A Sustainable Consumption Scenario in a System Dynamics Model

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* I am thankful to Friedrich Hinterberger for helpful comments

Introduction

Since the introduction of the sustainability concept by the Brundtland-Commission in 1987 it has been the starting point for a strand of projects trying to find a way towards ecologically healthy societies that at the same time foster economic well-being, intergenerational and intragenerational justice. This paper stresses the relationship between the economy and the environment, the target of social justice is dealt only in the sense that the well-being of the European population is an object of the presented scenarios. The third world problematic is left aside.

As the complexity of the ecological system makes it impossible to forcast its exact carrying capacity nobody knows precisely where the dividing line between a sustainable and an unsustainable economy lies. This is why, starting at the input side of the industrial metabolism, as a rule of the thumb, a ten-fold reduction of the total material requirement of the economy is proposed as a goal to be reached during the next 40-50 years. This approach is called „dematerialization“ [1].

The socio-economic system offers several starting points for such a massive reduction of the total material requirement whereof substantial rises of the production efficiency are often over-emphasized. Further means are on the one hand the increase of the so-called service efficiency which is the ratio between the existing stock of products and the actual use thereof and on the other hand the desired level of services. Here the potential of an increasing service efficiency will be investigated.

There is a variety of ideas how the service capacity of a material stock can be exploited to a higher degree. This paper investigates two of these ideas[2]: the substitution of short-lived goods by long-lived goods and the substitution of the purchase of material goods by eco-efficient services[3] because in these cases one service unit regularly requires less material than if it was consumed in the conventional way of buying and individually owning and using a product.

The strategy of changing use patterns to reach above dematerialization goal can be operationalized by a change of the structure of demand. This leads to the following questions: How can such a change of the structure of demand influence environmental as well as economic variables from a dynamic and system oriented point of view? What will happen to the well-being of the population: Wíll it decline continuously, remain steady, or even rise in the long run? To what extent will the intended savings of material input by

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1 Schmidt-Bleek 1994

2 This was done in the frame of the TSER-project „Modeling Sustainable Europe“ (Contract No. SOE1-CT96-1018), coordinated by Joachim Spangenberg, Wuppertal Institute for Climate, Environment, Energy

3 Eco-efficient services are services that replace the purchase of a material product: instead of the material good its mere function is bought, e.g. the use of a public washhouse instead of the private washing machine or the participation in a car-sharing organization instead of the purchase of a private car.

above substitutions be eaten up by rebound and/or other dynamic effects? And of course: How about the job situation in the affected sectors?

To answer these and other questions a macro system-dynamic simulation model was developed for Europe in a project called „Modeling Sustainable Europe“. The model is able to simulate either one or several dematerialization strategies at the same time[4]. For reasons of complexity the change of demand structure was carried through for only one element of final demand: private consumption[5].

This paper shows that for the domain of consumption the exploitation of the technical service capacity can be raised to a degree which is necessary to reach the factor 10 goal of dematerialization, that is the object of a 90-percent reduction of the material input into the economy. The economic consequences are a stop of the growth of manufacturing output in energy terms but a higher level of employment as in the reference run as well as a still continuing rise of the service availability for the population.

Theoretical Background

The strategy of dematerialization can be based on the following tautology[6]:

$$W = W/S * S/Y * Y/MI * MI,$$

where W means the well-being of the population achieved on the basis of S, the total of all service units derived by actually using the goods of Y, which is the gross national product. The national product is produced with the help of the material input MI which can be seen as an estimate for the potential ecological impact.

Since above formula is just a tautology further analytical tools are necessary to identify the points of departure for dematerialization by connecting the level of well-being of the population with its environmental basis and the linking efficiency ratios.
It depends on the questions to be tackled how the variables are precisely defined. In order to encompass the wide range of possible ecological impacts of the industrial metabolism the concept of material input should be life-cycle oriented and so comprise not only every kilogram of material that was used for the production of a certain product but also translocations[7], intermediates and the use of machinery. The existing calculations of the total material requirement for various reasons cannot yet meet these exacting demands[8]; the material input concept used in the applied model includes the material (in tons), water and air used for the production of the products and for the production of intermediates.

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[4] more about the model and further tested strategies can be found in Spangenberg et al. 1998
[5] one of the reasons for this approach was that all production functions would change if the investments were also affected by the substitution strategy
[6] modified from Femia et al. 1996
[7] especially translocations that took place before the production process itself like the devastation of many hectars of landscape for the exploitation of resources; for further information see Schmidt-Bleek 1994
[8] e.g. Stahmer et al. 1996, Schuetz 1997

The gross national product Y normally is accounted for in money terms. However, it does not have to be: It could for instance be calculated in tons using only the weight of the output (which would mean that services had a value of 0). Or the calculation could be stretched upon losses in intermediate production.
As the model at hand calculates in energy terms, here the output of production is accounted in accumulated energy requirement where the accumulation starts with the energy content of imports.

The service units S are not to be confounded with the market services sector in the national accounting system. They stand for the level of the service availability for the population, that is the non-emotional part of its well-being. Theoretically, they are the sum of the main function, be it material or immaterial, of all products; the main function being the reason most products are bought for. This concept is the most difficult to grasp — especially on a meso- or macroeconomic scale, because there is no common unit to aggregate the service units „haircut“ and „leasure trip to Wuppertal“. To our knowledge, the aggregation problem can only be circumvented by creating indicators that are able to at least *compare* the levels of service availability of different situations.

The concept of well-being W is a subjective one, and though sufficiency´s contribution to a dematerialization strategy which is represented by the ratio W/S (the „well-being efficiency of services“) should be kept in mind, this is not a topic addressed in this paper.

In the context of the above formula the factor 10 goal means that the total material requirement MI of the economy is to be reduced by 90%. Then it follows that if the total amount of well-being W should at least not decrease (W = const.) the three ratios „well-being efficiency of services“ W/S, „service efficiency of national production“ S/Y and „production efficiency of material input“ Y/MI on avarage have each to be increased by a factor of 2.15. Or: Each of these efficiencies has to rise by roughly 1.6 % per year if the adaption period is designed for 50 years.
This decomposition of the linking elements between material input and well-being implies[9] that the efficiency terms are independent of each other. This, in reality, they are not; but the approach makes it possible on the one hand to point out the several starting points for sustainable behaviour and on the other hand to study the potential contribution of each of these efficiencies.

This paper focuses on increasing the service efficiency of the material stock S/Y. This means that the stock of already produced material goods is conceived as a store of potential service units which are consumed if the material products are applied. In reality this potential is used only to a small percentage, e.g. statistically a car is resting for nearly 23 hours of a 24-hour-day[10]. About the same applies to vacuum cleaners, washing machines, dish washers and much industrial equipment.

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9 of course, this is only *one* way of decomposing total material requirement and well-being
10 Meijkamp 1996

More about the Model

SuE (Modeling Sustainable Europe) is a system dynamic modeling tool[11] based on the ECCO model[12] to simulate the macro-economic and economic-ecological interdependencies in the EU-15 economy. Seeking to grasp the complexity of the economy-environment relationship the model uses energy as a numeraire and additionally keeps track of all material flows connected with economic decisions. The use of „embodied energy“ as numeraire reflects the modelers´ intention to account for the interdependence between economic activities and the rise of entropy in the ecological system.

The model is constructed as an interplay of 13 sectors which do not exactly correspond to economic sectors. Most sectors produce output like manufacturing or construction goods with the help of their accumulated capital stock and the use of the output of other sectors. The output is measured in embodied energy; the material flows related to it are accounted for in the categories abiotics, water and air. Thus the model SuE is an appropriate means to test the outcome of sustainability strategies aimed at reducing the material throughput of an economy.

Rather than forcasting the economic and ecological consequences of a certain scenario the model depicts the development potential of the physical side of an economy. Attached to this potential one can find variables like specific outputs, jobs, ecological indicators and the development of the service availability to the consumers. The available time period in the model are the years 1995 to 2020.
The idea behind the model is to get further information about the dynamic interdependencies of the basic elements of the European economic-environmental system and to offer a decision tool to political agents which can be handeled quite easily.

Implementation of Service Efficiency Strategies in the model

Among the above mentioned starting points for dematerialization (see section: „Theoretical Background“), the role of the increase of the service efficiency in an economy is to make more out of less: If the use of a — physically declining — stock of material goods is intensified, the total of service units that is actually consumed with the help of this stock draws nearer to its technical potential.

There is a variety of ideas about how this could be achieved. Among the most prevailing are eco-efficient services that replace the purchase of a material product

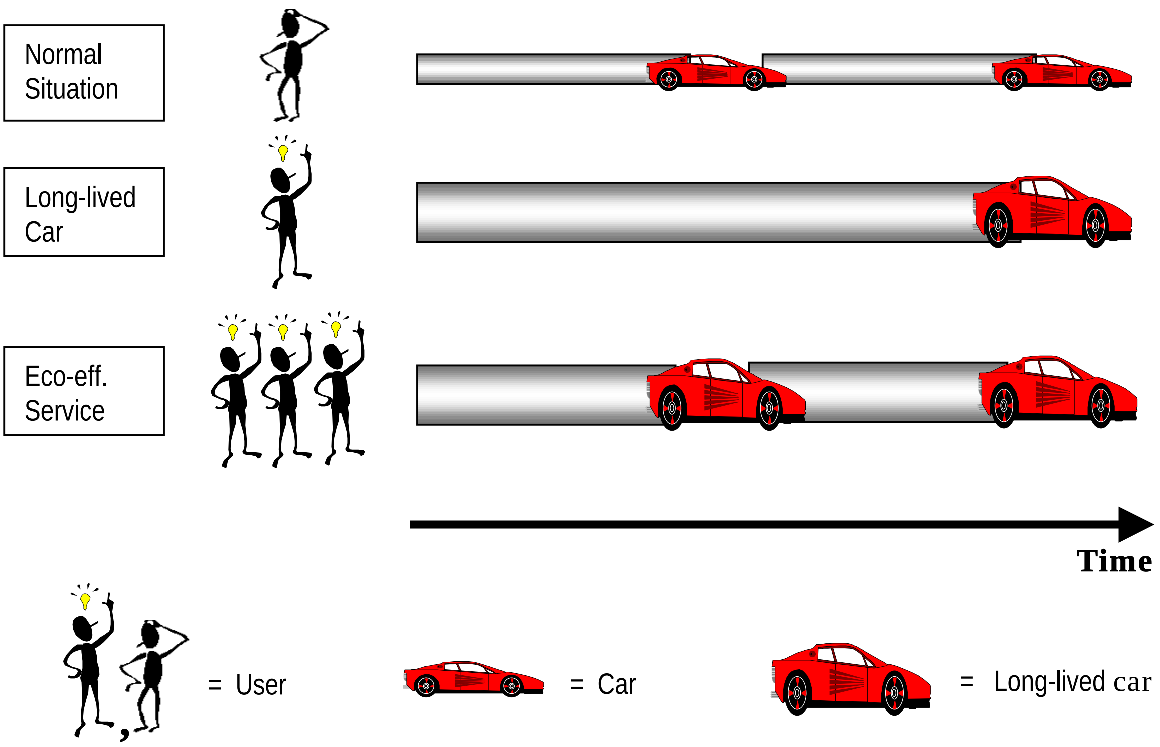
[11] it was developed during the TSER-project (Targeted Socio-Economic Research) „Modelling Sustainable Europe“ which is an international project funded by the European Commission that will be terminated in April 1998.
[12] Slesser et al. 1994

by the purchase of a greater or smaller set of its functions and the increase of the life-time of material goods. Another proposal is to incite the offer of better instructions for the use of products so that defects or waste are avoided. In reality elements of above mentioned strategies are combined in various ways.

These strategies can be applied for every process where a stock of service potential is set to use, be it on the production or the consumption side, be it private or public. For reasons of complexity, especially concerning the input-output structure of intermediaries, the scenario was carried through for consumption.

Not all of above described sustainable consumption strategies could be implemented in the model at hand. As SuE is a production system oriented model the impact of the change of the use pattern of consumers onto their economic activities had to be assessed. Thus the strategies that translate most easily into market and from there on into production decisions were chosen: The substitution of normal material goods by long-lived goods and of material goods by eco-efficient services.

Figure 1: Sustainability Strategies: Longevity and eco-efficient services



The first sustainability strategy implemented here is to rather buy long-lived than short-lived material goods[13]; because regularly the amount of material and energy needed additionally to build a long-lived product are more than compensated by the extension of the technical use potential. This approach shows even more than the other one that in reality the increase of the service efficiency in an economic system is not independent of the production efficiency because the latter changes even without technical progress if the structure of the produced goods changes.
Eco-efficient services[14], the second implemented sustainable consumption strategy, can be divided into eco-leasing, where consumers rent the product instead of buying it, in pooling or sharing, where several users share one material product, and in system optimization, where the most eco-efficient way of satisfying the exact need of the user is searched for. Transferred onto mobility needs this could mean in the first case, that a user rents a car instead of buying one, in the second that he or she shares it privately or through a car-sharing organization with others. And the third kind of eco-efficient service would be to ask when, how far and to what end the user intends to travel; finally he or she would probably take the train or the tram instead of a car.

Figure 1 illustrates the idea of both implemented sustainable consumption strategies: During a given time-span a mobility desire can be fulfilled by either buying two short-lived cars or one long-lived car which requires less material and energy than two normal cars. Another alternative is an eco-efficient service where for instance three people share two long-lived cars instead each using one normal car. They will need two long-lived cars because the more intensive employment of the car consumes the technical use potential more quickly than if a car was used only by one person. However, per person the material and energy requirement can be less than in any of the other cases depending on the design of the eco-efficient service.

In order to implement these strategies consumption was modeled in a three-fold way. There is a macroeconomic sector for conventional consumption which alone is activated if the reference scenario is run. Then there are two sectors the building up of which is influenced by the changing consumption attitude of consumers: one is the sector for eco-efficient services and one the sector for long-lived material goods.
The construction of these two sectors[15] was based on the following assumptions:

- From a micro-economic point of view it is assumed that the service efficiency — that is the ratio between the main service (or function) of a product and the total material requirement needed for one service unit — can be raised by substituting short-lived by long-lived goods and material goods by eco-efficient services. There are several studies that prove this relationship for singular

[13] see e.g. Stahel 1981, 1994
[14] see e.g. Hockerts 1995
[15] The sector for long-lived material goods was constructed by Raphie Essling, University of Edinburgh.

cases[16], but in this context it is assumed that it holds for the whole fraction of private consumption that is substituted.

- Concerning the production processes in these two sectors it is assumed that long-lived goods (with a life-time that is doubled compared to normal goods) need about 10% more energy, material, labour and intermediates than normal goods. As there are no exact data about the production function of long-lived compared to normal goods, this is a cautious assumption based on two quite well studied examples: a kitchen with the life-time of 50 years needs about 47 tons biotic and abiotic material, water and air, whereas a 20 years living kitchen uses about 80 tons of the same materials[17]; and in order to produce cars living twice as long as normal cars, about 10% more energy would be necessary as Stahel found out in an expert questioning[18].

- For eco-efficient services we assume that they are produced with the help of exactly the same production function as market services to people in the service sector. This assumption is unsatisfactory, but acceptable for the lack of data.

- It is assumed further that the introduction of new products by the above describe new sectors can be achieved on the whole without introducing new technologies, but rather using known technologies.

- In a production oriented system-dynamic model the substitution has to take place via the building up of capital stock and the starting of production in the new sectors. In the beginning of the substitution process it is assumed that there are no products on the market that satisfy the new consumption wishes.

- The building up of the sector for eco-efficient services starts when the changed consumption attitude of consumers leads to them rejecting to buy as many material products as the industry has planned for them to buy. This, industry takes as a signal to invest in the new sector and in the end of the same period the first eco-efficient services are available.

- The sector for long-lived goods is constructed in a slightly different way: The reluctance of consumers to buy merely normal-lived goods makes part of the capital stock in the manufacturing sector obsolete. This leads to a splitting up of investment into less investment in the old sector producing the same goods as ever and into the erection of a second one that produces long-lived goods.

Simulation Runs

[16] see Stahel 1981; Hinterberger et al. 1994, Liedke et al. 1997
[17] see Liedke et al. 1997
[18] see Stahel 1981

Scenarios

A scenario is started by the manipulation of the parameters in the model that activate the sectors „Manufacturing of long-lived goods“ and „Eco-efficient services“. That means that there is no complex phenomenom explaining why these substitutions in the domain of consumption take place, the scenario is rather the implementation of the question: If people decided to consume in a more sustainable way and to that end substituted short-lived against long-lived goods and material goods against eco-efficient services, what would happen?
Furthermore the scenario runs are carried through in an unchanging social and economic frame, that means that labour cost or jurisdiction do not react onto the impulse of the modified demand structure.

For comparison four different scenarios were executed with the simulation starting in 1995 and ending in 2020, so that the more precice question is the following: If the assumed changes of the consumption pattern had started in 1995 how would the development of the European economy and environment deviate in the following 25 years from the **business-as-usual scenario**, which serves as reference run?

In order to determine sensible values of the scenario parameters a two-fold procedure was chosen: a bottom-up approach which asks for likely changes in demand structure and a top-down approach which searches in a trial-and-error process for those parameter variations that lead towards the factor 10 goal. In all scenarios it is assumed that these changes take place slowly and are just about reached at the end of the simulation period.

For the bottom-up approach a final substitution ratio of about 10% was fixed for the replacement of material goods by eco-efficient services as well as for the substitution of normal goods by long-lived goods so that all in all a fifth of consumption is modified. In the figures this scenario is called **„bottom-up scenario“**.
As there are no market potential analyses for eco-efficient services nor for long-lived goods these ratios were set rather intuitively although bearing in mind that more than twenty years are quite a long time span for the development of consumption patterns and should be enough for about one fifth of the consumption of durables and perishable goods to be organized differently.

The top-down approach implements the necessary contribution of a rise of the service efficiency to the factor 10 goal (see section „Theoretical Background“).
There are two aspects of that goal; the first of which being the absolute reduction of the overall total material requirement into the economy by a factor of 10. This scenario is named **„radical scenario“** in this paper. However, it should also be known which structural changes lead to a ten-fold rise of the material efficiency in

an economy (the so-called **MIPS[19]-scenario**), so that the differences between the results of these two approaches give an impression about the influences of growth dynamics on dematerialization. Both of these aspects were implemented with the following specifications: Given a constant level of welfare the necessary contribution of the development of service efficiency to the factor 10 goal is an efficiency increase of a factor of 2.15 over 50 years or –30% over 26 years which is the time span of the presented simulations.

Results

Consumption is only one component of final demand[20]. That means that a change in the structure of consumption needs not change the whole material input or service efficiency by –30% but only that part of this ecological indicator which is related to consumption. In the figures the ecological indicator „abiotic material input“ and the economic-ecological indicator „material intensity per service unit MIPS“ (which is the reciprocal form of service efficiency) account for this fact by each relating to the equivalent of consumption[21]. Thus these two indicators reflect the degree of achievement of the material input reduction goals: MIPS should be reduced by a factor of 1.4 in the scenario that aims at the mere increase of the service efficiency (the MIPS-scenario). The total material requirement related to the standard of living should be reduced by the same factor in the the absolute reduction scenario (the radical scenario).

In figure 2 – 5 the **development of material consumption including eco-efficient services** is presented on the whole[22] and disaggregated in long-lived and normal goods and in the consumption of eco-efficient services can be seen. Thus it is possible to trace the changes in the consumption patterns as assumed in the scenarios. In the business-as-usual-scenario there is no output of eco-efficient services and long-lived goods[23] (figure 2), in the bottom-up scenario there are only slight changes (figure 3). The necessary contribution of changes in the consumption structure to a ten-fold raise in the service efficiency results in an absolute decrease of the purchase of normal goods in the second half of the simulation period. The consumption of eco-efficient services and long-lived goods, however, gains significance until each of these categories amounts to about one sixth of above

[19] MIPS is the abbreviation for **M**aterial **I**ntensity **P**er **S**ervice unit, a measure introduced by Schmidt-Bleek 1994 which focuses on efficiency strategies.
[20] final demand is the basis for the calculation of service efficiency
[21] In the model SuE consumption is not defined in the conventional economic way; it is called „standard of living“ and comprises additionally those parts of public services which can be attributed to individuals, but on the other hand does not include energy purchases by private households (see Klingert 1997).
[22] „Whole consumption“ here is a rather reduced term only comprising those elements of the standard of living which are changing in the scenarios: normal goods, eco-efficient services, long-lived goods
[23] Of course there are always long-lived goods in an economy, they can be found in the aggregation of normal goods; the sector for long-lived goods is understood to be a sector for the extension of normal life-times.

described wohle consumption (figure 4). In the radical scenario the consumption of normal goods breaks down to under 0 which is quite disconcerting at first sight (figure 5). However, the model works with stocks and flows, and a negative consumption level just means that more of the stock is depreciated than replaced by purchases of new goods. The next set of figures will show that this does not have negative consequences for the availability of services of the population because this is more than compensated by purchases of long-lived goods and eco-efficient services.

Figure 2: Consumption in Reference Scenario

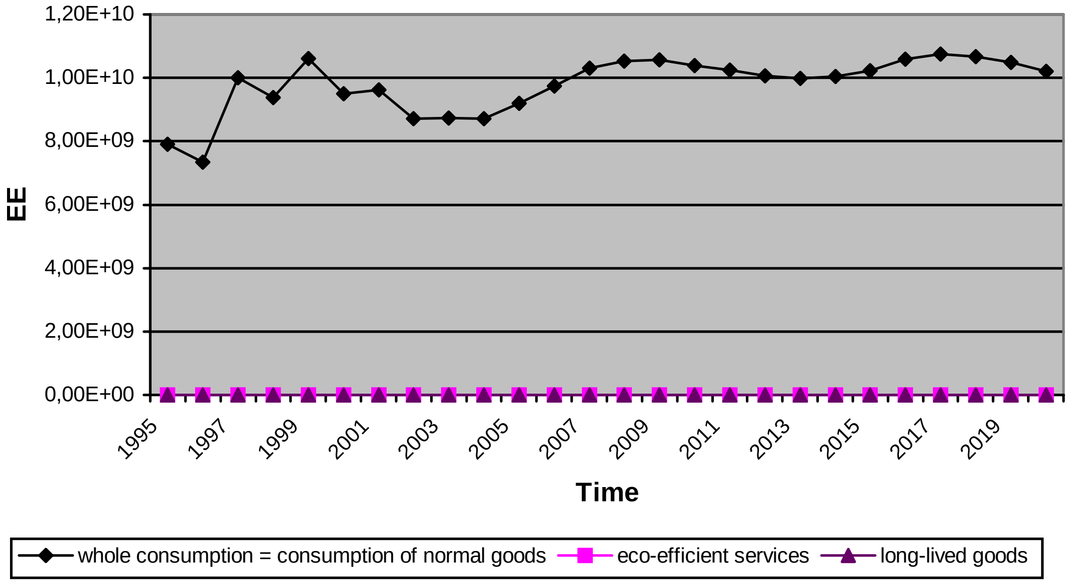


Figure 3: Consumption in Bottom-up Scenario

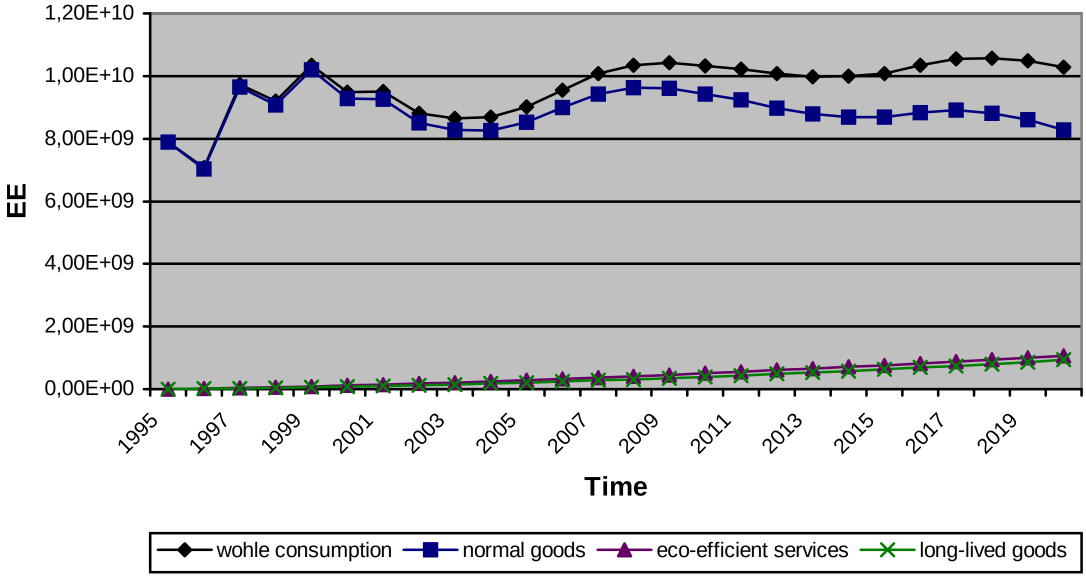


Figure 4: Consumption in MIPS-Scenario

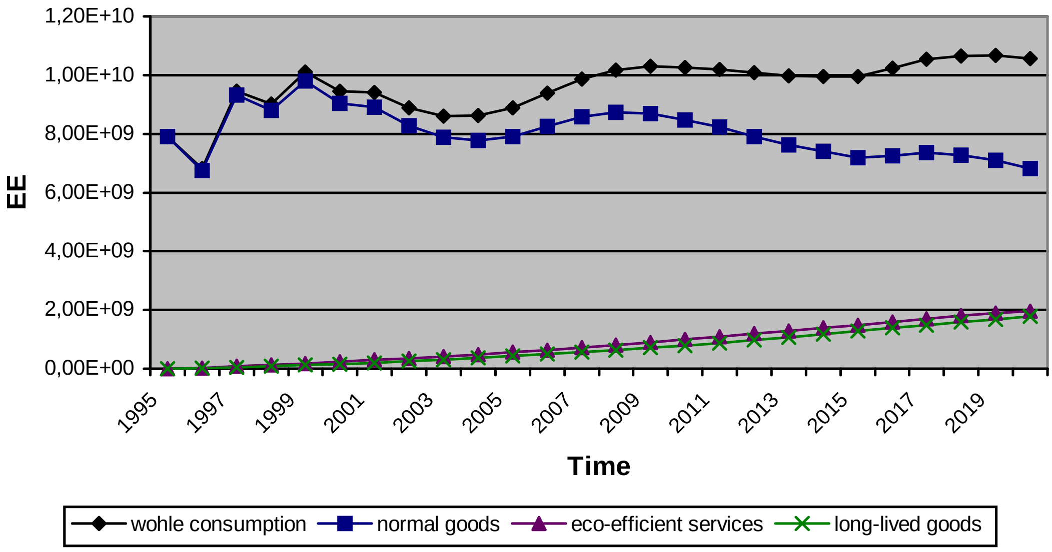


Figure 5: Consumption in Radical Scenario

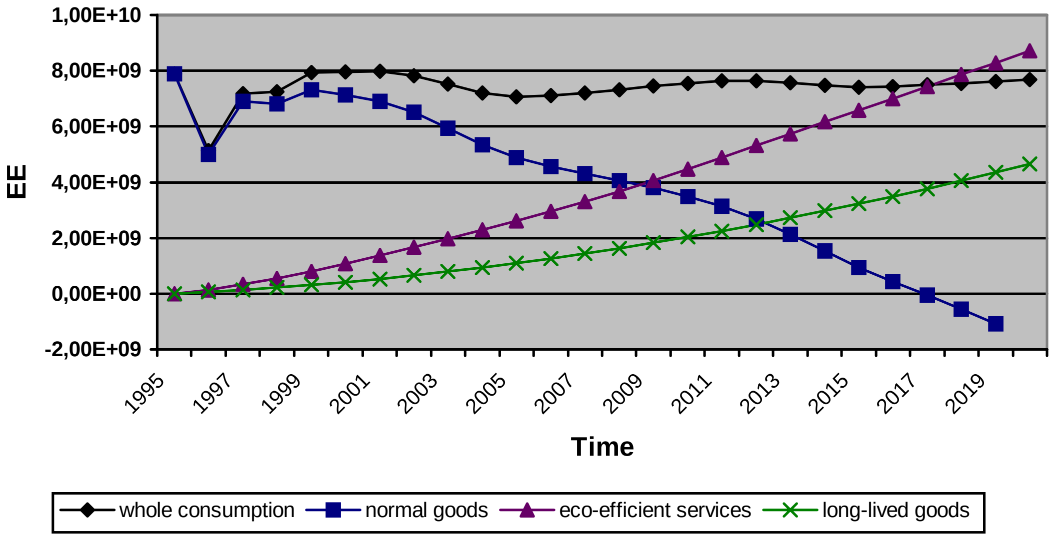
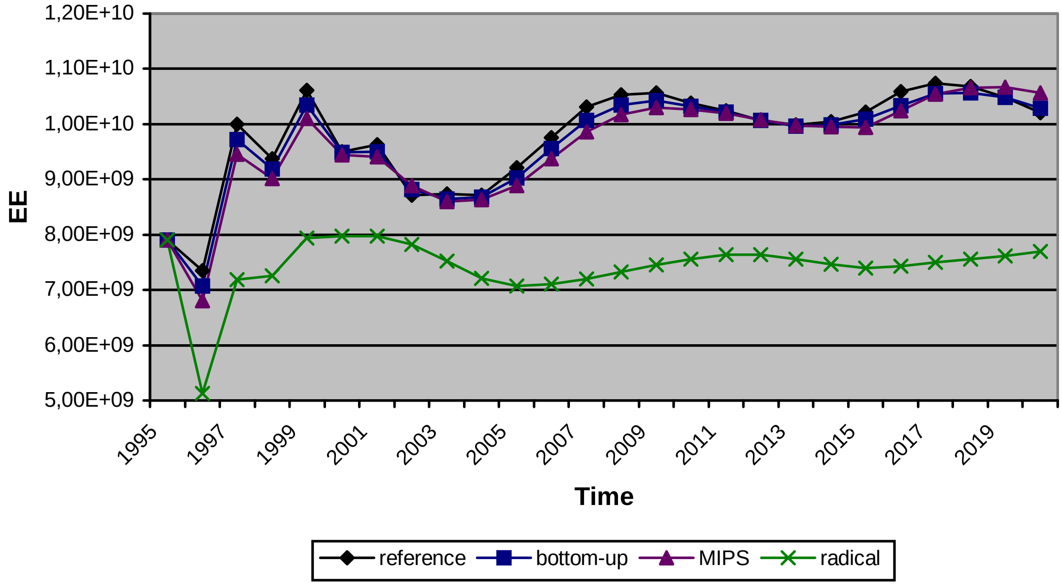


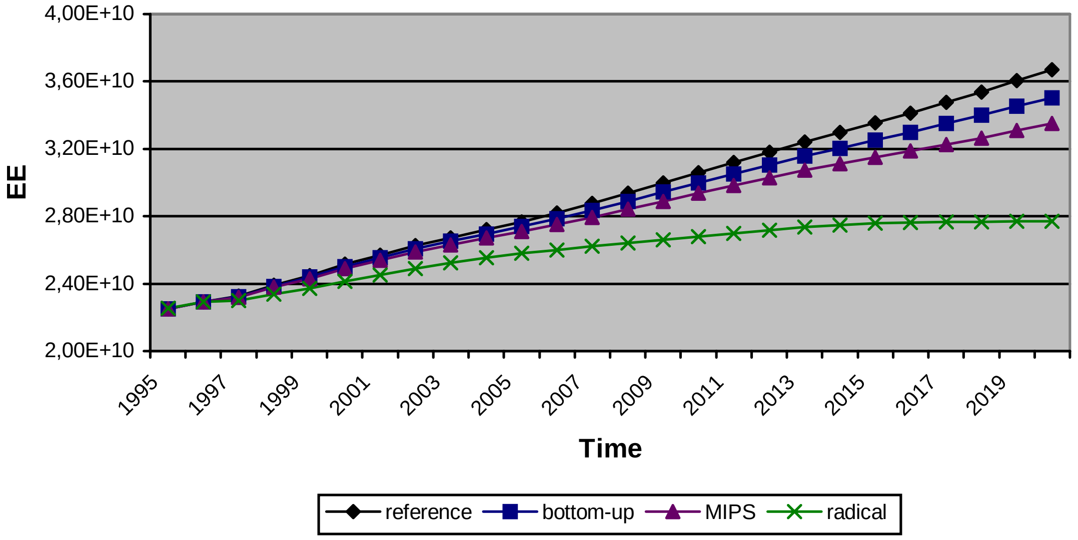
Figure 6 compares the development of the **sum of the consumption of normal goods, of eco-efficient services and of long-lived goods** in the four different simulation runs: The energy accounted niveau of material consumption is reduced considerably only in the case of the radical scenario.

Figure 6: Whole Consumption



The figures 7 – 9 give an impression of the **reaction of the rest of the economy**. In all scenarios the new structure of consumptive demand results in a reduction of manufacturing output compared to the reference run (figure 7). But only in the radical scenario the growth trend of manufacturing output is broken.

Figure 7: Manufacturing Output



In figure 8 the development of the service availability is depicted. To do this, the indicator „service accounted standard of living“ was created that is able to compare the niveaus of different service levels that are consumed by the population. Here the slightly oscillating movement of the consumption curve is not reflected because of the different leveling weighs of the consumption elements. The growht trend, however, is about the same as in the reference scenario. Contrary to the energy accounted consumption term the service availability raises the more sustainable the structure of consumption gets. This is because the increasing share of service intensive product groups outweighs the overall material reduction process.

Figure 9 shows that the job situation in Europe does not look promising for the next decades if current trends continue: In the business-as-usual scenario the number of jobs might go down by around 28% between 1995 and 2020. These prospects can be improved if any of the described dematerialization strategies is persued. This is above all because the work intensity of eco-efficient services more than compensates the shrinking job offers in manufacturing industries. Again, the radical scenario is the only that leads to a stabilization of the number of jobs in Europe; in this case the losses of jobs might be only 6%. All scenarios include the assumption that the distribution of jobs remains constant over the depicted time span, that is that there will be no more reductions of work time.

Figure 8: Service Accounted Standard of Living

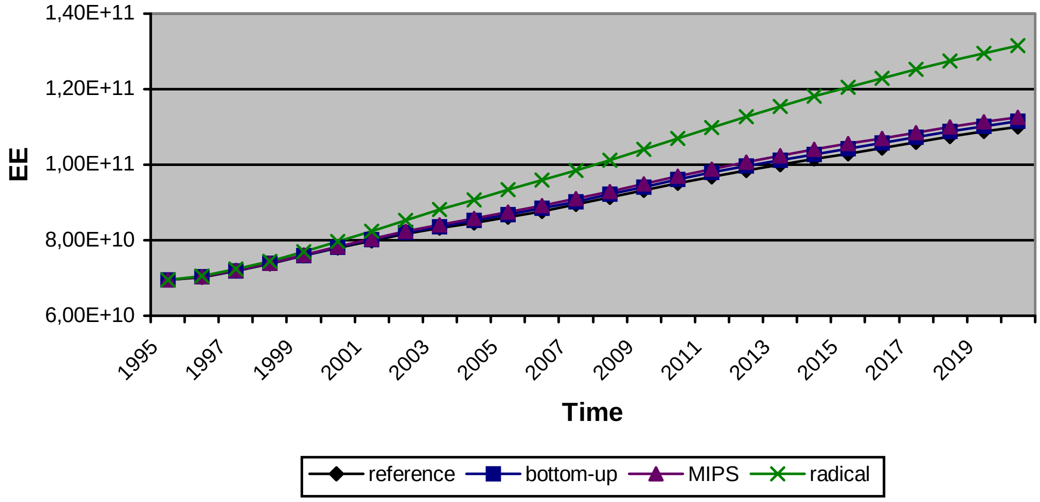
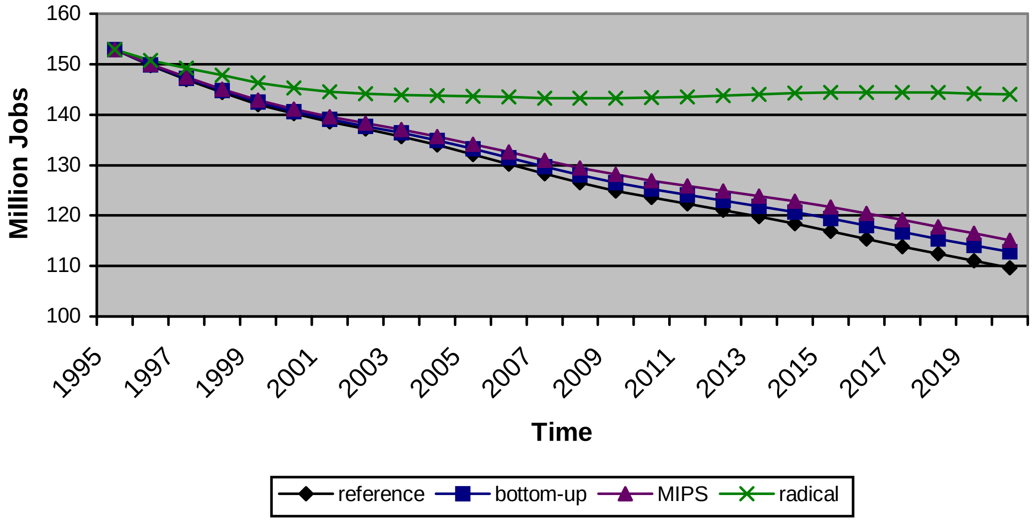


Figure 9: Jobs



There are, on the other hand, two assumptions affecting the development of unemployment unfavourably in the presented scenarios compared to a probable reality: It is not likely that the assumed changes of the attitude of the population that result in a restructuring of consumptive demand will take place without incentives like eco-taxes which according to the proposal of the European commission[24] would be used to reduce labour costs. Additionally, long-lived goods need more maintenance and repair than normal goods and are thus more labour intensive, a fact that is not implemented in the model structure.

The last set of indicators to be looked at illuminates the **economy-ecology relationship** (figures 10 – 12): MIPS, the material input per service unit, is an indicator that stands for the interface between economy and ecology. The total material requirement as well as the industrial CO2 development are pure ecological indicators. In the model both indicators are vectors consisting of the three elements abiotic material, water and air. Concerning MIPS, again it should be stressed that it was not possible to measure service units as we measure material input; rather the development of service availability is reflected in a relative form — thus the MIPS-term here is a rather imperfect implementation of Schmidt-Bleeks MIPS-concept[25].

In the reference run due to extrapolated technological trends MIPS related to abiotic material will be reduced by 19% until 2015 (figure 10). In the same time, because of growth effects, the absolute abiotic total material requirement for the production of the here defined standard of living will rise by 28% (figure 11). With values of +1% and +59% the development of the use of water for the standard of living is even worse.
In the cautious bottom-up scenario MIPS related to the standard of living is reduced by 25%, but this is not sufficient because, as can be seen from figure 11, the material input is still rising.

Even if the service efficiency of consumption (the reciprocal value of MIPS) is raised by a factor 2.15, in the presence of growth these gains are eaten up, so that on the whole the total material requirement of abiotics is still — although slightly — going up. Only the radical scenario makes this indicator declining by a factor of 1.4 until the year 2020 which is the necessary contribution of service efficiency to an overall factor 10 dematerialization target within 50 years.

[24] Commission of the European Community 1992
[25] Schmidt-Bleek 1994

Figure 10: MIPS of Standard of Living

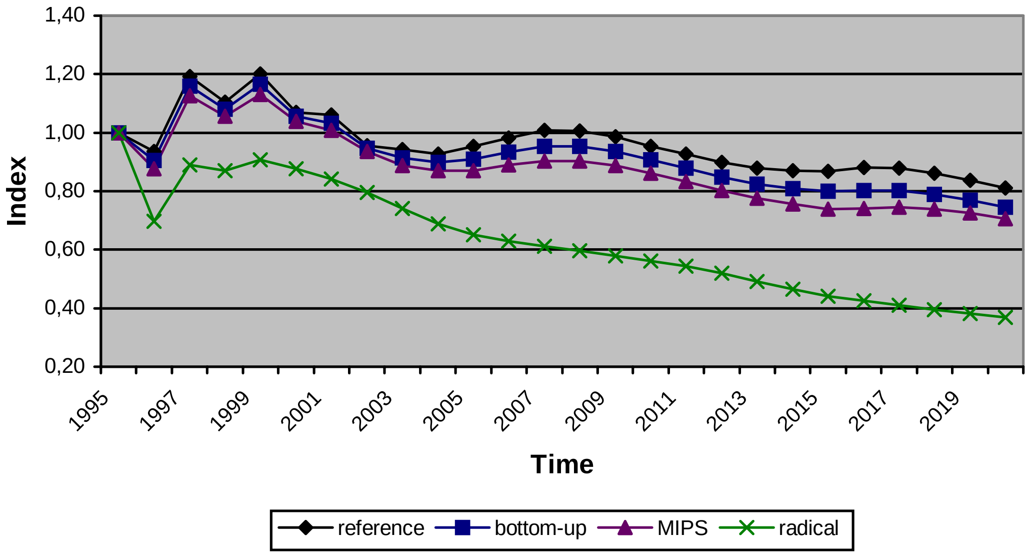
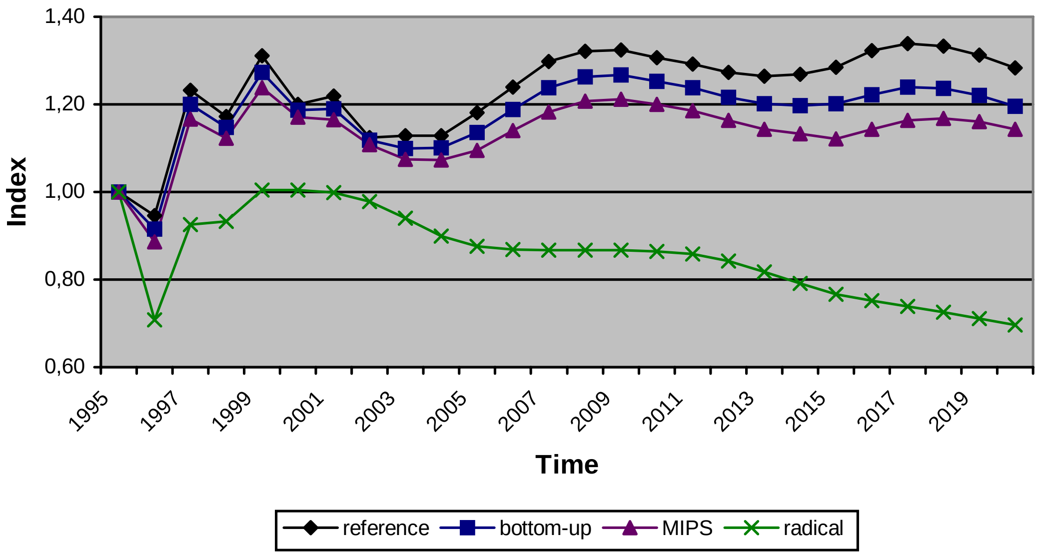


Figure 11: Abiotic Material Input related to Standard of Living

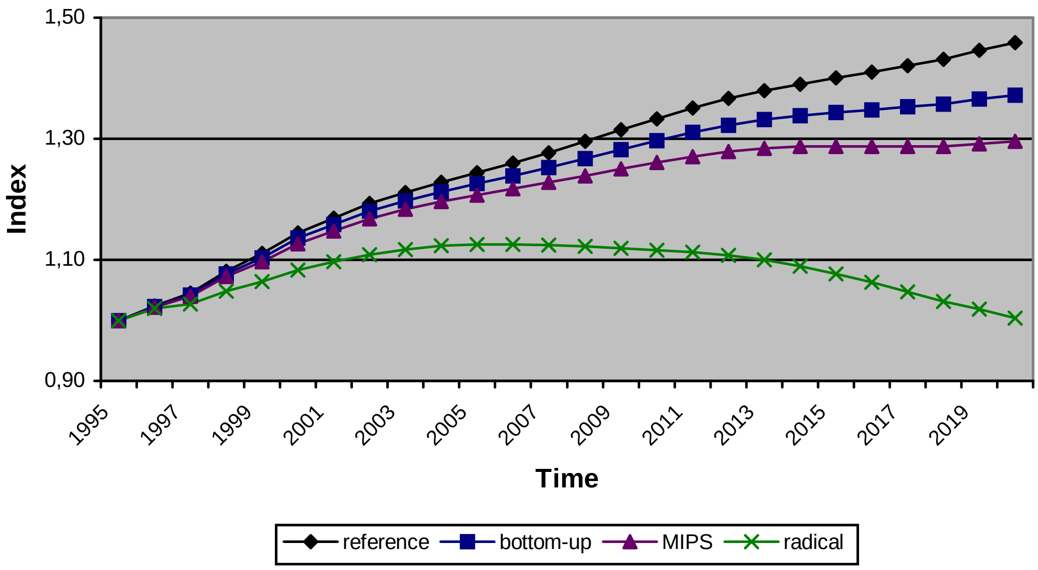


The CO2 curve in figure 12, contrary to the indicators above, relates to the industrial sectors as a whole and not only to ecological impacts induced by elements of private consumption.

Thus the power of mere changes of consumption patterns can be shown: The bottom-up scenario does not change trends, neither does the MIPS-scenario. The massive changes in consumption patterns assumed in the radical scenario are necessary to bring about an absolute decrease after more than five years of continuing growth; however, the whole simulation period is needed for the CO2-

curve to reach its starting value until it might probably later on sink absolutely as further simulations[26] propose.

Figure 12: CO2-Index of Industrial Production



Conclusion

The essence from these findings is that moderate, sustainability oriented changes in the consumption structure effect in a moderate relief of the environment without a serious disturbance of economic stability. But they are not apt to bring about a lasting improvement of the ecological compatibility of a still materially growing society. In this paper the radical scenario where the purchase of normal consumption goods was reduced in such a way that in the end the accumulated stock of those goods is decreasing for the benefit of an increasing stock of long-lived goods proves to be the only scenario that breaks growth trends in the economy which endanger the environment. However, the absence of the growth of manufacturing output in this scenario does not impover the European population in a sense that people do not have access to a living standard that they have got used to; rather there is still a growing availability of services for the population, although people will not always be the proprietor of the goods they are using.

[26] In another simulation the radical scenario was implemented very fast so that the substitution process was finished after the first half of the simulation period — in this case an absolute reduction of the industrial CO2-emissions was found for the last 8 years with a still continuing downward trend. Although in this scenario the job losses were about as little as in the here presented radical scenario, towards the end of the simulation period a downward trend seems to elope.

Finally, it has to be underlined that these results are the results of modeling and thus of the modelers´ view of the world. A model at such a rough aggregation level is not designed in a way to give exact forcasts about how the economy will develop, but as a system-dynamic model it should rather grant a more precise insight into the dynamic interdependencies of a living system and offer decision support for political agents.

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