lags in the risk assessment of deliberate releases of GMO´s (informational delay) or the role of system inertia causing non-linear system behaviour in ecosystem exposed to acidification (material delay). Another important example is the long material delay occurring in the mixing of gases between the troposphere and stratosphere (the lower and middle layers of the atmosphere). CFC gases emitted in the troposphere take approximately thirty years to cross this boundary, so that damage effected to the ozone layer by these chemicals is related to emissions not from present human activities, but rather the activities of thirty years ago. This in turn gives rise to an informational delay of some thirty years, as no physical symptoms of CFC release appeared in the environment until some thirty years after they were being released in large quantities. Note also that the delay gives rise to a level of CFC gases sitting in the troposphere. This level is added to by the rate of emissions of the gas at the planet's surface, and reduced by the rate of entry into the stratosphere.

In system dynamics modelling pure delays usually are not used but they are replaced by a series of first order processes.

3.1.3.4 Feedback Loops

A feedback loop occurs where two or more variables exert a mutual direct or indirect influence upon one another. Feedback loops are best described by examples.

Returning to the model of the mining activity described earlier, consider the relationship between the stock (level) of mining equipment and the rate of ore extraction from the ground (a material flow, created by the use of man-made capital to exploit natural capital ([24])). Increasing the stock of mining equipment requires a diversion of materials and energy from other areas of the economy. Now consider the source of those materials and energy. The mining equipment will be largely made of metal, available initially as metal ores, extracted by mining. These ores require energy to be refined, smelted and shaped, mostly as heat. Coal, for example, is a suitable source of this.

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[24] On the risks of misunderstandings associated with the term of natural capital see Hinterberger/Luks, Schmidt-Bleek, Material flows vs. "Natural capital" - What makes an economy sustainable ?, in: Ecological Economics 23 (1997) 1 - 14

So, in building up the mining industry, a supply (material flow) of metal ores and coal, or similar, needs to be secured. The greater the supply of these, the faster the stock of mining equipment can be built up. The greater the stock of equipment, the greater the supply of coal and metal ore. Thus both sides of the industry promote the growth of the other. This is known as a positive feedback loop, i.e. a feedback that reinforces any existing trend. Consider the situation of decline, where the coal or ore supply was diminishing. If the availability of inputs to the stock of equipment declined the same way, the rate of extraction would decline further.

Positive feedback loops are often unstable (depending, of course, on the dynamics), and, unless their behaviour is moderated by other factors, they will result in either an imploding or an exploding system - in the real world as well as in the model. In the real world, however, the every precondition of their long-term existence is that they are somehow controlled or moderated, since otherwise they would have imploded or exploded for long (unless the feedbackloop includes an extreme delay of e.g. a generation or more). Consequently, the functioning of „pure“, uncontrolled positive feedbacks is a good example of how some kinds of real world features can only be analysed by using a model.

Negative feedback loops, in contrast, are the mode of interaction where the growth of one factor restricts that of the other. This often provides a stabilising influence (depending again on the dynamics of the system), pushing the system in the opposite direction of any perturbation. A common example of a negative feedback loop is the temperature-controlling mechanism found in warm-blooded animals, known as homeostasis. In humans, several homeostatic mechanisms operate to keep the body close to it's original temperature of around 37 Centigrades. Perspiration is one; when the body gets too hot, glands release liquid droplets onto the skin, which subsequently evaporate, cooling the skin in the process. Shivering is another, whereby a cold body experiences involuntary muscle movements in an attempt to produce heat.

When coupled to delay functions, negative feedback loops tend to result in oscillating model behaviour, around an „ideal value“ for each variable in the loop (this again depends on the dynamics of the system). The feedback attempts to compensate for old perturbations rather than current ones, and so never fully "catches up" with the current state of the system. The Lotka-Volterra relationship between predator and prey, a classic system dynamics model from population ecology, is a prime example of this ([25]). As a general rule, the longer the delay time, the larger the oscillations will be.

3.1.3.5 Influence Diagrams

Influence diagrams are a useful means of characterising the interaction of components in models, however, they must be backed up by more numerical information to provide full understanding of the model. Importantly, they provide a good means for identifying feedback loops within model structures at first glance.

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[25] For a number of examples see e.g. May, R.M., Theoretical Ecology, Oxford 1976.

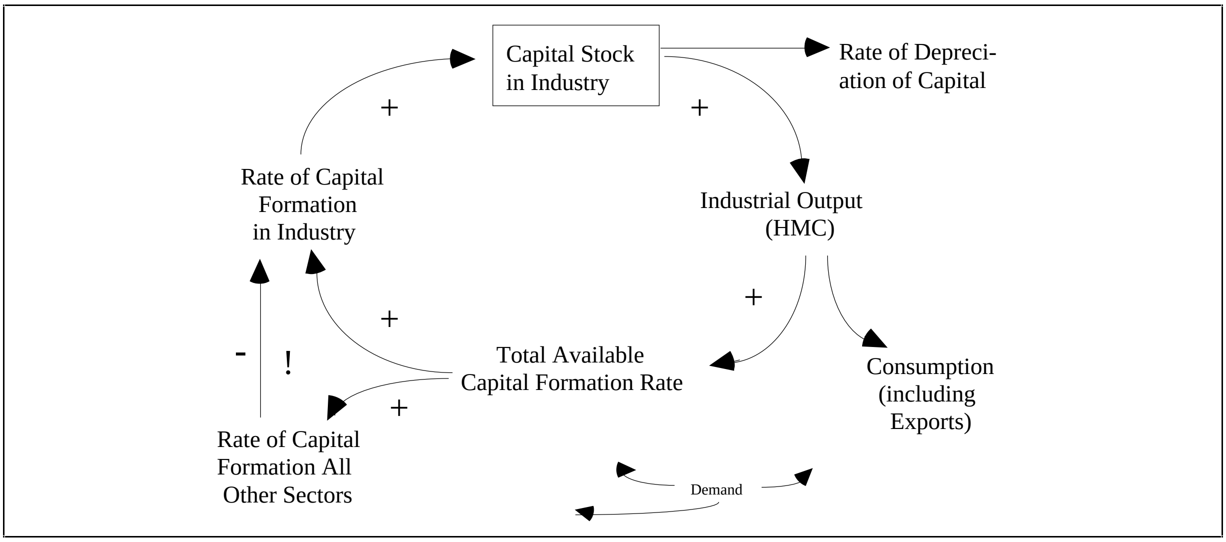

Figure 2: Influence diagram of the core model structure and one of the core feedback loops (with focus on the constraints for capital formation)[26]

In an influence diagram, all dynamic variables (those that change value over time) in the model structure are represented as points on the diagram. Arrows connect the variables together, indicating no physical or information flows, but merely lines of influence. An arrow points from an influencing variable to an influenced variable (i.e. cause to effect). A small sign, either plus or minus, is written by the arrow head, to indicate whether the influence is complementary or antagonistic.

A complementary influence, indicated by a plus sign, means that the influenced variable will move in the same direction as the influencing variable. An antagonistic influence, indicated by a minus sign, means that the influenced variable, will move opposite to the influencing variable.

Feedback loops appear in influence diagrams as a closed circuit of arrows all moving in the same direction. In a positive feedback loop, the number of minus signs will be even (including zero). In a negative feedback loop, the number of minus signs will be odd. We will use influence diagrams to illustrate the basic structure of the SuE model.

3.2 Roots 1: An ECCO-type Model and its Basic Methodology

The model of a socially and environmentally sustainable Europe (briefly called SuE) presented in this documentation, has been developed based on the ECCO methodology, with a number of extensions, amendments and structural changes. They affect the dynamic as well as the kind of indicators generated as output of the model. Nonetheless it seems important to first present the basic ECCO methodology and development procedure before going to introduce the refined SuE model.

3.2.1 The ECCO Methodology

The aim of the ECCO methodology is to provide a tool for examining the overall impact of specific policies upon an economy (usually a national economy). The method employs a computer model, which describes the activities of the economy under study, in terms of the

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[26] The exclamation mark beneath the arrow from RCFOS to RCFIND is used to stress the fact that investment requirements of all other sectors "dominate" those of the industrial sector (residue theorem of investment concerning the available capital for the industrial sector).

energy resources used. Applying the principles of energy analysis, the ECCO methodology attempts to identify the underlying physical limits operating upon an economic system, in terms of that economy's ability to extract natural resources and process them into capital and consumer goods and services.

Typically, the model should describe all (significantly large) sectors of the economy, providing a holistic overview of the way in which that economy processes raw natural resources (both energy and non-energy). This description need not be very detailed, so long as the underlying behaviour of the economy as a whole can be replicated sufficiently. It is important that the interactions between the different sectors of the economy, as well as the internal behaviour of each sector, be represented within this basic structure, as the aim is to provide a holistic description of the behaviour of the economic system.

This holistic structure can then be employed to determine the holistic impacts of any given policy, by comparing the outcome of a model simulation in which that policy is adopted with a "business-as-usual" scenario (provided, of course, that all other conditions within the two model simulations are identical). This method has advantages over traditional impact analysis techniques in that the "knock-on" effects of a policy in one sector are automatically carried through to other sectors of the economy, and possibly return to the sector of interest, via feedback loops. Thus the counter-intuitive nature of the real world is represented to some extent.

Consider, for example, the case of energy conservation policy in a particular sector of the economy, say, domestic housing. Better insulation provides a reduction in the direct fuel requirements of the housing stock, and so goes towards reducing the overall energy-resource demand of the economy. However, the insulation material is "human-made capital", and requires energy to be consumed during the manufacturing process, both directly as fuels, and indirectly as the energy that was initially required to build the manufacturing machinery, factories, etc.

Clearly, at a macroeconomic level, there is a trade-off between the direct energy resources saved, and the additional energy requirements created elsewhere, in the manufacturing sector of the economy. Before implementing a policy of energy conservation one would wish to know the relative sizes of these energy savings and requirements, and determine at what point, if any, domestic insulation becomes a net energy "saver" or "spender".

A traditional process analysis of this problem would calculate the energy cost of the insulation process by measuring the embodied energy of the insulation hardware. That is, it would follow the process of making, assembling, transporting, etc. the capital, back from the point at which it is installed to when it consisted of raw materials not yet extracted from the ground or otherwise impinged upon by human activity. In other words, it would attempt to assess the total amount of work (in the thermodynamic sense) undertaken by the human economy in implementing the insulation policy.

Thorough as the above may sound, ECCO attempts a more wide-reaching analysis of the policy. In focusing a part of the work available (in the thermodynamic sense) to the economy into implementing that policy, the pool of work available for the sustenance and development of the economy as a whole is affected to some extent. Because it adopts a holistic structure, the model can attempt to measure this pool of available work, or embodied energy. (Contrast this with the one-directional flow of the traditional process analysis, backwards from the point of interest to the entry of the resources into the system.) Having done so at one point in time, the model can then determine the extent to which this curtails (or enhances, if increased over a previous point in time) economic activity in subsequent time-steps, subject to the set of policies being examined. As the model evolves through time, the limits imposed previously will constantly impinge on the current performance of the economy, providing a self-limiting economic growth. This affects the behaviour of all sectors of the economy to some extent, and so provides the path through which a policy implemented in one part of the economy ultimately alters the whole thing.

Returning to our example of a domestic insulation policy, increased investment in energy conservation will temporarily reduce the surplus human-made capital (measured in embodied energy EE) that is available for re-investment in manufacturing. This will reduce the growth of the industrial sector of the model in the short run, and hence create a smaller industrial output in subsequent timesteps, a consequence of the structure of the central wealth creating feedback loop. Thus, ultimately, the energy cost of providing the insulation capital will be greater than the traditional process analysis would reveal. (Whether this would make it not viable or it´s not a different matter entirely.) However, this feedback loop is only one - and for that, an often neglected one - occurring in the real world.

Whereas a lot of them is represented in the model, money - triggered feedback loops (called „rebound effects“ by the economists) are not directly in, but are modelled to reflect their physical impacts. Consider e.g. the money saved by the households which share the house that has been insulated: they will not only serve energy, but as well part of their energy bill. This money, however, will not go unused: it is either consumed by the households themselves, or saved - which means reinvested into the by banks, savings etc. Since it is hardly possible to imagine a more energy intensive way of spending money than buying energy, and thus every alternative use of the money saved has a high probability of being less energy intensive, this effect will nonetheless reduce all savings efforts by stimulating consumption in other sectors. Physically, this means that the energy saved but available can be put to another wealth creating use increasing the capital stocks somewhere else in the economy, once the investment of embodied energy for the insulation investment has been paid back.

In the sense of allowing for comparisons of alternative policies under otherwise identical circumstances, then, the ECCO provides a "value-free" method of policy analysis, and one in which the full impacts of each policy on the physical restraints to the economy are considered. In the broader sense, of course, the model is not value-free, in that it cannot provide an unbiased prediction of future events ([27]). All of the wealth consumption sectors of the model are driven by policies over which the real world has a measure of control. In order to minimise the introduction of individual prejudices into the model, and to provide a realistic baseline scenario, the policies inherent in the model assume that, unless otherwise stated, things will continue largely as they are at present. This is what we call the business as usual scenario (BAU).

Having mentioned these business-as-usual policies, it is worth noting that they too have an effect on the performance of the economy, and that the more attractive of two policy alternatives under a business-as-usual scenario may not always be more attractive where a third policy is introduced in both simulations. For example, under a business-as-usual scenario, replacement of fossil fuel generated electricity with renewable resources may produce too heavy a drain on the wealth creation loop, pulling the economy into decline. When coupled with a policy of reduced domestic consumption, however, the burden created at one part of the

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[27] However, it does not intend to predict in the first place, as pointed out earlier.

wealth creation loop is counterbalanced by a reduced demand elsewhere, allowing the policy to be implemented under conditions of modest economic growth.

3.2.2 ECCO Models

In this section, the aspects of the economic system which are and aren't addressed by the model will be identified. The general framework discussed here underlies models like the UKEcco and has been used as well in the development of SuE.

The first point to note is that the model is concerned primarily with human activity, and the human-made parts of the nation. ECCO distinguishes between natural and man-made capital. The former refers to all unprocessed flows of materials and energy which may be used by an economic system, such as fossil fuels, fresh water, tourist-attracting natural beauty, etc. It is difficult to define natural capital accurately, and impossible to numerically value it in a rigorous way. The ECCO model does not attempt to measure natural capital beyond a few simple parameters that describe the degree of difficulty in bringing it into the human economy.

This is illustrated by the progress of natural capital through the economic system: Material passes through different sectors of the economy, and eventually, the material is returned to the natural world, in the form of waste. (Here, waste means any material not used by the economy. Practical definitions will alter as the technology of production alters, say, in incorporating recycling options.)

The resources are extracted from nature and processed. They then enter the production process as "raw" materials. These raw materials have been processed by the economy already in a cursory way, e.g. refining of oil, cutting of timber. Hence, they have a non-zero embodied energy, and can be considered as human-made, rather than natural goods.

The production process converts the raw materials into a variety of finished goods, such as buildings, machinery, paper, clothing and processed food. These goods are used by wealth consumption sectors, such as the government, services, the domestic sector, and industry itself. Note that, in order to perform any task, physical inputs are needed. Hence all economic sectors consume wealth.

At each stage in the transformation of the materials, some waste is produced. This is an inherent feature of all transforming systems, resulting from the second law of thermodynamics.

In a more detailed approximation to the economic system as reflected in ECCO models, natural capital can be sub-divided into energy and non-energy resources. This classification is purely anthropocentric: a tree in a forest may be classified as either type when used, depending on whether it is used as fuel wood or timber.

The distinction is made at this early stage for the important reason that all transformations require an input of energy. Further, all energy in the economic system ultimately derives from natural capital. All economic sectors require a direct input of fuels in order to operate. This special role played by fuels in an economy is central to the ECCO methodology.

In ECCO models, processed non-energy resources, in contrast, feed only into the production process. This statement is axiomatic, in that the production process is defined as an aggregate representation of all economic activity concerned with the transformation of raw materials into useful products. (SuE is different from ECCO in some of these respects)

As a next step, processes of physical decay can be introduced into such a model. This requires that a certain amount of the output of the production process is used to maintain existing human-made capital, before expansion of existing stocks can be considered. In implementing this, we distinguish between two output streams of goods. Firstly, there are consumer goods. These are assumed to have a negligible life-span, and hence require no maintenance. ([28]) The second stream is that of fixed, or investment, capital, which is assumed to have a significant life-time. Because it persists through time, it is necessary to measure the accumulated stock of such capital. Investment adds to these stocks, and depreciation, i.e. decay, reduces them.

Note that the production process must consume some of its own output in order to maintain itself, and more of it in order to expand. The potential for economic growth can then be calculated by knowing the total demand of the system, and what is left over for investment into the industry once this demand has been met. This introduces an important physical limit to growth, allowing the model to calculate its own economic growth rate. This feature alone sets ECCO models apart from most other economic models.

A further step to differentiate the model is to introduce feedbacks between the human and natural systems. Waste streams leave the economy and hence re-enter the natural system as pollution, as there is nowhere else to go. Because the ECCO model does not extend to a detailed description of the natural world, the effects of pollution on nature cannot be accurately described. Pollution control or abatement policies must be determined by the user.

What the model can do is calculate the amount of waste generated by the economy, and the investment required to deal with it, using whatever technology is available. Options such as containment, emission reduction and alternative technologies can be compared, with the calculations based on embodied energy as a numeraire.

3.2.3 The Actors

So much for the system, but what about the actors in the system, we the people? A simulation, once initiated will run forward in time for as long as the User wishes, or until the system crashes through some programming defect or from lack of resources. But an economy is more than just a machine into which one pours fuel, and awaits the inevitable outcome; for the outcome is not inevitable. The whole purpose of such a model is to be able to explore a range of feasible futures. Thus within each feed-back loop there implicitly sits an individual user - a decision-maker. That decision-maker can choose whether to meddle or to leave well alone.

The decision to meddle, to change the nature or magnitude of a link between a cause and an effect in a particular feed-back, should be made rationally on the basis of selected criteria (indicators) of economic performance or environmental impact, or in a pursuit of normative goals or popular views (opinion polls), or even irrationally in the pursuit of blind prejudice. The purpose of the model is to demonstrate over the longer term what the consequence of such intervention will be. Thus both to come to the first decision and to judge the result, one needs criteria of performance. Thus ECCO models calculate a range of such indicators, though only a part of them are of holistic significance.

Because ECCO is not an optimisation model, the burden is placed upon the User to decide whether the outcome of a decision is satisfactory. Let us illustrate this with the example of investment in energy conservation.

The model will not invest in energy conservation, unless a decision-maker, an actor, steps into the necessary feed-back loop and demands that investment occur. That decision should be based on the current and future performance of the system in a Business-as-usual (BAU)

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[28] In a detailed model such as UKEcco, special exceptions are made for large items such as cars and houses, which have long lifetimes and significant maintenance needs.

mode, that is the model and its feed-backs as they are in the starting year. The User should demand of the model all the output data germane to the question of energy conservation. Such data might be:

- thermal and electrical energy demand by sector
- investment rates in the sector
- growth rates by sector
- energy resource sources and reserves
- material standard of living
- the data-base on the amount of investment required to provide the same user-service at less fuel demand. This data is embedded in the model, and can be modified by the User in the light of new or superior knowledge

Many other outputs might be sought depending on the objectives and inclinations of the User, say business orientated or environmentally motivated.

The User makes a decision to invest such and such an annual amount into energy conservation in a particular sector. The program allows for this to be done by a single tap of a key on the computer keyboard. The User then requests the Computer to simulate the outcome for as many years ahead as is wished, and then examines the output data, and compare it with BAU. Some consequences may be found desirable, some not. Some may be desirable for a while and later not, while undesirable factors may improve with the passing of time. This is the inherent benefit of a dynamic model able to simulate into the mid- to long term.

Armed with fresh insights, the User may now reconsider the degree and nature of the original intervention. It is an iterative, learning procedure, in which the User is central to the process. S/he is the actor, the model is the slave. A satisfactory outcome may then become a policy.

3.3 Roots 2: Material Flow Accounting

In the introductory chapter, we have already argued why material and energy flow analysis is important when judging about sustainability. In the SuE model, we have complemented the existing, energy based ECCO approach with a representation of material flows (for more details see or the technical handbook). Here we introduce the methodology of material flow accounting to make the reader familiar with the concept and some basics of its application.

3.3.1 A Methodology for Measuring Material Flows

To become operational, any quantitative target set must be based on a standardised methodology, delivering meaningful, transparent and replaceable information about the total material brought about by a certain product or service. For this purpose, the resource-efficiency measure *mips* (material input per unit of service) was introduced ([29]).

mips is a methodology to measure material inputs (*mi*) at all levels (product, company, national economy, region) including all their "ecological rucksacks", i.e. the total mass of material flows activated by an item of consumption in the course of its life cycle, and to refer this *mi* to the end user service *s* derived from that flow as a standardised reference. Briefly, *mips* relates the material inputs *mi* necessary for the production, distribution, use, redistribution and disposal to

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[29] See Schmidt-Bleek (1994), op. cit. and Schmidt-Bleek, F., Das MIPS-Konzept. Weniger Naturverbrauch - mehr Lebensqualität durch Faktor 10, Basel 1998.

the end-user service provided by any given good. This allows for comparisons among different yet functionally equivalent products.

In summary, we can say that material intensity and flow accounts are analytical tools to illustrate just how much material and energy flows through the economic system at the sectoral, national, regional and international levels. These tools are aimed at quantifying the efficiency of economic operations, such as determining the material and energy flows per unit of service (*mips*); at addressing equity questions, such as questions on how much material and energy is used by whom and how it is distributed; and at illustrating global patterns in provenance and movement of material and energy.

Decreasing resource throughput in absolute terms does not mean compromising wealth (service availability and well-being) since technological and social innovations that generate increasing resource productivity can compensate or even over-compensate for the difference in material use. There are already a number of commercially interesting examples to prove this point ([30]).

Besides being an analytical tool, *mips* can as well be applied as an instrument to establish a system of resource management. Any such system, based on the *mips* concept should help to make pro-environmental decisions faster, more reliable and comprehensive and cheaper, i.e. in an environmentally as well as economically sound way. Practical suggestions have already been made for *low mips products* and *eco-efficient services* ([31]), the latter being basis of one of the scenarios (see chapter 6). Material input calculations can also be referred to intermediate and macroeconomic entities like whole sectors or economies, in analogy to national accounting systems. Where reliable input-output accounts are available, they constitute a particularly precious instrument for tracing the „responsibilities“ of the uses of materials.

3.3.2 The *mips* - Methodology of Measuring Material Flows and the Resource Intensity of the Economy

The material intensity analysis of any economic output according to the *mips*-concept ([32]) comprises all inputs of materials, respectively raw materials, influenced by anthropogenic use (ores, minerals etc.), differentiated by categories and summed up in kg. Included are all materials which had to be moved in order to extract or harvest raw materials or to build infrastructures, e.g. non-saleable production (overburden, gangue etc.), drainage water and logged trees.

Furthermore, all materials are counted which have been consumed indirectly for the production, packaging, operation or use (washing agents, water, fuels etc.), maintenance (paints, cleaners etc.) and repair (spare parts etc.), as well as for re-use or recycling of the economic output under consideration. In addition, all materials are counted, as far as possible, which have been necessary for the production or operation and disposal of an economic output, e.g. materials consumed for energy generation and also the share of - normally already existing - infrastructures like transport-, extraction-, production-, and disposal-installations - including all inputs necessary for erection, operation, maintenance and destruction. Not

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[30] Fussler, C., Driving Eco-Innovation, London 1996

[31] See Tischner, U., Schmidt-Bleek, F., Designing goods with MIPS, in: Fresenius Environmental Bulletin, Vol. 2, 1993, No. 8., p. 479-484; Tischner, U., Die Kühlkammer: Ein umweltfreundliches Kühlkonzept für den Haushalt, Bergische Universität Gesamthochschule Wuppertal, Wuppertal 1993; Meta, A., Ein umweltfreundliches Gerät zur Bodenreinigung im Haushalt, Bergische Universität Gesamthochschule, Wuppertal 1994.

[32] For more details of the calculations and for the necessary conventions mentioned in this paper see F. Schmidt-Bleek et al., MAIA, Einführung in die Materialintensitätsanalyse (Introduction to Material Intensity Analysis), Wuppertal 1998 (in pr.)

included, however, are the material flows associated with the other production factors, i.e. capital and labour, that have been activated in order to create the process analysed.

3.3.2.1 Definition of "Ecological Rucksacks" and Categories of Flows Analysed

The "ecological rucksack" results directly from the listing and accounting of all materials which stand behind a final product or a service, or any economic output in general, as described above. It is defined in general as the sum of all materials which are not physically included in the economic output under consideration, but have been necessary for production, use, recycling and disposal. Thus, by definition, the "ecological rucksack" results from the life-cycle-wide material input (MI) minus the mass of a product itself. In order to provide transparency of the results, ecological rucksacks are presented according to the five main categories of material flows (see next page).

Material inputs are calculated and presented separately by five main categories:

- I. Abiotic raw materials
- II. Biotic raw materials
- III. Moved soil (agriculture and forestry)
- IV. Water
- V. Air

This basic differentiation already implies the rough distinction between non-renewable (I) and renewable (II) materials in general. Going into greater detail, it may be found useful to allow for further differentiation, e.g. to exclude wood from primary non-managed forests from the category "renewable materials". The same applies for water (IV), e.g. deep ground water to be presented as a separate category. The situation is, however, more complex in the case of moved soil (III).

In general, the procedure known as life cycle approach applies to the allocation of backward chains to specific products. In practice, all processes involved in the production of a specific product (or service) will have to be analysed and assembled in flow diagram by using standardised survey sheets. These should be as specific as possible regarding individual processes and the geographical location of those (with regard to combination with country specific properties of material flow analysis, e.g. iron ore mined in Brazil vs. Australia). Again, a number of individual standards and conventions have to be introduced for practical reasons, which can be found in the handbook. Finally, all material inputs allocated to a certain time-period for the production of a defined product type will be summed up according to the five main categories of material flows and related to the total output quantity of products.

3.3.2.2 By-products and recycling

By definition, by-products are all products which result from a process that has not been established to produce them (additional products) and which can substitute main products as inputs in further processes. By-products may become main products due to changing situations of markets, especially in the field of chemicals. The rucksacks of by-products are those input materials which have to be provided for further processing. In case that the original process consumed inputs which exclusively relate to the improvement of quality and, thereby, the better use of by-products, those inputs will be accounted for the ecological rucksack of the by-product. The mass of by-product itself is contained in the rucksack of the main products.

Recycling, in general, refers to processes from which materials are provided in such way that they can replace raw materials or materials in other processes. If materials are materially recycled (secondary raw materials), the material input necessary to run the recycling process is counted as their ecological rucksack. The mass of secondary raw material itself remains with the main product of the original process and will not be counted again for the recycled product.

In practice, data collection for material flow analysis will proceed on the highest level of disaggregation, allowing to classify data according to the main sub-categories and categories of material flows. This is relatively easy for raw materials and for most semi-manufactured materials. In the case of highly complex materials, however, only a backward analysis of individual constituents to the level of raw materials will permit the basic classification procedure to be applied.

3.3.3 TMR – An Indicator to Measure the Material Basis of Regional and National Economies

Based on the *mips* -concept the Wuppertal Institute developed the indicator TMR (Total Material Requirement) in order to monitor material flows on a regional and/or national level. On this basis, joint international comparative studies have been undertaken with a number of partners, in particular with the World Resources Institute, the Netherlands Ministry of Housing and the Japanese National Institute for Environmental Planning ([33]).

The Total Material Requirement or TMR of a national economy comprises all materials which are extracted from the global environment to support the economic activities of that country. It is the sum of domestic and imported primary natural resources, including their ecological rucksacks. All materials extracted from the environment are considered without water and air.

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[33] Adriaanse et al., op. cit.

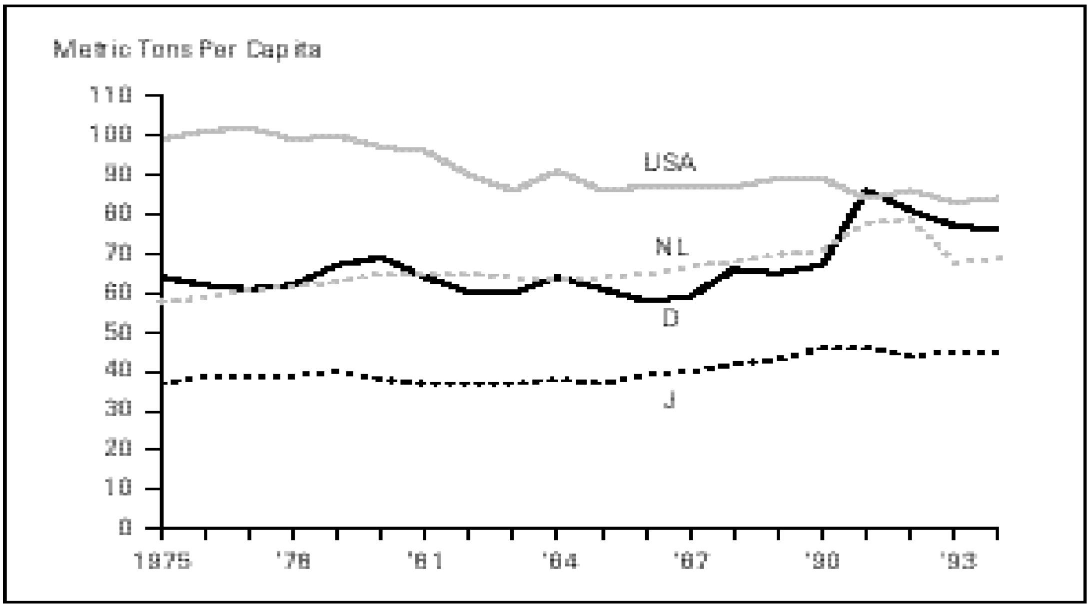

Figure 3: Total Material Requirement for the USA, Netherlands, Germany and Japan - annual flows per capita (based on Adriaanse et al. 1997, with revised Dutch data)

3.3.3.1 TMR measures economic activity in physical terms thus complementing economic information such as GDP by providing a more complete view of the size and scope of an industrial economy. TMR can also be considered an approximate indicator of the potential pressure exerted by an economy on the global environment, - though precise measures will depend on the disaggregated components of TMR and their environmental impacts. For the purpose of international comparison, the indicator was calculated in tons per capita per year.

In the joint study mentioned above, the Material Intensity of four industrial economies was examined and expressed as Total Material Requirement (TMR) per capita to point out and to compare the degree and trend of natural resource use on the national levels.

Starting from 1975, the TMR per capita varied considerably, but over time the trends converge. In Germany, the Netherlands and the United States, per capita natural resource use appears to be levelling off at about 75 to 85 tons per year. The decline in US TMR per capita in the first third of the period was due primarily to major reductions in soil erosion after the enactment of the Conversation Reserve Program (farmers were paid for not farming highly erodible lands) and the completion of much of the federal interstate highway system. The TMR per capita of Japan showed a slightly rising trend, similar to that of Germany and the Netherlands, but at significantly lower levels, about 45 metric tons per year. The sharp rise in German TMR in 1991 reflects the reunification with the former East Germany; the trend in West Germany had been relatively constant until then.

3.3.4 The European physical input-output table (EU-PIOT)

Physical input-output tables (PIOT) comprise like traditional input-output tables the product flows (but here in physical terms) and, in addition, material flows between the environment and the economy. The balancing procedure for material inputs and outputs can be performed for individual economic activities (branches, sectors). For the first time, such a complete material flow analyses for a national economy on sectoral levels had been performed for West Germany

1990 by the Federal Statistical Office of Germany in Wiesbaden ([34]). The Wuppertal Institute was significantly contributing to this work.

The European physical input-output table (EU-PIOT) developed from material flow accounts for the 15 member countries in this study underlies the same principles and concepts as the German PIOT. Basics of the development of physical accounts for EU 15 in a modular way and their assembly for the EU-PIOT is described in detail in the appendix of the technical report.

Physical input-output tables describe stocks and flows of materials and energy which are extracted, transformed and discharged back into the environment by economic activities (Figure 4). The economy is disaggregated on a meso level into branches (industries) and into household consumption activities which together constitute one type of economic activities. The other type of economic activities is environmental protection and recycling. In addition, two types of produced assets are described (controlled landfills of wastes and other produced assets including consumer durables). The economy is surrounded by the non-produced natural assets, the domestic environment. In a similar way, the rest of the world (imports and exports) surrounds the national economy and domestic environment.

The uses and supplies of three major groups of materials are described in the PIOT:

- raw materials
- products
- residuals

(for further classifications refer to the technical appendix). The further breakdown of material flows depends on the aim of the analysis, it is of course limited by data availability. For example, disaggregated data on emissions into air (like CO2) can be used as a base for information on emission structures. They can further be applied for weighting procedures (e.g. with regard to greenhouse gas potential), leading to indicator systems, especially to pressure indices, or others.

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[34] Stahmer, C., Kuhn, M., Braun, N., Physical input-output tables, German experiences, in: third meeting of the London group on natural resource and environmental accounting, Proceedings Volume, May 28-31, 1996, Stockholm, Sweden, pp. 279-322.

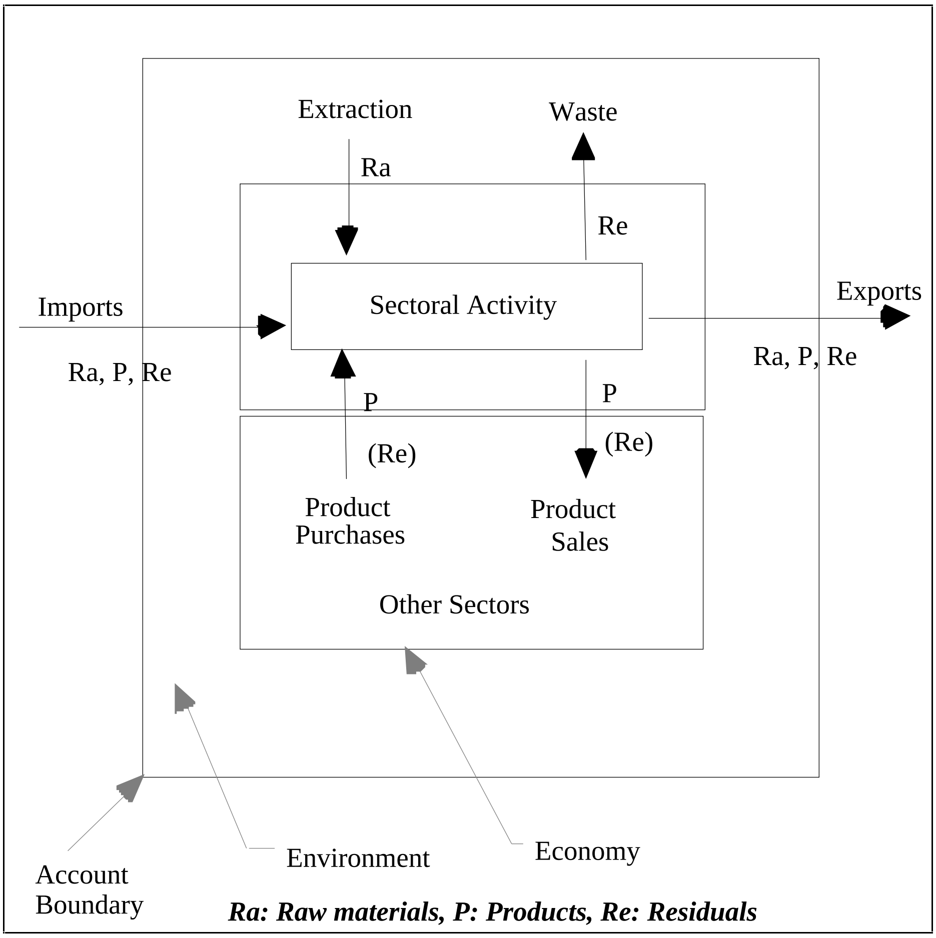

Figure 4: General overview of input-output balancing of economic activities

An outcome of material flow analysis by physical input-output balancing procedures can be the Material Flow Account of a whole national economy ([35])Bringezu and Schütz 1995, for Germany). This is illustrated here for the first time for EU 15 in 1990 (Figure 5 on page 38). The picture clearly underlines that EU 15 -like Germany and other industrialised countries- can be classified as a material throughput economy. Most of the material input into the economy of about 17329 Mio. tons is counterbalanced by exports and by material outputs to the environment (82 %), mainly as wastes, emissions into air and erosion from agricultural land. The additional material stock accounted for about 3 billion tons of materials which increased the technosphere mainly in forms of additional buildings, roads and other infrastructures. In view of the enormous size of the material input, recycling constitutes with about 448 Mio. tons only a minor contribution to save inputs of primary materials taken from the environment. In addition, by far most of the material input is represented by the ecological rucksacks of resource extraction within the domestic environment of EU 15, which amounts to 9254 Mio. tons (non-saleable extraction, excavation and erosion) or 53 % of the total input. This rucksack, of course, also dominates the material output (and pressure) to the environment.

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[35] Bringezu, S., Schütz, H., Wie mißt man die ökologische Zukunftsfähigkeit einer Volkswirtschaft ? Ein Beitrag der Stoffstrombilanzierung am Beispiel der Bundesrepublik Deutschland, in: Bringezu, S. (ed.): Neue Ansätze der Umweltstatistik: ein Wuppertaler Werkstattgespräch, Wuppertal Texte, Birkhäuser Verlag, Berlin, Basel, Boston, 1995, pp. 26-54.

The rucksacks (abiotic materials) of imported materials for EU 15 could only be estimated for imported ores and fossil energy carriers. It amounted to the same magnitude as the absolute imports of about 1.5 billion tons. Most probably, based on the experience with German material flow accounting, a significantly larger part of rucksacks in forms of abiotic materials for other imports than ores and fossil energy carriers can still be assumed. Also, the magnitude of other rucksacks than abiotic materials (e.g. erosion, biotic materials) may pose another significant environmental pressure in foreign countries due to imports in EU 15.

The (incomplete) total material requirement (TMR, see also 3.3.3) of EU 15 in 1990 amounted to about 16512 million tons (without air). This equals about 45 tons per capita. In view of a large portion of rucksacks of imports which is still missing in that number, the comprehensive TMR per capita of EU 15 will be significantly higher than that of Japan (about 46 tons per capita, see also 3.3.3.1). However, whether the final number for EU 15 will be as high as TMR per capita for USA, Germany and Netherlands (around 80 tons per capita) remains unknown. If the rucksacks of imports are subtracted from TMR, the magnitude of material flows is obtained which physically enters the economy. For EU 15 in 1990, this equals about 41 tons per capita, considerably less than for Germany which has about 73 tons per capita. A major reason for the high per capita resource input in Germany is domestic lignite mining with high overburden to coal ratios, which alone contributes about 35 tons per capita.

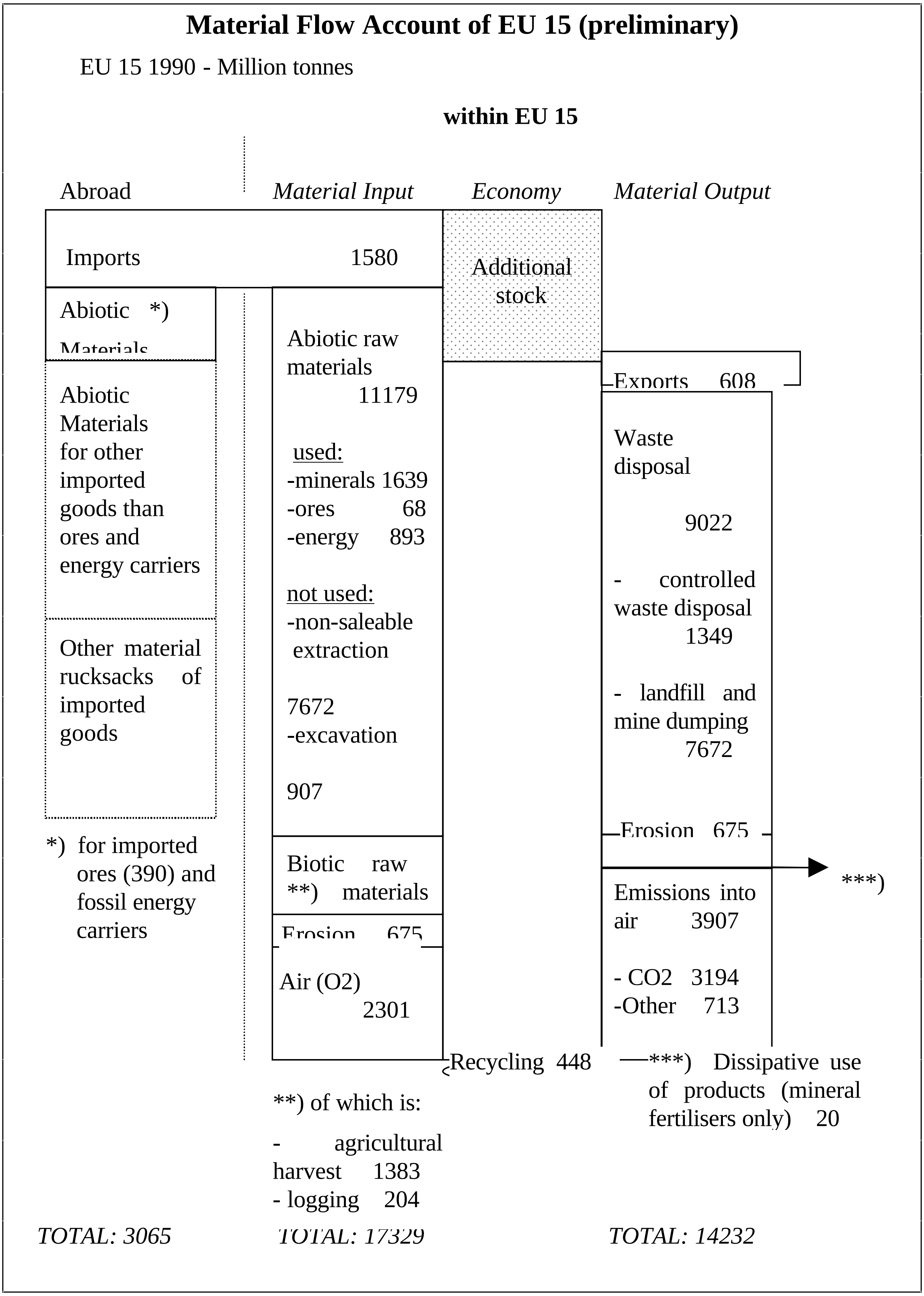

Figure 5: Material Flow Account of EU 15 in 1990 (Million tonnes)

3.4 Roots 3: The Study „Towards Sustainable Europe“

While the SuE model is a tool for assessing policy measures in terms of their impacts on the economy and the labour market, it is neither designed for to nor capable of defining sustainability targets. It cannot give any kind of information whether or not the measures under consideration are sufficient to reach the state of sustainability, unless sustainability has been exogenously defined in the first place. This information, however, is crucial for any kind of sustainability scenarios and for judgements about the appropriateness of the measures tested in the model.

As a source of quantitative targets of (physical) sustainability we have chosen to use the study „Towards Sustainable Europe“ ([38]). This study provides us with a narrative sustainability scenario based on normative targets derived from the calculation of the maximum carrying capacity and specifically the environmental space available to the citizens of Europe. The combination of this backcasting approach with the SuE model forecasting one intends to deliver both, information on the way how to reach sustainability, and the cost involved.

Since the basic philosophy behind the study and the SuE project is of a quite similar nature, we do not have to explain the philosophy in all detail, but we have to provide the information about the methodology used for the quantitative calculation of sustainability targets.

3.4.1 Sustainable Europe - Key Targets

The sustainable Europe project was chosen as a source of sustainability targets since its calculations are based on physical data (energy, material flows, land use) and its intentions and targets (including social and economic sustainability) fit well into our framework. The list of priority targets (quoted from the project summary) demonstrates this:

1. To give a first rough estimate of the Environmental Space (and thus the sustainable level of resource consumption) for Europe.

2. To propose a direction of policy making which will with some certainty lead towards more sustainability. Although the reliability of any quantitative threshold values can only be limited, together with a reliably identified direction and described by the indicators chosen they give a helpful framework for policy development and assessment.

3. To link the Environmental Space discussion and the resulting indicators to the debates about the necessary changes in economic and societal framework conditions to establish a sustainable path of economic development, maintaining (EU) or increasing (CEE) the level of social and economic welfare.

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[38] Spangenberg, J.H. (Ed.), Towards Sustainable Europe, A Study from the Wuppertal Institute for Friends of the Earth Europe, Luton 1995 (financed by the Commission of the European Communities).

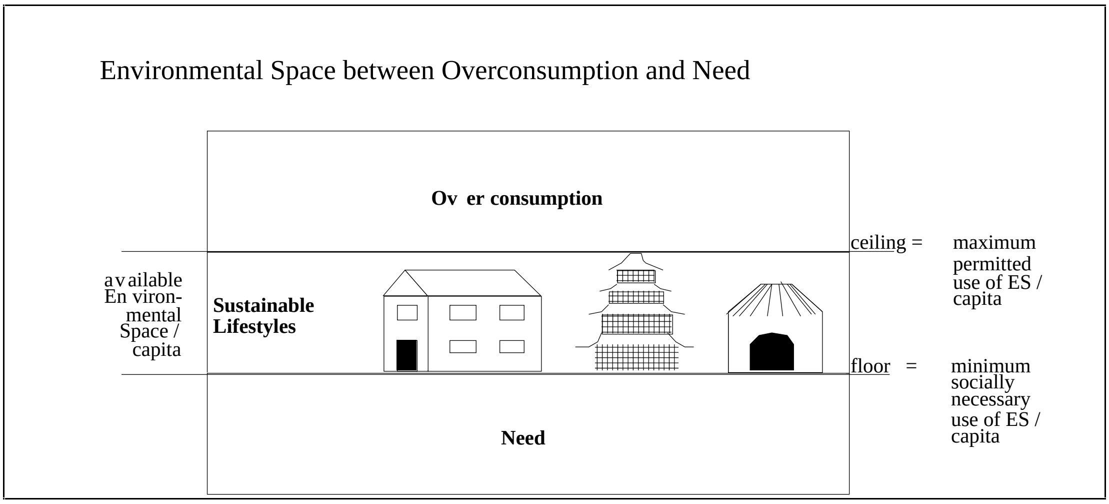

Figure 6: Environmental Space between „Overconsumption“ and Need

3.4.2 Environmental Space

The maximum amount of energy, raw materials (incl. water) and land (incl. wood) we can extract within the limits given by the Earth’s carrying capacity is called the „ceiling“ of the „Environmental Space“ ([39]) . The extraction is measured when a good passes from the ecosphere into the technosphere; in line with chapter 4.3 repeated use of goods circulating within the technosphere is only taken into account as far as additional input is taken from the ecosphere to maintain circulation.

The minimum amount to be used („the floor“) is defined socially: it must be enough not only to overcome need and poverty, but enable citizens to actively participate in their respective societies. The resources needed for that purpose obviously differ in different societies.

The Environmental Space as an opportunity space is a *socio-environmental* concept by it's very definition. Whereas the lower threshold, the "floor" is neither easily quantifiable nor necessary for the SuE study, the ceiling of the environmental space needs to be defined by giving quantitative data on consumption maxima.

These criteria are input - based (as explained in chapter 3.2.4), although some of the calculations to estimate the limits to extraction are based on output - related considerations like estimated sink capacities. „Living within our environmental space“ hence is a definition for the environmental dimension of sustainability: a necessary, although not sufficient criterion.

As modern economies are not only using national resources but are built on international commodities trade, the calculation of the environmental space a national economy uses has to be based on an estimate of the total material and energy requirement of that national economy. The available environmental space gives a ceiling for that requirement, the permitted level of using and depleting natural resources. The environmental space used, however, does not give any information about the kind and level of welfare derived from the resources available, since they can be used in very different manners to meet societal demands. There could be significant differences according to cultural or personal priorities and based on the efficiency of technologies and consumption patterns prevailing or accessible.

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[39] The term Environmental Space was coined and applied to the sustainability debate by H. Opschoor. It was first used for a national sustainability strategy by FoE Netherlands in their Action Plan Sustainable Netherlands. For the Sustainable Europe study it has been modified as described in the methodology section of this chapter.

Dematerialisation of products, substitution of products by less resource-intensive services ([40]), reuse and recycling are just some well known means to avoid resource extraction and thus large scale environmental degradation from the availability of resource - based services. These strategies have been modelled in the SuE sustainability scenarios.

3.4.3 The Equity Principle

The global environment as the basis of human health and wealth is a common good under threat by national politics lacking international responsibility. This calls for a new definition of international safety: since no country alone has the power to combat global environmental risks, a mutual dependency has emerged, not yet recognised by many decision makers but essential for future policy development. Common action is needed but will be possible only if a fair division of responsibilities is realised, taking into account the resources available on a global scale. Sustainable development, as pointed out in Agenda 21, needs social balance as well as environmental balance. Therefore the permitted use of environmental space per capita is the same for every citizen of the Earth.

The acknowledgement of limits to the earth seems, therefore, to be firmly linked to the question of resource distribution. Comparing the actual use of Environmental Space and the permitted use based on an equitable global distribution of access to environmental space gives input reduction quota to be achieved by national economies in order to bridge the sustainability gap, i.e. to reach a sustainable situation. Output reduction (e.g. waste, CO_2) is achieved by reducing the corresponding input.

3.4.4 Methodology

- *Energy* and raw materials are seen as global commodities, their amount of use - although countrywise different in structure through preferences and by technologies used - should in average not exceed a common global maximum of Environmental Space used per capita world-wide. A reduction of world-wide anthropogenic material and energy flows to one-half of the present dimensions, is a reasonable indicative goal ([41]). For primary energy, a reduction by half until the midst of the next century is demanded based on the results of climate models and the IPCC recommendations. This results in a reduction of about 75% for Europe in the long run.
- For material flows, the data situation is less satisfactory, with only broad assessments at hand ([42]). If it turns out that in the long-run, not 50% but 40% or 60% reduction in material

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[40] Hinterberger, F. et al., Increasing Resource Productivity through Eco-efficient Services, WI papers No. 13, Wuppertal 1994

[41] For a more detailed reasoning and for references see e.g. Spangenberg, J.H. et al., Material Flow Based Indicators for Environmental Reporting, EEA Expert Corner Series, Copenhagen 1998, i.pr.

[42] Schmidt-Bleek, F., Wieviel Umwelt braucht der Mensch, Berlin/Basel 1992; Weterings,J., Opschoor, H., The ecocapacity as a challenge to technological development, Publikatie RMNO nr. 74A, Rijswijk 1992;
Buitenkamp, M., Venner, H., Wams, T., Nederlands Duurzaam, Amsterdam 1992; Maxson, P./IEEP, The Netherlands Sustainable Technology Program: The International Dimension, Brussels 1992; Wackernagel, M., How big is our ecological footprint ?, Vancouver 1992; Jänicke, M., Ökologisch tragfähige Entwicklung, FFU Report 93 - 7,
Wackernagel, M., et al., How big is our ecological footprint? A handbook for estimating a community's appropriated carrying capacity, Vancouver 1993, Opschoor, H., Costanza, R., Towards environmental performance indicators based on preserving ecosystem health, manuscript, Wuppertal 1994;
Wackernagel, M., Rees, W., Our Ecological Footprint - Reducing Human Impact on Earth, New Society Publishers, Gabriola Islands, B.C. Canada, 1995; Wackernagel, M., How big is our ecological footprint ?, Vancouver 1992; for the current state of the debate see e.g. Hille, J., The Concept of Environmental Space, EEA Expert Corner Report,

flows is needed to reach a sustainable use level, this makes no significant difference in terms of policy decisions to be taken today, since the necessary reversal of the current trend of globally-increasing material flows is the same, as any sensitivity analysis shows ([43]).

The proposed 50% reduction of *material flows* (the mineral itself plus its „ecological rucksack“, i.e. the material flows activated by extraction, processing or disposal on a global scale) translates into a 80 - 90% reduction for the EU 15 average ([44]). Reduction targets for specific materials as given below are not based on numerical scenarios or models, but are mere exemplifications of the global reduction target of about 50% for material flows, together with the equity principle (which turns out to be the dominating factor in this case). As obviously demanded by the material flow concept, substitution of a certain amount of one material against a lesser amount of another one (including „rucksacks“) delivering an equivalent service or well-being is regarded highly desirable.

- These goals, to be reached in a *30 to 50 year time-span*, are equivalent to an annual increase in resource productivity of 4.5% for materials and about 3% for energy, and considered a pragmatic, feasible and necessary policy target ([45]). The long time span is needed to allow the technical, social and economic dynamics to adapt and adjust without major conflicts with the requirements of economic sustainability. This is all the more necessary if, alongside technology improvements and the resulting efficiency gains, a culture of sufficiency is to emerge among the populations of industrial countries, accustomed to levels and - more important and problematic - forms and dynamics of well-being which clearly cannot be maintained for a very long time.

- *Wood and agricultural products* are regarded in the study as continental resources (i.e. no „land import“), assuming exclusively organic agriculture, sustainable forestry ([46]), 10% of all kinds of land to be set aside for nature protection and ecosystem migration, and no growth of built-up area.

  In the SuE model, land use is a variable mainly used in the agriculture, forestry and fisheries (AFF) sector. Consequently, these sustainability targets are tested for their overall impacts by implementing them in scenarios focused on the AFF sector.

- In the Sustainable Europe study, *water* is considered a regional/local resource, with the availability and the permitted use to be calculated on a catchment area basis. On the contrary in the SuE model, water flows are counted on the European level as an element of the material flow accounting procedure (see chapter 3.3.2). Local water shortage, however, the most frequent water problem in Europe, has neither been assessed in the Sustainable

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Copenhagen 1998; Spangenberg, J.H. et al., Material Flow Based Indicators for Environmental Reporting, EEA Expert Corner Report, Copenhagen 1998 (i.pr.).

[43] Spangenberg, J.H. (Ed.), Towards Sustainable Europe, A Study from The Wuppertal Institute for Friends of the Earth Europe, Luton et al. 1995.

[44] For more details of reasoning see: Factor 10 Club, The Carnoules Declaration, Wuppertal 1995. The way of calculation is stepwise explained in Spangenberg, J.H. (Ed.), Towards Sustainable Europe - The Handbook, Luton/Wuppertal 1995.

[45] See Factor 10 Club, The Carnoules Declaration, Wuppertal 1994.; Spangenberg, J.H., Towards Sustainable Europe, op. cit.

[46] If a pan-European approach including CEE and European NIS countries is chosen as the geographical basis, even 50% increase in average wood consumption would be possible on a sustainable basis. The actual use will however differ according to culture, tradition, climate etc., with the Scandinavian and Baltic countries having a higher demand for wood than the Mediterraneans. This is counterbalanced e.g. by the equally different but opposite distribution pattern of cement use - an example that biotic as well as abiotic resources must be included in material flow accounting, since they can substitute each other. These distributional patterns, however, cannot be reflected in the SuE model, which works on the level of European averages.

Europe study nor can it be modelled in SuE: it is hidden behind national and European averages in water statistics.

- In the study, qualitative categories like the preservation of *biodiversity* are covered not by quantitative targets, but by normatively set policy measures designed to reduce the pressures identified (like exclusively organic agriculture). The organic agriculture scenario (see chapter 6 and the technical handbook) can therefore also be considered as one aiming to protect biodiversity in Europe's anthropogenically managed countryside.

Whereas the Sustainable Europe study had to calculate on the basis on constant allocation of resources to the different sectors, the dynamic model SuE is free from these restrictions. This permits to take into account the relatively fast and frequently occurring (often supply-side and technology driven) intrasectoral developments, as well as the slower, but more fundamental (and to a certain degree demand side driven) intersectoral structural change. Thus the scenarios developed already give reliable indications not only of the direction to go - a kind of a political compass, but also offer elements for more detailed road maps and speed indicators.

All calculations undertaken are based on best available data and are therefore due to improvement according to the progress of science. This, however, will make the targets more detailed and precise, but will not change the direction nor the dimension of necessary changes outlined ([47]).The following targets in absolute terms per capita are valid for the whole of Europe (EU 15, EFTA, CEE and the European part of the former Soviet Union), whereas the relative reduction targets (%) are referring to the use of EU 12 countries in 1990 (or closest year available).

Resource	**Present use per cap.p.a in EU 12**	**Environmental Space (Per cap p.a.)**	**Change needed by 2050 (%)**
CO_2 emissions	**7.3 t**	**1.7 t**	**-77**
Primary energy use	**123 GJ**	**60 GJ**	**-50**
Fossil Fuels(a)	**100 GJ**	**25 GJ**	**-75**
Renewables(b)	**7 GJ**	**35 GJ**	**+400**
Non-renewable raw materials			
Cement	**536 kg**	**80 kg**	**-85**
Pig iron	**273 kg**	**36 kg**	**-87**
Aluminium	**12 kg**	**1.2 kg**	**-90**
Chlorine	**23 kg**	**0 kg**	**-100**
Land use pattern			
Built-up land	**0.053 ha**	**0.051 ha**	**- 3.2**
Inland waters	**0.009 ha**	**as now**	**0**
Protected Sites	**0.003 ha**	**0.061 ha**	**+1933**

(a) coal, lignite, oil, gas; (b) Wind, hydropower, fuel wood, biomass incineration, solar heating etc.; (c) incl. perennial crops, excluding permanent meadows and pasture land.

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[47] Schmidt-Bleek, F., A new dimension of environmental protection, Wuppertal Papers No. 24, Wuppertal 1994.

3.4.5 Assessing the Socio-Economic Impacts

Based on the principles lined out above and the targets derived from them, the study Towards Sustainable Europe has come to some conclusions about the socio-economic impacts of sustainability as well as about the necessary societal preconditions for the success of any such strategy. These are neither normative settings nor political demands, they are the result of a policy impact assessment of some strategy considerations on how to implement and operationalise the targets calculated. They represent logical or at least plausible conclusions from the sustainable consumption targets as defined above. However, they have not been used for cross-checking with the results of the SuE simulations, but have been the basis for a number of scenarios. This includes the effects of dematerialisation, eco-efficient services, sustainable agriculture etc. on economic growth and employment ([48]). The prevalent income distribution is not modelled in SuE, however income redistribution (e.g. via the social security system) is part of the model.

3.5 Roots 4: Economic Background Considerations

3.5.1 The Economics of Dematerialisation: An Evolutionary Path Towards Sustainability

The limits defined by the sustainability objective constitute general boundaries, within which the allocational and distributional problems remain the primary aims of economic policy; even more important, within these limits as little restrictions as possible should be imposed on human self-determination and the innovation potential of firms in the market economy. The dematerialisation approach, in shifting the emphasis from particular activities and specific regulations to general objectives, is better suited to serve the latter requirements. The fact that the reductions mentioned above are to be achieved as average result of economy-wide structural and technological change implies a great flexibility of the strategy, leaving also significant degrees of freedom to the policy-maker for the pursuit of objectives other than sustainability. Some activities may even expand their use of natural resources, provided others save them to a sufficiently high extent ([49]). This allows exploiting a dematerialisation potential which is unevenly distributed - but quite substantial, as many examples collected by the Wuppertal Institute show - without requiring great previous knowledge about the allocation of such potential.

It should be obvious, at this point, that we do not think of dematerialisation as of some optimal policy in the traditional economic sense, that is one that maintains the economy on a narrowly and precisely defined path on which the best possible outcome for society is realised; rather we think that it is necessary to keep the economic development within the "guard-rails" of the material flow targets. These guard-rails define an opportunity space, in which the evolutionary process of the economy can develop by "artificially" introducing economic scarcity into the market system, where ecological threats are not automatically transformed into market incentives and disincentives. The "guard-rails" should be as transparent as possible and fixed in advance for a considerably long run, in order to provide the economic actors with the necessary certainty, needed even more than usual in a situation requiring adaptation to changing conditions. The dematerialisation goal would limit the effects of the vagaries and the discretionary power of the political-administrative system, because political decisions would made in more general terms and less for specific cases; at the same time, it would leave open

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[48] However, the SuE model cannot reflect the changing quality of labour as discussed in the study.

[49] See Hinterberger, F., Luks, F., Stewen, M., Ökologische Wirtschaftspolitik, Basel u.a. 1996; Spangenberg, J.H., Bonniot, O., Sustainability Indicators, Wuppertal Paper No. 81, Wuppertal 1998.

the opportunities for innovative behaviour on the part of individual economic agents. Moreover, economic agents (entrepreneurs and households) would need to take into consideration for their decisions fewer parameters than under an approach where the fine-tuning of individual substances and emissions is pursued.

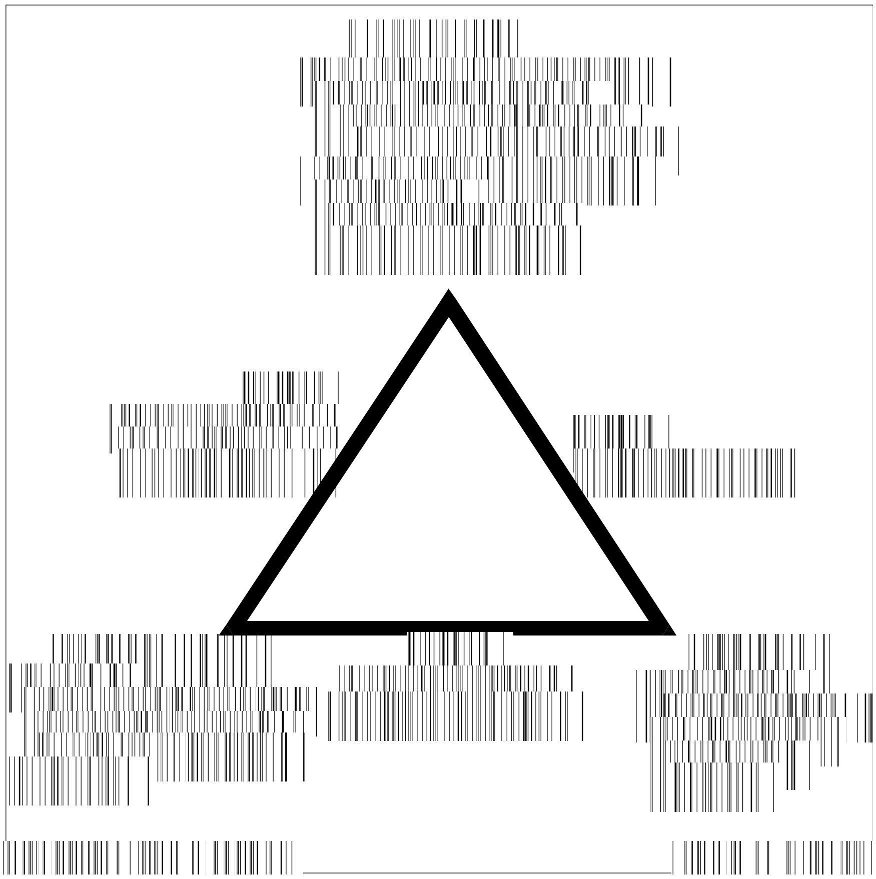

Figure 7: Indicators and elements for different dimensions of sustainability

3.5.2 Trade

With dramatically reduced throughput and probably politically induced increasing transport cost per ton and km, international trade would sooner or later be gradually reduced and totally restructured. Whereas today the majority of material transport are bulk materials (mainly raw materials), increasing transport expenditure would justify long range transport only for those goods, which have a significant added value.

This would not necessarily mean a decreasing value of trade or a reduced income from it, but the restructuring of global trade towards the exchange of processed goods instead of raw materials, as it is already the case between the OECD countries at large (50).

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[50] Although SuE is a macro-economic model (without considering behavioural aspects), sharing many features with traditional economic models, the fact that it reflects a (non-monetary) physical-oriented view of the economy makes it uncapable to deal with this structural change, unless the increase in value goes together with a similar increase in energy embodied in the products. The delinkage of monetary and physical flows cannot be easily calculated, neither in money-based nor in a physical flow based models.

Such a restructuring of markets implies a stronger role for local and regional economic structures, a development that unfortunately is beyond the reach of a European model like SuE.

3.5.3 Outlook: The Growth Problem

Since a dematerialisation by a factor of ten in the next 50 years was considered necessary to meet the environmental demands whilst maintaining a constant amount of services, the factor will increase in the case of a growing economy ([51]) just in order to keep the throughput of raw materials through the economy on the environmentally justifiable level. So, with an annual growth rate of 2% the necessary factor of dematerialisation will be 27, and with an annual rate of 3% it will be 45 (or 200 within the next century).

Whereas the scenarios (see chapter 5) illustrate that significant progress towards dematerialisation and energy saving is imaginable, the long-term problem of unlimited, permanent growth becomes all the more obvious. What is necessary is a delinkage of GDP growth and environmental space used: The necessary delinkage of economic growth and environmental space ES use must not only be relative (See Figure 8, graph (1), reduction per product/unit of GNP/GDP, overcompensated by growth), but it must be absolute (graph 2, reduction of environmental space use in absolute terms). This is the right direction, but we must furthermore take care that the dematerialisation targets are reached in due time (graph 3, within 50 years). We call this *dematerialised* or *problem solving growth*.

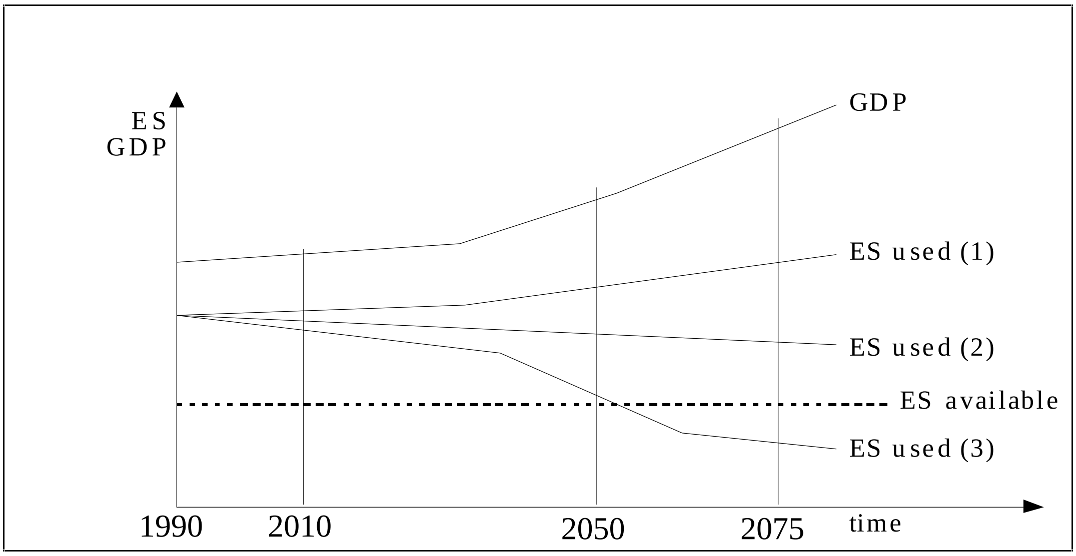

Figure 8: Different paths for delinking GDP and use of environmental space ES

The limits to material flows translate into limits to growth: to maintain or decrease a given level of throughput, economic growth must be at maximum equal to the annual increase in resource productivity. This however means, that in the long run the level of the annual increase of resource productivity forms a ceiling to growth, unless an unlimited productivity growth is

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[51] based on GDP calculations. GNP/GDP may be misleading indicators when read as characterising wealth (or, even more misguided, well-being: for a critical view see W.v. Dieren, Taking Nature into Account, Basel 1995), but they are perfectly suitable to measure the financial turnover of national economies and thus to characterise the dematerialisation needs for a stabilised resource throughput in terms of tons per ECU.

foreseen. This, however, is not physically possible at least in the very long run. Obviously, growth as such cannot solve our problems.

3.6 Roots 5: The Advisory Boards' Inputs

3.6.1.1 Policy relevance

The discussion of the Societal Advisory Board focused primarily on the model and its relevance as a policy tool. To be useful in improving policy decisions in the European Union, the model must reflect a realistic picture of the potential and structure of the EU, in a global context.

3.6.1.2 Regionalisation

The Societal Board pointed out that the cultural, economic, environmental, social and behavioural differences in the European Union are significant. Three hundred and sixty eight million citizens exhibit marked differences in life-style, and there are wide variations in the infrastructure. It was suggested that a model not treating the European Union as a single block would be highly desirable. However, although the team fully subscribed to this point of view as a medium term perspective, our task was to make an aggregate model of the entire European Union and due to the high level of aggregation the current SuE models can only replicate averages for the entire EU 15. But doing so, it can depict the differences resulting between one policy and another, which is the most important immediate objective and the key element of our project. At a later stage, if there is a wish to explore a single country or region within the EU (as considered desirable by our advisory boards at least in the long run), or a specific sector not yet included, then at least we have created a framework within which to insert it.

3.6.1.3 Sustainability Targets

Another discussion focused on how to define sustainability criteria, i.e. in the framework of our concepts, limits to input into the economy. Obviously, substantial sustainability targets must be defined within the political arena, as it has recently been done with the dematerialisation targets of Factor 4/Factor 10 by the OECD Environmental Ministers Conference 1997, the Nordic Council or (by the way of support from the EU) by the UNGASS Rio+5 conference 1997. Energy use reduction targets are familiar since the 1970s, but have gained new relevance in the framework of the climate change negotiations. Since Sustainability in SuE is always user defined and related to the different scenarios that can be simulated, those targets (52) can be made cornerstones of SuE scenarios.

Delinking physical and monetary flows has been identified as a core issue for any sustainability strategy. The board considered it helpful to combine the SuE model with others, generating a number of additional variables and indicators, based in the monetary field.

3.6.1.4 Econometrics

During the meeting with the Scientific Board the type of modelling used by the team was discussed, and compared with other approaches, for example econometric modelling. The differences in terminology from one specialist field to the next was identified as one obstacle for the more wide spread use of SuE-like models in policy development, since the language

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[52] For a collection of indicators, which can be derived from ECCO see SLESSER, M. et al., Non-Monetary Indicators for Managing Sustainability, Edinburgh 1994.

problems are causing confusion amongst decision makers and should therefore be avoided as far as possible.

3.6.1.5 The Role of Money

The SuE model does not include a price mechanism, and this was considered a weakness by the boards, who questioned the political acceptability and relevance of such a model to test policy packages (including tax variations etc.). However, to a significant degree, monetary effects (like trade balance, savings, investments etc.) are already inherent to SuE as they are to ECCO models. Additional proposals (like combining SuE with a money-based econometric model or introducing an additional monetary layer in the model) are highly interesting, but obviously beyond the scope of the current project.

3.6.1.6 Investment

Another field of discussion in this context was the modelling of investment in the SuE model. In the model, the available capital to invest in the industrial sector or other sectors is dependent on the net available HMC produced by the European Union economy (or imported) after investment in non-manufacturing sectors has been taken into account. This is defined as the potential rate of growth of manufacturing (the „residue theorem“). In economic thinking, on the contrary, the decision to invest and the investment volume usually do not depend on the output or/and consumption but on anticipated profits, according to investment theory based on future demand and price developments. To satisfy these requests, as a first and improvable step, an optional consumption driven modus of investment was introduced, however so far driven by a not yet internalised consumption development. Elements of an investment function stronger based on economic theory have been developed, but have not be implemented so far (for details see the technical handbook).

Another concern that the board raised was that by investing in sectors according to the ‚potential‘ of that sector to grow, the current utilisation of facilities already in place is ignored. The fact that unused production capacity is a typical situation in most European economies was cited. The risk of confusing potentials and reality becomes even more worrying in the medium to long term, since the difference between potential and reality tends to increase ([53]). To take this concern on board, the concept of load factors for the existing production capacity of HMC was introduced into the model (for details see the technical handbook). So far, however, these load factors are not yet endogenously driven, but set externally: in investment modelling, there is still significant room for improvement.

3.6.1.7 Technological Change

Referring to the critical issue of technological change, it was underlined that to some degree it should already be part of the BAU scenario, since technology based structural change is all the time happening in reality. Recent economic theory endogenises technical progress and tries to model explicitly those underlying factors in society that actually influence the rate of technical progress, such as investments in education, health and so on - and incentives are provided for example to the industry to increase investments rather than consumption. Given the necessary reliable data, this could be also a way to integrate technology into SuE. Being a physically

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[53] The Edinburgh Team stresses that the concern raised under this point may be based on a misapprehension. Investment in sectors is not according to their potential for growth (though the inverse is true that investment defines their rate of growth). It is driven by a number of factors including population, material standard of living, the requirements of other, related sectors, etc. The residual, of course, goes to industry.

based model, this however has to be done without basing it on behavioural assumptions that are not part of the model (see chapter 3.2 and the technical handbook).

In the model, technology change is not developing endognously (e.g. based on investment in education and/or in R&D), but used as an external variable. Some proposals for internalisation have been developed, but could not be implemented due to lack in reliable data (for details see the technical handbook).

3.6.1.8 Social feedback mechanisms

The boards underlined the fact, that sustainability politics must be based on public support, i.e. it is the social conditions that are decisive for the success of any such strategy. One important social precondition for a broad acceptance (besides employment) has been identified to be decreasing instead of increasing income disparities ([54]). This assumption has so far not been introduced into sustainability scenarios, since the SuE model is well positioned to illustrate the generation of HMC and the level of equity in its distribution to people, but not the economic effects of the resulting satisfaction - or, otherwise, social unrest. This would only be possible by exognously altering variables, e.g. decrease the load factor of capital stocks to model the effects of strikes etc.

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[54] The poverty developing in parts of EU 15 and particularly in Eastern Europe might pose a specific risk for any transformation towards sustainability in the countries concerned.

4 SuE model description

This chapter will provide an explanation as to how the physical economy model SuE we have developed can serve to identify paths to a sustainable future. This regards there main aspects:

- the **niche** that the model seeks to occupy,
- the **way** in which it is constructed, and
- the **role** they can play.

4.1 The niche

A model is a metaphor, a way of associating things not obviously connected (see chapter 2.2). For example, ”*money is a veil draped over the physical asset*” is a popular way of stating the implicit link between money and physical reality. In creating a model that could be used to tackle the issue we undertook to deal with in this project, namely *what set of policies can lead to a more sustainable Europe*, our metaphor has to engage the dilemma of a Europe simultaneously striving for environmental sustainability, growth in material welfare and fuller employment - all in a world of abundant resources, but with diminishing availability of environmental space (see chapter 3.4) and thus opportunity to use them sustainably. The interesting question is whether there are enough degrees of freedom in the socio-economic system to achieve all these aspirations. It is one of several objectives of this study to see if by a process of *dematerialisation* of production ([55]) they may be achieved.

4.1.1 The role of Nature within an economic model

”*Man conquers Nature by obeying her*”. That wise advice was stated - almost four centuries ago - by Francis Bacon ([56]), and, like most advice that stands in the way of human ambition, it has been studiously ignored. If we are to succeed in our remit we have to connect the humanly contrived economy with Nature. Unfortunately it is not possible to directly graft Nature’s contribution onto an econometric model since its driving forces and effects are not directly economic, but physical: Nature has no income, no bank account, no ambition and is not driven by market forces. Therefore only model designed to work on the basis on not monetary, but physical accounting can directly assess the effects from and to Nature. Obviously, the connections and issues that we deal with in this project go beyond the domain (in the systems sense) of money which specifically deals with human-to-human interactions.

Nature is quite indifferent to the fate of the human race. Yet she is the source of our present and future wealth. It may be she grudgingly yields up her vital resources, but we humans have found clever ways of prising them free. However, recently we have become acutely aware that she plays another role essential to our well-being. She absorbs our wastes. But it turns out even Nature has a limited capacity to do so, and so as the second millennium draws near we begin to appreciate that we can no longer do just as we like. Bacon is being proven right! Nature and Humankind must work together. As Nature cannot alter, we must ([57]). The issue of

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[55] Schmidt-Bleek, F., Wieviel Umwelt braucht der Mensch, Basel et al. 1994

[56] Bacon, F., Novum Organum, London 1620. This work by the famous English philosopher was written in Latin. The quote is thus a free translation

[57] See e.g. Spangenberg, J.H., Systeme zwischen Evoultion, Trägheit und technischer Beschleunigung, in: Renner, A., Hinterberger, F., Zukunftsfähigkeit und Neoliberalismus, Baden-Baden 1998 (forthcoming).

sustainability is to consider to what extent and in which directions we (as a society) must and can change.

How then can Nature be incorporated into a model of the economy? Do we ascribe to Nature monetary values for her resources and environmental space? Do we use a different but solely econometric procedure in order to be able to forecast in a rather traditional way economic and ecological effects on the basis of some assumptions about human behaviour ?

Or do we forego some of the advantages of an econometric model in favour of one which only spells out the physical consequences of human behaviour? If we do this, we lose the ability to model monetary flows not directly linked to and thus not measurable in terms of physical flows, but gain a means of quantifying the physical flows within the economic system. More can be extracted from such a model than at first would appear.

A model can only be a representation of reality, not reality itself. That must be so, because it is apparent to all that the inter-connections between people, the economy and Nature are so many and varied that no-one is in complete mastery of them all. Moreover, even were one able to structure such a theoretical model, the data would not be to hand. Thus in searching for a means of representing the interactions of the humanly contrived economy with Nature one has to restrict oneself to the essence of the question posed in this contract, which is how does Nature's role affect our prospects for a sustainable economic development and vice versa ? Are there any strategies imaginable which promote the one without neglecting the other ? Is there the degree of freedom mentioned, and how can it be made use of?

4.1.2 The Laws of Thermodynamics

It is not enough to visualise Nature a stock of resources. She, like ourselves, is a bio-physical entity governed by immutable laws. Two of the most important of these are the first and second laws of thermodynamics. The second, in particular, constrains us in a rather interesting way; because it bears upon the vital economic activity of production, through which we create wealth. We have learnt, through science, that all production is a process of reducing entropy. By that, in simple terms, is meant the reversal of chaos. We have learnt to do these things with consummate skill, but at a price. That price has been that somewhere else there has had to be an increase in entropy at least as great as (and in reality significantly greater than) the reduction attained ([58]). To cut a long story short, the source of that negative entropy is exploitable low entropy natural resources such as fossil energy, high grade ores etc., resources which are finite, if huge. In particular the energy in our modern civilisation is almost entirely drawn from the Earth's fossil energy resources, which due to Nature's limited absorption capacities we are not even allowed to use to their full extent in order to prevent irreversible changes of the Earth's atmosphere. We have built a complex and marvellous infrastructure by utilising the Earth's stored sources. Humankind has gone through a cycle from living on low resource consumption levels by the bounty of the sun, to intensifying life and production through the large scale mining of ores and minerals and the application of energy resources, and may soon be on the brink of having to go back to low resource consumption with the energy source being the sun, which, fortunately, beams down upon us energy at a rate ten thousand times more than we currently consume.

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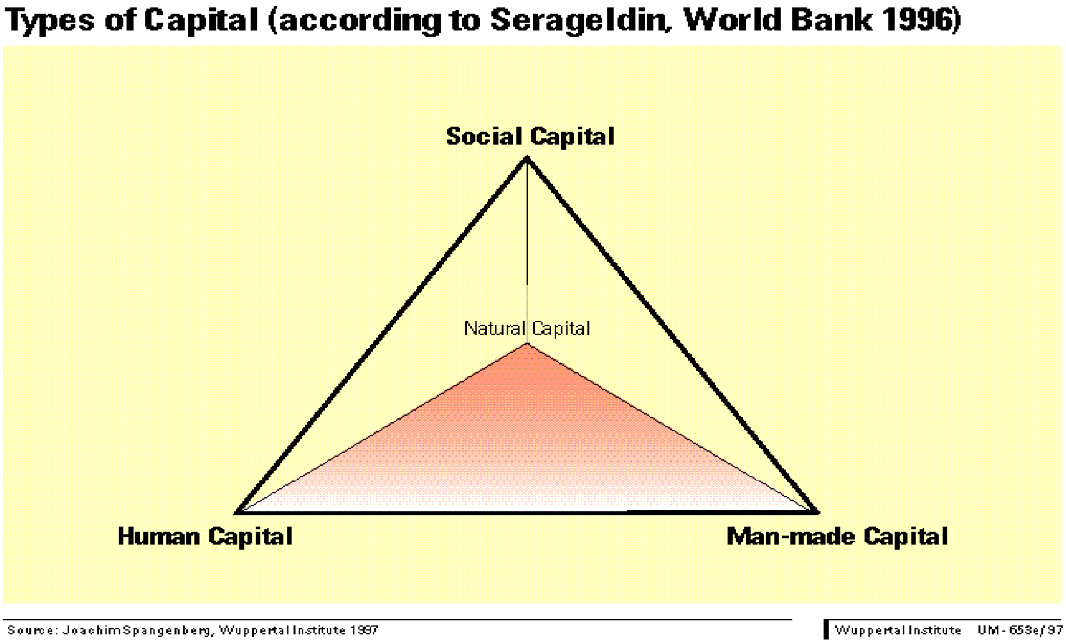
[58] Kummel, F., Energy as a factor of production and entropy as a pollution indicator in macro-economic modelling, in: Ecological Economics, Vol. 1 (1989), pp 161-180.

Creating a model that reflects all these mechanisms and interactions is for sure an ambitious undertaking, however fortunately it is not as prohibitively difficult as might at first sight appear.

4.2 The way - Embodied Energy Accounting

The procedure chosen is embodied energy accounting (otherwise in modelling known as Natural Capital Accounting (59)), developed initially in the systems analysis division of the European Commission‘s Joint Research Centre at Ispra (Italy) under the name of Natural Capital Accounting in 1978 when Malcolm Slesser was its head, and further developed and refined under this name at the universities of Edinburgh (60) and Groningen (61), and by the Resource Use Institute (62). One articulation of this approach, which has been used in the development of SuE, is ECCO - ”Evaluation of Capital Creation Options” (see chapter 4.2). It differentiates between *Human-Made Capital (HMC)* (i.e. physical capital) and *Natural Capital (63).)*

SuE quantifies Human-Made Capital in terms of the non-renewable and renewable energy that had to be dissipated (as an increase in entropy) in its manufacture, linking this with the associated total material input (64).



Types of Capital (according to Serageldin, World Bank 1996)

Source: Joachim Spangenberg, Wuppertal Institute 1997

Wuppertal Institute UM-653e/97

Figure 9: Types of Capital according to Serageldin (World Bank 1996)

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[59] We here try to avoid this term in order not to cause confusion with the differing economic defintion of natural capital and the limitations inherent to this term, see e.g. Hinterberger, What is Natural Capital, op. cit.

[60] Crane, D.C. et al., Methods of Initialising Energy Intensity Data in ECCO Models, in: Proceedings of the Second International Symposium on Energy-Based Models, Edinburgh 1995.

[61] Noorman, K.-J., Biesiot, W., The Netherlands ECCO Model, in: Proceedings of the Second International Symposium on energy-based models, Edinburgh 1995.

[62] Crane, D.C. et al., Regional UK ECCO User’s manual, Edinburgh 1995.

[63] For a discussion of natural capital in the light of the material flow approach see Hinterberger, F., Luks, F., Schmidt-Bleek, F., Material flows vs. ‘natural capital’: What makes an economy sustainable?, in: Ecological Economics, Vol.23 No.1 (1997), pp 1-14.

[64] We will in this text refer to it as HMC to make a clear distinction of terms between the economic one of capital and the specific understanding of Human Made Capital, measured in embodied energy EE, as used in our model.

Natural Capital

Any naturally provided stock, such as aquifers and water systems, fertile land, crude oil and gas, forests, fisheries and other stock of biomass, the landscape and the earth's atmosphere itself. The category is thus broadly equivalent to what are often termed *natural resources* in their broadest sense:

- Renewable Natural Capital:
    1. renewable energy flow resources (wind, tidal, wave, solar flows)
    2. renewable but exhaustible stock resources
        a) renewable biological stock resources (forests, fish, biomass, ...)
        b) renewable physical stock resources (soil structures and fertility, water systems, ozone layer,...)
- Waste processing capacities of environmental systems
  based upon the assimilative capacity of Nature
- Non-renewable (depletable) Natural Capital

is of the type that, when used, the physical components remain, but their useful attributes are lost. Examples are oil, gas or coal on combustion, copper, other ores, etc.

Human-Made Capital

Examples are plants bred for human use, equipment, buildings and infrastructure accumulated by devoting part of the current production (economy's output) to investment purposes. HMC is build up by investments and diminished by depreciation (losses).

SuE is based on the accounting of Human Made Capital measured in embodied energy EE. For the differences in the definition of the term „capital" in economics and in system dynamics see below.

Human Capital

This comprises the stocks of learned skills, embodied in individuals, accumulated for example by investments in the educational system, or by training efforts inside the private sector.

Its particular importance for the functioning, progress of a society and the competitiveness of the respective economy is underlined by the current debate about life-long learning.

Social Capital

Social capital is the totality of habits, including conflict moderation, and values (e.g. distributional justice, role of labour) in a society.

It also includes the „Intellectual Capital". This comprises the stock of useful knowledge, which we might term as the state of technology - accumulated for example by investments in Research and Development.

In this approach, one can think in terms of a manufacturing sector, whose role is to produce HMC, measured in terms of embodied energy. HMC is a summarising term, covering - economically speaking - investments as well as intermediate goods and services (as far as they are based on energy use). Some HMC is of short life, in particular in the case of consumer goods, some is for export, and some is long-life. Long-life HMC (i.e. investment goods, long-life consumer goods, infrastructure) underpins every aspect of the economy, whether it be a pizza-parlour, an oil refinery or an expansion of the industrial and manufacturing sector itself. However, for simplicity the flow of HMC generated by the industrial sector - here solely the embodied energy - is used in both ways as consumer goods and as investment goods. *So, obviously, the term "capital" in the model differs significantly from the understanding of capital in economics, which refers only to long living goods which are capable of producing other goods*.

4.2.1 Production

The physics of production are well enough understood and the statistics good enough to be able to determine how much of Nature's bounty is extracted (and dissipated) in order to manufacture any given type of HMC. As with money, there must be capital investment in order to yield output. In such a model all matter is traceable, quantifiable and computable.

Two main things are required to operate HMC in the model. One is fuel (derived from energy and computed in Joules - usually Giga-Joules: GJ), the other is management: the user's decision to invest /decision on the allocation of the available investment capital. Energy in the model supplies the thermodynamic work of production, while human beings provide the management. Both are modified by cultural attributes and advances in technology. Monetary flows, interest rates, bank deposits and investments in monetary terms are by definition not reflected by the model, except for their impacts on energy use patterns. Material flows are integrated into the model to some degree.

The model has a supply side and a demand side. The supply side determines how much HMC is available for investment at any moment in time. The demand side computes the amount of HMC required to maintain the given level of activity in all sectors so as to satisfy the policy objectives in place. To give an example, to utilise a particular set of investments of HMC, such as a service sector, will require a flow of fuels and materials of various sorts. To supply these requires the investment (of HMC - produced in the economy or imported) in the means of energy and resource extraction and the delivery of the required refined fuels and materials. Clearly the higher the demand for fuels and materials the greater the investments that will be needed in the energy and resources sectors. Once again we have positive and negative feed-back loops. Similar relationships exist for other sectors. In such a model one cannot use HMC that has not first been produced.

4.2.2 Structure

The SuE model structure largely exhibits the same cause and effect relationships that are to be found in an econometric model, though sometimes in ways that puzzle the newcomer. Here is an example. If a country exports machine tools, the monetary value of these exports add to the balance of international payments. However in an physical model while this remains true, there is also another effect. That export represents a loss of HMC, so while the monetary balance of payments is indeed improved, the available HMC is diminished. Of course the exports allow for imports, which may be spent on HMC, but equally may be spent on leisure pursuits.

It is for this reason that the most precise and logical way to use the SuE model is to structure it so as to ask of it one simple, but essential question. *"What is the rate of economic growth in terms of HMC that would arise in the context of user-defined policies, technologies and environmental objectives*". Any change in these considerations will result in a different growth rate. Thus when the model is run, the difference in output (using whatever criteria chosen by the user) between one set of policies and another allows of the generation of a "cost curve" (expressed in physical terms such as a higher or lower 'material standard of living') for that specific policy ([65]). This formulation of the model we shall call the *System-driven model (SuE-SD)*. Since there are considerable influences from economy's demand on the investment we also developed a version in which investment in industry is no longer a market-clearing residual (as in the system-driven version) but is driven by externally set consumer demand. We call this the *consumption-driven model (SuE-CD)* (Figure 10).

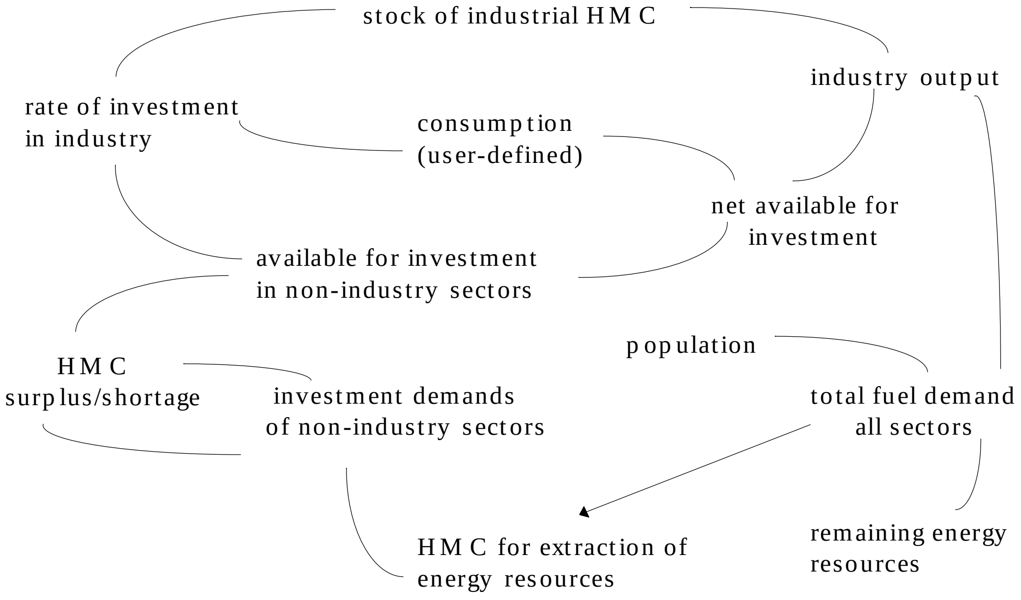

Figure 10: An influence diagram of the consumption-driven version of SUE

SUE-CD is used to explore the outcome of reduced or increased demand in consumption (consumer goods). When this is done the model generates a surplus or shortage of HMC which must be allocated or deducted elsewhere. At the moment any surplus or shortage is directed to the domestic dwellings/housing - sector. Other possibilities could be transport, services (market and non-market services) or any proportional distribution to all of these sectors.

In our model, market clearance is essential, so supply and demand for HMC has to be matched. In the system-driven version market clearance is achieved automatically whereas in the consumption-driven version a surplus or shortage has to be allocated. If the values for consumption of goods generated by the SD-version are inserted into the CD-version the resulting growth of the economy is identical (ceteris paribus).

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[65] Crane, D.C., Balancing pollutant emissions and economic growth in a physically conservative world, in: Ecological Economics Vol.16 No.3 (1996), pp 257-268.

The user has the option to switch between both versions.

4.2.3 Domain and system boundary

It is important to appreciate the extent of the domain of this type of model. In a chessgame the domain is the chessboard, the pieces are the actors who move in different ways, while the managers are the two players. The domain in SuE is the physical-oriented snapshot of the European economy; the user acts as the manager and can explore the physical impact of self-defined policies in the long run by having economic and non-economic policy variables at hand. It is up to the user to draw assumptions on future human behaviour. SuE then spells out the long-term physical consequences - not attempting to make forecasts based on assumptions on behaviour and preferences inherent to the system.

The domain of an econometric model is also the economy. However, an econometric model - generally built for the short and medium term - is explicitly based on certain behavioural assumptions which are assumed to be unchanging principles and as such integrated into the model, being represented e.g. by estimated elasticity coefficients. These models are then used to make forecasts.

The system boundary of the SuE model extends from resources in the ground to their eventual rejection as wastes into the biosphere, mediated by the humanly managed actions in between.

Once a model of a particular system, such as the EU, is built, tested and validated, there is considerable freedom within the model to use it to explore the physical viability of a wide range of policies, technologies and environmental objectives. In this context viability means whether they are in fact physically possible. Because the model spells out the physical consequences of user-imposed policies, it at once becomes clear whether any particular set of policies are mutually compatible. In other words the model can inform one what is physically and thus economically NOT possible. This is as valuable as determining what IS possible.

4.2.4 Sectors

Choosing the sectors to be represented in the model, we have followed a combination of theoretical analysis and pragmatic modelling needs. As D. Jacobs points out (66), mega clusters structuring the European economy are the manufacturing sector, chemical industry, energy, transport, agriculture and food, construction, media, health, market services and non-market services.

In the model, chemical industry and food processing are included in the manufacturing sector. Media is part of the market and health part of the non-market sector - besides these aggregations, the structure has been implemented in the SuE model. The SuE sectors based on this analysis are:

- Manufacturing
- Transport (roads, rail, air & infrastructure)
- Agriculture, forestry and fishing
- Construction
- Market services

Eco-efficient services

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[66] Jacobs, D., Wissensintensive Innovationen: das Potential des Cluster-Ansatzes, in: The IPTS Report 16 (July 1997).

Non-market services (government - health, education)

Since energy accounting is so basic to the model, the energy sector has been differentiated in two subsectors, extraction and electricity generation:

- Fossil-energy extraction (coal, lignite, natural gas, oil)
- Electricity generation (nuclear, coal, natural gas, hydro, other renewable)

Since the selection of sectors had to be based not only on economic factors like their relevance for HMC creation and their influence of the dynamics of the economy, but as well on their importance for energy supply and material flow activation, we added some more sectors:

- Non-energy physical resource extraction
- Domestic housing
- Water

To make the model run, and to generate some of the results we are looking for, some additional modules had to be intraduced into the SuE model. They account for:

- Consumption (consumer goods, services, transport, fuels)
- Capital transfers (external to EU), balance of international payments
- Internal and external debt
- Income re-distribution (pensions, benefits), average (EU-wide) taxation
- Environmentally significant outputs (CO2, SO2)
- Employment (employment generation by broad sectors)

The SuE model divides the entire human economy into these sectors calculating the temporal development of sectoral HMC formation rates, HMC stocks, energy and material use etc.

4.2.5 Labour

Although environmental politics is no substitute for labour politics and its successes should not be measured in terms of jobs created, sustainability policy will have significant impacts on the labour market. Of special interest for the Modelling SuE Project is the examination of employment effects caused by the different scenarios and policy-strategies.

In the model, sector-specific job creation coefficients, based on empirical data are used to reflect the impact of economic activities on the labour market. Changes in labour productivity would then result in a change in these coefficients. Changes in daily or weekly working time are directly implementable, since the total volume of labour is counted in hours, not in jobs, and the total number of people employed can be derived from the total number of working hours and the kind of work time structure the user wants to assume.

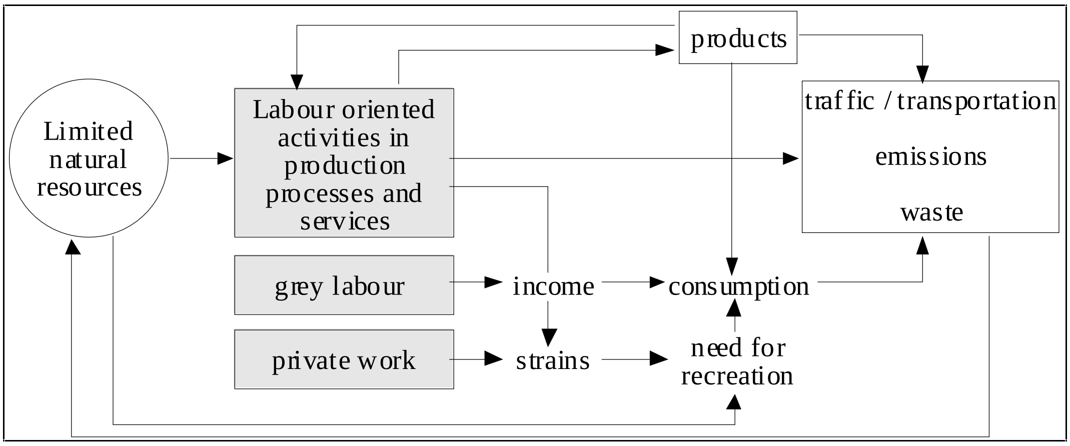

Figure 11: Labour, resources and income - new production patterns will change labour as well (only partly integrated into the SuE model)

So far, there is no feed-back from the employment (labour demand/supply) variables of the different sector to any demand-for-consumption-variables of the own and other sectors except in the educational service sector, but such a feed-back could be modelled easily.

4.3 The Role

Now that we have defined the inner structure and the components of the model, and as we know from economic research that the sectors we have chosen to include in the model indeed represent the main driving forces of economic development, we are well positioned to apply the model to policy impact analysis.

4.3.1 Policy implementation

Those unfamiliar with embodied energy accounting often enquire how such models can be used for economic management and - more general - for political strategy development. A second, more recently asked question refers to indeed what possible relevance could such models have in a world where market forces dictate what happens. There are two connected answers to these questions.

On the second question, we do not (yet ?) live in an entirely market driven economy and society. Governments apply taxes not merely to secure income for re-distribution, but to mould the market to its will. Thus we have taxes on fuels, and in an effort to curb carbon dioxide output, there are EC proposals for a carbon tax and recently an “energy product” tax. Though this has yet to be clearly enunciated, it is likely to be close to the concept of the embodied energy of a product, a value which SuE computes. Policy is still possible, and indeed is shaping our countries, so the proactive assessment of the impacts is still a necessary tool for the identification of improved strategies.

Secondly, the policies that many users will choose to explore will be those that derive from established economic perceptions. The model assists by providing many criteria (indicators) of system performance. The user must use these to arrive at the ”best” compromise between the competing factors in the development equation: environment, pollution, resource use, economic growth and material welfare. The definition of ”best” is not one for the model builders to define, but for the model users to decide. However, once this ”best” or ”acceptable” outcome is identified, then the decision-maker must move back into the political and economic domain, and ask the question ”*what sort of instruments will achieve these directions?”*.

4.3.2 Assessing sustainability

What can a physical economy model contribute to the assessment of sustainability? In the first place, the model is uniquely adapted to quantify physical flows, which are at the source of all environmental disturbance potentials generated by the European economy. This is important since a sustainable economy must have a sustained (i.e. available and acceptable) supply of physical resources, and the model spells out what these must be for any user-defined set of policies. Thus it is an appropriate model for exploring the total environmental effectiveness (are the goals achieved at a socially and economically justifiable price ?) of proactive environmental policies such as de-materialisation, energy conservation, new manufacturing practices and consumption patterns, or switches to new energy technologies by assessing their system-wide impact on energy consumption, material flows and economic development. Moreover it also quantifies (on the basis of input data) the physical effort of bringing resources into the economy. Secondly, by its ability to assess the system’s potential for growth (and this is so for both SUE-SD & SUE-CD), it can spell out the future prospects resulting from any user-defined set of policies. These prospects are measured in terms of criteria or *indicators*. For examples of application (e.g. the scenarios in the 1996 EC study -*Vision 2020* ([67]) see chapter 4).

Recent studies on the state of the environment, such as the detailed Dobris Assessment for Europe ([68]) paint a sorry picture of the present state of the European Union-15, while the projections are based largely on extrapolations of existing trends. Here, then, is an excellent role for a well-founded dynamic physical model of the economy by providing model-based trend assessments of the future.

Finally, the model can measure the physical flows from and into the bio-sphere, and so provide the basis both for planning of ameliorative action and for imposing constraints.

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[67] EC-DG XI (Ed.), ‘Vision 2020’ Scenarios for a Sustainable Europe, A Working Document Prepared for the General Consultative Forum to DG XI, Brussels 1996

[68] Stanners, D., Bordeau, Ph. (Eds.), Europe’s Environment - The Dobris Assessment, Copenhagen 1994.

5 Scenario Results

As pointed out in the model description, SuE is no standard economic model intending to predict economic development, its main purpose is to be a tool for scenario testing and policy comparison. Helping to identify more or less successful approaches, long term rebound effects and the mutual influence of different policy goals it can be used by decision makers to improve the information basis of their day-to-day work.

The fact that the model does not claim predictive powers has two benefits: no long term assumptions on human behaviour are needed to make the model work (although such kind of assumptions can be tested regarding their impact on economic and environmental factors), and the degree of exactness needed is not overly ambitious. We do not intend to give a weather prognosis, but we have something to say about climate change. And that is good enough to compare different policy approaches and their interactions on a sufficiently comparable basis.

The obvious starting point for any such comparisons must be the status quo. However, since we are working with a dynamic model, the status quo cannot be the state of today, but must reflect today's dynamics, resulting in a business as usual scenario as reference against which to compare our model runs.

5.1 Business as Usual

Being a reflection of the current dynamic, the business as usual (BAU) scenario must be based on trend analysis. That is to say that all model-relevant trends in the economy are supposed to continue for the analysis period as they have been in the last ten years, our reference period.

5.2 Environmentally Efficient Production

Before developing what could justifiably be called policy scenarios, i.e. a complex set of model assumptions reflecting the cross-cutting effect of a number of combined policy measures, we have first tested a number of single parameter changes to see which is the effect of which factor according to our model. Later, these modifications are integrated to give a comprehensive picture of different policy approaches (policy-mix scenario). Therefore, employment projections derived from the different scenarios are to be considered a first impact assessment, not a final result.

5.2.1 Energy Efficiency

A number of scenarios includes elements of energy policies, like the sustainable energy scenario modelling the effect of promoting different renewable energies, of phasing out nuclear at a quite early date, or of energy saving (please, see Technical Report). Here we have not separated out energy policy, but treated it as part of an overall efficiency scenario for energy and material, since there is some close interaction not visible from the energy viewpoint alone ([69]).

So, for example, substituting lignite and coal with energy from renewable sources is a normal element of energy scenarios, but usually not accounted as an efficiency measure. From a material flows point of view, that's exactly what it is, since the substitution by renewables tends

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[69] Energy efficiency improvements from technical change are discussed in some more detail in the technical handbook, chapter 1.1.3.

to deliver an equivalent amount of end energy with comparably less material flows activated. Therefore the following paragraph covers both, energy and material efficiency.

5.2.2 Material Input Reduction / Material Efficiency

This scenario is designed to assess the potential for energy saving and dematerialisation of the economy due to technological improvements (technical efficiency with respect to resource use). The results should clarify the question whether the assumed efficiency increases can lead to an absolute reduction of physical throughputs, or whether the efficiency gains are overcompensated by economic growth.

On the other hand insights are possible which level of efficiency improvements were necessary to actually reach a predetermined absolute reduction of throughputs (set to be 30% by 2020) without assuming additional limits to growth.

For the first question, a model run was programmed using a bundle of technical improvement potentials (including a switch from fossil to renewable energies) based on empirical, however more anecdotal information, since it was found that no comprehensive overview of technical efficiency potentials exists in Europe. For the second question, a top-down approach was implemented.

In this isolated approach, a stabilisation and slight reduction of CO_2 emissions is reached, with economic growth virtually unchanged. This is paid for by a slight but measurable decrease in employment and the material standard of living (top-down more than bottom-up). However, the standard of living index based on service availability increases.

For the total material input, a stabilisation and slight reduction in absolute terms is achieved; however to reach a 30% absolute reduction would require almost 5% average annual efficiency increases of non-energy resource use in the construction and manufacturing sectors throughout the next generation. Although a significant efficiency increase may be feasible due to the current underexploitation of material efficiency potentials, it cannot be considered sure that the level (5%) as well as the duration (annually for 25 years) of the efficiency gains can be realised. However, a significant share of this is indeed possible, since the current debate tends to underestimate the material efficiency potentials systematically by focusing on end-of-pipe measures instead of prevention.

In the further course of the scenario, more detailed information is given on the effect from and to different sectors, so to explain (and allow for modifications of) the picture briefly described above.

5.2.3 Organic Agriculture

As the EU's Common Agricultural Policy CAP is being reformed in the process of Agenda 2000 and the planned EU enlargement, the question is all the more urgent which direction should be taken in order to reduce overproduction, but secure food supply, safeguard the landscape and ground water quality (in particular by closing the nitrogen cycle) and - last but not least - securing farmers' incomes.

As pointed out earlier, also preservation of biodiversity is one of the most pressing tasks agricultural politics has to address, and for this behalf as well as for balancing nutrient flows and in particular avoiding the nitrogen contamination of ground- and surface waters organic agriculture has been proposed and in fact in recent years been supported by the CAP.

The scenario presented tries to test out what would be the effect if the whole of the EU agricultural area was under organic agriculture - other scenarios could be developed to reflect intermediate approaches (like the Sweden 2020 scenario of the Swedish Environmental Agency).

According to the scenario, organic agriculture (as opposed to the BAU intensive farming) is well positioned to balance nutrient flows, and - assuming present levels of overproduction - the so far set aside land would be used for organic farming (+15% as opposed to -20% in BAU). This opens the opportunity to reduce overproduction - in that case, the land required under a 100% organic scenario would be 4% less than today.

This suggests that it would be worthwhile to consider an even stronger support for organic agriculture, due to positive effects on biodiversity, employment, environmental balance and the economically desirable reduction of overproduction. The cost saved this way might then be used to safeguard the standard of living in rural areas - if necessary by directly transferring money saved from overproduction treatment to farmers, an approach the Commission has already included in the CAP part of Agenda 2000.

5.2.4 Transport Policies

It is all too obvious by now that our patterns of mobility, and in particular of auto-mobility form one of the major obstacles to sustainable development. Cars and commercial vehicles consume an ever growing share of fossil fuels with all efficiency gains overcompensated by higher driving volumes as well as more, faster and heavier cars. Whereas some steps have been taken to reduce the burden commuting, by now leisure time car use is the source of the majority of trips, and still growing.

However, leisure time in current statistics includes a lot of involuntary work relocated from the business sector on the consumer (buying at a hypermarket and driving goods home saves business the expensive last 10 km of distribution, as compared to a corner shop) or simply not necessary a generation ago (mothers driving their kids to school, sports etc., where they once could walk).

Special relevance must be attributed to the freight transport for its damage to the environment, to individual well being (about half of all German citizens suffer from road noise), to accidents, congestion etc.

Measures proposed in public policy making include

- technical improvements like low noise lorries,
- efficiency increases for trucks and cars,
- changing the modal split to strengthen public transport by better service, appropriate pricing, awareness raising and financial incentives,
- reducing the need for transport (by a range of measures from more accessible public infrastructure, promotion of local shopping of regional goods, strengthening the regional economy, increased price to reflect the full cost of transport, dematerialisation of the economy, telework and teleshopping, etc.)
- a reduced level of consumption (and thus of production).

Of all these approaches and the variety of measures under discussion, only a fraction could be tested for their impacts in the time given, but most others can be explored by the user. Being a physical model, however, SuE cannot explore the effect of changed transport prices but with the physically relevant effects of such policies.

Therefore we have tested two approaches, one being a number of runs with different developments of the modal split. Here it turns out that given the expected increase in total transport volume for the EU as reflected in the BAU scenario, the effects in a *Trend Reversal scenario* are only moderate. Even under the more ambitious *Vision* run, energy consumption and CO_2 emissions cannot be curbed, despite a limited but visible effect on growth and employment. Obviously, the hopes that many political decision makers have been airing about a solution to transport problems by combined transport or more rail transport have to be considered overly optimistic: these measures may be helpful as such and for local problems, but they will not solve the problem on the EU level.

We tested as well the impact of assuming changed behaviour patterns concerning the passenger load of car trips. The average number of passenger per car (the car occupancy rate) was gradually increased from the EU15 average of 1.68 in 1995 up to 2.16 in 2020. This measure has about the same effect as the modal split *Vision* scenario.

How measures taken in different sectors can be supportive for transport reduction is shown by the assessment of the dematerialisation strategy mentioned above on total freight transport ([70]). As the most obvious results come from the more drastic assumptions, we have tested the effect of a 2/3 reduction of material flows by the year 2020.

The results are striking: Not only the growth of freight is curbed, but a slow decline in freight transport is to be expected. This has positive effects on emissions, reducing the number of commercial vehicles etc. This policy contributes significantly to the EU targets for CO_2 reduction set out at the Kyoto climate conference.

5.2.5 Eco-Efficient Production

As a next illustrative step we have combined a number of the scenarios outlined above (policy mix) which are part of the current policy debate. We have chosen to integrate technical efficiency regarding energy and non-energy resources, modal split in transport and organic agriculture using the assumptions outlined above.

In combination, this set of policies still results in increasing industrial output by half by 2020 (10% less than BAU), with positive effects on CO_2 emissions and material flows. However, the "Kyoto-target" of the EU-15 with respect to CO_2 emissions can not be reached by eco-efficient production only. Furthermore, the increase of unemployment is slightly worsened as compared against BAU from 30% to 34% in 2020. Obviously, these strategies alone, for all their environmental benefits, are not socially sustainable, although there still is a significant increase in the standard of living.

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[70] Due to the fact that SuE is an EU 15 model, the tendency towards a shortening of trips due to increased levies on transport to internalise indirect subsidies as well as environmental and social costs has not be modelled. Such policies would result in a promotion of local economies, integrated production and regional consumption, with significant efforts not only on transport, but on the thriving of communities and people's well-being. It is up to the users to define his/her favourite set of policies towards this direction and to test the outcome, as far as the SuE model can generate meaningful results.

5.3 *Eco-Efficient Services*

The eco-efficient services scenario focuses on the efficient use of goods instead of efficient production. It is based on the assumption that a similar consumer satisfaction and thus standard of living can be generated from permanently maintaining and upgrading a high quality good as from purchasing a new one after only limited use time, and from substituting goods for services (71).

Thus more services per good and year and long-lived goods are the two key elements of this scenario, with slightly higher prices and labour (10% more investment of energy, resources and labour is assumed) needed for the generation of long-lived goods. Other parameters like labour costs are not changed, but this could be done by the user if s/he feels that this would be more appropriate.

Furthermore, at this point it should be highlighted that the scenario does not assume new technologies not yet available on the market, but is based not only on known technologies, but on those dominant in the market. A technology push guided and supported by direction safe demand pull strategies would definitely make it easier to reach the ambitious dematerialisation targets without generating the negative impacts which inevitably occur under the "known technologies prevail" conditions.

Assuming in a first run that the market share of long-lived goods slowly increases up to 10% from 1985 to the year 2015, and that as well 10% of material goods purchases are substituted by services, growth in manufacturing output is slightly reduced. So is the growth in material standard of living, however this is obvious since by definition it does not account for the number of services available. Taking these into account, even an acceleration in the growth of living standard shows up. Whereas in the BAU scenario about 20 Mio jobs are lost by the year 2015, the service scenario reduces this losses by 20%. However, the CO_2 emissions, due to be reduced according to the EU proposals presented in Kyoto, instead do increase by 110% (as compared to 140% in the BAU scenario). The scenario obviously works towards the right direction in a number of aspects, however without generating sufficient results.

The next scenario run was therefore undertaken not in a bottom-up, but in a top-down manner in order to identify the measures necessary for significant effects. Pushing the increase in service efficiency high enough that a relative reduction of throughput compared to BAU can be achieved (72), it turns out that the reduction in normal good is significant (about 20%), but even more significant are the in durable goods and eco-efficient service provision, which together provide as much services by 2015 as the total consumption did in 1985. This becomes much more dramatic, if we go for an absolute reduction as compared to current levels of throughput. In this case, and given the restrictions imposed on technological change, the model economy is not able to cope with the policy measures introduced, signalling "too much of a good thing".

This is all the more a pity since this scenario delivers the highest standard of living (measured in services) and the highest number of jobs, while significantly reducing the environmental impact.

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[71] One way of doing so is the sharing of goods, which can help save expenditure without compromising on service accessibility.

[72] As an extremely rough first estimate (remember: technology leapfrogging has been excluded so far and all rates assumed here are designed to be simple, not realistic), we assumed that three relevant efficiencies would equally contribute to a dematerialisation by a factor of 10 within 50 years. They are the production efficiency of material input (e.g. in ECU GNP/t), the service efficiency of GNP (e.g. in S/ ECU GNP) and the well-being efficiency per unit of service enjoyed.

Further work would be needed to clarify whether it is the resilience of the model or the economy that has been overstressed here, and what additional assumptions (e.g. which technologies) could make this scenario a sensitive and economically successful one.

5.4 Employment and Technology

The scenarios presented so far have included some preliminary estimates of their related effects on the environment and employment, however they are yet not combined with an analysis of the impacts changes in technology. SuE contains a structure which allows the user to explore the relation between investment, technical change and employment. The following brief scenario result descriptions give a general idea of these relations by testing the options of cutting the unemployment gap by increasing borrowing-fed economic growth. Two options are analysed both focusing on the reduction of life-long work time (job sharing scenario and reducing pension age scenario).

5.4.1 Problem Solving Growth

An average annual growth rate of about 4% would be needed to bring unemployment down to below 5% by the year 2020. However, it is not only unclear how any government could reach that level of growth, but as well the impacts on resource consumption, environmental pollution and dependency on foreign resources are tremendous. Primary energy demand would more than double, bringing CO_2 emissions up by plus 140% and self sufficiency in energy supply down to 18% of demand.

If financed entirely by borrowing from external sources, total debt would accumulate to 21 trillion ECU - if anyone anywhere were able to provide this amount of investment, and with all consequences of interest payment for the public budget.

Neither economically nor environmentally, this can be regarded a sustainable perspective. Consequently, efforts to solve the unemployment problem by strengthening economic growth are not only difficult, but even not desirable from an integrated sustainability point of view.

5.4.2 Limits to Technical Change

First we checked the obvious: if the job replacement rate of investment would not increase along the lines it did in the last ten years, but stay at 1995 levels, the number of jobs would decrease by 30% (BAU scenario). In terms of sensitivity analysis it is interesting to see that, if technical change was brought down to zero in specific sectors, the highest effect (unemployment 7.5%) could be reached if technological change was curbed in the non-market services sector, with manufacturing coming only second (11%) and mineral extraction last (29%).

A second run assumes that the dynamics of the last ten years is maintained (not knowing whether such a development of labour productivity and investment cost is feasible at all). In this case, the reduction in the number of jobs required to run a certain capital stock would outnumber any gains from growth and result in unemployment roaring up to more than 50%.

What happens if labour replacement continues in the manufacturing sector, but is reduced by half in the market services and reduced to zero in non-market services (a strategy based on the publicly discussed if questionable assumption that services is the sector where efficiency gains are least likely to occur)? This being stepwise introduced, total unemployment would first be stabilised and then reduced to about 5% for the EU 15.

Obviously, neither the continuation of the past trends, nor even the status quo of rationalisation is socially sustainable. Whether on the other hand curbing technological progress in the services sector (or the assumption it would not happen anyway) is realistic, remains highly questionable, not least based on current trends in market services.

5.4.3 Reducing Working Time

In this scenario, two proposals from the public debate concerning reducing the working time have been put to analysis by the model: reducing the number of weekly working hours and reducing the pension age.

Actually, the length of the average working week is differing by sector, from 45 hours in agriculture to 37 hours in non-market services (differences by country cannot be replicated in the model). If all these working weeks are reduced to 35 or 30 hours respectively, however without assuming financial compensation for the time lost, and as a result of limited cost increases for the employer ignoring the substitution effect, unemployment is reduced to well below 5% before the year 2015, but then on the rise again due to continued productivity increases.

Opposed to this, the effect of reducing the pension age is more short term and sharp, but does not change the dynamics. As a result, unemployment in 2020 is reduced by 10%, with the total public benefits increasing due to additional pensions costing more than saved unemployment benefits compensate for. This is obviously a short-term effective measure which for financial reasons should be - if used - handled with care.

In a benefit system, where pensions are not based on public spending but come from an insurance system, early retirement would further reduce pension benefits (which might already be diminished due to a reduction in working hours). This underlines clearly that for most employment-boosting strategies a change of the calculation base for pension schemes away from the "standard working biography" underlying it nowadays is needed.

5.5 Towards a Sustainable Development

In order to illustrate the interaction of policy measures and how a set of policies could be implemented in SuE we have combined a number of single policies outlined in the above sections which are part of the current policy debate.

We have chosen to integrate eco-efficient production, eco-efficient services and a labour policy which is reducing working time to the on average preferred time of 33 hours per week.

Generally speaking, the environmental effects of the approach can be considered fine and - not too surprisingly - stronger than under eco-efficient production assumptions. The reduction target with respect to CO_2 emissions set out at the Kyoto climate conference is reached and the total material input into the EU economy is reduced by 27%. However, there are two points which deserve special attendance: the development of employment and of the overall standard of living.

This combination of scenarios here reveals that whereas mere eco-efficient production is decreasing the employment slightly, this effect is strongly overcompensated by effects of the eco-efficient services. Compared to the BAU scenario, where unemployment is increasing to 30%, this loss of jobs is reduced by more than a third, resulting in a (still unsatisfactory) unemployment rate of 18%. By furthermore introducing the labour policy - i.e. reducing weekly working hours to 33 in all sectors - an unemployment rate of a few percent is reached.

Interesting insights are provided by the analysis of the standard of living index: its development is strongly dependent on the definition. As already visible in the eco-efficient production scenario, the more the standard of living is not defined to measure out *command of material goods*, but the *access to services* derived from them, the more positive the eco-scenarios have presented themselves to the customer.

Integrating the service efficiency approach, this becomes all the more striking: whereas under conventional measurement the material standard of living decreases by half, seemingly indicating wide-spread poverty, only the service-based index gives a realistic picture: although much less material and (embodied) energy for the production of consumer goods and services is needed - compared to BAU - the service availability resulting from long-lived material goods as well as from eco-efficient services (see section 2.5) is even increasing. In other words, you are not suffering from not buying new lawn mower or vacuum cleaner, if the old one is well maintained, upgraded and works fine. You just save the money for other purposes, resulting in a doubling of the service-based measurement in the standard of living.

The strong increase in service availability indicates that the standard of living could be maintained despite a reduction in the average wage which is connected with the policy of "reducing working time" - at least as far as the implementation in the SuE model goes.

The results from the policy mix described above show that a path towards a sustainable development can not be reached by any of the single policies alone. Measures leading to an eco-efficient production are not sufficient but must be supported by active labour policies in order to meet the target of a socially sustainable Europe. In this respect also the - currently still underestimated - eco-efficient services play an important role. Thus, all three elements make essential contributions to a strategy targeting at a sustainable development of the European Union, however further aspects may still be included.

6 Outlook

Increasing employment opportunities (as compared to business as usual, or even in absolute terms) is possible without damaging the environment or undermining the economic competitiveness. However, this demands a sophisticated combination of measures that have to be analysed one by one and in their interaction in order to avoid counterproductive side effects. This can already be seen from the necessarily limited number of scenarios presented here.

Whereas our scenarios can only be a fraction of those already aired in the public domain, they still illustrate the usefulness of the model and its potential to deliver meaningful results. Although improvements are always possible, the model as it stands can be used to improve the information basis for political decision making by illustrating interference of policy strategies and their medium-term results.

It is up to the user to transform any kind of policies (except for regionalisation approaches, which by definition cannot be modelled with the given structure) into model scenarios and combine any such sets of measures towards comprehensive sustainability strategies for economic, labour, environmental and technology policies.

The Modelling SuE teams appreciate any application of the model, be it to assess policy planing, improve measures in the pipeline or elaborate future policies. Anyway it should be clear that no single policy can bring us towards sustainability, and that for meaningful integration models such as SuE are a helpful tool for policy formulation. May it be used and useful!