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MODELLING IMPACTS OF LIFESTYLE ON ENERGY DEMAND AND RELATED EMISSIONS

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Abstract:

An approach to analyse and quantify the impact of lifestyle factors on current and future energy demand is developed. Thereby not only directly environmentally relevant consumer activities such as car use or heating have been analysed, but also expenditure patterns which induce environmental damage through the production of the consumed goods. The use of household survey data from the national statistical offices offers the possibility to cover this wide range of activities. For the available social-economic household characteristics a variety of different behavioural patterns have been observed. For evaluating the energy and emission consequences of the consumed goods enhanced Input-Output models are used. The additions implemented - a mixed monetary-energetic approach for inter-industry flows and a separate treatment of transport related emissions - improve the reliability of the obtained results. The developed approach has been used for analysing current emission profiles and distributions in Germany, France and the Netherlands as well as scenarios for future energy demand and related emissions. It therefore provides a comprehensive methodology to analyse environmental effects in a consumer and citizen perspective and thus contributes to an increased transparency of complex economic and ecological interconnections.

Key words: Energy demand, Emissions, Lifestyles, Consumers, Modelling

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[1] A slightly different form of this paper has been published in Energy Policy Vol. 28, pp. 549-566. The underlying studies have been carried out to a large extent within the project „Consumers' Lifestyles and Pollutant Emissions" involving also Martin O'Connor and Sylvie Faucheux and their research team at C3ED, Université de Versailles, Saint-Quentin. During the study Adriaan Perrels represented ECN, the national energy research centre in the Netherlands. We gratefully acknowledge financial support by the European Commission, DG XII under the Environment Programme (Contract NO. EV5V-CT94-0373).

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Tiivistelmä:

Tutkimuksessa kehitettiin lähestymistapa nykyiseen ja tulevaan energian kysyntään vaikuttavien elämäntapatekijöiden analysoimiseksi. Lähestymistavassa ei vain kateta kuluttajien toiminnan suoria ympäristövaikutuksia, esimerkiksi lämmityksestä aiheutuvia, vaan huomioon otetaan myös kulutushyödykkeiden tuotannosta aiheutuvat epäsuorat vaikutukset. Tällainen analyysi on mahdollista kansallisten tilastojen pohjalta käytettävissä olevaan kotitalouksia koskevaan dataan pohjautuen. Moniin kotitalouksien sosio-ekonomisiin piirteisiin liittyen on havaittu erilaisia käyttäytymiskaavoja. Kulutushyödykkeiden tuotannon energia- ja ympäristövaikutusten arvioimiseksi on käytetty parannettuja panos-tuotosmalleja. Näissä malleissa on omaksuttu – tulosten luotettavuuden parantamiseksi – ns. yhdistetty monetaaris-energinen lähestymistapa sektoreiden välisten virtojen analysoimiseksi sekä erillinen liikenteen päästöjen käsittely. Lähestymistapaa on sovellettu Saksassa, Ranskassa ja Hollannissa sekä nykyisten päästörakenteiden että tulevaisuutta koskevien energia- ja päästöskenaarioiden analysoimiseen. Lähestymistapa mahdollistaa kokonaisvaltaisen metodologian kuluttajan ja kansalaisen näkökulman huomioon ottamiseksi ympäristövaikutusten analysoimisessa. Se siten osaltaan lisää monimutkaisten taloudellisten ja ekologisten vaikutusten välisten riippuvuussuhteiden läpinäkyvyyttä.

Asiasanat: energian kysyntä, päästöt, elämäntapa, kuluttajat, mallintaminen

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Contents

1 Introduction

Although it is widely agreed that societal energy consumption and related emissions are not only influenced by technical efficiency but also by lifestyles and social-cultural factors (e. g. household size and composition, greying of society), to date few attempts have been made to operationalise these insights in simulation models for future energy demand. This has lead to the unsatisfactory situation that in spite of a broad consensus on the importance of lifestyle effects for the development of sustainable development in general (e. g. Duchin, 1996) and energy demand in particular (e. g. Schipper et al., 1989), consensus dwindles when discussing the character and extent of these influences. This methodological gap even may be seen as one major source for the lack of confidence in energy demand modelling among the wider public.

The approach described in the following aims at bridging this gap by modelling future energy demand based on a consumer perspective. Thereby not only households' direct energy consumption is accounted for but also the embodied energy demand, i. e. the indirect energy consumption caused by households' purchases of non-energetic goods and services. The research focuses on factors related to longer term structural changes in society, which have an impact on the volume and composition of consumption patterns. This could be termed the long-term lifestyle. Based on earlier work (Perrels et al, 1995; Perrels, 1996) we subscribe to the hypothesis that in the context of (domestic) energy use lifestyle can be identified by means of expenditure patterns of time and money. In turn these patterns are on the one hand influenced by broad societal and technical changes and on the other hand the expenditure patterns predetermine to a significant extent the required type and amounts of energy. This approach is summarised in Figure 1. As regards the operationalisation in the study it means that lifestyles are understood as the patterns of equipment ownership, expenditures of time and money and energy use of households[1]. Similar to most lifestyle concepts in sociological research, lifestyles expressed by just mentioned patterns are perceived as dependent variables, of which influencing factors are investigated. Contrary to approaches often found in marketing research, no lifestyle groups or types have been identified since earlier studies in this direction provided no satisfactory results. Rather, households have been differentiated by household types according to their position in the lifecycle (young singles, young couples, middle-aged families etc.) in order to account for the impact of the position in the lifecycle on household consumption. Additionally, the influence of social-economic household characteristics such as income, education level, type and number of employment, and size of municipality is investigated. In

[1] We are aware of the variety of lifestyle concepts developed in social sciences (for an overview see e.g. Müller 1989). However for the purpose of energy demand modelling the proposed definition seems to be the most workable. Though we certainly advocate a more elaborate use of time budget and timing information.

summary as shown in figure 1, the core of the models and the study is in the middle segments, but both the broader societal context and the first line environmental implications with respect to resulting emissions is taken into account into the modelling approach.

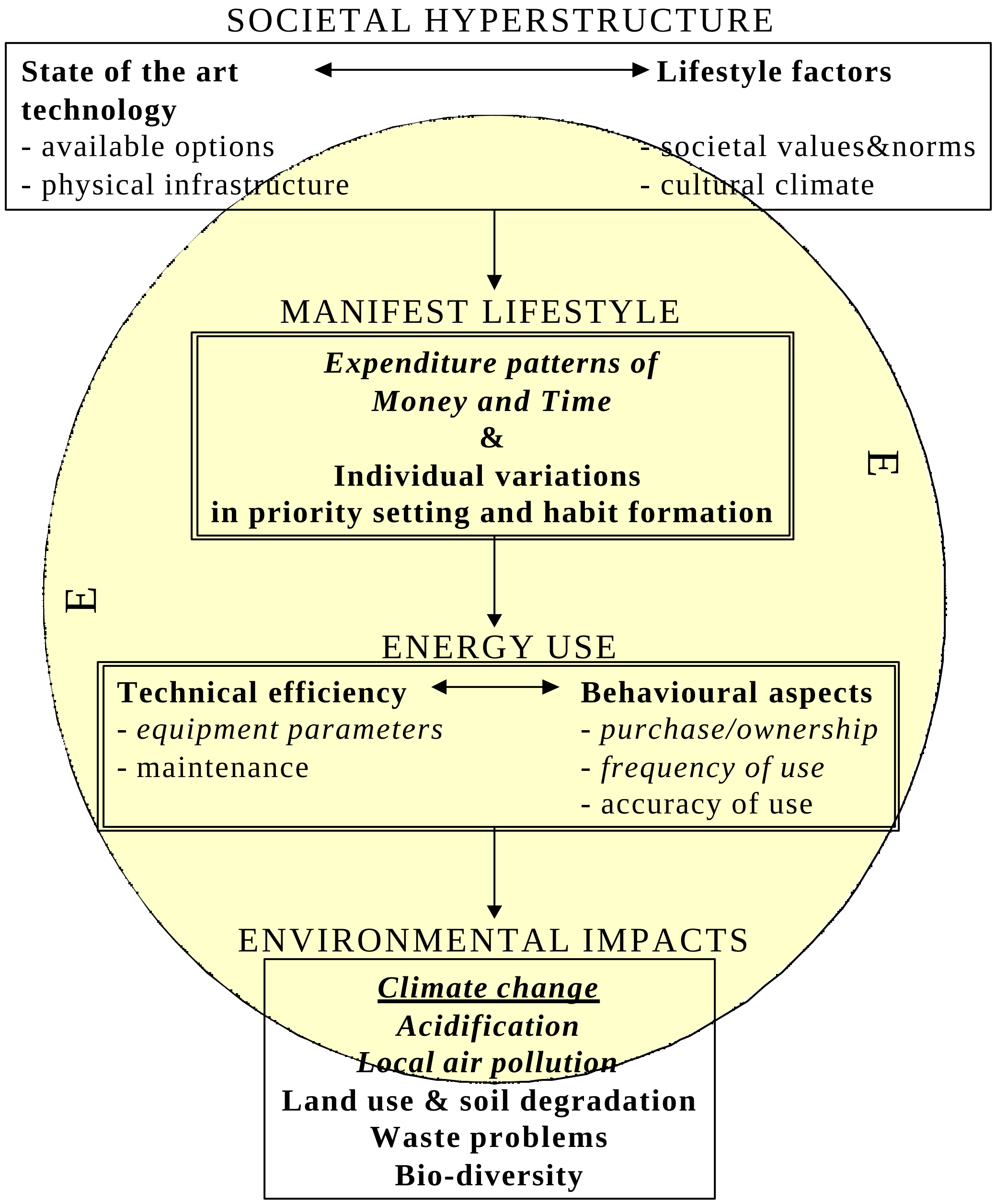

Figure 1. The embedded long term lifestyle approach and coverage of the models.

The choice of an explicit consumer focus has been made for three reasons: firstly, private consumption is the largest demand category in most economies. In addition, large parts of export production (for most countries the category second in importance) are also meant for foreign consumption. Thus consumption of households is eventually the main driver for the volume and assortment of commodities produced. Secondly a detailed modelling of household consumption patterns offers increased possibilities to account for the effects of non-economic influences on direct and indirect energy use and related emissions of households. Finally at a conceptual level both economic mainstream and the self-understanding of modern democracies postulate the consumers/citizens to be the ultimate sovereign. Consequently a modelling approach placing the consumers in the focus of interest may contribute to give this perspective real standing in the political process. It may thus be a valuable tool for the necessary political discourse on future energy options, providing a common perspective for experts from various disciplines as well as decision makers and the wider public.

During the study and after its completion several comparable, but not identical approaches were identified. In Finland the study be Nurmela (1996) should be mentioned. He uses a household cohort approach. In several countries a linkage between a consumption expenditure model and a input-output model has been used to model impacts of residential changes in direct and indirect energy use and emissions. Examples are the UK (a fairly aggregate model by Hawdon and Pearson, 1995) and Spain (Labandeira and Labeaga, 1999)

The remaining paper is organised as follows: first the modelling approach is described, then briefly some results from the empirical investigation of existing consumption patterns are presented. Subsequently the applied scenarios are discussed and results from their evaluation are presented. Finally a concluding discussion points at further research requirements.

2 Modelling concept

Most energy-economy-environment models to date account for social and behavioural aspects only in a rather aggregate and implicit way by defining e. g. aggregate penetration rates of different types of equipment or instead their average annual consumption. Furthermore also the different aspects of energy related behaviour are modelled separately so that the internal consistency of scenarios can not be tested but has to be taken for granted. The models discussed here attempt to overcome these shortcomings by modelling household behaviour in detail, accounting for all aspects of energy-relevant household consumption in an integrated approach. Furthermore eleven different household types are distinguished according to their position in the lifecycle (cp. Table 1) so that differences in consumption patterns and the effects of demographic shifts can be analysed in detail. Through the use of individual household data for deriving empirical relationships the validity of the obtained relationships should also be considerably improved. By endogenising non-economic phenomena or letting them operate on economic phenomena from the scenario module a better integrated assessment of technological, economic and social factors is what we aim at.

Table 1. Household types considered and corresponding frequencies in the samples.

Household type	Number of adults	number of children	age of reference person	Number of households in the sample		
				Germany	France	Netherlands
young singles	1	0	below 35 years	2037	410	116
young couples	2	0	below 35 years	1788	441	240
Young one-parent families	1	1 or more	below 35 years	315	197	21
young families	2	1 or more	below 35 years	4080	1019	583
Middle-aged singles	1	0	from 35 to below 60 years	2559	677	98
Middle-aged couples	2	0	from 35 to below 60 years	4349	1005	212
Middle-aged one-parent families	1	1 or more	from 35 to below 60 years	1269	588	63
Middle-aged families	2	1 or more	from 35 to below 60 years	15131	2671	917
elderly singles	1	0	60 years and more	4100	839	166
elderly couples	2	0	60 years and more	6426	874	298
others[1]	2 or more	any	any	1888	317	-

1. This household type comprises households with more than two generations (enlarged families) as well as one-parent families and families with a reference person older than 60. For the Netherlands these households have been reattributed to other household types, therefore the household type "others" is empty.

The models distinguish between direct energy use and indirect energy use. Direct energy use refers to the consumption of energy carriers purchased by the household itself, in order to cater for energy services, such as space heating, heating tap water and propulsion of a car. The indirect energy use refers to the energy used during various stages of production (and distribution) of commodities, also referred to as 'embodied energy'. The evolution of direct energy use can be adequately described by technical-economic models (with social entries), while the description of indirect energy depends more heavily on (social-)economic concepts, notably consumption functions and input-output models. The approach is summarised in figure 1 below.

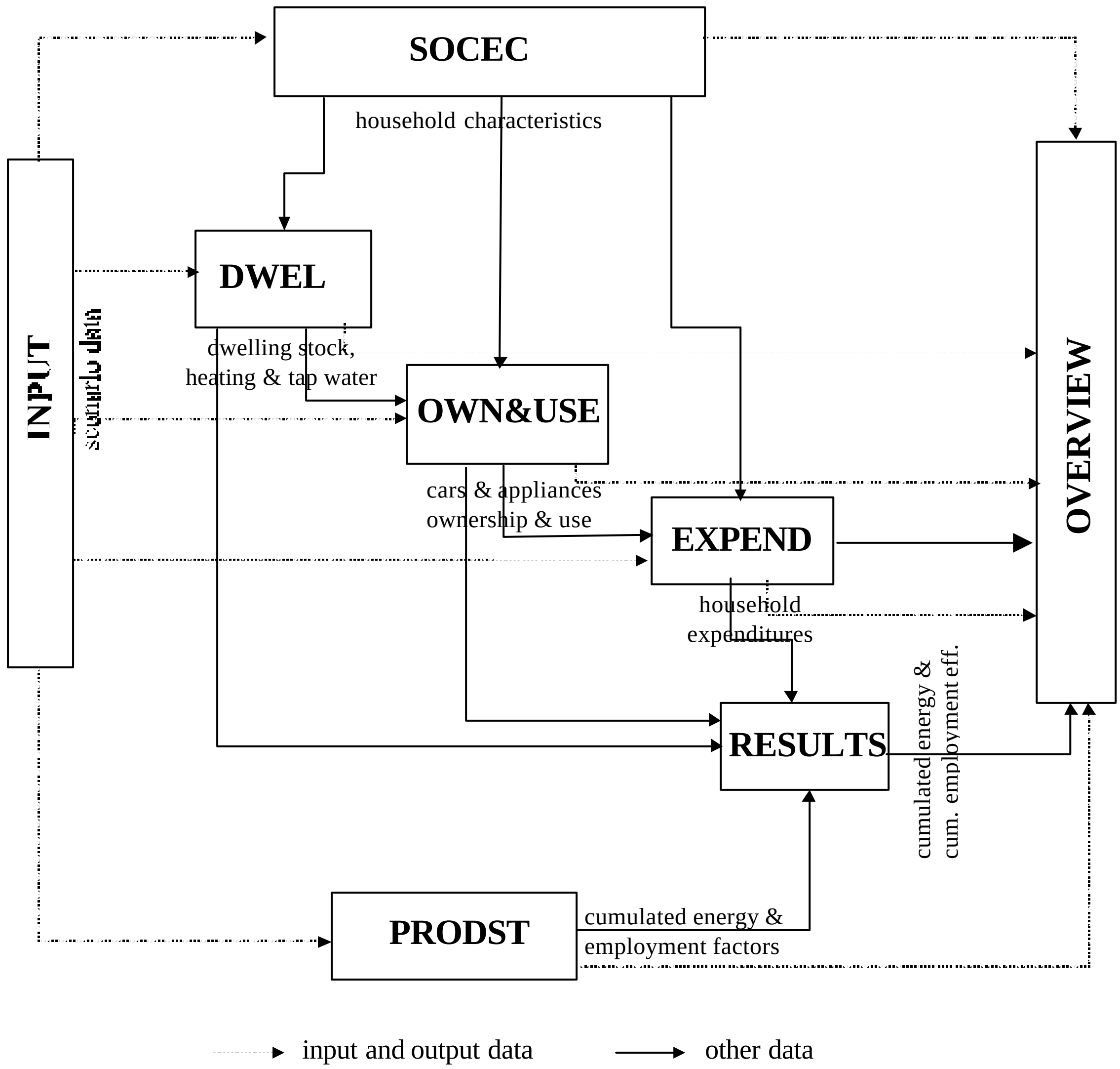

Figure 2. General structure of life-style oriented energy and emission models.

The description of direct energy use is split up in:

- thermal applications usually connected to the heating equipment fitted in dwellings, which is further distinguished in:
  - space heating,
  - tap water heating,
  - cooking,
- electricity use of appliances and lighting,
- demand for motor fuels for private cars.

The thermal applications module is modelled around the evolution of the dwelling stock. Dwellings are simultaneously distinguished by vintage, building type and type of space heating - hot tap water equipment combination. New vintages are assumed to consist of better insulated dwellings. Furthermore, the entire household population is distributed over the available dwelling stock. Different household types in the same dwelling type can have different energy consumption levels and respond differently over time to changes in background variables. For further details see de Paauw and Perrels (1995), Perrels et al. (1996) and Weber et al. (1996b).

The modules for electricity use and the consumption of motor fuels both use discrete choice models to describe the evolution of ownership. Admittedly, for new or recently penetrated appliances such an approach is not feasible. In that case either an ad-hoc expert opinion based penetration curve is entered (e.g. an electrically heated water bed) or a reasoned substitution mechanism with respect to an existing appliance is applied (e.g. in the case of an integrated washing machine and dryer). Appliances can be further distinguished between those continuously running, such as a refrigerator, and those that need a signal from the user, the so-called discrete appliances. For the major discrete appliances, the intensity of use is depending on the size and type of the household. For every appliance and for private cars an annual improvement of the energy efficiency of newly sold appliances and cars is specified. This means that the lifetime of appliances and the share of first-time buyers influence the speed with which the actual national stock of appliances reduces its specific energy consumption. Further details are given in Weber et al. (1996b), de Paauw and Perrels (1995) and Perrels et al. (1996a).

The total indirect energy requirement of a household depends on the volume of its non-energy expenditures and its distribution over expenditures categories. In some categories the average energy intensity of the products and services is much lower than in other ones. For example, on average food products have a higher energy intensity than textiles. It should be noted that – so far - this approach does not allow for specific consumer choices between high quality versus low quality products (often implying a lower energy intensity per monetary unit spent [2]) nor for the related problem concerning the extent of environmentally aware purchases. This would require a much more detailed treatment i.e. on a product by product basis. However, such level of detail is methodologically very difficult to combine with a dynamic description of consumption and production in a society. There are developments regarding so-called hybrid methods (e.g. Wilting 1996), but they still lack a lot of information concerning the dynamics at the consumption side. Another solution could be offered by the so-called metabolism concept (Noorman and Schoot Uiterkamp., 1997), but this approach eventually focuses on parts of residential energy consumption, despite its comprehensive potential. We chose to combine an elaborate set of consumption functions with an input-output system that traces back the required production by sector given the simulated expenditures by category. However the accuracy of results is considerably improved by using a mixed monetary-energetic Input-Output model for a refined treatment of energy deliveries and energy sectors. Furthermore a detailed treatment of transport requirements and the corresponding emissions has been developed.

It should be noted that by this approach the total energy demand and related emissions induced by a consumption unit (be it a single household or all households in a country) are determined independently of the geographical location of the emission source. For example, consumption of German households induces partly emissions in Germany, but partly also abroad. Both categories of emissions are accounted for in the lifestyle-oriented energy and emission models. In the model version discussed here similar production and energy conversion technologies are assumed for the emissions abroad than for domestic production, but this heroic assumption may be abandoned if international interconnected Input-Output tables are used. The emissions attributable to German exports are on the other hand not included in the German emission budget in order to avoid double counting.

[2] High quality comes usually at a higher price, while the embodied energy has not increased commensurate. The result is a lower energy intensity per money unit spent.

3 Empirical findings

For the empirical investigations data sets from the household surveys conducted by the national statistical offices in three European countries - West Germany, Netherlands, France - have been employed. Although all surveys cover a wide range of energy and emission relevant patterns of household consumption some items are not available for all countries. For example, in the Dutch survey dwelling type and number of rooms is recorded but not the floor space, whereas in the French data set information on domestic energy consumption is mostly given in monetary units only. Due to the differences in available data, in several points of the analysis country specific approaches had to be chosen. A further difficulty arose from the fact that in Germany and France large household surveys are not conducted every year but only every five years and in irregular intervals respectively. Therefore no common year of analysis could be retained. Also, the French and German surveys do not cover possible motivational or cognitive factors, while the Dutch survey contains some variables concerning this aspect, such as education level, religious, political and other societal affiliations, hobby preferences.

The empirical investigation of the different aspects of energy related household behaviour show that depending on the type of behaviour the explanatory factors considered vary substantially in importance[3]. Even within the category of appliance ownership the explanatory power of the various factors depends on the appliances considered (cf. Table 2), e. g. dish washer ownership is most strongly influenced by household income. For many of the other appliances household size has the largest impact. As regards freezer ownership the dwelling type and the size of the municipality are however even more important. Also for different appliances the considered variables explain different shares of the observed variance. Whereas washing machine and dish washer ownership are well explained by the social-economic factors included here, for tumbler and multiple TV ownership explanation is far less satisfactory. Here the inclusion of attitudinal factors may lead to considerable improvements. For car ownership and dwelling size income turns out to have the largest impact, followed by household size. In both cases the degree of explanation is rather good. However that does not apply to multiple car ownership. So, for the explanation of ownership of more luxury equipment motivational and cognitive factors seem to be of more importance than for standard equipment.

[3] For measuring the relative importance of the various explanatory factors in discrete choice models standardised derivatives, averaged over all observations in the sample, are used. They measure the average change in ownership probabilities, in case the explanatory variable varies by one standard deviation. Thus they combine the advantage of easy interpretation with the possibility to compare the relative strength of effects (the latter similarly to the standardised effect coefficients proposed by Long (1987).

Table 2. Influences on ownership of electric appliances in Western Germany - Standardised derivatives.

Appliance	own.ship rate	AGE	EMP	SOC	MUN	ln (HHS)	ln (INC)	DSIZ	DTYP	Pseudo -R^2
Washing machine	86 %	non-linear		+0.6%	-0.4%	+5.4%	+0.5%	+5.8%		0.262
dish washer	29 %	non-linear	-3.4%	-1.6%	+1.7%	+5.6%	+16.3%	+7.7%	-0.9%	0.223
Tumbler	17 %	-4.4%	-1.8%	-0.6%		+5.2%	+6.8%	+2.7%	-2.7%	0.102
TV-Set	95 %	non-linear	+1.5%	+0.9%		+1.3%	+0.5%	+0.8%	+0.4%	0.084
Multiple TV-Sets	32 % of 5	non-linear	+2.4%	+3.2%	+2.0%	+6.3%	+8.9%	+2.7%	+0.5%	0.095
Cooling equipment	97.2%	non-linear				+0.4%	+0.6%	+0.8%	+0.4%	0.122
Freezing equipment	73 % of 6	non-linear	+1.0%	+0.8%	-0.4%	+7.6%	+3.7%	+5.0%	+0.5%	0.192
Large freez. eq.	74 % of 7	non-linear	+1.6%	+0.9%	-5.0%	+4.7%	-2.5%	+5.0%	-6.9%	0.126
Data basis: German household survey 1988 Non-significant influences at a 90 % level eliminated										

For the use of the electric equipment household size turned out to be by far the most important factor, the same holds for tap water use. Space heating, by contrast, appeared to be influenced only to a small degree by social-economic household characteristics. A major finding in this field was, that the insulation standards issued in the past have been probably far less effective than presumed (see also Schuler et al. 1997). Further research should clarify whether this is due to lack of control in the application of the standards or whether changes in tenants' behaviour occur in the better insulated buildings[4]. Car use turned out to be influenced mostly by income although there the degree of explanation was not very satisfactory. This is however partly due to restrictions of the data bases used which do not allow to analyse spatial patterns.

For household expenditures a wide range of influences has been identified, with important differences between household groups. The expenditure patterns are described in a three tier system. Firstly, from the attributed household income[5] the estimated share of voluntary savings is separated. Subsequently, cross sectional consumption functions are applied to allocate the budget to expenditure

[4] For example, during preparatory investigative stuides regression analysis hinted at the impact of a ‘hobby factor’. In short it means that over time dwellings are adapted to the occupiers needs. On balance this has some deteriorating effect on the energy efficiency (e.g. dormers are a popular ‘add-on’, that degrade the roof insulation).

[5] In the version for the Netherlands, the model contains also a macro-economic module, depicting economic growth, labour market and the distribution of jobs over households and, the attribution of (net) household income.

categories. Finally, the influence of prices is added, thereby adapting the budget shares per category. The main findings of the estimation of cross-section data for six broad expenditure categories are summarised in Table 3. Additionally the effects of price changes has been estimated using meso-level time series data. The prices refer to the price level per consumption category. The apparent segmentation of household expenditures by category implies that for a given income level and household type, price changes are preponderantly compensated for within the own category, consequently the (visible) impact of pricing is limited. Housing was in fact the only category for which price rises seem to be significantly compensated for by also cutting down in other categories. Please note that the actual ownership and use of large electric appliances was handled separately (see above). The expenditure functions are important for the calculation of indirect energy use, not the direct. Yet, as far as detail allowed, consistency checks between the different modules was taken care of.

Table 3. *Signs of estimated parameters for the effect of income, household size and age on budget shares of six main categories of goods.*

	Income	**household size**	**age**
food	-	+	+
home	-	+	+
clothes	+	?	-
leisure	+	-	-
transport	+	-	-
other	-	-	+

The backtracking of the energy and emission consequences of the consumed goods showed that more than 50 % of the total energy consumption induced by household consumption are related to direct household energy use. In the graph of the Netherlands the fraction ‘transport’ contains only public transport, slow modes and telecommunication, all car related expenses incl. fuel, maintenance, purchase, etc. are in energy for transport’. The same holds for the emissions of CO2 and NOx, whereby in the case of NOx the most important fraction is stemming from private car use.

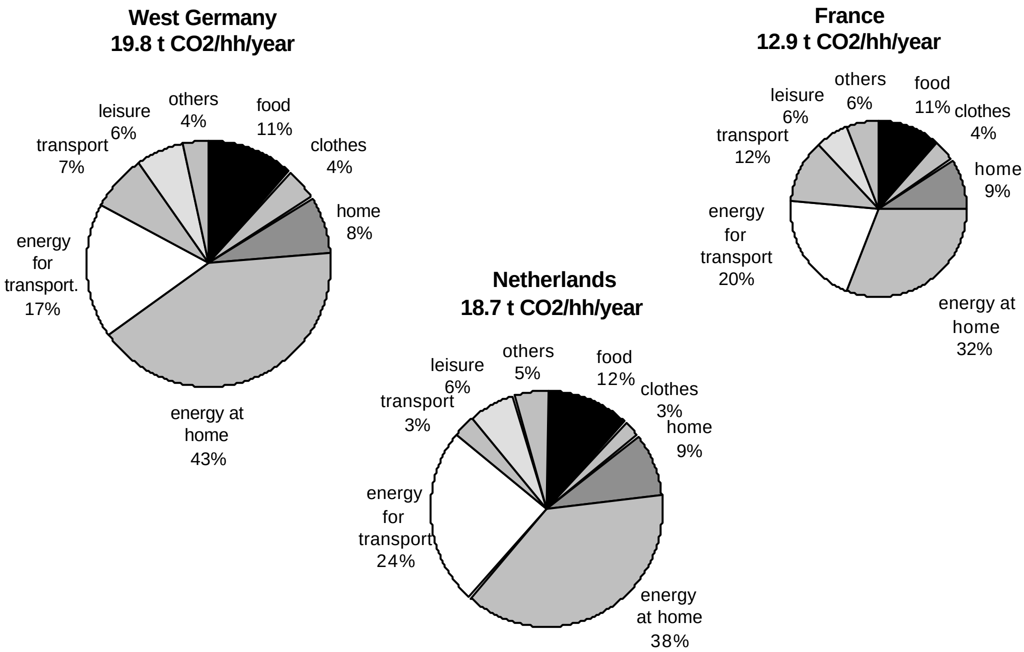

Figure 3. Comparison of total CO2 emissions per household for France, Western Germany and the Netherlands in 1990.

For CO2 important differences appear between countries as indicated in figure 3. Particularly the absolute level of emissions per household is considerably lower in France then in Germany and the Netherlands. This is partly due to climatic differences, degree-days in France are on average 25 % lower than in Germany and the Netherlands and correspondingly energy use for space heating both in households and in the production sectors is lower. Therefore also the share of energy at home is considerably lower in France than in the two other countries. The major part of the difference has however to be attributed to the largely fossil-free electricity generation in France and the higher share of electricity in final energy use of households and production sectors. Besides these international differences important differences within one country may be observed between different household types (cf. figure 4). Here not only the absolute figures differ among household groups by almost a factor three, but also the shares of the various contributions: E. g. young singles have on average higher CO2 emissions due to private transportation than middle-aged singles although their overall CO2 emissions are lower.

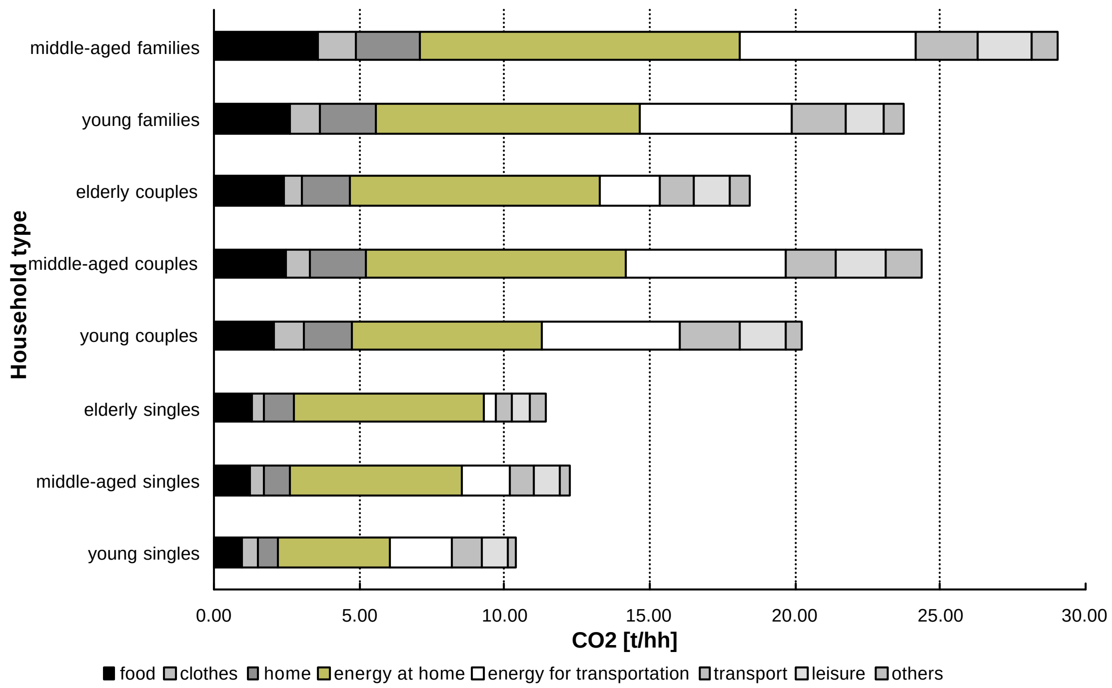

Figure 4. *Comparison of total CO2 emission of various household types in West Germany 1990.*

4 Scenario projections

Besides the investigation of current consumption patterns also the analysis of possible future lifestyle developments and their impact on energy demand and emission levels is of interest. Therefore, four scenarios have been created. They are meant as an illustration of the use of the developed methodology for scenario calculations. In the same time they provide an overview of possible developments in the future and give an orientation on the emission consequences of major societal and political choices in the fields of lifestyles, economy and technology use. As base year for the scenarios the year 1990 has been taken. The year 2010 has been chosen as time horizon with intermediate results evaluated for the year 2000. As will be shown in the following, already in the period up to 2010 rather contrasting developments of lifestyles and emissions may be obtained depending on the scenario settings[6] . The results for the year 2000 should not be taken as precise forecasts for the near future but correspondingly to the aim of the scenario analyses they are meant to concretise and quantify approximately the expected developments resulting from the interaction of the various effects.

Scenario definitions

The scenario ‘storylines’, illustrating the general idea underlying the scenarios, have been defined in a common process involving all partners of the “Consumers’ Lifestyles and Pollutant Emissions” project (cf. Weber et al., 1996a). These general outlines provide the foundation for the choice of specific parameter settings and thus avoid scenarios being just an arbitrary combination of parameter choices. Since both descriptive and normative scenarios are of interest, it has been decided to distinguish two pairs of scenarios. The first pair of scenarios has mainly descriptive character. It represents two different ways of prolongation of current trends into the future. The second pair is built around the vision of sustainable development and investigates different ways for achieving substantial emission reduction through important policy changes.

The descriptive scenarios are called:

I *“Stagnation” or “Tendencial Bleak”* (abbreviated “Stagn.”);

II *“Business As Usual” or “Tendencial Rosy”* (“BaU”);

[6] Of course, it is of interest to explore lifestyle changes and the corresponding emission consequences in an even longer perspective, although prospects on lifestyle developments and technological changes in the long run are more subject to uncertainty. Within the project “Consumers’ Lifestyles and Pollutant Emissions”; C3ED has used SEESM-type models to extrapolate to the year 2030 the developments investigated in detail by means of the E3life and ELSA models for the period to 2010 (cp. Ryan et al. 1996).

This "Tendencial" pair assumes that the currently observed developments of economic globalisation and liberalisation are continuing in the future.

The "Tendencial Bleak" (Stagnation) version develops the view that this process will lead to a reinforcement of social tensions and increasing inequalities between wealthy and poor social groups, both world-wide as well as in the countries considered. Morose economic perspectives, increasing job uncertainty and lower social security levels lead to diminishing interest in environmental questions and further improvements in this field are not attempted.

The "Tendencial Rosy" (Business As Usual) scenario is based on a more optimistic view of prolongation of the present tendencies. The on-going globalisation provides growth opportunities for global and national economies, income inequalities are not raising but economic growth is profitable for all social groups. Increasing material standard of living remains a major political and societal concern, so improvements of environmental quality are achieved to the extent that they do not seriously impede growth perspectives.

The second pair of scenarios is more normative in stead of descriptive. They do not represent probable outcomes, if current trends are continuing in the future, but assume that political and societal choices are made, aiming at a fundamental change in consumption-environment links. The preoccupations of a sustainable development are gaining real weight in political decision processes. Again, two versions are developed, called:

III *"Sustainability through Technological Breakthrough"* ("Sust. Techn.");

IV *"Sustainability through Reflective Consumption"* ("Sust. Cons.").

Although the main objective of scenario III and IV is the same - moving towards sustainability - the way to achieve this target is very different.

The "Sustainability through Technological Breakthrough" embraces a technologically optimistic view. It is characterised by the assumption, that scientific and technological progress in the future will be very important, inducing high economic growth. But at the same time, also the technological progress leads to significant improvements in energetic and environmental efficiency. The society as a whole is very open-minded to new technologies, consumers and producers are inclined to invest in most effective technologies and critical views expressed on some technological developments, such as nuclear power, are decreasing in importance.

The "Sustainability through Reflective Consumption" scenario develops the vision of a society, where goals of environmental quality and social justice take a pre-eminent place, so that economic growth is no longer the predominant societal objective. In this common pro--cess of moving towards sustainability, private enterprises contribute by developing especially environmentally friendly technologies. Controversially debated technologies, such as nuclear power, are abandoned. Consumers are not focusing on a growth of their material standard of living, but attach importance to environmental quality of products.

Both scenarios are thus oriented towards Sustainability, yet they differ considerably in the conceptualisation of the term Sustainable. The technologically optimistic scenario clearly stands for a concept of "Weak Sustainability" allowing substitution of nature capital by man-made capital and with Sustainability mainly being perceived as achievement of environmental goals. By contrast, the reflective consumption scenario embraces a wider concept of Sustainability stressing also equity goals. In the formulation chosen here it certainly not fulfils the requirements of a "Strong Sustainability" - i. e. constancy of natural capital stocks[7] - yet it tends at least towards a replacement of energy supply from finite stocks by renewable energies.

Whether the sustainability oriented (and the other) scenarios really allow improvements of environmental quality can not be decided in advance. Regarding airborne emissions the results of quantitative investigations are discussed in the following, but before the scenario assumptions have to be quantified for the use of lifestyle oriented energy and emission models.

Key scenario assumptions

In order to determine the effects on energy and emissions of the scenario settings these have to be translated into numeric specifications for the computation. The key assumptions are summarised in Table 4. Further details on scenario assumptions are given in Weber et al. (1996a, b).

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[7] From a theoretical point it seems even questionable whether constancy of natural capital stocks is possible at all (see Schäffler, Fahl 1995)

Table 4. Key scenario assumptions.

	Stagn.	**BaU**	**Sust. Techn.**	**Sust. Cons.**
Population & household growth	medium official forecasts			
Economic growth	1990 -2000: 1.5 % after 2000: 1.0 %	2.0 %	1990 -2000: 2.0 % after 2000: 3.0 %	1990 -2000: 1.5 % after 2000: 1.0 %
income distribution	more disparities	unchanged	unchanged	less disparities
labour productivity growth[a]	2.0 %	2.5 %	1990 -2000: 2.0 % after 2000: 3.5 %	0.5 %
Labour time	0 %	- 0.5 %	-0.5 %	- 1.0 %
prices of other goods	Specific developments, see (Weber et al. 1996b)			
energy efficiency households	no improvements	moderate improvements	important improvements	important improvements
Production structure	unchanged except energy sectors and energy inputs in other sectors			
energy efficiency industry & abatement technology	moderate improvements	moderate improvements	important improvements	important improvements
Fuel mix	unchanged	tendencial	more nuclear	more renewables
Consumers' preferences	unchanged			
[a] Per full time equivalent in base year				

The exogenous settings varying across scenarios may be categorised in (macro)-economic driving variables on the one hand and "clean" technology use on the other hand. Population and household development as well as consumer preferences have not been changed across scenarios, although this would have added to the "flavour" of the scenarios. Indeed the scenario settings described in the previous section may be interpreted as having implications both on household formation and consumer preferences, e. g. larger household size in the Stagnation case due to economic restrictions for large parts of the population, or shifts of consumer preferences towards environmentally more friendly goods in the Sustainability through Reflective Consumption scenario, yet these effects are difficult to quantify and any assumption therefore would be largely arbitrary. Since investigations of technological possibilities for energy efficiency improvements and emission abatement were not the main purpose of the present study, the future evolution in these fields has been deduced from existing studies for Germany and the Netherlands, especially those carried out for the Inquiry Commission of the German Parliament on climate change (Enquete-Kommission, 1995) and for the German IKARUS data base.

Among the scenarios discussed here, the Tendencial Bleak scenario is a worst case combining low economic growth, increasing social disparities as well as few efficiency improvements and emission abatement investments. However, some efficiency improvements and abatement technologies have been allowed for, that reflect already enforced legislative standards, e. g. the introduction of catalytic converters for cars and subsequent emis-sion standards, which induce lower emission rates for future cars than for the current stock. Also, energy efficiency improvements in the production sectors are assumed to continue. Exactly in a stagnation period investments are usually defensive and cost oriented and therefore a basic interest in cost effective energy efficiency will remain.. For the Tendencial Rosy scenario, as indicated by its name, the economic growth assumptions are more optimistic, social tensions are assumed not to deteriorate and additional efficiency improvements, particularly for household energy use are achieved. Especially in West Germany, furthermore, the fuel switches observed in the last decade (mainly from coal and light oil to gas) are assumed to continue in the future.

For both Sustainability oriented scenarios, the higher priority attributed to environmental goals is reflected in large efficiency gains and emission abatement investments. However the two scenarios differ substantially by the economic growth rate corresponding to the different assessments of this societal goal in both visions. This leads to an economic growth comparable to the Tendencial Bleak case for the Sustainability through Reflective Consumption scenario, but with decreasing social disparities, since equity is an important societal goal in this case. On the contrary, the technological optimism of the Sustainability through Technological Breakthrough is reflected in a high economic growth rate. Furthermore the fuel mix - particularly for electricity generation - differs notably among both visions following a different assessment of the role of nuclear energy for moving towards Sustainability.

Equipment and expenditure patterns

In the following the scenario outcomes are described in parallel for the three countries investigated following the computational order inherent to the lifestyle-oriented models, i. e. starting with household equipment, continuing with household energy use and expenditures and then describing production structure and total emissions. Finally, also a decomposition of the observed changes according to important influencing factors are presented. For the interpretation of the figures one has to bear in mind that - as noted already earlier - the focus of the study has been on household behaviour and its impact on emissions, and technological developments have not been investigated in detail in the project. In particular, a cross-country comparison of technological potentials was not within the scope of this study. Neither has been paid explicit attention to the possible impacts of liberalisation on energy markets and its probable somewhat different political treatment in the various scenarios. All in all therefore we like to stress that the resulting emissions have to be regarded as indicative values rather then exact forecasts of future emission levels.

As an example of equipment development the development of the total car stock for Germany is displayed in figure 5. Thereby net differences between the scenarios appear, mostly related to the differences in GDP and consequently income growth. Yet although for the Stagnation and the Sustainability through

Reflective Consumption scenarios similar income developments are assumed, notable differences in car stock may be observed, due to a different distribution of income over household types. It turns out that car ownership is more income-sen-sitive for those household groups better off in the Sustainable Consumption case, i. e. the elderly and the one-parent families, than for those profiting of the income distribution of the Stagnation case, namely young and middle-aged singles and couples. The total number of cars shows particular important increases for the elderly singles and elderly couples. Besides income increases this is the effect of their increasing share in population. The number of cars owned by elderly people would be even more important, if instead of supposing that ownership behaviour of the elderly in the future is the same as the one observed today, the assumption were chosen that households maintain their ownership behaviour when ageing.

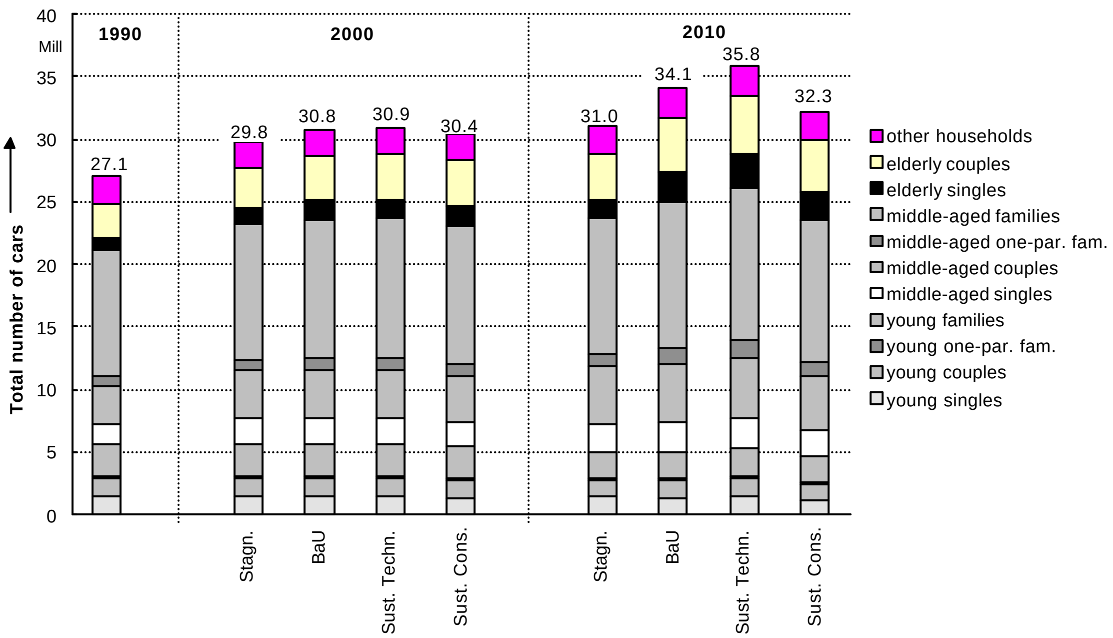

Figure 5. Development of car stock in West Germany 1990 to 2010.

In figure 6 an international comparison of the penetration rates for cars is shown, i. e. the average number of cars per household [8]. Thereby the highest penetration rate in the base year is observed in France, yet this is also the country with the highest average household size, therefore the average number of car per capita is higher in West Germany. In all three countries the important income increase in the Sustainability through Technological Breakthrough scenario after 2000 lead to an important rise in penetration rate. Also in the Business as usual case the

[8] Due to multiple car ownership the ownership rates shown here suggest a higher share of car holding households than is actually the case (e.g. the Dutch share of car owning household in 1990 was 75% - having at least one car).

average penetration rate rises by more than 10 % whereas in the two other scenarios only small increases are observed [9]. Therefore in these cases the major part of the aggregate increase in car stock as displayed in figure 6 is due to the increased household numbers.

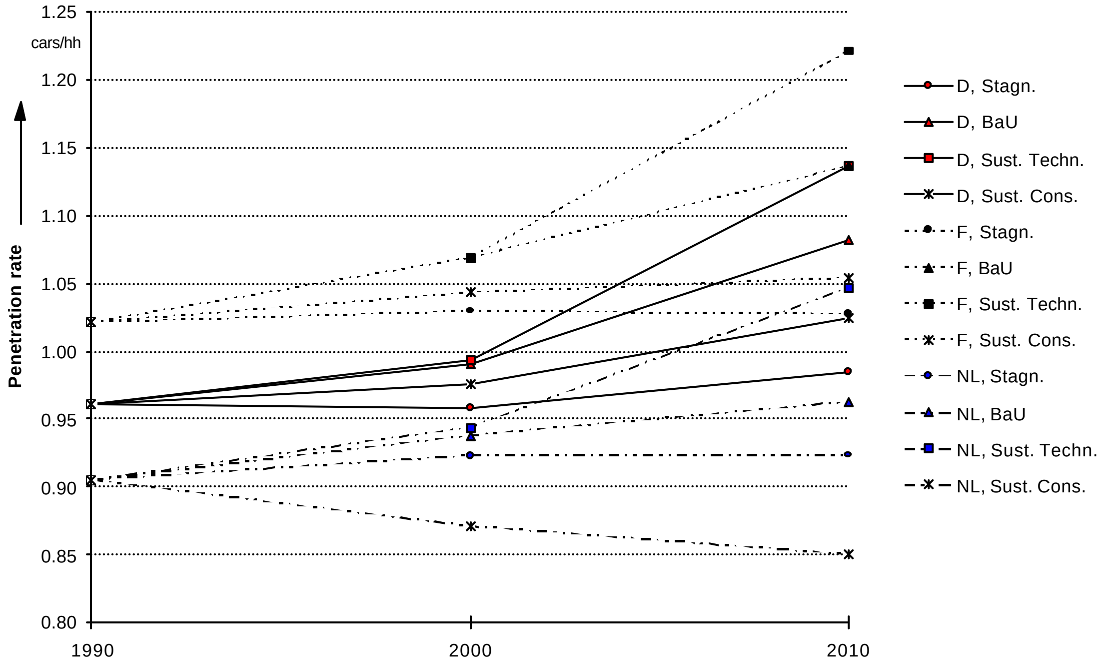

Figure 6. Average number of cars per household in West Germany, France and the Netherlands 1990 to 2010.

In figure 7 the development of direct energy consumption per household is displayed for Germany. The simulations show that due to energy efficiency improvements the final energy consumption per household is decreasing although the equipment rates are rising as shown in figure 7. The utilisation of the equipment is hardly influenced by income increases (see above) and the equipment increases are outweighed by efficiency improvements of dwellings (insulation and heating systems), cars and appliances. In the Netherlands however, the larger increase of the number of households (in%) and a slight increase in the consumption per dwelling causes a substantial rise of aggregate domestic energy consumption.

[9] In the Netherlands even a decrease of the penetration rate is obtained in the Sustainability through reflective consumption scenario. This is mainly the effect of exogenous assumption on declining multiple car ownership, since due to data limitations multiple car ownership can not be derived from empirical equations for the Netherlands.

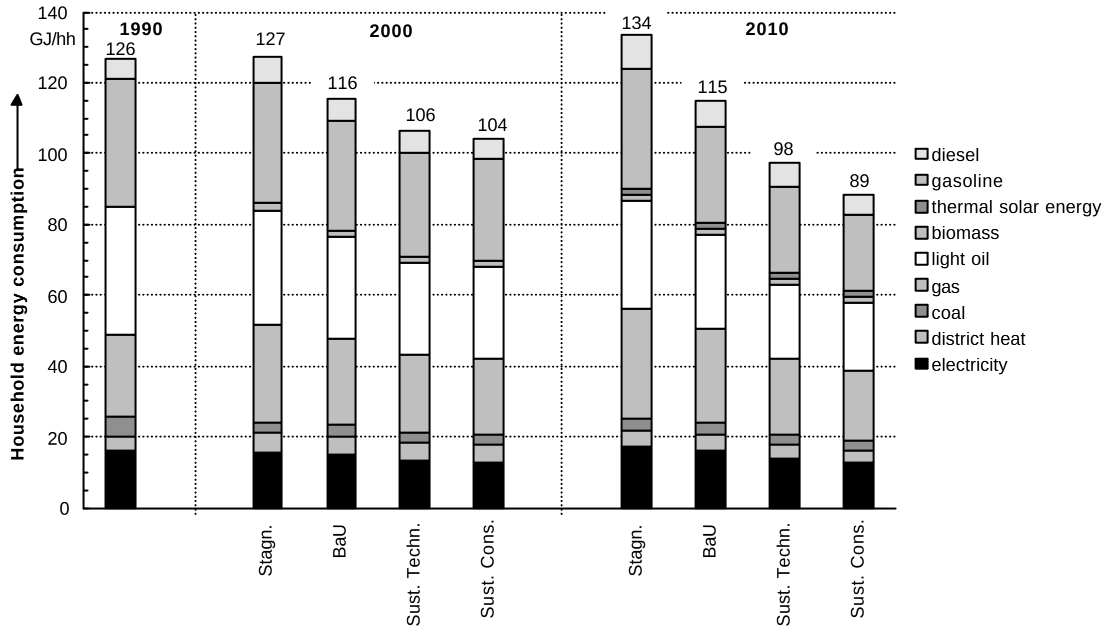

Figure 7. Final energy consumption per household in West Germany 1990 – 2010.

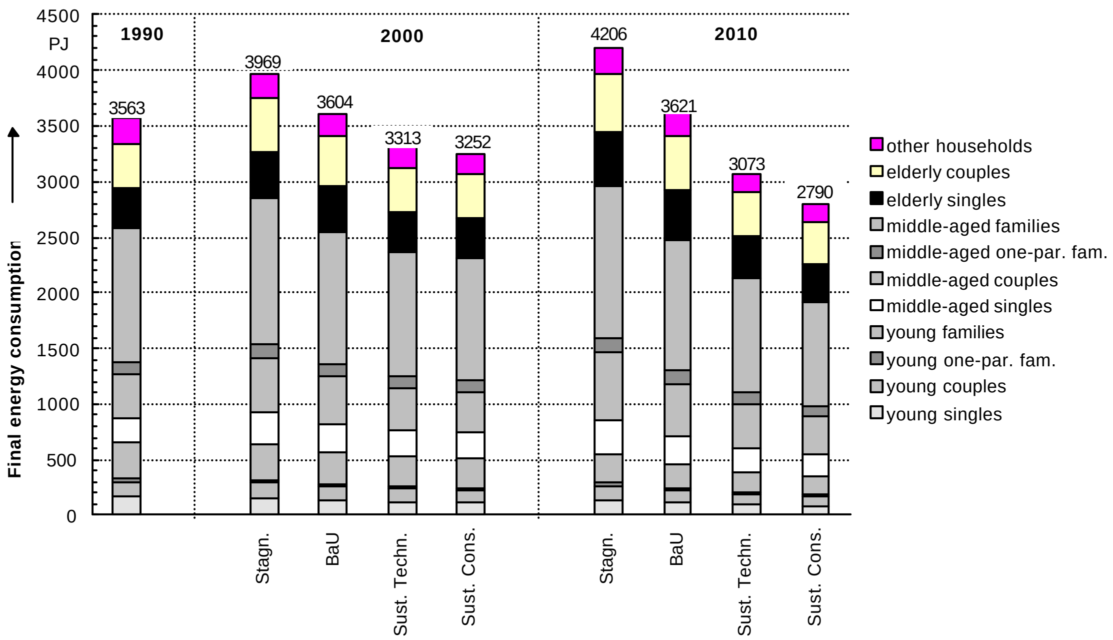

Figure 8. Total final energy consumption of households in West Germany 1990 – 2010.

Aggregate final energy consumption of households is of course decreasing less than per household consumption since the number of households is still increasing, as shown in figure 8 for West Germany. Especially in the Business as Usual case total final energy consumption is increasing although at a per household level decreases are observed.

The development of consumption expenditures in the different scenarios is shown in figure 9 for the Netherlands. Thereby expenditures in national currencies have been converted to purchasing power standards (PPS in ECU) by means of purchasing power parities as established by the OECD. Whereas up to the year 2000 no important differences appear between the scenarios, in the second period the higher economic growth rate in the Sustainable Technology case leads to an increase of consumer expenditures per household by over 28 % compared to 1990. This is sensibly higher than the increase by 5 %, 13 % and 7 % observed respectively in the Stagnation, the Business as usual and the Sustainability through Reflective Consumption case. Thereby in all scenarios expenditures for home and particularly leisure show a clear disproportionate increase, whereas the expenditures for food are even declining in the two tendencial scenarios, due to the corresponding relative price drops.

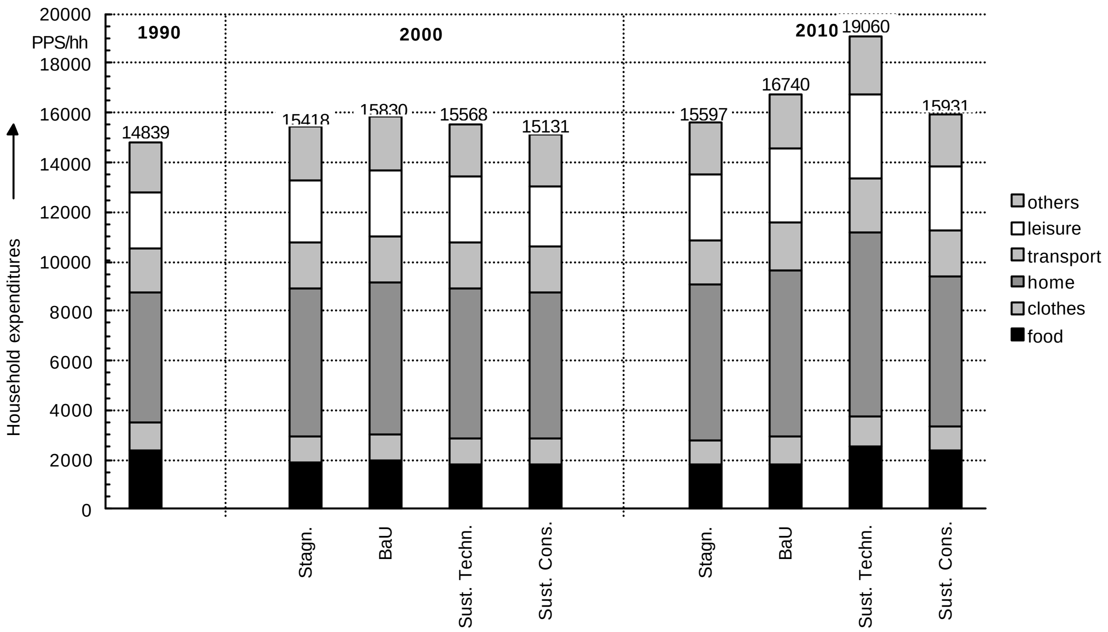

Figure 9. Consumption expenditures per household in the Netherlands 1990 to 2010, in purchasing power standards (PPS).

In figure 10 the development of aggregate consumption expenditures and its repartition by household groups is shown for the example of the Netherlands. As for the development of the car stock again the increasing importance of elderly households appears, their share in consumption expenditures rises from 22 % to 26 % to 27 %, depending on the scenarios, with a particularly important increase for elderly singles.

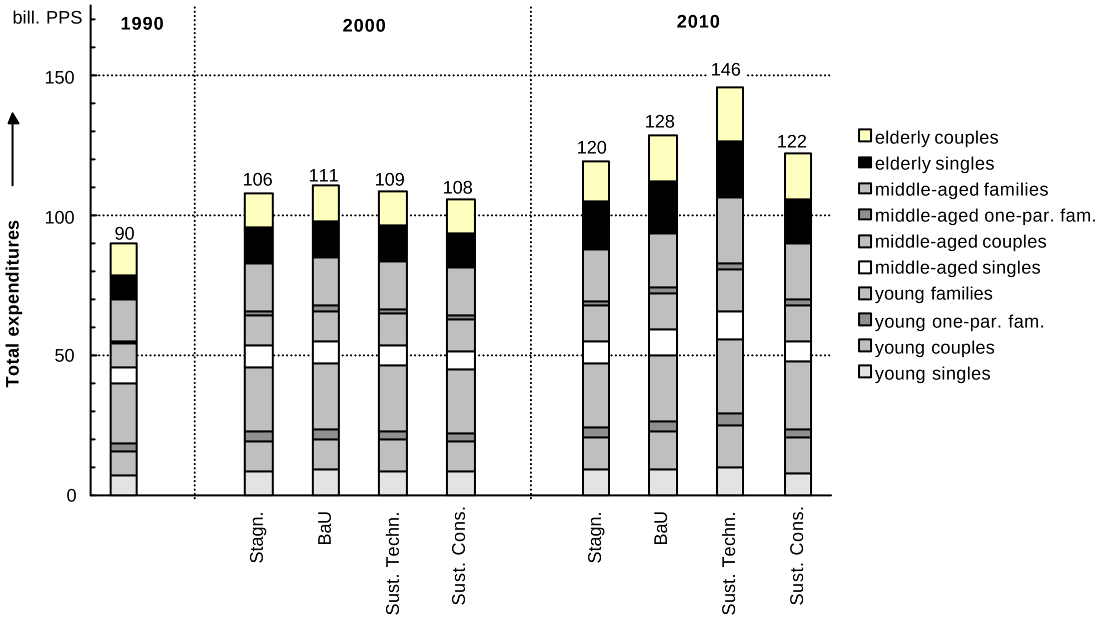

Figure 10. Aggregate consumption expenditures by household type for the Netherlands 1990 to 2010.

Energy demand and related emissions

Of course the different growth paths of household consumption in the different scenarios lay potentially different pressures on the environment. However, besides the development of household expenditures and household energy use the resulting emissions are also influenced by the production structure, the energy efficiency developments and abatement technologies. This is shown in the following for the examples of CO2 and NOx emissions. Further results covering also other emissions may be found in Weber et al. (1996), Weber et al. (1996b), Perrels, van Arkel (1996).

Whereas for the classical air-borne emissions such as NOx and SO2 in the period up to 2010 important emission decreases are obtained for all scenarios and all countries, the picture for CO2 is more contrasted. As indicated in figure 11 emissions for Germany remain roughly at the same level in the tendencial scenarios, with a slight decrease for the rosy variant (- 3 %) and contrary a small increase for the bleak case (+ 6 %). Particularly the CO2 emissions related to direct energy use are substantially higher in the bleak than the rosy variant which is of course related to the higher direct energy consumption of households in the Stagnation case (cf figure 11). In contrast the two sustainable scenarios show that substantial emission decreases can be obtained - about 23 % in both cases - although they differ substantially in the way this goal is achieved.

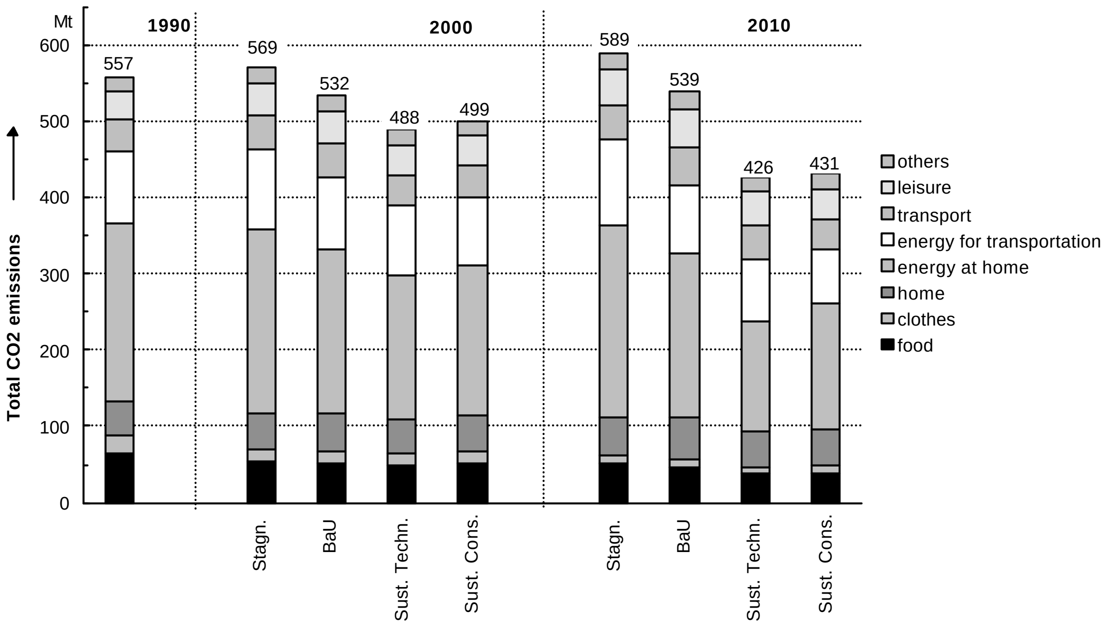

Figure 11. Development of total CO2 emissions induced by households in West Germany between 1990 and 2010.

As already stated above the energy efficiency improvements are rather similar in the two scenarios as far as industry and households are concerned, yet major differences arise from the fact that nuclear is supposed to fade out in the reflective consumption path by the year 2010, whereas in the technology oriented path its share in electricity production is assumed to increase from 32 % in 1990 to 60 % in 2010. Thereby CO2 emissions of about 60 Mt are avoided - by expanding a technology, where the risks are still rather controversially debated. This carbon-free form of electricity production permits to offset the higher emissions induced via the higher economic growth assumed and the corresponding higher consumption.

For France the potentials for fuel switching are less important (given an already largely fossil-free electricity generation) and consequently the emission levels of all scenarios except the Sustainability through reflective consumption case are higher in 2010 than in 1990 (see figure 12). Still however the CO2 emissions per household remain lower than in Germany. They amount to 12.9 t/hh for all scenarios except for the Sustainable Consumption case (10.3 t/hh), compared to a range from 13.5 t/hh (Sustainability through technological Breakthrough) to 18.7 t/hh (Stagnation) for West Germany in 2010.

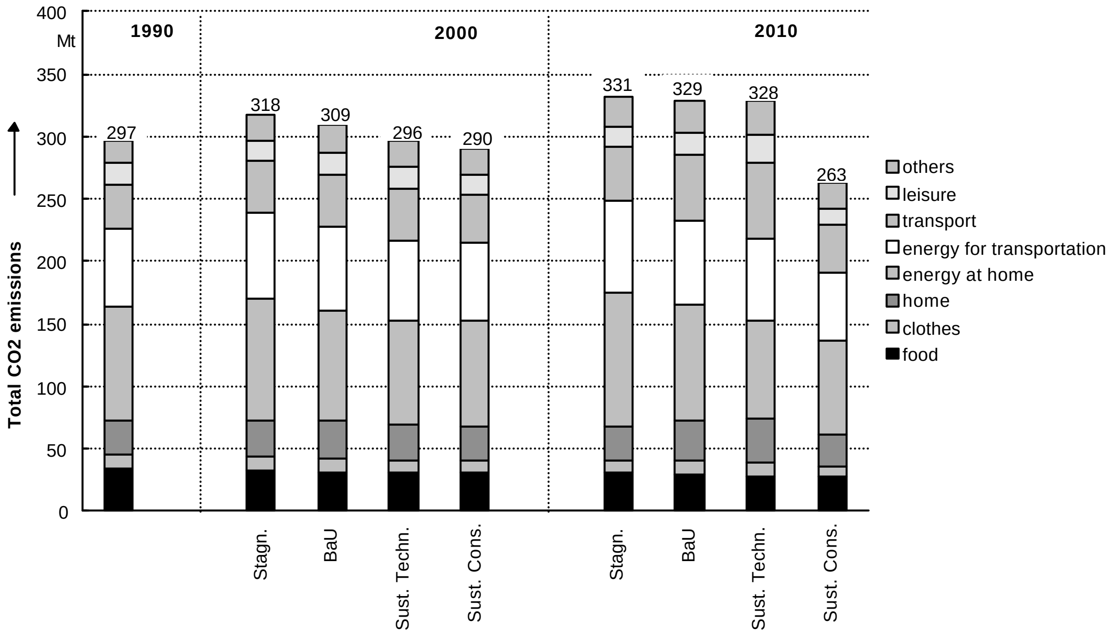

Figure 12. Development of total CO2 emissions induced by households in France between 1990 and 2010.

For the Netherlands the results obtained are even worse (see figure 13). Only in the Sustainability through Reflective Consumption a stabilisation of CO2 emissions in the year 2010 vs. 1990 is obtained, for all other scenarios increases by 10 % or more are observed. Of course this is related to the lower potential for energy efficiency improvements (particularly insulation) assumed in the Dutch case. Here the international comparability of assumptions should be checked carefully. Yet, some additional efficiency gains introduced for the Netherlands plus the introduction of thermal solar collectors for tap water heating did not modify substantially the outcomes [10].

[10] Given the new tightening of the Energy Performance Standard (EPN) these collectors are expected to be used in newly built houses and a part of the thoroughly renovated houses.

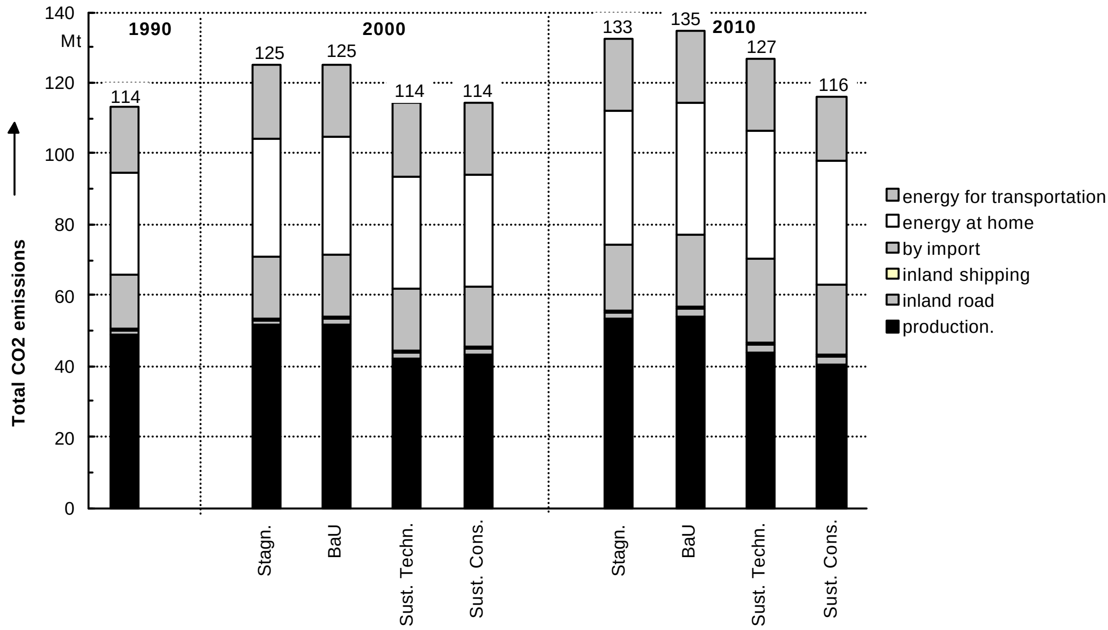

Figure 13. Development of total CO2 emissions induced by households in the Netherlands between 1990 and 2010.

The importance of efficiency gains in the production sectors for achieving CO2 stabilisation or reduction targets is illustrated by figure 14, where CO2 emissions per unit of production values are indicated for West Germany. For all scenarios specific reductions of more than 15 % are obtained for all expenditure groups, in the Sustainability through technological Breakthrough scenario even nearly 50 % are reached for some expenditure groups. These reductions are of course besides energy efficiency improvements also induced by fuel switches, namely from coal to gas or - in the case of electricity production - to nuclear.

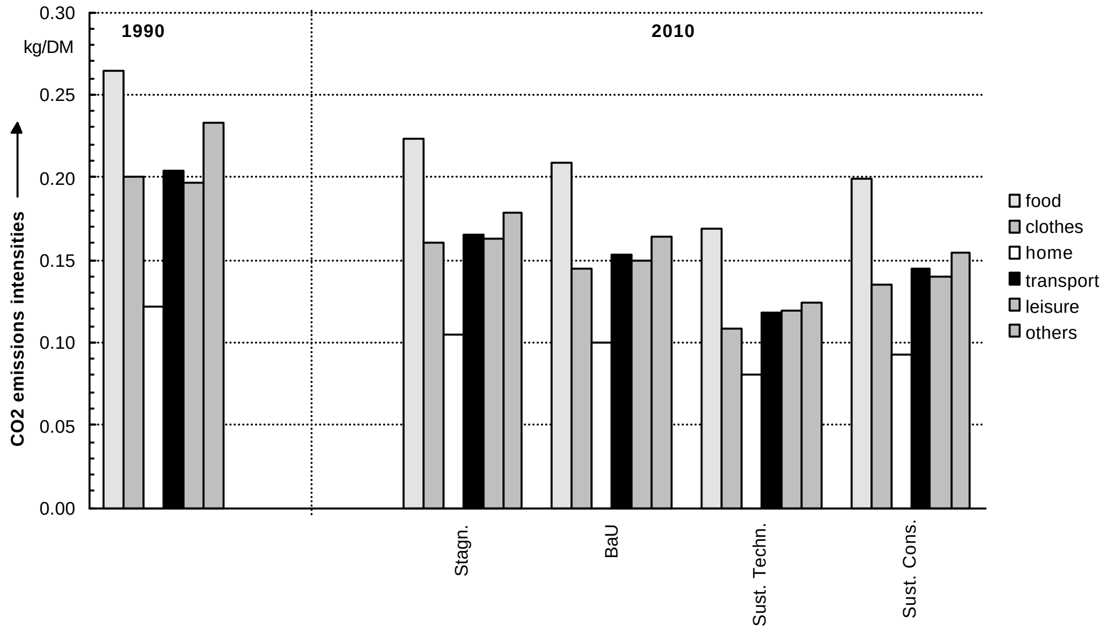

Figure 14. Development of CO2 emission intensities for main non-energy expenditure categories in West Germany between 1990 and 2010.

Since the conclusion of the study reported here the development of the greenhouse gas emissions has been such that the model results presented above still seem to have their signalling value as regards the way the transition of the economy is often modelled. The poorly observed costs of adaptation of consumers and producers will require more detailed analysis, e.g. by means of transaction cost approaches. A few examples of modelled and actual trends are shown in table 5. As regards the efficiency of the car stock the actual on-the road- efficiency is shown. As has been argued by others (e.g. Schipper et al 1999) the transport sector appears to have the strongest rebound effects. The potential gains from better engines, go for the greater part up in smoke due to heavier and more powerful cars and new add-ons such air-co in countries with moderate climates. The lower set of figures gives an overall impression of CO2 emissions. For some sectors or applications progress is made, but in other sectors – such as transport – the counter forces can be strong., which results in a less swift reduction of emissions than is necessary to achieve the targets of 2010. The current economic development comes most near to scenario ST.

Table 5. Model trends in ELSA and actual developments up to 2000 (sources: CBS (1999), ECN (1998)).

1. Fuel efficiency of the private car stock (the Netherlands; liters/100km):						
	Observed	Trend 90-97	Model SG	Model BU	Model SC	Model ST
1990	8,5					
1997	8,3					
2000		8,2	8,1	8,0	8,1	8,0
2010		7,9	7,5	7,1	6,9	6,7
1. CO2 emission development index (the Netherlands; 1990=100):						
	Observed	Trend 90 – 97	Model SG	Model BU	Model SC	Model ST
1990	100					
1997	112					
2000		110-114	110	110	100	100
2010		??	114	118	102	111

Although various impacts of lifestyles on energy demand and related air-borne emissions have been investigated before, the developed approach provides for the first time a comprehensive methodology to analyse the interconnections between lifestyles and energy consumption. Also a wide range of factors influencing energy relevant behaviour has been analysed for the different relevant aspects of household expenditures – detailed by categories in each case. Thereby particularly the variety of the observed influencing patterns is of interest – since it clearly shows that simplistic views and models of lifestyle-energy relationships are inappropriate to capture a complex reality. The observed patchwork of relevant influences could even be enriched further, if motivational and cognitive factors were included as explanatory factors, however this was not possible on the basis of the official household surveys used here.

By integrating the obtained empirical findings in simulation models a tool for investigating scenarios of future energy demand is obtained which allows to deal both with distributional aspects of societal developments and the composition of consumer demand. From the scenarios investigated we conclude that both the distribution of employments and income as well as the composition of consumption affect future energy demand.

A major advantage of the approach adopted here is that the analysis of energy demand and emissions in a consumer and citizen perspective provides a possibility for policy making to deal with “Sustainable Development” by having a “Customer orientation”. The determined energy and emission profiles and influencing factors give an easily interpretable image of the energy and emission consequences of consumer behaviour and thus contribute to an increased transparency of complex economic and ecological interconnections. This could be used in the future in the context of information campaigns to raise the environmental awareness of the general public but also for providing a common basis for experts and politicians with various backgrounds but in the quest of a common well-being. Since this study the model approach has been used for new studies as well, all of them typically aimed at decomposing macro trends and underlying driving forces into better recognisable factors at the meso and micro level (see inter alia Perrels et al , 1998). The model approach has also been use in a large framework that also encompassed case studies and a CGE model in order to assess the employment creating capabilities of energy efficiency investments and the influence of contextual macro and micro conditions on these capabilities (see inter alia Jeeninga et al, 1999).

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