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Modelling Sustainability with PANTA RHEI and SuE

Andreas Bockermann, Bernd Meyer,
Ines Omann, Joachim H. Spangenberg

Abstract

Sustainable Development is probably the key new paradigm on which to base policies for the future. However, so far the concept remains vague at best in many aspects, and in particular as regards the interaction environmental, economic and social politics. Based on some theoretical considerations this paper defines minimum conditions for sustainable development. They provide criteria for assessing the suitability of different economic models for sustainability questions, as well as means to prove the sustainability of the scenarios presented in the remainder of the paper.

This paper presents two models suitable for simulating sustainability strategies. One (PANTA RHEI) is a highly sophisticated econometric model for the German economy (Meyer, Bockermann, Ewerhart, Lutz 1999). The other one (SuE) is a less disaggregated system dynamics model for the EU 15 economy (Spangenberg, Scharnagl 1998). Both include the measuring of energy and material consumption and are thus well suited to indicate the linkage of economic development and environmental impact. Similarly, both calculate the employment effects of a given policy, permitting to include one key social concern in the evaluation of sustainability policies as well. Both models introduced are shown to meet the sustainability requirements as defined earlier.

When identifying similarities in the outcome of comparable strategy simulations runs on both models, their inherent structural difference rules out any methodological bias or system artefact. All the more relevant are those outcomes that point into a similar direction for policy development, having a base in two structurally independent policy impact assessments. Key results include:

- There is a trade off between growth and employment on the one and environmental concerns on the other hand, however sustainable compromises are possible.
- No single policy instrument (neither legal measures nor economic incentives) is able to deliver a sustainable economy. What is needed is an intelligent mix of economic, social, environmental and labour policy measures.
- If such a combined strategy is applied, it is possible to reduce the currently unsustainable high unemployment levels to significantly below five percent of the labour force, while at the same time reducing resource consumption and safeguarding or increasing the standard of living without running into significant public debt.

Key Words: Sustainability, Modelling, IO-Analysis, Embodied Energy Accounting, Dematerialisation, Employment.

1. Introduction

Since it was brought to broad public attention at the UNCED Conference in Rio de Janeiro in 1992, the concept of sustainability has developed into a new socio-economic paradigm (UN 1993). However, all too often it is not much more than a mere catchword without any operational strategies linked to it. The remaining ambiguities cannot be clarified by means of one dimensional (be it economic, social or ecological) analysis, but need integrated approaches that can illustrate the interlinkages between the dimensions of sustainable development.

In order to overcome the current policy stalemate, a sound scientific basis for political decision making is needed, based not only on environmental targets (e.g. for CO_2 emission reduction), but as well taking into account the social needs of society and the economic impacts of the sustainability strategy chosen. It must be able to assess policy strategies and to identify synergistic effects as well as trade offs. Questions whether growth is or can be sustainable should be replaced by developing criteria indicating which *kind of growth* can be sustainable, whether it is socially and economically viable and how it can be brought about.

In an attempt to become more reality based, the policy debate on sustainability has moved from the suggestion of single policy instruments (like green taxes) to scenario and indicator development and further on to integrated modelling. Quantitative models, like the ones presented in chapter two (PANTA RHEI) and three (SuE) provide the opportunity to see a dynamic picture instead of a static snapshot. Their respective structures are explained and some simulation results presented.

Models help to take into account the potentially counter-intuitive outcomes resulting from rebound effects, but they miss out the qualitative aspects scenarios can cover. Therefore it is essential to base the modelling on broader scenarios, however given the restricted room available this paper focuses on a comparative description and comparison of the two modelling approaches and their results.

Although the models used are fundamentally different, as are the data sets (national and EU level), the outcomes of different strategies are remarkably close to each other (chapter four and five). This paper explains how these results have been derived. Although a direct comparison is not possible, given the fundamental differences of the two approaches, this fact also underlines that the results are by no means model or methodology artefacts. Consequently it is suggested to regard the results as well founded, based on this comparative analysis. Finally, some conclusions from the comparison are drawn as regards future work on sustainable development modelling (chapter six).

1.1 Sustainability

As regards the definition of sustainability in the public debate, an unanimous consent has not yet emerged. Therefore some clarifications regarding the approach chosen are provided here to illustrate the basis of the further analysis.

In the understanding of the UN Commission for Sustainable Development (UN CSD 1996), sustainability has four dimensions: the social, economic, environmental and institutional one. Whereas the environmental dimension can be defined to be the sum of all bio-geological processes and the elements involved in them (referred to as "environmental capital" by economists), the social dimension ("human capital") consists of the intra-personal qualities of human beings, their skills, dedication and experiences. Institutions (confusingly called "social capital") are the result of interpersonal processes, like communication and co-operation, resulting in systems of rules governing the interaction of members of a society. The economic dimension ("man-made capital") includes not only the formal economy, by as well all kinds of informal settings that provide services to individuals and groups and thus increase the standard of living beyond the monetary income (World Bank 1997).

The fact that the analysis is dividing society in four separate subsystems should not be understood as denoting the permanent interactions of the economic, social, institutional and environmental subsystems. These interactions constitute the linkages of the four dimensions. They can be characterised by interlinkage indicators, which do not refer to one single dimension of sustainable development, but are socio-environmental, institutional-economic and so forth. The models presented here focus on policy strategies and economic development, as well as their respective influence on employment and environment, thus covering core aspects of all four dimensions or subsystems of sustainable development.

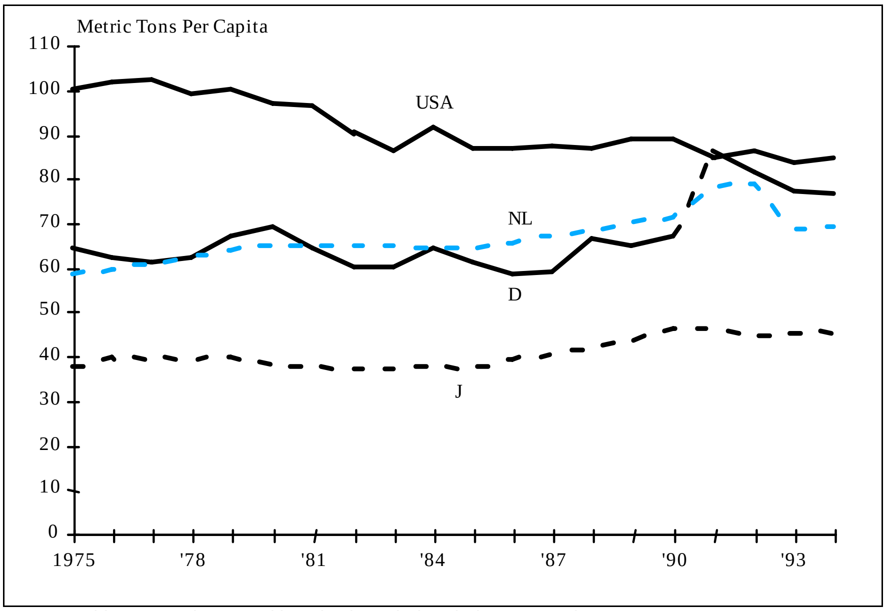
For economies to develop in a sustainable way, this means that they have to establish a way of using these four kinds of capital by which their sustainable use and self-reproduction become mutually reinforcing processes. However, this does not come at zero cost: to maintain the four types of capital needs investments *into each of them* to maintain their respective value as production factors. These “investments” are the core of sustainability policies.

In terms of systems analysis, each of the four subsystems is a complex self-organising system. Their character is non-linear, i.e. gradual changes of pressures on the system do not necessarily result in gradual changes of its state. Instead, the system may be able to buffer such pressures for a certain time, only to "flip” into another state with the next incremental increase of pressure, or even with a constant or declining one after a system specific time lag. This makes the behaviour of the system quite unpredictable and rules out any successful attempt to steer it towards some externally defined targets by hands-on management. Even less than for a single subsystem it is possible to steer the fourfold complex of embedded systems towards sustainability by external interventions. Instead, the self-reproducing capabilities not only of the economic subsystem, but also of the social, environmental and the institutional subsystem need to be enhanced in a way that the maintenance of the systems guaranteed (Daly 1996). In other words, sustainable development calls for safeguarding the viability of each of the subsystems as well as their functioning interplay.

1.2 Sustainability and Growth

A widely acknowledged key problem of economic growth is that the industrial metabolism (Ayres, Simonis 1994) seems to require too much throughput (Daly 1996) in relation to the carrying capacities of global environmental space (Spangenberg 1995). Exaggerated material flows, energy consumption and intensive land use are the primary driving forces behind most environmental stresses such as climate change, ozone depletion, loss of biodiversity, waste generation, acidification, eutrophication etc. (Lorek, Spangenberg 2001).

Figure 1: Total Material Requirement for the USA, Netherlands, Germany and Japan



Source: Adriaanse et al. 1997, with revised Dutch data (Bringezu 1997).

Given this analysis, the total resource consumption is one core measure of the long-term *environmental disturbance potentials* (Schmidt-Bleek et al. 1998), and its reduction turns out to reliably contribute to a de-escalation of most environmental problems, although not necessarily proportionally. In the past decades, we have seen a relative delinkage of energy consumption and material flows from economic development: both stabilised despite significant growth (Figure 1). On the other hand, this implies that an absolute delinkage, i.e. an absolute reduction of the environmental impacts was not achieved despite all efficiency gains (nature does not care too much how much wealth creation was the side effect of a certain damage done to it).

Consequently, with Y defined as the output of the economy and R as the total volume of resources used, Y/R is the *resource productivity*[1]. Only if in a given period of time this productivity increases faster (or drops slower) than the volume of output Y, an absolute reduction has been achieved. This criterion $dY < d(Y/R)$ has to be met by all environmentally sustainable strategies; it is a necessary although not sufficient criterion, since the speed of delinkage might be too slow to solve our problems.

On the other hand, the total output Y can be written as the total active labour force L multiplied by the labour productivity Y/L, measured as the average *per capita production*. The production per capita is given as the output per hour Y/h multiplied by the working hours per capita h/L. The number of people employed L only increases in any period of time if during that period the economy grows faster than the average production per capita, that is if $dY > d(Y/L)$. Whenever the creation of additional jobs is regarded as an indisputable precondition of social sustainability, this relation describes a necessary, although not sufficient precondition for social sustainability.

Y/L can be written as the product of labour productivity and working time: $Y/L = Y/h * h/L$. Here Y/h is the average hourly productivity and h/L the average number of working hours per member of the working force L. The average per capita production is increasing with growing labour productivity per hour and decreasing with reduced working times. So working time, early retirement, part time employment etc. are captured here in their effect on employment.

Combining the two sustainability - inequalities above

$dY > d(Y/L)$ and (1)

$dY < d(Y/R)$ (2)

it can be concluded that as a necessary minimum condition growth can only be sustainable if

$$\mathbf{d(Y/L) < dY < d(Y/R).} \qquad \mathbf{(3)}$$

This relation is the *minimum condition of socio-environmental sustainability* (Spangenberg, Omann, Hinterberger 1999). As a minimum condition, it helps to distinguish growth patterns that are definitely not sustainable from those that might be so. Although for the development of more detailed simulations and the valuation of their results more details will be needed, this minimum conditions already explains some of the necessary conditions any scenario for integrated sustainability must meet. Any such scenario has to cover:

- Economic Growth
- Domestic consumption levels, i.e. the standard of living
- Labour productivity
- Average working hours
- Total resource consumption (by key categories)
- Resource productivity

Only if data regarding these categories are provided by a model, it can be judged whether or not a scenario suggested at least might be sustainable. A final judgement would then have to be based on more details regarding the targets achieved and might differ individually and by scientific discipline. Nonetheless, without the above-mentioned categories covered, a model cannot provide information on the sustainability of any scenario tested. Unfortunately, only few models do meet this minimum condition; PANTA RHEI and SuE are two of them.

Additional information would be needed for fully assessing the social sustainability including the standard of living (which can be defined in different ways), and the distribution of income.

2. The PANTA RHEI Model

PANTA RHEI is an ecologically extended version of the 58 sector econometric simulation and forecasting model INFORGE (**IN**terindustry **FOR**ecasting **GE**rmany) (Meyer, Ewerhart 1997, 1998). In contrast to INFORGE, PANTA RHEI is additional equipped with a deeply disaggregated energy and air pollution model, which distinguishes 29 energy carriers and their inputs in 58 production sectors and households as well as 8 air pollutants and their relations to 29 energy carriers. The version of PANTA RHEI, which is used in this study, is also extended with biotic and abiotic material inputs and

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[1] The resource productivity could be differentiated into energy-, material- and land use productivity expressed as embodied energy EE (or energy cost, Stern 1999), total material requirement TMR (Adriaanse et al. 1998) and land degradation (Lorek, Spangenberg 2001) per unit of GNP or GDP (Hinterberger, Renn, Schütz 1999). As a rough estimate we use TMR/GDP, including energy carriers and anthropogenic material flows from land use.

the erosion of ground. Hence the total material requirement of the 58 production sectors and of the final demand is described. This is done for the direct domestic material requirement and for the indirect material requirement respectively[2].

PANTA RHEI belongs to the class of econometric input-output models, which differs from neoclassical approaches assuming bounded rationality. The models of the INFORUM network (Almon 1991) and the European system E3ME (Barker, Gardiner 1996) belong to this category. Neoclassical models appear in the literature in two variants, empirically and theory based. The first category, comprises the few models with econometrically estimated parameters (Jorgenson, Wilcoxen 1993). The second group, General Equilibrium Models (CGE models) is much more popular. Models of this type only use the data for one year in order to fix their parameters, while all other results are calculated based on the general equilibrium theory (Böhringer 1996, 1999; Schmidt 1999; Schmidt, Koschel 1999; Welsch 1996, 1999).

Neoclassical economists emphasise the clarity and generality of their theoretical approach, which derives behavioural functions from an optimisation rule and centres them into an equilibrium concept. Econometric input-output models are criticised, because bounded rationality enforces ad hoc assumptions. On the other hand neoclassical theorising is based on unrealistic assumptions about the agent's information in complex decision situations. From this perspective, there is more generality in the picture of the interdependency of volumes and prices presented by an econometric input-output model than in stories told by neoclassical approaches, because it is not necessary to base the analysis on the restrictive assumptions of general equilibrium (Barker 1997). A comparison between neoclassical CGE models and PANTA RHEI is given in Frohn/Leuchtmann/Kräussl (1998) and in Forum für Energiemodelle (1999).

In econometric input-output models, the lack of a predetermined theoretical concept is compensated by emphasis on the empirical database. Agreeing with Selten (1991, p. 19), it is better to use empirically tested ad hoc assumptions than unrealistic principals of high generality and elegance. The agents in PANTA RHEI follow empirically tested routines (Nelson, Winter 1982). So for example instead of equilibrium prices the mark up hypothesis is used.

The performance of PANTA RHEI is based on the INFORUM philosophy (Almon 1991) to build econometric input-output models *bottom up* and *fully integrated*. The construction principle *bottom up* says that each sector of the economy has to be modelled in great detail and that the macroeconomic aggregates have to be calculated by explicit aggregation within the model. The construction principle *fully integrated* means a model structure that takes into account the input-output structure, the complexity and simultaneity of income creation and distribution in the different sectors, its redistribution among the sectors, and its use for the different goods and services the sectors produce in the context globalising markets. In this way one succeeds describing properly the role of each sector in the interindustry relations, its role in the macroeconomic process as well as its integration into international trade.

These conceptual advantages end up in a consistent and powerful processing of sectoral and macroeconomic information. The about 40000 equations of PANTA RHEI describe the interindustry flows between the 58 sectors, their deliveries to personal consumption, government, equipment investment, construction, changes in stocks, exports, as well as prices, wages, output, imports, employment, labour compensation, profits, taxes, etc. for each sector as well as for the macro economy. In addition the model describes the income redistribution in full detail.

PANTA RHEI has a high degree of interdependency. Additional to the common interdependencies of income generation those of volumes and prices as well as those of wages and prices are depicted. Further the model is characterised by nonlinearities, which appear by multiplicative combinations of variables in definitions and estimated equations and double-log specifications. The consequence of the overall interdependency and the nonlinearity is the necessity to solve the model as one simultaneous block. Of course such a structure produces difficulties in handling the system, but on the other hand each run of the model is a strong test: A bad hypothesis will produce instabilities and the solution will not converge.

The model has a high degree of endogenisation. Exogenously given are only some tax rates, labour supply, and the world market variables of the international INFORUM system. Since PANTA RHEI itself is a part of the international system, the world market variables are also endogenous in a

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[2] A description of the equations of PANTA RHEI is given in (Meyer, Bockermann, Ewerhart, Lutz, 1999; DIW, WI, WZB 2000, Appendix D).

linked run of all models. The high degree of endogenisation has the advantage to completely depict all effects in a simulation.

The model was estimated econometrically over the period from 1978 to 1994. The transition from West Germany to Germany was managed using additive and multiplicative dummy-variables.

As mentioned above PANTA RHEI is a part of the INFORUM International System (Nyhus 1991) that links 13 national input-output models on the sectoral level via export and import flows as well as the corresponding foreign trade prices. The information gain of this system in comparison to isolated models allows for a reliable analysis of the important contribution of exports for the performance of the German economy. The International System forecasts the economic development of Belgium, Germany, France, Great Britain, Italy, the Netherlands, Austria, Spain, USA, Canada, Mexico, Japan, and South Korea in full sectoral disaggregation. This world trade model is being developed steadily, in the near future models for China, Taiwan, and Poland will be integrated into the System (Ma 1997; Nyhus, Wang 1997). Besides the goods markets the INFORUM International System also represents the international financial markets, though in a less detailed way: American interest rates as indicators for the international capital market condition have a weighty influence on German interest rates and by this means once again on the German good markets.

Figure 2 gives a rough impression of the structure of PANTA RHEI. The INFORUM International System delivers the vector of world import demand for product groups, the vector of world market prices for product groups, and the US rates of interest.

Final demand has the components private consumption, government consumption, equipment, construction, exports, inventories in the disaggregation of 58 domestic and imported product groups.

The most important determinants of final demand are the disposable income of private households (explaining private and government consumption), the interest rates and profits (explaining investment), the world trade variables (explaining exports), and the relative prices for all components and product groups of final demand.

The intermediate demand of domestic and imported goods of the firms is depicted including energy demand and energy conversion. For all intermediate inputs deliveries from domestic production and imports are distinguished. In general the input coefficients are variable and depend from relative prices and time trends.

Given the final and intermediate demand, the production and the imports of goods can be calculated. The direct domestic material requirement, which is concentrated in few sectors (Agricultural products, forestry and fishery products, coal mining, other mining, crude petroleum and natural gas, stones/clays/buildings and construction materials, buildings and civil engineering works) is calculated from the production of goods by using empirically based coefficients. Furthermore, there is an indirect imported material requirement in nearly all imported products. This indirect material requirement is calculated similarly, based on the imports of goods and specific coefficients. The imported services have no material requirement.

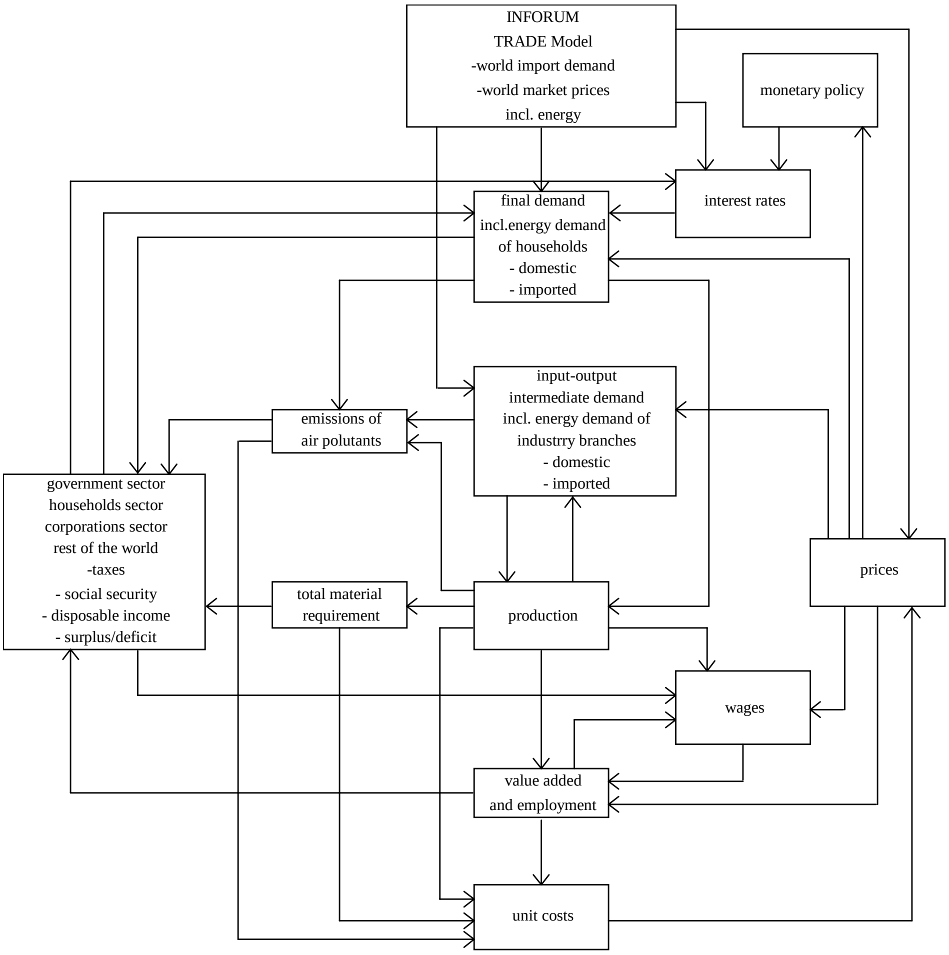
The energetic air pollutant emissions are derived using constant (CO_2) respectively variable (NO_x and SO_2) emission coefficients for the demand of private households and 58 production sectors, disaggregated for 29 energy carriers.

The determinants of employment are the production volume and the real wage rate of the sector. Wage rates are estimated based on labour productivity and prices. Profits and unit costs are given by definition. Unit costs of the product group and the prices of competing imports are the most important determinants of sectoral prices.

Besides the deeply disaggregated input-output account the model contains the system of national accounts SNA for Germany with the institutional transactors public households, private households, business sector, and the rest of the world, and the functional transactors production, generation of income, distribution of income, redistribution of income, capital account and financial account. This system contains the whole income redistribution of social security and taxation between the government, private households and business and thus allows to calculate disposable income figures of public and private households, which are central determinants of final demand. Other important outcomes of the SNA part of the model are the lendings and borrowings of the institutional transactors, which have influence on the interest rates.

Interest rates are further determined by the US rate of government bond and monetary policy variables, which react on price signals.

Figure 2: Structure of PANTA RHEI



The most important application of PANTA RHEI so far has been the simulation of an eco-tax reform (Meyer 1998; Meyer, Bockermann, Ewerhart, Lutz 1998, 1999; Meyer, Bockermann, Lutz 1999). In the present study a base run without eco-taxes and a simulation with taxes for material requirement and CO_2 are compared. Such taxes influence the total material requirement and the CO_2 emissions by increasing the related cost and prices, and increase the tax revenues of the government sector. According to earlier studies using PANTA RHEI, the most significant effects on economic growth and the labour market could be obtained by channelling back these revenues by reducing the employers' share of social security payments (Meyer, Bockermann, Ewerhart, Lutz 1999). Hence in this study the simulation was made in a similar way: 67 percent of the redistribution of the total-material-requirement-tax and the CO_2 tax reduces the employers' social contribution and 33 percent of the taxes reduces the employees social contribution. In this case the real wage rate and the unit costs, which determinate the prices, were reduced. Hence the domestic prices of sectors, which are employment intensive fall, the domestic and import prices of sectors, which consume much material arise, and the domestic and import energy prices of secondary energy carriers arise as well. Also the government expenditure is less than before, because the costs of the government employment is reduced, and the transfers of social security payments is less than before.

In the base run the taxes on the total material requirement and on CO_2 are zero. In this case the total material requirement and the CO_2 emissions do not have any economic effect, as externalised environmental cost are not calculated by the model.

3. The SuE Model

Introducing a new model needs an explanation of the rationale behind, given the abundance of economic models already existing. “Sustainable Europe” or SuE is a system dynamics model for the analysis of long-term dynamics. There is no intention to use the model for short-term economic forecasts, and indeed it would be very weak in doing so. However, by focussing on a few feedback loops it can point out the long-term restrictions imposed on economic development by limited resource supply (energy saving, dematerialisation etc.). This makes the model particularly useful to analyse the appropriateness of long term policy strategies for sustainable development. In this sense the model cannot substitute any other effort undertaken so far, but complements them with a tool for assessing the underlying long term dynamics resulting from specific policy approaches (on the usefulness of applying several restricted models instead of developing one integrating all aspects see Bouman et al. 2000). SuE is unable to predict the weather, but tries to capture climate changes.

The model is not based on a specific economic theory (like e.g. all equilibrium models are), but on physical accounting of resources. Whereas for money the economy is a closed system with a circular flow, for physical resources it is an open one, characterised by the volumes of throughput and the “residential time” of resources before they become waste. Since the resource flows through the economy are sometimes parallel, sometimes opposite to the money flows, the way of seeing the economy changes completely when the view is taken from the resource flow perspective. Nonetheless the model provides economically meaningful results, since the embodied energy for all products except primary energy has been empirically shown to correlate with the market value in monetary terms (Costanza 1980; Subak 1999). Embodied energy accounting is also known as energy cost (Stern 1999) or natural capital accounting[3] (Slesser et al. 1998).

SuE makes no assumptions about consumer behaviour, rational choices etc., is neither based on the "Homo Oeconomicus" nor on any other such paradigm. Nonetheless it needs an element to prioritise the use of available resources (i.e. energy investments) in the normal case of different interests competing for them. This is given by a specific dynamic driving economic development included in the model. This model element is structurally different from, but functionally equivalent to the investment function of econometric models, but not necessarily constant over time. SuE can run on a consumption driven as well as on a production driven mode, providing the opportunity to compare the two basic philosophies within the same model, using the same set of parameters.

Since not working with a monetary, but a physical numeraire, SuE accounts directly for energy consumption, instead of deriving it from the price elasticities of different sectors for energy. In other words: The model will not calculate the reduction in energy and materials consumption resulting from resource taxation, but it will be capable of demonstrating the long term impact on economic development and resource consumption such a reduction in physical supply will cause. The estimate of the effectiveness of price-based strategies is set by the user, e.g. based on simulations with models of the PANTA RHEI type (O’Connor, Ryan 1999).

The biggest challenge for the model is how to cope with the success of strategies it was designed to test: If a delinkage of economic growth and resource consumption can be brought about e.g. by resource taxation, the close correlation of embodied energy and monetary value in the market would only be maintained if the increase of energy productivity would exactly equal the increase in energy prices. Although both will tend to have the same direction, there is no clarity as to the significance of the correlation in the long-term future.

Since the model is based on physical quantities, it does not include qualitative aspects whatsoever. This does not necessarily have to be a a disadvantage, on the contrary: based on the physical calculations qualitative aspects can (and will be) discussed without the risk of mixing model parameters and interpretation (see chapter 5 on SuE scenarios and results).

SuE has been designed to answer just one simple, but essential question. "What is the rate of economic growth that would arise in the context of user-defined policies, technologies and

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[3] We 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. For a discussion of natural capital in the light of the material flow approach see (Hinterberger, Luks, Schmidt-Bleek 1997).

environmental objectives". Any change in these considerations will result in a different growth rate. The SuE model provides considerable freedom 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 is 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**.**

3.1 Embodied Energy Accounting and Material Flows

The procedure chosen to determine the stocks and model the flows of capital is embodied energy accounting. Embodied Energy EE is quantified in terms of the non-renewable and renewable energy that had to be dissipated (as an increase in entropy) in the manufacture of the capital stocks, linking this with the associated total material input. It takes into account all energy spent from the first step of extraction to final consumption and disposal, including the trade balance. Capital stocks in this text will be referred to as Human Made Capital HMC (computed in Giga-Joules GJ) to make a clear distinction of terms between the economic one of capital and the specific understanding of Human Made Capital as used in the model. 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. In the model, the flow of HMC generated by the industrial sector is used 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. Such HMC accounting has been used for economic modelling in the past (Noorman, Biesiot 1995; Crane, King, Slesser 1995; Schembri 1999; Ryan, O'Connor 1996).

Furthermore, SuE incorporates the first EU 15 wide physical input-output table PIOT. The material flows are coupled to the energy flows by empirically derived, sector specific coefficients which can change over time to reflect technology improvements. Restrictions in material flows can be analysed regarding their impact on producers and primary users, as well as their trickle down effect throughout the economy.

3.2 Structure

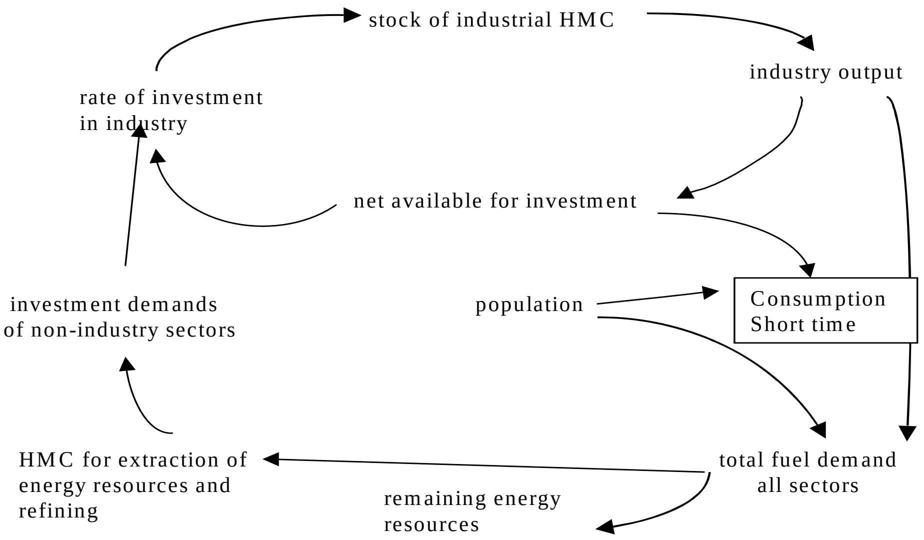
The SuE model structure largely exhibits the same cause and effect relationships that are to be found in an econometric model, though sometimes in quite different ways due to its physical base. As with money, there must be capital investment in order to yield output. The HMC stocks increase by means of investment a decrease through depreciation. Physically this means that stocks are considered to be worn down. In such a model all matter is traceable, quantifiable and computable.

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. In such a model one cannot use HMC that has not first been produced.

HMC is produced in the industrial sector and (re-)invested into industry, into other sectors, consumed or exported (exports generate a loss of HMC, imports a surplus). Consumption and sectoral investment needs create HMC demands, which are met before the demand of the industrial sector is satisfied. *Thus a kind of residual theory of investment is assumed in the simplest version of the model, as well as permanent complete market clearance.* This creates the positive feedback loop of the growth circle (see Figure 3), which is checked by two factors. One is the negative feedback from limited resource availability, be it as absolute scarcity, by decreasing resource quality (i.e. increasing energy cost through the exploitation of poor or not easily accessible resource stocks), or through increasing resource prices, brought about e.g. by energy and material taxation (for the material input tax MIT see the PANTA RHEI model scenarios below). The other is the demand from sectoral investments based on user-defined policies, e.g. investments in public transport and the like. This reflects the fact that extreme changes in sectoral policies have the potential to undermine overall prosperity by consuming an disproportionate share of the total wealth produced.

Thus when the model runs, the difference in output between one set of policies and another allows the generation of a "cost curve" expressed in physical terms such as a higher or lower 'material standard of living' for that specific policy (Crane 1996). This formulation of the model is called the *System-driven version* (SuE-SD, Figure 3).

Figure 3: An influence diagram of the system-driven version of SUE



Source: Scharnagl et al. 1998.

In a slightly more complex version of the basic model (included in Figure 3) the residual investment approach is given up. Once again we have positive and negative feedback loops and a balance brought about by two facts: no HMC can be invested that has not been produced (or imported) beforehand, and market clearance is assumed to be permanently given. Since there are considerable influences from economy's demand on the investment, in the *consumption-driven version* (SuE-CD, Figure 4) investment in industry is no longer a market-clearing residual, but is driven by externally set consumer demand.

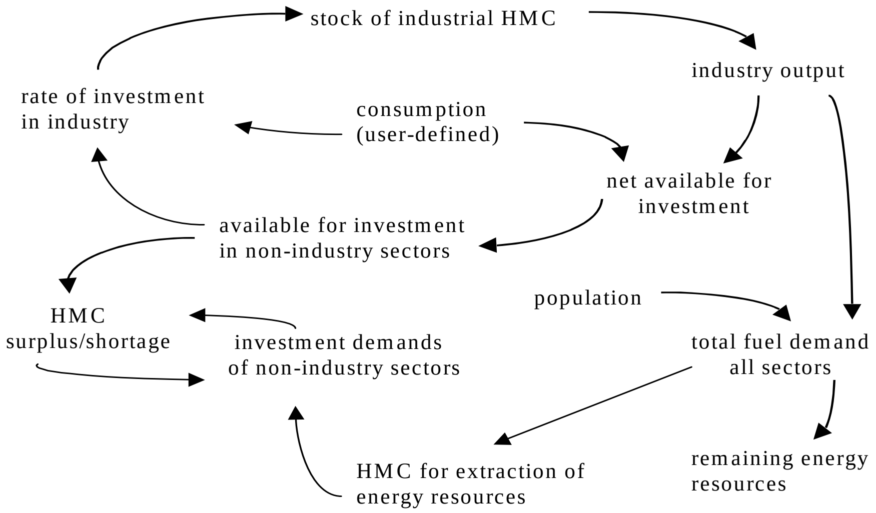
SuE-CD is used to explore the outcome of reduced or increased demand in consumption (consumer goods). When this is done the model generates a surplus or shortage of HMC, which must be allocated or deducted elsewhere. At the moment any surplus or shortage is directed to the domestic dwellings/housing – sector, the most important source of material flows. 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). The user has the option to switch between both versions.

3.3 Sectors

Choosing the sectors to be represented in the model has been based on a combination of theoretical analysis and pragmatic modelling needs. The European economy is structured by ten mega-clusters (Jacobs 1997), which have as well been the basis of the modelling approach. They are the manufacturing sector, chemical industry, energy, transport, agriculture and food, construction, media, health, market services and non-market services. In the model, three simplifications have been made: The chemical industry and food processing (modelled as a subsector) are included in the manufacturing sector, media is part of the market and health part of the non-market sector. The SuE sectors based on this analysis are:

Figure 4: An influence diagram of the consumption-driven version of SUE



Source: Scharnagl et al. 1998.

Manufacturing

The sector produces three types of goods: physical long-life capital goods, consumer goods and export goods. The rate of investment is either externally set (SuE-CD) or endogenously calculated as a residual (SuE-SD). The input is thermal energy and electricity demand figures from statistical sources, the output HMC to be distributed.

Modifications in the model include the introduction of a load factor, reflecting the fact that not always 100% of the capital stock are put to a productive use. This is one key factor behind the divergence of production potentials as calculated by comparable models (ECCO UK etc.) and the real output figures.

A second modification established a second capital stock for extended-life products. This permits simulations of structural changes towards long-life products and capital stocks regarding their effects on growth, resource consumption, the material standard of living and on employment. Energy saving policies can be simulated similarly.

The food and beverage sector has been modelled as a specific subsector, fed with input from the agricultural sector and delivering to final consumption as well as to industry. The balance of food and industrial biomass production can be changed in different scenario runs.

Construction

The sector represents one of the ten industrial clusters of Europe; it is responsible for the lion’s share of the material flows. Besides energy and minerals, water flows are accounted as inputs. HMC is produced as output, based on the capital stock size and again a load factor. The load factor, the lifetime of buildings and their energy efficiency are scenario variables.

Market services

The sector comprises two independent subsectors, market services to industry and to individual consumers. They deliver the services assumed in the respective scenario. If the intention is to assess a development of human preferences from predominantly material goods to eco-efficient services this is possible by assuming a substitution process between the two former subsectors and a third one, called eco-efficient services sector.

Non-market services (government, health, education)

This sector reflects activities that are environmentally as well socially relevant, but the way they are provided can hardly be influenced by the consumer (Lorek, Spangenberg 2001). Variables include the government capital stock, health and education expenditures, the rate of students per age group etc.

Transport (roads, rail, air and infrastructure)

The sector calculates the capital requirements for the transport system, differentiated into persons and freight transport and according to transportation mode. It permits to test changes in modal split, for both passengers and goods, and in the load factor of passenger cars. One interesting element is the freight sector and the changes due to reduced material flows, regarding mainly primary and intermediate, but less final products.

Agriculture, forestry and fishing

The model balances agricultural production and consumption via food and feed trade. Factors accounted for include fertiliser and land use, wood harvested, changes in the stocks of wood and animals, and food produced in tons of protein. Policy options in the simulation runs include the promotion of organic agriculture, and monitors its impact on fertiliser and pesticide consumption and the resulting impact on capital stocks and production. A second option is to test the impacts of reduced overproduction and one behavioural component: What would a movement towards less meat intensive nutrition patterns do to European agriculture?

Energy

Since resource accounting is so basic to the model, the energy sector has been differentiated in two subsectors, extraction and electricity generation, and to mirror material flows non-energy resources, housing and water have been added:

- Fossil-energy extraction (coal, lignite, natural gas, oil) module
- Electricity generation (nuclear, coal, natural gas, hydro, other renewable) module
- Non-energy resource extraction module (mining and quarrying)
- Domestic housing module
- Water module (water supply, use and disposal)

These modules are not identical to specific economic sectors, but of a more cross cutting nature. Parameters to change in different scenarios include production and use efficiencies, and the scarcity of certain resources.

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

- Consumption (consumer goods, services, transport, fuels)
- Capital transfers, balance of international payments, internal and external debt
- Income re-distribution (pensions, benefits), average (EU-wide) taxation
- Environmentally significant outputs (CO_2, SO_2)
- 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.

3.4 Labour

Since sustainability policy will have significant impacts on the labour market, the examination of employment effects caused by the different scenarios and policy-strategies is of special interest for a sustainability modelling tool like SuE. 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 (in terms of jobs created per Mio. $ investment). 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. However, the empirical results of labour productivity increasing investments triggered by reductions in working hours and the resulting rebound effect, that leads to a significant reduction of the number of jobs created (as a rule of thumb about by half), could not be included in the scenario runs due to the lack of European data.

In SuE, 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. PANTA RHEI Results

In the course of the research project “Labour and Environment” (DIW, WI, WZB 2000) an "integrated scenario" was developed and the quantifiable elements of its recommended strategies simulated with PANTA RHEI. The scenario was designed to demonstrate the policy conditions for sustainable development in Germany. Sustainability is described as comprising four dimensions, the economic, the social, the environmental and the institutional one. These dimensions are not independent from each other, but interlinked, which makes the concept a complex one, requiring sophisticated solutions. The strategies developed affect all dimensions in different ways, by different means and in different intensities. Some of them are quantifiable such as the material input tax, some only partly like basic income provision, some are not quantifiable in an econometric model, like e.g. gender issues.

As can be seen from Table 2, the quantitative parameters PANTA RHEI uses are either measured in DM or in tons. Consequently, not all elements of the integrated scenario could be expressed by model variables. The part included in the model runs can be seen in Table 1.

Table 1: Selected policy strategies pursued in the scenario, as inputs for PANTA RHEI

Parameter	Comments
Real wage	Orientation on labour-productivity per hour
Working week & overall lifetime work are shortened	About 50% of the increase in productivity are transformed into reduction in working hours
Transfers abroad	Foreign aid is increased to 0.7% of GDP until 2010, payments to the EU increase to 2% of GDP until 2010 and then remain constant.
Material Input Tax	Quantitative tax on material flows, gradually increased to 60 DM/ton in 2020.
CO_2-Tax	Tax on emissions, gradually increased to 250 DM/ton in 2020.
Subsidies	Restructuring and reduction between 2000 and 2020 following ecological criteria
Investment-Plan	One third of the revenues gained by a cut in Subsidies are used for investment in some economic sectors
Expenditures on research	Doubled between 2000 and 2020 from 15 to 30 bio DM
Value Added Tax	Gradually raised to the EU-average (20%), however, reduced VAT of 10% for certain products which are chosen using social, cultural and ecological criteria

Source: Spangenberg, Omann, Hinterberger 1999.

Despite this fact the integrated scenario is well reflected in PANTA RHEI, providing (together with the qualitative elements of the scenario) a realistic sustainability strategy for Germany. In other words: the simulation offers a good representation of the quantifiable aspects of the scenario, which are complemented by the qualitative considerations without significant impact on the quantitative calculations.

In order to assess the sustainability of the scenario according to the criteria developed in chapter 1, equation (2) can be applied to different classes of resources R, e.g. for material inputs (MI) and CO_2-emissions. They both have to grow with a lower rate than the economy (Y stands for the GDP) in order to be sustainable. For the social aspect see equation (1).

$d(MI) < d(Y)$ (4)

$d(CO_{2)} < d(Y)$ (5)

The analysis of results will be focussed on five indicators giving a comprehensive overview of all relevant parameters. They are the GDP and the budget deficit as economic indicators, the CO_2 emissions and the total material input into the economy (Total Material Requirement TMR) as environmental indicators and the unemployment rate as a social indicator (income distribution, which would be an obvious second social parameter, is not calculated by the model). All five are quantitative parameters, the economic ones measured in DM and the environmental ones in physical terms, i.e. in tons. Table 2 shows the development of the indicators (absolute and in growth rates) from 2000 to 2020.

Table 2: Results in absolute terms and growth rates of selected indicators

Indicator	**2000**	**2005**	**2010**	**2015**	**2020**
GDP in 1991 prices (bio DM)	3409.9	3759.0	4089.8	4448.4	4809.0
MI (Mio t TMR)	8667.0	7542.3	6817.3	6458.8	6257.8
CO_2 (Mio t)	856.3	761.3	723.1	717.3	726.8
Budget deficit (bio DM)	21.1	15.1	18.0	8.4	-11.8
Unemployment rate (%)	12.0	10.6	9.2	6.3	3.3
Indicator/Growth rates	**2000-2005**	**2005-2010**	**2010-2015**	**2015-2020**	**2000-2020**
GDP (%)	1.97	1.70	1.69	1.57	1.74
MI (%)	-2.74	-2.01	-1.07	-0.63	-1.61
CO_2 (%)	-2.32	-1.02	-0.16	0.26	-0.82
Resource productivity (%)	4.84	3.78	2.80	2.21	3.40
Labour productivity (%)	0.92	0.57	0.65	0.56	1.55

Source: DIW, WI, WZB 2000, Hinterberger, Omann, Spangenberg, Schmitz 2000, Simulations with PANTA RHEI.

4.1 Assessing the Results – Applying the Sustainability Criteria

At first glance it is obvious that the GDP is growing significantly throughout the simulation period, however at a slightly reduced rate as compared to a growth-focussed reference scenario, and with a decreasing tendency. The environmental indicators are both decreasing, i.e. exhibiting negative growth rates from the first year the policy measures set in, resulting in an absolute delinkage (Luks 1995) and thus for every period satisfying the sustainable development conditions set out in equations 4 and 5 above.

But as can be seen from Table 2, the negative growth rate of the material inputs (i.e. the reduction of resource consumption) is getting less significant over time, despite the continuously rising material input taxation. The same is true (with inverted signs) for the growth rate of the resource productivity. The growth rate of the GDP is slightly decreasing, but remains positive. Together, these signals indicate that the effects of the policy measures tested are worn out over time. In the very long run (which PANTA RHEI unlike SuE is not designed for) this trend might ceteris paribus lead to a situation where the growth rate of the GDP and the one of the material inputs would approach or even cross each other, a non sustainable development according to the equations above. To prevent that kind of dynamics, in the medium term (30 years) additional policy measures need to be taken.

Regarding the CO_2-emissions as calculated by the model, the equation is as well satisfied, but the result is not satisfactory in the long run. The growth rate is negative, indicating reduced emissions, but getting positive again in the last period after having provided an absolute reduction of emissions beforehand.

However, a significant number of scenario assumptions regarding the reduction of energy consumption and for material flows could not be included in the model runs. This includes:

- The promotion of efficiency technologies (“leapfrogging”),
- the establishment of a remanufacturing sector (Striewski 1998; Ferrer, Ayres 2000),
- voluntary agreements on reducing CO_2 emissions in the business sector,
- measures to reduce road transport of goods (in particular bulk materials will fall victim to dematerialisation, see SuE results) and people (due to new levies charged), or
- changed activity patterns in construction following the shift of subsidies from single house building to maintenance (in the scenario) and upgrading the existing housing stock (as subsidised by the German government).

These measures, decided, planned or suggested, will significantly reduce resource consumption beyond the PANTA RHEI model prognosis. Existing case studies (Liedtke et al. 1999) and comparative analysis (DIW 2000) suggest that including these measures CO_2 emissions would decline by about 60% as compared to 1990, and material flows by up to 50%. These measures could not be built into the simulation runs, partly due to limited resources not permitting to exploit the model options to the maximum, but as well due to limits of the model regarding the representation of technological innovation processes.

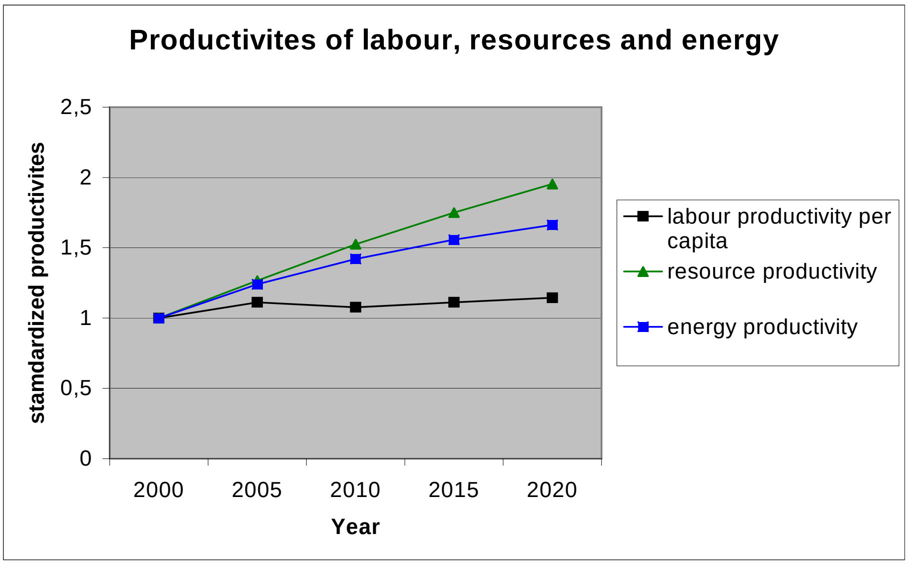
In the integrated scenario, the budget deficit phases out, providing a revenue surplus for other instruments (again non simulated, for similar reasons as above) like the negative income tax above the relative poverty line as a means of basic social security.

Social sustainability as expressed in equation (1) is satisfied, the growth rate of the labour productivity is always below the growth rate of the GDP. The unemployment rate is decreasing

The personal income distribution, however, is not reflected in the model, so no results can be provided. The different productivities can be seen in Figure 5. The resource and energy productivity are both increasing, labour productivity remaining quite constant over time.

Despite these results, the impression that the trade-off between economy and environment might have been overcome does not hold, just the opposite: the trade-offs have become obvious, and a very specific growth pattern is needed to bring economic growth in line with social and environmental sustainability. For 20 years, the strategies recommended in the scenario and integrated into PANTA RHEI lead to an absolute decoupling (Luks 1995) of economic growth and resource depletion, but in the long run additional policy measures will be necessary to cope with the effects of continued economic growth.

Figure 5: Productivities of three indicators



Source: Hinterberger, Omann, Schmitz, Spangenberg 2000.

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4.2 Sensitivity Analysis

The results presented so far could be solid prognoses, but also an extreme case or even be invariantly produced by the model. In order to validate the results two kinds of sensitivity analysis have been undertaken. First small variations have been introduced into the inputs to PANTA RHEI and the result observed; they were stable with small deviations to the original results. Secondly we simulated more than one scenario with the same model. Besides the environmental-social sustainable development scenario or "integrated scenario" which delivered the results pointed out above, two more scenarios, a supply-side based "cost cutting scenario" as reference and a more demand side focussed sustainable development scenario (the "growth scenario") were simulated with PANTA RHEI.

The central element in the **cost cutting scenario** is reducing the burden of costs on firms, in particular the burden of wage costs. This is achieved through wage moderation, the flexibilisation of collectively agreed provisions and reductions in indirect labour costs. Additional cost reductions, like in public spending, are suggested.

Table 3: Selected indicators in absolute figures for all scenarios[4]

Year	2000	2005	2010	2015	2020
GDP (bio DM)					
Cost cutting	3369.3	3701.6	3946.1	4235.9	4472.5
Growth	3428.8	3891.0	4309.0	4765.3	5178.4
Integrated	3409.9	3759.0	4089.8	4448.4	4809.0
MI (Mio t TMR)					
Cost cutting	8511.2	9141.3	9819.4	10911.1	12265.3
Growth	8666.7	8943.2	9729.3	11165.8	13209.9
Integrated	8667.0	7542.3	6817.3	6458.8	6257.8
CO_2 (Mio t)					
Cost cutting	837.2	844.8	852.0	979.7	907.4
Growth	844.8	803.6	789.9	798.9	815.0
Integrated	856.3	761.3	723.1	717.3	726.8
Unemployment rate (%)					
Cost cutting	13.6	13.9	14.2	11.8	9.1
Growth	12.9	12.3	10.2	6.8	4.1
Integrated	12.0	10.6	9.2	6.3	3.3
Budget deficit (bio DM)					
Cost cutting	43.2	69.8	85.9	73.1	39.9
Growth	21.1	50.5	62.7	76.2	92.6
Integrated	21.1	15.1	18.0	8.4	-11.8[5]

Source: Simulations with PANTA RHEI.

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[4] For some variables in 2000, the base year of the comparison and the beginning of the policy measures shows different values of the indicators in the different scenarios. This is due to the fact that after the validation period the model had to run free, based on the available data of 1994, to generate the starting points for the three scenarios. Since for technical reasons some scenario-specific variables had to be fixed from the initial date, different starting values in 2000 developed for the three scenarios.

[5] A negative budget deficit means a surplus, a positive budget. However, since the transfers for the basic security provision through a negative income tax could not be included in the model, the figure signals the available room for manoeuvring more than an actual surplus. However, the budget deficit figures show that the intended model of social security would not overburden public finances. Indeed, the public debt would be lower than in the growth scenario.

The **growth scenario** is a more demand oriented scenario. Aside from one environmental criterion (reduction of CO_2-emissions) it focuses on economic growth in order to reach full employment and a stable social security system. The following policy fields are influenced: working time policy (reduction and flexibilisation), the social security system (basic security and subsidised low-income sector), training and education policy (employability), infrastructure policy and ecological tax reform (focused on CO_2). Cost-benefit criteria determine environmental goals, the pursued strategies focus on efficiency considerations. For comparison, the **integrated scenario** is based on an ecological-economics theoretical background. The main ideas are derived from the critique of the prevailing policy approach regarding the environment. Alongside the realisation of environmental goals (CO_2- and MI-reduction), this scenario emphasises the social components of sustainability (employment and basic income), as well as the economic (e.g. innovation and competitiveness) and institutional (e.g. participation and gender issues) dimension. Besides the instruments, as presented in Table 1, a variety of additional strategies in the fields of education and research, land use, transport and revaluation of non-compensated and/or honorary work are suggested. The results of five core indicators in all three scenarios are presented in Tables 3 and 4.

The GDP takes a similar development in all scenarios. The growth rates are shrinking over time, and as compared to the integrated approach, the GDP in absolute terms is always higher in the “growth” and lower in the “cost cutting” scenario. Economic growth is the central goal within the growth scenario, which reaches this goal having the strongest growth, although the gap towards the integrated scenario is narrowing over time. For the budget deficit the results are different in all scenarios: while it is increasing continually in the growth scenario, it decreases in the integrated scenario leading to a surplus in 2020 (not including the expenditure for the negative income tax). The cost cutting scenario shows a reduction after 2010, but remains on a high level. The unemployment rate is significantly reduced in the both sustainability scenarios, but only slightly in the cost cutting scenario.

Table 4: Growth rates of selected indicators in all scenarios

Time **Growth rates (%)**	**2000-2005**	**2005-2010**	**2010-2015**	**2015-2020**	**2000-2020**
GDP					
Cost cutting	1.90	1.29	1.43	1.09	1.43
Growth	2.56	2.06	2.03	1.68	2.08
Integrated	1.97	1.70	1.69	1.57	1.74
MI (TMR)					
Cost cutting	1.44	1.44	2.13	2.37	1.84
Growth	0.63	1.70	2.79	3.42	2.13
Integrated	-2.74	-2.01	-1.07	-0.63	-1.61
CO_2					
Cost cutting	0.18	0.17	0.64	0.62	0.40
Growth	-0.99	-0.34	0.23	0.40	-0.18
Integrated	-2.32	-1.02	-0.17	0.26	-0.82
Resource Productivity					
Cost cutting	0.45	-0.15	-0.69	-1.24	-0.41
Growth	1.92	0.35	-0.74	-1.68	-0.05
Integrated	4.84	3.77	2.80	2.21	3.40

Source: Simulations with PANTA RHEI.

The economic growth rates have to be compared to the environmental indicators: both the cost cutting and the growth scenarios end up with higher CO_2-emissions and significantly higher material flows (Table 4) than the integrated one. According to the simulation, t he growth rates of material inputs in the cost cutting and the growth scenario simulations remain positive. This is a logical consequence of the strategies pursued in the cost cutting scenario, because none of them influences the environmental indicators in a positive way. Looking to the growth scenario, the result is quite astonishing. The growth rate is the highest from 2005 on, despite the effects of the ecological tax reform. However, the way the policy strategy has been designed obviously influences the material productivity in a negative way. The growth rate of material productivity is decreasing, getting slightly positive only in the last period.

However, similar considerationsas pointed out for the integrated scenario in section 4.2 apply to the non-modelled elements of the growth scenario. They may lead to a reduced growth or even to a slight decrease in material consumption and thus to a more positive development of the resource productivity In the cost cutting scenario, the CO_2 emissions increase as expected, as no strategy for reducing emissions has been applied. In comparison, the positive impact in the growth scenario is smaller than in the integrated one and lasts even shorter.

The delinkage of economic growth and environmental pressure, which is described in equations 4 and 5 is given throughout the twenty years in the model runs of the integrated scenario. For the cost cutting scenario, it is detectable only in the period 2000 to 2005, and for the growth scenario it phases out by 2010 according to the simulation results.

The results of the three scenarios lead to a straightforward conclusion of the sensitivity analysis: it is not the structure of the models that determines the results, independent from the input. Instead, the significantly diverging results obtained from the same model underscore that the simulation outcome reflects the different strategies chosen rather than the inherent characteristics of the model.

Furthermore, as the gradual variations introduced throughout the simulation process have resulted only in minor, i.e. also gradual changes of the results, the simulation outcome can be considered as successfully tested regarding its sensitivity and stability.

5. SuE Results

Given the lower level of differentiation of the economy, scenarios in SuE are less complex than in PANTA RHEI (for an exception see the transport, the energy and part of the agricultural sector), but easier to model. Therefore, a number of complementary scenarios has been developed, building one integrated sustainability scenario by bottom-up combination of tested elements.

As a standard to compare the simulations run with the SuE model a business as usual (BAU) scenario has been chosen. Being a reflection of the current dynamic, it is 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, the reference period.

5.1 Elements of Environmentally Efficient Production

Before developing what could justifiably be called policy scenarios, first a number of single parameter changes was tested to see which is the effect of which factor in the 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, more qualitative impact assessment.

Energy and material use 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 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 gained 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 bundle of technical improvement potentials (including a switch from fossil to renewable energies) was simulated, based on empirical, however more anecdotal information. 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. However, the standard of living index based on service availability increases.

Organic agriculture

The scenario presented tries to test out what would be the effect if the whole of the EU agricultural area was under organic agriculture. According to the simulation, 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.

Transport policies

Unlike in PANTA RHEI, in SuE transport strategies can be modelled that are not based on cost factors. Two approaches have been tested, one concerning the modal split and the other consumer behaviour. For the former it turns out that given the expected increase in total transport volume for the EU, the effects are only moderate. 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.

For testing changed behavioural patterns, the average number of passenger per car was gradually increased from the EU 15 average of 1.68 in 1995 up to 2.16 in 2020. This measure has about the same effect as the ambitious version of modal split changes.

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. As the most obvious results come from the more drastic assumptions, the effect of a 2/3 reduction of material flows by the year 2020 has been tested.

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 as well significantly to the EU targets for CO_2 reduction set out at the Kyoto climate conference.

Eco-efficient production

As a next illustrative step, technical efficiency regarding energy and non-energy resources, modal split in transport and organic agriculture were combined 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 material standard of living.

5.2 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. 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 needed for the generation of long-lived goods (10% more investment of energy, resources and labour is assumed).

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 non-material living standard shows up. Whereas in the BAU scenario about 20 Mio jobs are lost by the year 2015, the service scenario reduces these 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, but 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[6], it turns out that the reduction in normal good is significant (about 20%), but even more significant is the growth 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 even more dramatic if an absolute reduction as compared to current levels of throughput is implemented. 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. Further work would be needed to clarify what additional assumptions (e.g. which technologies) could make this scenario a sensitive and economically successful one. So far, it clearly illustrates the trade-offs between the goals of strict environmental protection, safe jobs, soaring consumption and a stable economy.

5.3 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 to explore the relation between investment, technical change and employment. The following brief descriptions of scenario results give a general idea of these relations by testing the options of cutting the unemployment gap by increasing borrowing-fed economic growth. Two options regarding labour policies are analysed, both focusing on the reduction of life-long work time (reducing working time and lowering pension age scenario).

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. At current efficiency levels, 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 Euro. 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.

Limits to technical change

First the obvious was checked: 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 (resulting unemployment rate 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%. Obviously, neither the continuation of the past trends, nor even the status quo of rationalisation is socially sustainable, ceteris paribus. Whether on the other hand curbing technological progress is realistic, remains highly questionable, not least based on current trends in market services.

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[6] 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.

Reducing working time

Currently the length of the average working week in Europe 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.

Lowering pension age

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 (like in the UK) but come from an insurance system (like in Germany), early retirement would further reduce pension benefits (which might already be diminished due to a reduction in working hours). This underscores 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.

5.4 Towards a Sustainable Development

In order to illustrate the interaction of policy measures and how a set of policies could be implemented in SuE a number of single policies was combined: 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 scenario 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%, the 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 about 3% 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 the *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, the service availability resulting from long-lived material goods and eco-efficient services is even increasing. In other words, one does not suffer from not buying new lawn mower or vacuum cleaner, if the old one is well maintained, upgraded and works fine, but just saves 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 spending which results from an uncompensated reduction of working time (reductions with different levels of compensation have not been tested).

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. Discussion

6.1 Comparison of the results

As the scenario design used for SuE and PANTA RHEI differs considerably, a detailed and straightforward comparison of the results shown in chapter 4 and 5 is not appropriate. This is no great surprise, since the models to be compared have been deliberately chosen to be extremely different, in order to demonstrate clearly the validity of the sustainability strategies and their core elements identified.

For PANTA RHEI the results are given in a quantitative manner for each of the twenty years, the simulation is running for the whole aggregated German economy and for each of the 58 sectors of the economy. The results of SuE are less differentiated but provide a tendency for different policy instruments, regardless of their direct cost effect. The scenarios used for simulation with PANTA RHEI are complex scenarios each containing a mix of policy instruments. The simulations with SuE started with partial scenarios, focussing on one policy field like agriculture, technology, transport, etc.; the sustainable development scenario, that is combining three policies - eco-efficient production, eco-efficient services and reduction of weekly working time - is a complex one.

Given these differences in structure and approach, the only possible comparison is that of the politically integrated SuE scenario with the sector wise aggregated PANTA RHEI scenario.[7] This, however, satisfies our initial intentions, since these two scenarios are based on a similar aim and combination of policy instruments. Table 5 presents the results for selected indicators.

Table 5: Comparison of the results for certain indicators

Indicator	**Sustainable Development (SuE)**	**Integrated (PANTA RHEI)**
GDP	+ 45% in 20 years	+ 32.7% in 20 years
MI	- 27% in 20 years	- 27.8% in 20 years
CO_2-emissions	- 15% in 20 years (absolute)	- 14.0% in 20 years (absolute)
Unemployment rate	about 3% in 2020	3.3% in 2020
Standard of living (service availability)	Increased	Increased
Disposable income	Decreased	Increased

Although the policy strategies applied in both scenarios have basic similarities, they differ in many ways due to the differing model capabilities. Despite these differences, however, and regardless of the extremely different models (see below), the results concerning the crucial parameters are quite similar. The unemployment rate as a social indicator and the material inputs plus the CO_2-emissions as environmental indicators show a similar development. SuE projects a slightly higher growth rate (it calculates growth potentials, which can be higher than the real growth PANTA RHEI tries to predict), a lower disposable income, but a comparable trend in the standard of living.

One conclusion can be drawn from this comparison: having in mind the same set of goals and objectives towards sustainable development in all four dimensions, simulations can lead to converging results despite totally different models. This shows the reliability of the strategy proposals and suggests that they are workable in a reality that is as different from any scenario as the scenarios chosen here are from each other.

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[7] For a dissaggregation of the PANTA RHEI results see Hinterberger, Omann, Schmitz, Spangenberg 2000.

6.2 Comparison of the models

As mentioned there are many differences between PANTA RHEI and SuE. In this section the differences between the two models are briefly described.

- Most basically, SuE is a systems dynamics model, whereas PANTA RHEI is an econometric one.
- SuE is based on physical accounting of embodied energy with no price mechanism included in the model, whereas PANTA RHEI is totally based on prices.
- In PANTA RHEI Germany is considered and SuE is developed for the European Union (EU 15) without regional disaggregation.
- The horizon of the forecasting capacity is different. In the two models the forecasts are always made up to the year 2020. Because PANTA RHEI is built for medium-term forecasts, 2020 is about the longest possible forecast horizon of the model. In contrast, SuE is a long-term model and the time horizon of 2020 is a medium one for the model.
- A more technical difference is the number of equations of the model. SuE has more than 1500 equations and PANTA RHEI has more than 40000 equations. One reason is that the SuE uses an input-output table with only 12 sectors based on a cluster analysis of the European economy, whereas in PANTA RHEI the economy is divided into 58 sectors according to the system of national accounts SNA. With input-output data of these 58 sectors the production is modelled in a very detailed way. Also the prices, the final demand, the labour market, and the World market are calculated for 58 sectors in PANTA RHEI. This makes PANTA RHEI scenarios necessarily much more complex than those run under SuE.

The characteristics above also determine the strengths and weaknesses of the respective model. Whereas SuE can cope with physical facts and behavioural changes beyond their economic characteristics, it fails to capture the price effects. On the other hand, PANTA RHEI is designated to assess structural change due to changes in relative prices, but has problems to reflect assumptions that cannot be expressed that way, or that are only part of an aggregated price effect (see below for the transport sector as an example).

As a result from this difference, the level of detail in modelling certain sectors is very unevenly distributed between both models, resulting in sector-specific strengths and weaknesses. SuE has one of its strengths in the electric power sector, where many technical aspects of this side of the economy were used in the model. Here SuE distinguishes between oil power plants, gas power plants, coal power plants, nuclear power, wind generated electricity, hydroelectric power and so on. Other technical variables in SuE are variables like the average consumption of gasoline per car or the average number of passengers per car. Another strength of SuE is that it takes the natural resources and reserves into account. Also the transportation sector is described in detail, permitting some kinds of strategy analysis not possible in PANTA RHEI. On the other hand, SuE has its weakness in the manufacturing sector, which is modelled as one aggregate.

In PANTA RHEI the production of electricity is modelled similar to every other sector with its 58 different material inputs. The energy inputs like gas, coal, oil and nuclear power are distinguished, but in PANTA RHEI the different power plants are not represented in a detailed way. Instead of this, PANTA RHEI has its strength in manufacturing, which is divided into 30 sectors. Also the transport, construction services and government sectors are described in detail.

PANTA RHEI uses economic variables instead of technical ones. That means PANTA RHEI uses real and nominal variables and therefore also prices. PANTA RHEI forecasts these sectoral and macroeconomic variables in nominal and in real terms. Also forecasts of the whole system of national accounts, the disaggregated employment, the disaggregated emission and the disaggregated material inputs are made.

Econometric models and system dynamics models have also some differences in the data and the determination of variables. In SuE many parameters are determined by assumptions of the model builders. Because of this for a number of parameters the system dynamics models need only the data set of an initial year, but a number of explicit assumptions e.g. on the physical impact of economic measures. Whereas PANTA RHEI “translates” such assumptions, the translation must be undertaken externally for SuE (which includes time dependent table functions as well).

In PANTA RHEI all parameters were estimated by econometric methods. For econometric estimates time series of data are needed. PANTA RHEI uses time series for Germany from 1978 to

1994. These data are time series of the input output tables of the German economy in a deep disaggregation. Both models are validated against some detail of statistical data.

These facts are illustrative regarding the functioning of the models, however they do not say much about the differences in the theory, philosophy, and technique. One such core difference is how each model copes with structural change. The most important point is the use or non-use of prices. In a physical model like SuE the user makes assumptions about exogenous variables, and these variables have direct effects on the technical changes. In SuE prices were not used, however the embodied energy as a numeraire is closely correlated to monetary cost. In PANTA RHEI, the situation is just the opposite. Here the prices are the most important variables of the model and the changes of relative prices are the reason for changes in the production structure, the consumption structure and the use of physical resources.

An example for the different modelling of structural change is the above-described average number of passengers per car. In SuE this number is given exogenously by the user, who has some ideas about the future of this variable and makes assumptions. The average number of passengers per car itself is a change in the consumption structure. It has also an effect on the other consumer goods because the demand for gasoline decreases and the relative shares of other consumer goods increase.

PANTA RHEI has no deep technical parameters like the average number of passengers per car. In PANTA RHEI the changing of price relations is the motivation for technological changes. If the price of gasoline arises more than the price of other goods, the demand for gasoline will decrease. In PANTA RHEI it is not important how this decrease of gasoline demand happens. The consumers can change their behaviour in using cars, they can use public passenger transport facilities, or they can use cars with a lower demand of gasoline. However, behavioural changes result from price changes, and developments that are not cost-related (e.g. behavioural changes for ethical or environmental reasons) cannot be reflected. In contrast, SuE is not dependent on assuming specific price elasticities for different aspects of human consumption behaviour.

The use and the non-use of prices and the modelling of structural change have also an influence on the number of exogenous variables. In PANTA RHEI this number is low. Because of its interdependency most variables are endogenously determined in the model. The formulation of structural change in SuE needs assumptions of technical values and hence the share of exogenous variables is high.

Table 6: Essential differences between PANTA RHEI and SuE

	SuE	**PANTA RHEI**
Kind of model	system dynamics model with a more technical view	Econometric model with a more economic view
Considered region	European Union (without regional disaggregation)	Germany
Object of the model	Development of scenarios for the future	real forecasts of the economy
Horizon of the forecast	long-term forecasts up to 2020 and longer	medium-term forecasts up to 2020
Degree of endogenisation	low, many technical variables are given exogenous	very high (98 percent)
Reason for structural changes	changes in exogenous variables, changes in the technology	changes in relative prices
Disaggregation level	low, 12 sectors	high, 58 sectors
Determination of the parameters	by experts or by the user	econometrically estimated
Production	via disaggregated input coefficients over an input output table	via disaggregated input coefficients over an input output table

6.3 Conclusions

This paper describes and compares two highly different models. Both of them have been used to run integrated sustainability scenarios. Given the differences in model construction, detailedness of sectors and different geographical scopes (and thus different basic data sets), the two models have virtually nothing in common except for the fact that they both include energy consumption and material flows into an economic model.

Both models have been used to test sustainability strategies for their environmental, social and economic impacts. Given the differences of the models, the convergence of simulation results has been striking.

According to the modelling results, it is possible by 2020 to come close to a sustainable state, by reducing unemployment to about 3%, CO_2 emissions by 15% and material flows by 25%, while the economy continues to grow (by 33% to 50%). The modelling results demonstrate as well that no single measure can come to such solutions, but that a skilful combination of policy measures from economic, environmental, social and labour policies is needed to bring about the transition towards sustainable development. Core strategy elements identified include:

- Increasing resource productivity by social and technological innovation,
- Reducing working hours, in particularly the monthly or weekly average,
- Stabilising carefully the social security system,
- Changing consumption (more long lived durable goods, more services instead of goods) and mobility patterns (modal split, frequency and distance of journeys).

Scientifically, these results underscore the necessity for interdisciplinary research in the field of sustainability. No single discipline seems to be able to provide all the necessary expertise. On a policy level, this kind of integrated approaches may well need new forms of integration and co-operation between authorities themselves and with the civil society.

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