Assessing the Impact of Social-Cultural and Social-Economic Trends on the Total Energy Requirement of Households

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SYNOPSIS

The paper discusses investigations that are made with the aid of a long term lifestyle oriented energy demand model for households.

ABSTRACT

In OECD countries trends such as the aging of the population while enjoying better pensions and the individualisation of lifestyles are important driving forces behind changes in aggregate consumption patterns. Ongoing motorisation, decreasing household size and the mechanisation of domestic tasks are well known changes. In turn these consumption trends imply substantial increases of the total energy requirement of households, despite the decrease of specific energy use of numerous appliances. From these observations alone one might derive that technologically induced improvements of energy efficiency constitute a major contribution to the reduction of energy demand. Yet, at the same time the evolution of the volume and composition of private consumption has demonstrated so far that the technical reduction potential can be more than offset by effects on the consumer side.

The present paper discusses investigations that are made by means of a long term lifestyle oriented energy model developed at ECN. An important idea underlying these investigations is that some of the basic trends in society as referred to above do not have to lead inevitably to increases of energy requirements of households (direct + indirect energy use). Rather, these outcomes depend on all kinds of (side) conditions, such as the organisation and quality of public and private infrastructure (e.g. organisation of time and space, flexible labour possibilities, attitudes about family care, etc). The paper will particularly deal with:

- the way social-cultural and social-economic trends can be traced back through the economy in order to assess the energy impacts;
- identification of relevant trends and demonstration of the impacts of differing (side)-conditions on these trends. An application will be shown with respect to the energy use for thermal applications[1] at home.

1. INTRODUCTION

Lifestyle can be identified with behaviour, more precisely with overall patterns of behaviour. In brief lifestyle can be linked to energy consumption as follows.
Behaviour that has consequences for the energy requirement of a household is identifiable as activities that involve the consumption of energy carriers (direct energy) and/or energy embodied in the goods and services purchased (indirect energy consumption). Household consumption in terms of purchasing and using commodities can be characterized by two principal entities, being the expenditures of time and money. So, differences in lifestyles as far as relevant to energy consumption should be identifiable in differences in expenditure patterns of time and money. In turn differences in expenditure patterns may be expected to correlate with household characteristics. Some characteristics may be easy to observe such as income and household size, others like the valuation of certain virtues are often difficult to include in a survey. Moreover, the latter kind of variables often operate indirectly through conditioning of observed activities.

Through the expenditures of time and money we target the entire consumption pattern of households rather then focussing exclusively on the purchase and use of energy carriers. In OECD countries the energy embodied in the purchased goods and services contains about as much (primary) energy as the (primary) energy consumed for typical energy functions in the home and for transportation (Vringer and Blok 1993). At the Dutch national level total direct and indirect energy consumption of households covers about 55% of total primary energy consumption. By targetting the entire consumption pattern one essentially includes energy use in a large part of the economy.
A long term lifestyle oriented household energy model in which both direct and embodied energy demand are included has been developed. In this paper the model is described. To illustrate the working of the model an analysis is made for changes in energy use for thermal applications from 1990 to 2015.

2. DESCRIPTION OF THE MODEL

2.1. Basic Concept and Purpose

The basic idea of tracing back energy impacts of household expenditures is illustrated in figure 1 below. Household expenditures are distinguished in spendings on energy carriers (direct energy) and other expenditures. The other expenditures are repartitioned over the supplying sectors, whereas the energy contribution of each sector is accumulated until a total indirect energy claim can be established. This procedure is especially applicable to the base year (1990). For future years supporting approaches are required in order to account for changes in expenditure patterns and changes in (energy) technology.

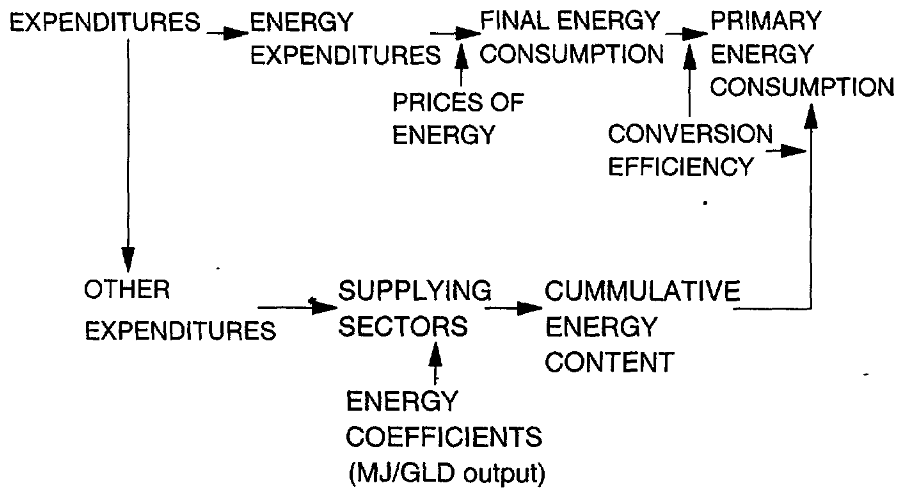


Figure 1. General Concept of Backtracking Energy Impacts of Household Expenditures

In practice the other expenditures are further distinguished in spendings on durables (notably appliances and cars) and the remainder, being daily expenditures. The separate treatment of expenditures on appliances and cars (i.e. the energy using part of the domestic capital stock) is related to the keeping track of the stock of appliances and cars. A detailed description of the appliance stock, i.e. through ownership rates differentiated by household type, allows for an engineering-behavioural based procedure to estimate annual direct energy consumption per household type. The engineering part refers to energy use per time of use and future efficiency improvements, while the behavioural part refers to the frequency of use in relation to household characteristics. The daily expenditures are further disaggregated by consumption category (e.g. food, clothing, etc). For each category so-called consumption functions can be specified and estimated. In the present approach both economic and non-economic (e.g. demographic, spatial) variables will provide explanatory power. For all categories, the levels of expenditures are first established at the individual household level, subsequently these levels are aggregated over all households in order to obtain aggregate demand of households.
The next step is to repartition this demand over producing sectors. Obviously, most demand for goods will be initially exerted via the retail sector. From that sector the expenditures flow 'back' toward the secondary (industry) and primary (agriculture and mining) sectors, either in the national production system or imported (foreign production systems).
The analysis of the energy requirement that results from accumulating the energy consumption (per unit of output) of contributing sectors is carried out by means of a multiple input-output system, containing value data, energy consumption data and optionally also emission data.

The model is meant for explorative studies that focus on long term societal changes, e.g. spanning 15 to 30 years. As has been explained in section 2.1 the model perceives energy demand as a result of consumer activities, either through purchasing commodities or through the direct use of energy carriers for heating, lighting and car driving. Consequently, the abilities to assess impacts on energy demand focus on the decomposition of changes in consumer activities, due to changes in (economic, social and cultural) scenario control variables. This does not mean that technology is entirely neglected. The energy efficiency of distinct energy applications at home and in cars are included in the model. This is done by means of efficiency index figures by vintage category. In addition to this the improvements of energy efficiency in the productive system are represented by changing technical coefficients in the input-output system. Also changes in the energy supply system itself are taken into account.

All in all the model is less suitable for investigations for the short run, neither is it meant for detailed assessment of the impacts of concrete technical options. It contributes to insights useful for strategic policies, e.g. to make them more robust. By doing so the model also stresses the importance of non-energy policies for the long term energy requirement of households. Typical applications of assessment studies should be found in long term infrastructure and spatial policy plans.

2.2. Overall Structure of the Model

The model starts with an endogenized scenario module in which social, cultural, technical and economic trends are translated into developments of key control variables, such as participation in paid labour by household type, hourly wage rates, urbanization, dwelling type choice, diffusion of new or improved technologies, etc. Subsequently, an important part of the model deals with the transformation of money and time budgets into direct energy use and indirect energy use. This transformation is accomplished in two stages. The first stage deals with stocks of homes, appliances, and cars on the one hand and allocation of disposable income to main categories on the other hand. The second stage transforms the utilization of stocks and the purchased commodities and services into primary energy equivalents. In figure 2 the main structure of the model is shown.

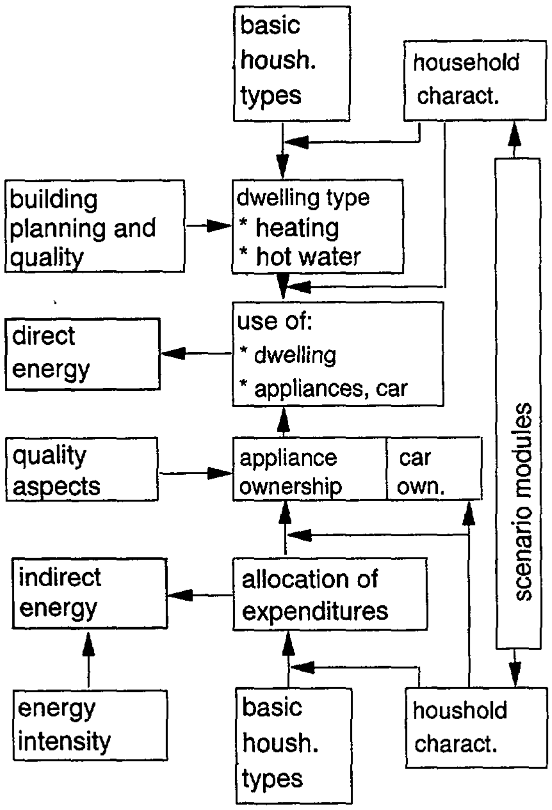


Figure 2. Main structure of the Lifestyle Energy Model.

Presently, the model is under construction and, given the various theoretical and practical complications, a gradual stepwise upgrading seems the most likely development path for the unfolding of the 'eventual' model. Section 2.3. will deal with some general computational principles, with respect to direct energy consumption of households. Subsequently, section 2.4 will explain the dwelling module and social-economic module in more detail.

2.3. Computational Backgrounds

The calculation of future energy requirements per category is based on the modelling of the allocation of consumer expenditures on the one hand and the computation of the energy intensity on the other hand. Eventually direct and indirect energy use can be aggregated by consump-tion category, however the preceding treatment in the model follows separate lines.

In the Netherlands mostly natural gas is used in thermal applications. As has been explained before we distinguish space heating, hot tap water, and meal preparation.
For space heating a further disaggregation is made by four types of dwellings (detached and semi-detached houses, flats and housing units) and three types of heating systems (individuel central heating, local heating or stoves and collective systems such as district heating). This provides us with a reference primary energy consumption for heating for twelve basic types. The housing stock is disaggregated into these basic types. This dwelling stock vector is matched with a stock matrix of household types based on a distinction by age group and composition. A further variation within each basic dwelling type is allowed for by functions based on linear regressions. Explanatory variables are age, household size, disposable household income, education of main wage earner, and construction period of the dwelling.

A technical module provides technical coefficients for the thermal applications, thereby allowing for improvements in the existing dwelling stock as well as for new vintages of dwellings with a higher energy efficiency than the existing stock. Similarly a social-economic module describes the dynamics in the household population, participation in paid labour and the resulting household incomes. All information put together yields a future distribution of household types, with updated characteristics, over the dwelling stock. Finally, future energy requirements for heating can be computed. A similar treatment allows for the computation of energy for hot tap water. For meal preparation the situation is somewhat more complicated as the range of available technologies is larger and the influence of daily behaviour is more important (substitution options to the market and/or technology).

The stock of domestic electric appliances and cars is also treated in separate modules. The future diffusion of appliances will be modelled by means of a discrete choice approach (Linssen 1994). Furthermore, the utilization of appliances (e.g. number of times in operation per week) will be explained by means of regression analysis of time use data. Previous research has shown that there exist rather straightforward relations between the frequency of use of the large domestic appliances such as laundry machines and characteristics such as household size (Perrels 1992). Finally, a technical module is added to allow for technical improvements in new vintages of appliances. Furthermore, the model should be able to digest new appliances.

All in all the computation of the direct energy consumption means that expenditures for gas, district heat and electricity have to be subtracted from the budget. Furthermore, consistency checks have to be built in to allow for a matching of purchases of appliances and private motorized vehicles with the development of ownership of these commodities. The remaining budget has to be allocated to main consumption categories. This allocation is modelled by a not entirely common function, since next to income and prices, household characteristics have been added.

2.4. The 'Dwellings Module'

2.4.1. Introduction

The direct energy use in dwellings may be largely distinguished between heating related purposes and power and light purposes. Obviously, the latter purpose is presently almost exclusively taken care of by means of electricity, while heating may depend on natural gas, district heat, light fuel oil and (for tap water and cooking) electricity. Contrary to the ownership of appliances the choice of a heating system is not related to the household type and social economic characteristics of a household, rather it is connected to the dwelling itself. The builder or the housing corporation usually decides about the installation. Indeed during analyis of the survey figures it appeared that the distincion of the dwelling stock by type of dwelling and by type of heating system substantially reduces the variation per dwelling-heating combination. A limited part of the remainder of the variation can be explained by household characteristics. The unexplained variation may be attributed to a range of causes, such as the orientation and exposure of a dwelling regarding sunshine and wind, degree of thermal insulation, state of maintenance of home and heating system, heating behaviour of neighbours (notably in appartment buildings), typical lifestyle features (presence, clothing), incidence of spilling or neglect, incidence of energy saving activities, etc. The just mentioned causes are so diverse and require so much extensive measurement that most of them may be presently regarded as unfit for including in the model.

The dwelling module merges the dwelling information with the household information and subsequently calculates a direct energy use for heating by household type given its distribution over dwelling types. This direct energy use is in a first stage determined by the technical features of the dwelling and the heating system, thereby producing a reference level. This reference level can change over time due to technical progress in new dwellings and retrofit of existing ones. In a next stage this actual consumption level is determined by allowing for adjustments both in the composition of the population per dwelling category and in the background characteristics of households.

2.4.2. A Description of the Dwelling Module

The dwelling module is composed of two sub-modules each containing a number of worksheets. The first sub-module is a scenario module describing the evolution of the size and quality of the dwelling stock by dwelling category. Dwellings are categorized by type and by vintage category (historical and future vintages). The development of the size of the dwelling stock is based on the numbers of removals, renovations and new houses by dwelling category per forecast period.

The energy quality of new dwellings (built from 1995 onwards) is assumed to be better than of existing dwellings, therefore for new vintages of dwellings a reduction of the reference energy consumption is applied. The reduction increases over future vintages and is differentiated by dwelling type. The energy quality of existing dwellings can only be altered after a renovation. Both sets of variables (reduction of the reference level energy consumption) are exogenous.

The second sub-module calculates the energy consumption for cooking, hot tap water and space heating. For each of the applications a reference level of consumption has been calculated for every dwelling type simultaneously disaggregated by vintage category and heating system. In figure 3 this sub-module is shown.

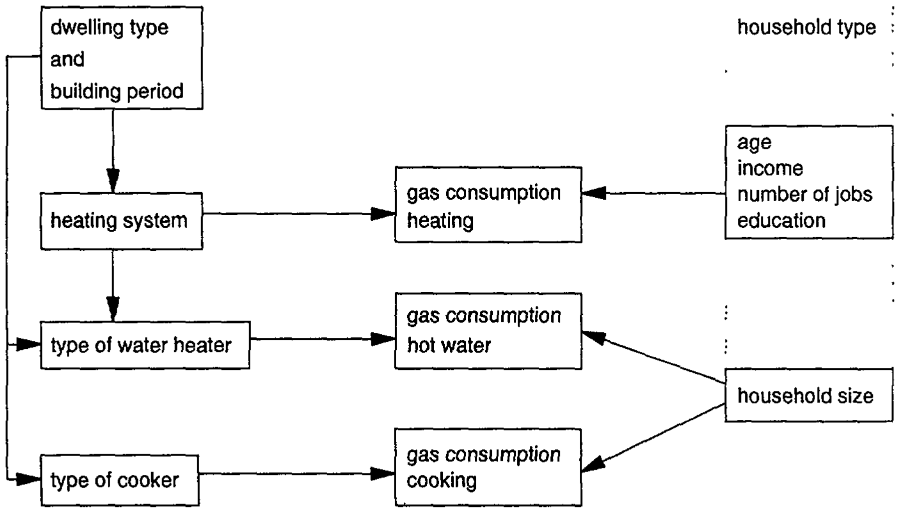


***Figure 3** Principal Relations in the Module Energy Consumption for Space Heating, Hot Tap Water and Cooking.*

Furthermore, it appeared that the occurence of a second hot tap water system in a home was a non-marginal phenomenon and constituted a substantial rise in energy consumption for tap water heating. Therefore, a discrete choice function has been estimated forecasting the share of homes (per dwelling type) with a second tap water heating system. The reference energy consumption level is adapted accordingly.
Subsequently, for each application the actual average consumption level of sub-populations by household type living in a particular dwelling type is calculated by modifying the reference level according to the influences of household characteristics. The equations operating these modifications have been identified in separate research based on a large household survey. The functions have been first estimated econometrically and in some cases additional information has been used to alter the original specification.

2.5. The 'Social-Cultural-Economic' Module

2.5.1. Introduction

The social-cultural-economic module is the principal module for manipulating household characteristics such as income, employment status, household size and type, level of education and distribution of households by degree of urbanisation. In the long run other variables or more fundamental aspects can change as well. In the descriptive scenario various of the latter aspects (such as the motivations for personal development) are taken into account. However, such qualitative changes are always translated into changes of one or more exogenous variables. In order to keep the consistency manageable various key variables such as income and employment have been endogenized. This means that the number of purely (macro) economic exogenous variables is limited to growth rates of value added and of labour productivity (both by sector). Other variables included such as working times have certainly economic meaning, however in this model they are typically perceived as scenario choice variables. The development of working times and part time work is seen as a choice for a certain kind of society.

Another set of exogenous (micro) economic variables relates to taxation and pensions. By manipulating these variables the distribution of disposable income can be influenced. As the model does not contain checks on the state of public finances the manipulation of taxes and pensions has to be handled with care.
The development of the other exogenous variables should be derived from the qualititative scenario and from demographic forecasts. Clearly, the translation of a notion of a certain trend into a set of numbers always constitutes some degree of arbitrary choice. This feature once again underscores the explorative character of the model.

2.5.2. A Description of the Module

Throughout the entire model ten household types are distinguished. The distinction has been based on age category and household composition/size. Although both household composi-tion/size and age effects could have been represented in the behavioural functions applied in the model, discontinuities in both effects stressed in the importance to decide in favour of an a priori disaggregation at this point.

There are four 'places' in the module were exogenous information can enter, namely:
1. the growth rates of value added and of labour productivity;
2. the work time variables (number of working weeks and average duration per week);
3. the household characteristics (education level, income etc.);
4. the composition of the population by household type and ability to work.

Given the labour volume in the base year (aggregate annual man hours per sector), the economic growth rates and the development of work times determine the size of the labour force (in full-time equivalents) and the number of employed persons (part-time and full-time) in future years. The number of employed persons is subsequently allocated to the potentially active population by household type. This allocation procedure allows for differences in employment probabilities per full-time and part-time jobs and by status in the household respectively. Thereby it is determined to what extent every household type participates in paid labour.

In a separate cross section analysis the differentiation of the wage rate across respondents in a survey has been specified as a funcion of age category, level of education, household phase, and a constant. The differentiation has been estimated for all economic sectors together. This implies that in the base year people with identical background characteristics are supposed to have the same wage rate regardless of the sector they are employed in. On the other hand for future years wage rates are allowed to divert by sector due to differences in growth rates in value added. After having determined the wage rates and the employment for every household type the average pre tax income level per household type can be calculated. Pensions are calculated on the basis of levels of labour income in a previous period. Finally, households without income from (past) labour are alotted a social security income. The level of social security is an exogenous variable. Finally, a simplified taxation scheme is applied to approximate net incomes per household type. These net incomes are the basis for the consumption functions relevant for the determination of the indirect energy consumption. The household expenditures are treated in a separate module.

Summarizing, the module provides a specification of the population distinguished by household type and further specified simultaneously by household income, participation in paid labour, number of working hours per week, education level, and population size of residence.

3. POSSIBLE TRENDS IN RESIDENTIAL ENERGY DEMAND FOR HEATING UP TO 2015

This chapter shows some exercises with the model concerning direct energy consumption for thermal applications (space heating, hot tap water and cooking). The shares of these applications in 1990 are 80%, 15% and 5% respectively.
The total number of households and dwellings keeps on to increase (CBS 1994).
The analysis below aims to illustrate changes in energy consumption for thermal applications. This exercise has been carried out in two stages:

1. the size and composition of the dwelling stock as well as the distribution of the population over this stock is adapted to the expected situation in 2015;
2. the shares of the various types of heating and hot water equipment are adapted to the 2015 situation and the specific energy use of these appliances is assumed to improve.

In figure 4 the total energy consumption in natural gas-equivalents in the base year is shown per type of household. The total number of households and dwellings is 6 million in 1990.
The total gas consumption also includes the electric consumption of electric boilers and electric cooking that are expressed in gas-equivalents.

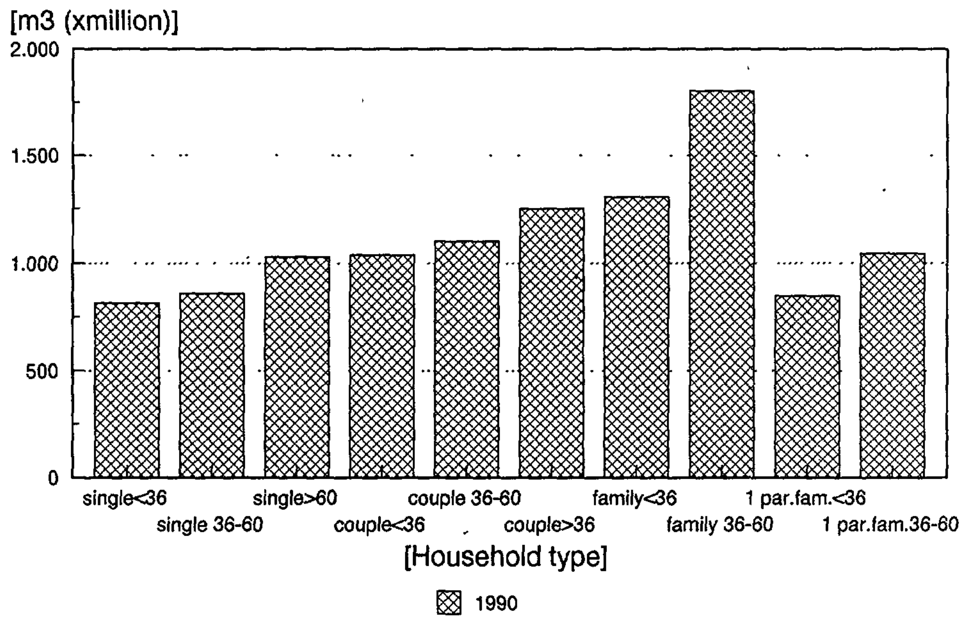
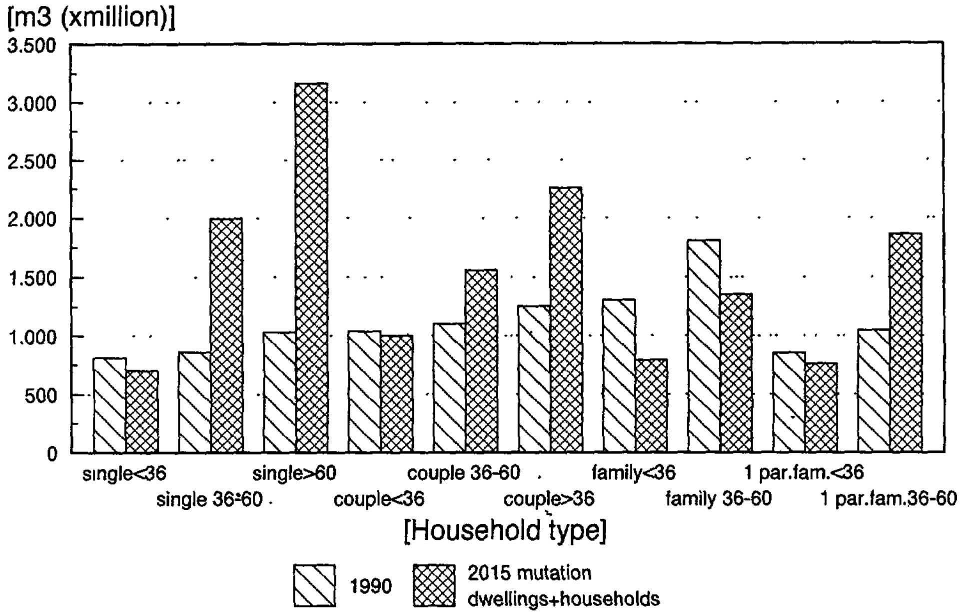


Figure 4. Total Gas Consumption for Thermal Applications in the Baseyear 1990 for Different Household typers.

In the future relative less flats and detached houses and relative more semi-detached dwellings will be built (VROM 1992, Weegink and Abbing 1993). The number of housing units remains at the same level. For 2015 a dramatic increase in the number of one person households (singles) is to be expected. Also during the next decades the aging of the population will increase. Conversely the share of families and the number of persons under 36 years old will stongly decrease (Van Imhoff and Keilman 1991). In figure 5 the impacts of these trends on the gas consumption is shown. The dwelling stock and number of households is estimated at 8,2 million (almost an increase of 0,1 million households per year).



Baseyear 1990 and 2015 for Different Household types after the Mutation in Dwelling stock and Households.

The share of central heating in dwellings will increase (Weegink en Abbing 1993) whilst stoves will slowly disappear. Also the share of district heating in semi-detached houses and flats will increase. For the hot water appliances a strong increase in the share of combi-boilers is to be expected. For meal preparation the share that cooks by electric will increase, because inductive cooking and microwaves become more popular. Of course appliances are expected to become more energy-efficient. But the change in the thermal appliances has a negative effect on the reduction of energy consumption.

In figure 6 the change in gas consumption caused by the above mentioned trends is shown. For all household types an increase is visible. The average gas consumption per household is between 1396 m^3 per year for an average single younger than 36 years old and 2072 m^3 per year for an average family of 36 to 60 years old.

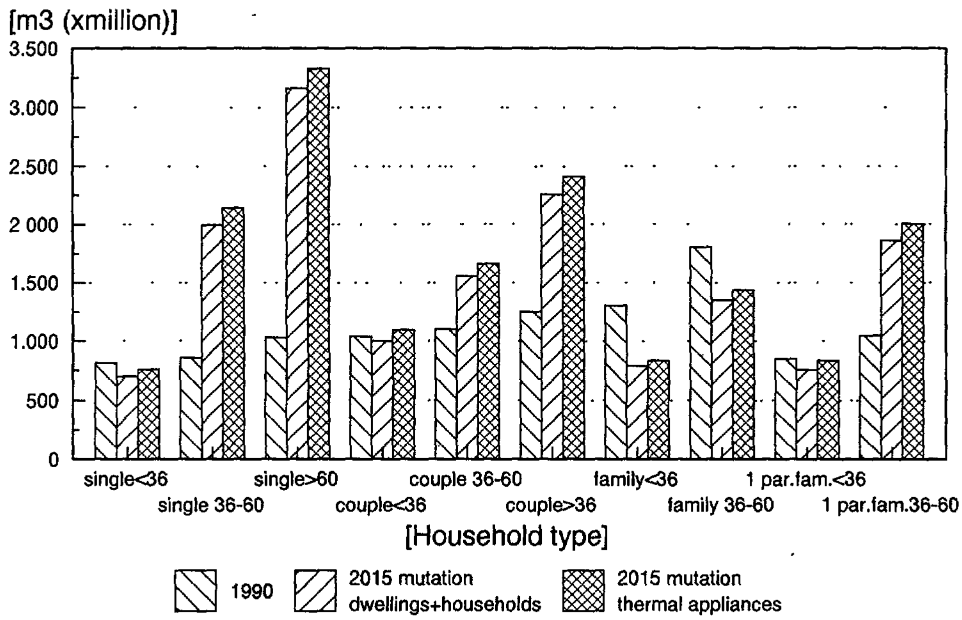


Figure 6. *Total Gas Consumption for Thermal Applications in the Baseyear 1990 and 2015 for Different Household types after the Mutation in Dwelling stock and Household and the Mutation in Thermal Appliances.*

A next step in this analysis is to assess the effect of an increase of income or educational level. Yet, due to the limited space available here, this subject has been left outside the paper.

4. DISCUSSION

In this paper a long term lifestyle oriented energy demand model for households has been described. Some investigations are made to forecast the energy use of thermal applications from 1990 to 2015. By an increase of the number of households, especially the number of one person households and elderly persons and a change in thermal appliances, an increase in energy consumption is to be expected. These are some effects of certain trends. There are more trends to be expected having also impact on the energy consumption of households.

Until now the major part of the social organisation of time (opening time, working hours etc.) is fixed. This means that various categories of activities are performed with a high degree of synchronisation (=simultaneously), e.g. think of commuting, shopping, holidays, etc.
More people start to work part-time instead of full-time. Also the number of working women has increased in the Netherlands (CBS, 1990).
The expectation is that the average educational level will increase which will contribute to a further development of personal lifestyles (i.e. enhancing individualisation). As a consequence the need for possibilities to choose the arrangement of time will increase; in other words a larger scope for more flexible and personal scheduling. Human development can evolve into different directions. One can think of development in a paid or unpaid job or a development in material (consumerism) or immaterial spending (participation in culture). All changes together maybe summarised as a transition from a synchronic to an asynchronous society.

What kind of effect would a asynchronous society have on the energy consumption?
If development takes place in a material oriented society the changing proces will happen quicker than in an immaterial oriented society. This offer more opportunities for energy saving but on the other hand a higher economic growth (which is associated with a material oriented society) leads to a higher energy demand. When consumerism becomes less prominent there is more chance for lifestyles being more energy efficient.
All in all it is not so straightforward to forecast the impacts of developments for future energy consumption. Reallocation of labour or time will give more options to the consumers. Yet their choices can shift toward products that are less energy efficient. Furthermore, shifts in consumer preferences may have cross-border effects in energy use, if the reallocated demand concerns commodities manufactured abroad. This kind of effects will be assessed in the ECN lifestyle oriented energy model.

5. ENDNOTES

1. These are applications used for space heating, hot tap water en meal preparation.

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